

# **GUIDELINES FOR THE DESIGN, CONSTRUCTION AND OPERATION OF MANUAL SANITARY LANDFILLS**

**A solution for the final disposal of municipal solid wastes  
in small communities**

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**Organización  
Panamericana  
de la Salud**

*División Regional de la*  
Organización Mundial de la Salud  
**AREA DE DESARROLLO SOSTENIBLE Y  
SALUD AMBIENTAL**



**Centro Panamericano de  
Ingeniería Sanitaria y  
Ciencias del Ambiente  
CEPIS/OPS**

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## Foreword

*It is an increasingly clear fact in Latin America and the Caribbean that inadequate final waste disposal has a negative impact on the environment and public health. The population has become aware of the seriousness of this problem and, in different places, people have demanded that their public institutions take more energetic measures to solve it. In response to these justified complaints, government authorities have started to take action to mitigate the negative effects of poor waste disposal practices.*

*The alternatives being offered to solve this problem today are based on an integrated management approach and place a great deal of emphasis on the sustainability of the proposed solutions. At the same time, the idea is for the solutions to be inserted into appropriate legal instruments as prescribed by the legislation of each country. It should be noted that in most of the nations of the Region sanitary landfills are already being demanded as the best solution for final waste disposal.*

*Although progress has been made, we cannot ignore the fact that the problem of final waste disposal takes on particular characteristics in small districts and rural areas, owing to several factors: a lack of funds because of the widespread subsidizing of the public cleaning service; absence of information on the negative consequences of open dumps; ignorance of the feasibility of joint solutions, which reduce costs of implementation and operation of manual landfills thanks to the application of economies of scale; ignorance, also, of the appropriate technology to dispose of residues without incurring in major investment and operating costs; and, in general, insufficient knowledge on how to address the problem of inadequate final waste disposal.*

*Hence the need for an up-to-date guide that will cover all the stages involved in setting up a manual sanitary landfill for small communities. Hence also the decision to revise our former publication on the topic, Municipal solid waste. Guide for the design, construction, and operation of manual sanitary landfills. The mere fact that this guide has had four reprints in six years is an indicator of the growing importance of the issue in the Latin American and Caribbean Region.*

*This version includes new topics that will help small communities in the Region to develop an integrated waste management system, to manage and monitor sanitary landfills, and to carry out cost analyses to ensure the sustainability of these activities. The document will be of great use in improving the environmental conditions and public health of a large sector of the populations of Latin America and the Caribbean.*

*The author of the original document is Jorge Jaramillo, an engineer, international consultant, and chief professor at the University of Antioquia, Colombia. To enrich this new edition, he has incorporated comments from different consultants working in this field in other countries. The Solid Waste Management Area of CEPIS/PAHO also cooperated in the preparation of the text and reviewed the final version of the document. Alvaro Cantanhede, engineer, Regional Consultant for Waste Management, and Leandro Sandoval, engineer, Advisor on Urban Solid Waste, participated in this task.*

*Finally, this new edition would not have been possible without the financial support provided by the PAHO/WHO Representative Offices in Mexico, Paraguay, Venezuela, and Peru. The translation was financed by the PAHO/WHO Representative Offices of Guyana, Trinidad and Tobago, and Jamaica.*



# **1. INTRODUCTION**



## 1.1 The problem of municipal solid waste (MSW)

The term “municipal solid waste” (MSW) covers wastes from different sources: from domestic, commercial, industrial (small and cottage industries), institutional (public administration, schools, etc.) activities; from markets; and from street sweeping and the cleaning of other public areas in urban communities. In all urban environments, the management of solid waste is the responsibility of the municipal authorities.

Solid waste management in general—and in particular the final disposal of the waste—is a complex task that has become a common problem in developing countries. This is reflected in dirty public areas, waste recovery in the streets, an increase in informal activities; garbage is thrown into streams and rivers, or disposed of in open dumps; and men, women and children sort through the waste in these open dumps, under subhuman conditions, exposed to all kinds of diseases and accidents.

The poor management of MSW is a problem in most cities and small urban communities, and it is a growing problem. Among the many factors aggravating the situation in certain regions are: rapid population growth and high concentration of the population in urban areas, industrial development, changes in eating habits, and the widespread use of disposable containers and packages resulting in huge amounts of waste.

The economic crisis and institutional weakness have also had a negative influence, making it necessary to reduce public expenditure and maintain low tariffs for public cleaning services. In addition, insufficient education on hygiene and sanitation, and a lack of community involvement mean that there is great reluctance on the part of the population to pay for the waste management and disposal service, to the detriment of the quality of the urban cleaning service. The poor quality of the service further aggravates the problem. This whole situation places public health at risk, increases the pollution of natural resources with the consequent environmental damage, and leads to a deterioration in the life quality of the population.

The growth of any human settlement always results in increased waste production. When different types of wastes are mixed, they not only lose their potential commercial value, but also affect the health of the local population and degrade the environment. It is in this context that the need to seek effective solutions for waste management and final disposal is an imperative one.

Under these circumstances, it is indispensable for municipalities and other institutions to tackle this issue of solid waste management decisively and pragmatically. There are several aspects they need to take into account: the level of environmental education of the population and whether they can afford to pay for urban cleaning

services; the implications of mixed wastes; the economic value of some waste and its potential market; the compatibility of treatment and final disposal systems; and the costs involved in the collection, hauling, treatment, and disposal services.

## 1.2 Characteristics of municipal solid waste

### 1.2.1 Production of solid waste

Solid waste is produced whenever materials are discarded by their owners as being of no further value, and as such they may be dumped or collected for treatment or final disposal (Table 1.1).

**Table 1.1**  
**Activities producing solid waste in Latin America and the Caribbean**

<b>Generating activities</b>	<b>Components</b>	<b>% of the total of MSW</b>
<b>Residential</b>	Kitchen waste, paper and cardboard, plastics, glass, metals, textiles, garden trimmings, soil, etc.	50-75
<b>Commercial</b> Warehouses, offices, markets, restaurants, hotels, and others.	Paper, cardboard, plastics, wood, food wastes, glass, metals, special and hazardous wastes.	10-20
<b>Institutional</b> Public offices, schools, universities, public services and others.	Similar to commercial.	5-15
<b>Industrial (small and cottage industries)</b> Manufacturing, clothing and shoe industries, tailor's shops, carpenters' workshops, etc.	Industrial waste, scrap iron, etc. This heading also includes food wastes, ashes, rubble from building and demolition work, and special and hazardous wastes.	5-30
<b>Street sweeping</b>	Waste left in public areas by pedestrians, dirt, leaves, excreta, etc.	10-20

*Source:* Diagnosis of municipal solid waste management in Latin America and the Caribbean – LAC. IADB-PAHO/WHO. Washington D.C., 1997.

### 1.2.2 Per capita production of solid waste

The production of solid waste can be measured in unit values such as kilograms per inhabitant per day, kilograms per household per day, kilograms per street block per day, kilograms per ton of crop, or kilograms per number of animals per day.

The production of household waste in Latin America and the Caribbean ranges from 0.3 to 1.0 kg/per capita/day. This quantity increases by 25-50% when commercial, institutional, and municipal waste is added to domestic waste. Thus, daily production is 0.5-1.2 kg/cap/day. Per capita waste production in industrialized countries is over one kilogram per day (Table 1.2).

### 1.2.3 Waste production and income

Although waste production indices are lower in developing countries than in industrialized countries, they are not lower in proportion to income. The income level is, nevertheless, considerably lower when compared with income figures for industrialized countries (Table 1.2).

**Table 1.2**  
**Indices of solid waste production and income**

Solid waste	Countries		
	Low income	Middle income	Industrialized
Per capita production kg/cap/day	0.3-0.6	0.5-1.0	0.7-2.2
ton/cap/year	0.2	0.3	0.6
Average income (US\$ of 1988) US\$/cap./year	350	1,950	17,500

Urban Management Program – UNEP. Regional Office for Latin America and the Caribbean. Solid Waste/ Private Sector and Sanitary Landfills. Urban Management Series. Vol 13.

Except for Argentina, which had an annual per capita income of US\$11,940 in 1999, per capita income in all Latin American countries stands at less than US\$6,000 per year. In other countries, such as Canada, the United States, Germany, and Japan, the annual per capita income ranges from US\$20,000 to US\$39,000.

Per capita production of solid waste varies not only from one country to another, but also from one city to another, and even among the different socioeconomic strata within a single city. This confirms that the amount of wastes generated depends on the degree of development of the country, the per capita income of the population, and the size of the cities.

#### ***1.2.4 Composition of solid waste***

Municipal solid waste is made up of the by-products of domestic, commercial, business, and industrial activities (commonly known as garbage). It can be divided into organic wastes such as left-over food, leaves and other garden trimmings, paper and cardboard, wood, and other biodegradable material; and inorganic wastes, namely glass, plastic, metals, rubbers, inert material, etc.

Studies on MSW composition carried out in Latin American countries coincide in indicating that there is a high percentage of putrescible organic matter (50-80%), and moderate contents of paper and cardboard (8-18%), plastic and rubber (3-14%), and glass and ceramics (3-8%).

Table 1.3 shows the composition of solid waste as another of the important factors to be taken into account when designing a waste management system, especially when determining the most appropriate recovery possibilities, as well as the treatment and final disposal systems.

It will be noted that the quality of solid waste in developing countries is quite poor in comparison with that found in industrialized countries. This is an important factor to bear in mind when treatment and recycling programs are being considered as economic options. In Latin American and Caribbean countries (LAC), for instance, MSW has a higher content of organic matter, moisture ranging from 35 to 55%, and a greater specific weight of 125 to 250 kg/m<sup>3</sup> when measured without compaction.

### **1.3 Effects of inadequate solid waste management**

#### ***1.3.1 Health risks***

Although the role of solid waste as a direct cause of diseases has not been clearly determined, it is assumed that solid waste does play a role in the transmission of certain illnesses; mainly through indirect routes.

**Table 1.3**  
**Composition of municipal solid waste**

Composition (% wet weight)	Countries		
	Low income	Middle income	Industrialized
Vegetables and other putrescible materials	40-85	20-65	20-50
Paper and cardboard	1-10	15-40	15-40
Plastics	1-5	2-6	2-10
Metals	1-5	1-5	3-13
Glass	1-10	1-10	4-10
Rubber and leather	1-5	1-5	2-10
Inert material (ash, soil, and sand)	1-40	1-30	1-20
<b>Other characteristics</b>			
Moisture content %	40-80	40-60	20-30
Kg/m <sup>3</sup> density	250-500	170-330	100-170
Lower calorific power Kcal/kg	800-1,100	1,100-1,300	1,500-2,700
Cointreau, Sandra J. <i>Environmental management of urban solid wastes in developing countries. A project guide.</i> Washington, D.C., World Bank, 1982.			

For a better understanding of the effects of poor solid waste management on human health, a distinction needs to be made between direct risks and their attendant indirect risks.

### **1.3.1.1 Direct risks**

Direct risks are those posed by contact with the garbage, because people are in the habit of mixing waste with hazardous materials — broken glass, metals, syringes, razor blades, human or animal excreta, and even infectious hospital wastes and hazardous industrial substances, all of which can be harmful to refuse collection workers.

The garbage collection service is regarded as one of the most arduous jobs there is, since it involves brisk movements lifting heavy objects, and it is carried out at

night or very early in the morning, conditions which make it a high-risk activity that can result in a high morbidity rate for the workers. Conditions are even more critical when the working hours are long, when preventive measures are not taken, or when appropriate protective equipment is not worn. Besides, collection trucks are not always in the best of conditions: in many cases, collection workers are exposed to gases and particles released by the vehicle, which cause eye irritation and respiratory problems. These workers are also exposed to greater risks of traffic accidents, and bruising caused by knocks and blows.

Waste scavengers are in a worse situation, since they sort through the waste materials in subhuman conditions and without any kind of protection or social security. Because of their precarious socioeconomic status, they are usually lacking in basic services —water, sewerage, and electric power— and often suffer from chronic undernutrition.

They are also more likely to suffer from gastrointestinal disturbances (parasitic, bacterial, or viral) than the rest of the population. Furthermore, they show higher injury rates than industrial workers. Such injuries occur to their hands, feet, and back, and may involve cuts, wounds, blows, hernias, and damage to the skin, teeth and eyes, respiratory infections, etc. Frequently, these health problems cause disability.

Scavengers may become vectors and potential transmitters of health problems to the people they are in contact with.

### *1.3.1.2 Indirect risks*

The most important indirect risk is the *proliferation of animals that are carriers of microorganisms, and that transmit diseases to the whole population*. These animals, known as vectors, include flies, mosquitoes, rats, and cockroaches. As well as feeding on the solid wastes, the vectors find in the garbage a favorable environment for reproduction and it becomes a breeding ground for the transmission of diseases, from a simple diarrhea to severe cases of typhoid or other more serious illnesses.

**Flies.** Their reproductive cycle varies according to the temperature. A fly can reach adulthood in 8-20 days and it can fly up to 10 km in 24 hours. It reproduces in moist human and animal excreta (farms, badly built latrines, open defecation, treatment sludge, garbage, etc.) (Figure 1.1). It is estimated that one kilogram of organic matter serves for the reproduction of some 70,000 flies.

Refuse is the main source of reproduction of the housefly, which transmits diseases and is responsible for millions of deaths worldwide. The key to getting rid of

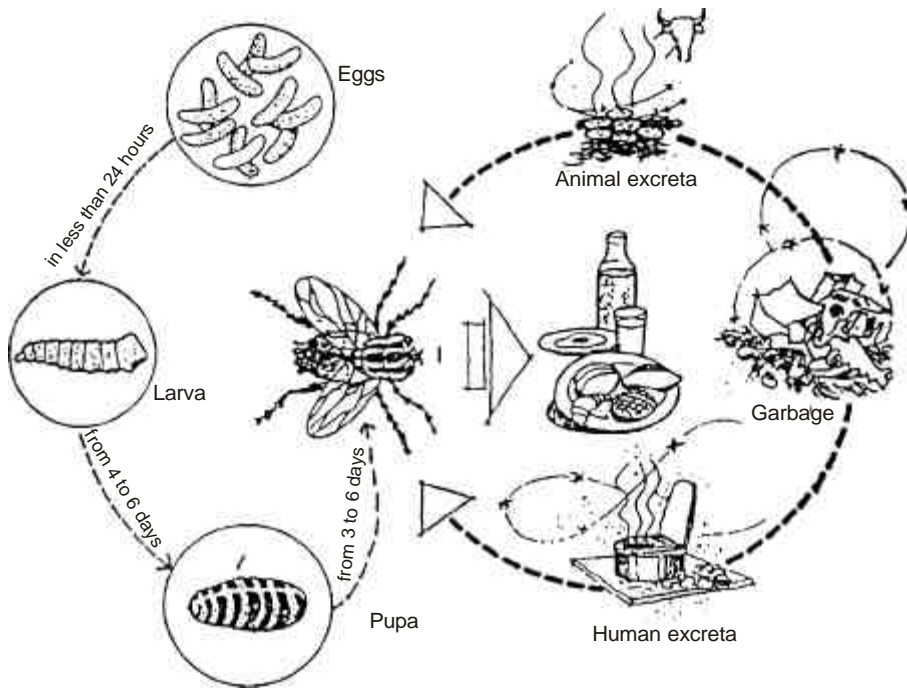


**Unhealthy conditions resulting from poor management of municipal solid waste are next in importance to those caused by human excreta and pose a serious threat to public health.**

**Table 1.4**  
**Vector-borne diseases associated with municipal waste**

<b>Vectors</b>	<b>Transmission routes</b>	<b>Main diseases</b>
? <b>Rats</b>	? Bites, urine, and feces ? Fleas	? Bubonic plague ? Murine typhus ? Leptospirosis
? <b>Flies</b>	? Mechanical route (wings, feet, and body)	? Typhoid fever ? Salmonellosis ? Cholera ? Amebiasis ? Dysentery ? Giardiasis
? <b>Mosquitoes</b>	? Female mosquito bites	? Malaria ? Leishmaniasis ? Yellow fever ? Dengue ? Filariasis
? <b>Cockroaches</b>	? Mechanical route (wings, feet, and body)	? Typhoid fever ? Feces ? Cholera ? Giardiasis
? <b>Pigs</b>	? Ingestion of contaminated meat	? Cysticercosis ? Toxoplasmosis ? Trichinosis ? Taeniasis
? <b>Birds</b>	? Feces	? Toxoplasmosis

*Source:* Departamento de Engenharia Sanitária e Ambiental, DESA/UPMG. Fundação Estadual do Meio Ambiente. *Manual de saneamento e proteção ambiental para os municípios*. FEMA, MG. 1995.



Source: Secretaría de Salubridad y Asistencia. Instructivo Sanitario. Ed. Limusa, México, 1980.

**Figure 1.1**  
**The life cycle of the fly and its importance in the transmission of diseases**

the housefly is, therefore, the proper storage, collection, and final sanitary disposal of garbage in sanitary landfills.

**Cockroaches.** These insects have existed for 350 million years. Given their extraordinary resistance to most insecticides and ability to adapt to any environment, they are believed to be the only living beings capable of surviving a nuclear war. They live around garbage bins, on kitchen shelves, near the dining room table, and in bathrooms. They feed on wastes and at night they walk on food, and sleeping animals or human beings contaminating them with their vomit and excrement. They transmit more than 70 diseases. Nearly 8% of the human population are allergic to cockroaches and develop serious respiratory diseases when exposed to places frequented by these vermin. Although the cockroach is one of the oldest and most repulsive insects, health and hygiene problems associated with this pest continue to affect us and are even on the increase.

**The presence of biological agents in MSW may play an important role in the direct and indirect transmission of diseases. Pathogenic microorganisms may be present in toilet paper, gauze, surgical tape, disposable diapers, or underwear disposed of by small clinics, pharmacies, laboratories, and mostly in hospital wastes mixed with domestic wastes.**

**Rats.** Rats have accompanied the human species over the centuries, and have always been regarded as one of the world's worst pests. In addition to transmitting serious diseases—leptospirosis, salmonellosis, typhus, bubonic plague, and parasitism—they also attack and bite human beings. Rats may seriously damage the electric and telephone urban infrastructure by peeling and eating the network cables, thereby causing a large number of fires. They also contribute to the deterioration and contamination of food. They reproduce quickly; they have from six to twelve pups per litter and a couple of rats may have up to 10 thousand offspring per year.

Another threat to public health is the use of garbage to feed animals (cattle, pigs, goats, poultry, etc.) without sanitary surveillance. This is yet another reason to make sure that solid waste is properly disposed of. The practice of feeding animals with garbage should be discouraged because it may cause several diseases, since such wastes are usually mixed with infectious wastes from hospitals, health care centers, or other contaminated places where refuse is disposed of without any prior sorting or treatment.

Another risk posed by inappropriate disposal of waste in open dumps, along highways, and near airports is that of *accidents* caused by reduced visibility from the smoke of burning refuse; or caused by *collisions* with birds commonly found in such places.

### ***1.3.2 Impact on the environment***

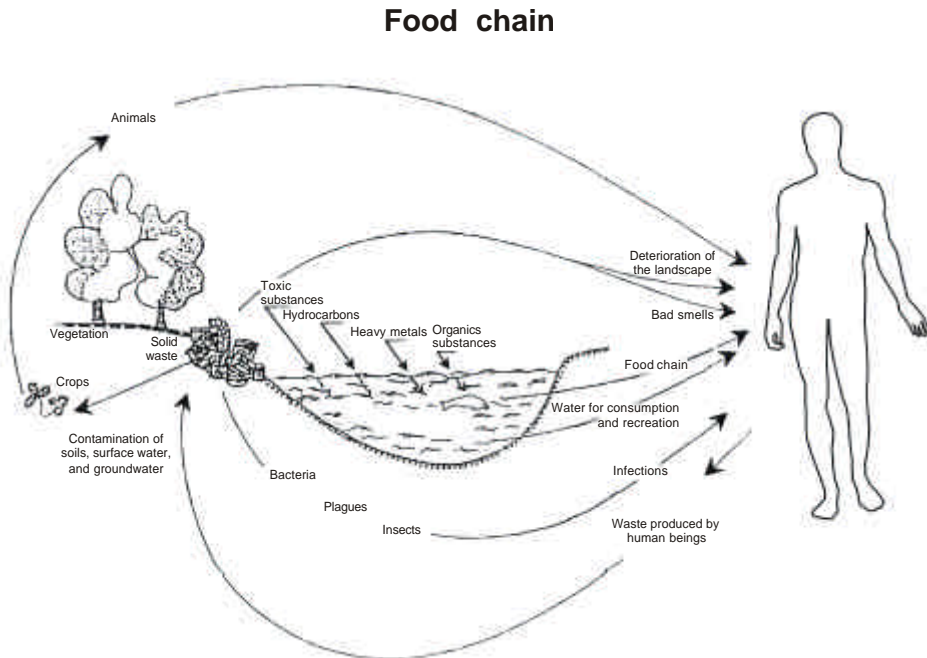
The most obvious environmental effect of inadequate MSW management is the aesthetic deterioration of both urban and rural landscapes. The degradation of the natural landscape caused by uncontrolled waste disposal is increasing. Open dumps and piles of garbage have become an increasingly common sight.

1.3.2.1 *Water pollution*

The most serious impact on the environment, although perhaps the least apparent one, is the pollution of surface waters and groundwater. Water pollution is a result of people's throwing garbage into rivers and streams, and it is also due to the leachate produced by the decomposition of solid wastes in open dumps.

The pollution of groundwater (also known as the water table or aquifer) calls for special attention since this is the source of water for entire populations. If not properly treated, polluted sources may lead to public health impairment and high treatment costs.

The disposal of solid waste in rivers and streams increases their organic load, thereby lowering the level of dissolved oxygen and increasing the content of nutrients that produce algae blooms and give rise to eutrophication; it causes the death of fish, produces bad odors, and detracts from the natural beauty of the river landscape. This has discouraged the use of water streams as a source of drinking water or for the recreation of the local population in many regions (Figure 1.2).



Source: M. Geltzschner; D. Mutz; Guidelines for an appropriate management of domestic sanitary landfill sites. Eschborn, Munich, GTZ GmbH, 1994.

**Figure 1.2**  
**Consequences of uncontrolled waste disposal**

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Throwing garbage into streams and canals, or onto the public highway also leads to the obstruction and clogging of canals and sewerage systems, with the result that flooding occurs during the rainy season, with the consequent loss of crops, properties, and —what is far worse— human lives.

#### *1.3.2.2 Soil pollution*

Another visible negative effect of open dumps is the aesthetic deterioration of villages and cities, and the consequent devaluation both of the land where the garbage dumps are located, and the surrounding areas. The pollution or poisoning of soils is another of the harmful impacts, because of the toxic substances disposed of in the dumps there and the failure of the environmental authorities to put an end to this practice.

#### *1.3.2.3 Air pollution*

Solid waste disposal in open dumps deteriorates the air quality in the vicinity of the dump site: the smoke from burning waste reduces visibility; wind-borne dust during dry seasons may convey harmful microorganisms that cause respiratory infections, and nose and eye irritation; the permanent bad odors are a serious nuisance factor.

### ***1.3.3 Risks for social development***

Extremely hard economic conditions and rural migration (poverty, in synthesis) have forced many families to use the resources contained in garbage as a means of survival. This situation will continue to exist until more decorous ways can be found for them to earn their living. Health risks are greater when domestic and hazardous wastes are mixed, as occurs in most LAC cities, since there is no selective collection of hazardous wastes. Only in very few cities are hospital wastes collected separately.

Scavengers are exposed to violence, including fights with knives and guns, as well as traffic accidents. These occurrences are a major health problem, not only because of their frequency but also because of their severity and their sequels. They imply a large social and economic cost for scavengers and their families and for the State, which covers most of the health care costs.

The health condition of the members of the scavenger's family who do not work with the garbage does not differ from that of the popular sector, where acute respiratory infections and diarrheal diseases are the main causes of morbidity in children; sexually transmitted diseases and those related to pregnancy, childbirth, and the puerperium are serious in women; and cardiovascular diseases are the most common in adults in general.

People sorting waste materials in final disposal sites need more attention and efforts on the part of the State to improve their living conditions because besides their being exposed to direct sanitary risks, they, in turn, are most likely affecting the health of the people around them.

For people in the high-income segments, domestic waste management involves merely the observance of refuse collection schedules and demanding the cleaning of the areas surrounding their houses.

Attitudes of the community, family members, professionals, and institutions, as well as the relationships among different actors of the sector, are profoundly marked by the culture, values, and perceptions of the different components of every urban and semi-rural society of the LAC Region. Any technical or operational proposal must therefore incorporate the social and cultural dimension of the place where the project is to be applied.

#### ***1.3.4 Risks for urban development***

Authorities habitually complain about the lack of social and civic discipline on the part of the population while, in turn, the population complain about the incapacity of public institutions to meet their obligations. The most frequent complaint on the part of the popular sectors is about the coverage. Coverage indicators are misleading, since they are based on the number of users who pay a tariff and do not refer to the quality of the service. Thus, many people who pay for the service do not receive it; while others neither pay for it nor receive it since their neighborhood is in an illegal situation with regard to land ownership and therefore beyond the reach of public services.

This situation is partly due to the lack of urban policies, which is reflected in an evident deterioration of living conditions in recent years.

Open dumps are often located in areas where the poorest members of the community live, compounding the deterioration of all conditions, and in consequence causing property prices to drop, and jeopardizing the development of the town or city.

**Inadequate MSW disposal also causes the deterioration of border urban ecosystems such as agricultural land, recreational areas, places of interest to tourists, and archaeological sites. The local flora and fauna are affected.**

In addition, both the scavengers and the middlemen who buy and sell the sorted waste materials from the garbage dumps typically build their precarious shanties in these areas, thereby expanding the area of extreme poverty and adding to the deterioration of the neighborhood.

It should be noted that one of the technical criteria for sanitary landfill sites is that they be located in places that have little value for the productive sector or for town development and that they have the capacity to receive wastes without producing major environmental impacts. Such land is usually cheap, and can be afforded by poor people.

This creates a vicious circle, because even when a sanitary landfill is built first, it won't be long before poor people start settling in its surroundings. Some local authorities even issue building permits without observing the prescribed setback (distance from the landfill): a potential cause of conflict, in later years, between the inhabitants and the municipal project.





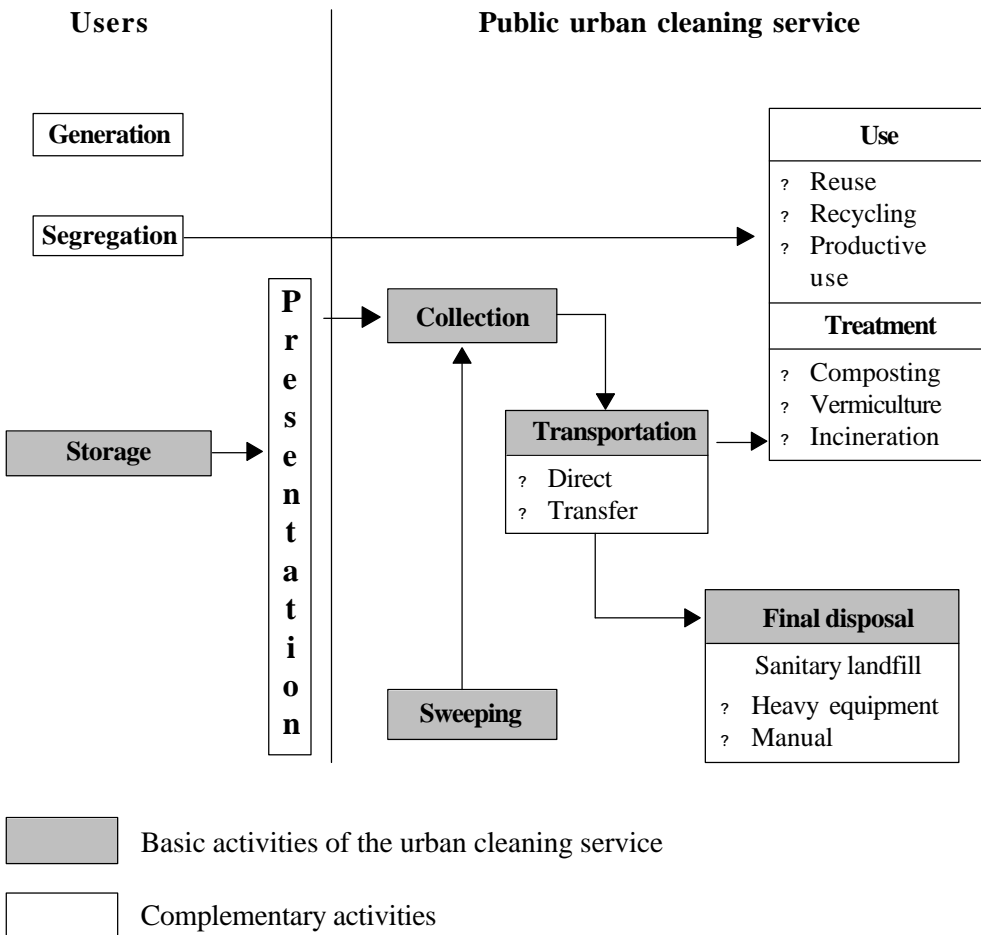
## **2. INTEGRATED SOLID WASTE MANAGEMENT**



## 2 INTEGRATED MUNICIPAL SOLID WASTE MANAGEMENT

### 2.1 Urban cleaning service

The urban cleaning service is mainly aimed at protecting public health and keeping the environment pleasant and healthy. The following activities make up the urban cleaning service: sorting or segregation of different types of waste, storage, presentation for collection, collection, sweeping, transportation, treatment, and final sanitary disposal of solid wastes. The latter is *indispensable* for solid waste



**Figure 2.1**  
**Integrated management of municipal solid wastes (MSW)**

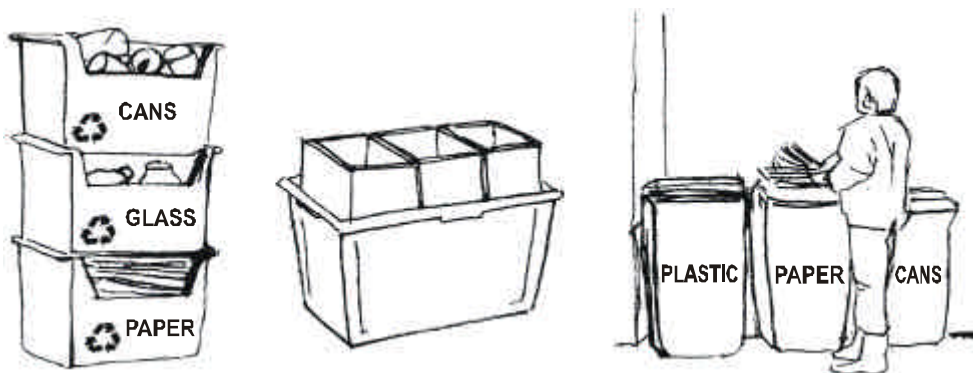
management. The responsibility for the first three activities lies with the generator of the solid wastes, while the municipality or institution in charge of the cleaning service is responsible for the remaining five activities.

As shown in Figure 2.1, generators of MSW (domestic, commercial, industrial, etc.) are users of the urban cleaning service and they are responsible for segregating their refuse, storing it in suitable containers, and depositing it in the place and at the times indicated by the operator of the service. Currently, there is a growing trend toward source segregation of MSW to facilitate recovery and recycling programs.

Either the municipality or the cleaning service operator is responsible for collection, transportation, street sweeping and the cleaning of public areas, and the disposal of all MSW in a sanitary landfill. The municipality or service operator can also process the waste for reuse, or treat it in order to obtain economic and environmental benefits or to render it harmless.

### **2.1.1 Waste segregation**

In LAC countries, MSW by-products are usually sorted manually, and this can be done at source, on the sidewalks, in the collection vehicle, or at the final disposal site. The latter is common in virtually all refuse dumps of large cities and even in small communities. Those involved in these activities are usually very poor people, who work under subhuman conditions to support themselves and their families, without any social security.



**Figure 2.2**  
**Containers for the segregation and storage of domestic solid wastes**

The municipality should take the first steps to eradicate solid waste segregation in open dumps, seeking the support of the commercial and industrial sectors and the community at large, to offer scavengers other opportunities. An outreach process offering training and support should be set in motion by the municipality to organize these people in self-managed cooperatives, which would enable them to work in decorous conditions at the source sites, or even to find other kinds of work to improve their livelihood and finally start leaving behind the humiliation and degradation of a marginal existence.

Experiences in developing countries with industrial facilities for solid waste segregation have failed. It is therefore recommended that municipalities of small communities support source segregation programs (domestic, commercial, industrial, etc.), and construct or adapt premises for use as a collection center where the sorters can sort and classify the different materials properly.

**Source segregation is an essential step for successful waste recovery, and this is the generator's responsibility.**

### ***2.1.2 Storage and presentation***

Storage refers to the fact that the user must place all MSW in bins or containers suited to the quantity and types of waste, and the frequency of collection. The containers should have a specific weight and design for handling by operators and equipment. Their design should ensure that the contents will not come into contact with the environment: they should have tight-fitting lids that will prevent water, insects, or rodents from entering, and be of a material which will prevent leakage of liquids. They should be easy to empty and may be returnable or disposable.

The presentation of solid waste for its collection is also the responsibility of the waste generator or user of the cleaning service. It involves placing waste containers in the proper place (by the curb or the door of the house, in a stationary box or multi-family container, in a basket, etc.) on the day and at the time scheduled by the municipality or the provider of the collection service.

### ***2.1.3 Collection and transportation***

MSW collection implies the transfer of the waste to the disposal site, which may be a sanitary landfill or any other facility for the processing, treatment, or transfer

of materials. Waste collection and transportation (also called hauling) is the most expensive activity of the urban cleaning service, usually accounting for 80-90% of the total cost.

Vehicles for waste haulage should meet all the conditions relating to this activity. Traditional compactors are used in cities, while unconventional systems are found in small towns and marginal areas, such as an agricultural tractor connected to a dump trailer, horse-drawn carts, tricycles, etc.

### ***2.1.4 Street sweeping and cleaning of public areas***

Street sweeping and the cleaning of public areas, complemented by collection, could be called the “cosmetics of urban centers.” The purpose of these activities is to keep public paths and areas clean and free from litter thrown on the ground by pedestrians, people attending shows or other public events, workers involved in the loading and unloading of materials, etc. The institution responsible for cleaning should ensure that the cleaning service is frequent enough to guarantee that the streets and other public areas are clean at all times.

### ***2.1.5 Transfer***

Transfer refers to moving the MSW from a small collection vehicle to a larger one. In cities where the distance from the collection point to the final disposal site exceeds 20 km or the journey takes more than 15% of the working day, transportation may place a heavy economic burden on the cleaning service. In such cases, transfer stations and different means of transportation —road, railroad or barges— are used.

### ***2.1.6 Use***

The supply of raw material is not inexhaustible and the recovery of material regarded as waste is essential for the conservation of natural resources. Consequently, reuse, recycling, and productive use of wastes are important activities in the integrated management of MSW; these activities are mainly aimed at reducing the volume of waste to be disposed of and, especially, increasing its economic value.

By recovering these materials at source, the municipality benefits in the following ways:

- ? Creation of organized employment through cooperative groups.
- ? Reduction of MSW volume.
- ? Less collection equipment needed.

- ? Longer life span of sanitary landfills, decreasing the demand for land—which is increasingly scarce and expensive.
- ? Lower costs of the urban cleaning service.
- ? Conservation of natural resources and environmental protection.

#### 2.1.6.1 Reuse

Reuse is a first level of waste recovery and involves the direct use of a product or material in its original form or function. The reuse of containers—bottles, plastic jars, tin cans, cardboard boxes, and wooden boxes—is an example.

Remanufacturing implies cannibalizing similar products for a subsequent process of cleaning, inspection, replacement, restoration, assembly, testing, and distribution. Automobile engines, transmissions and other parts, refrigeration or air conditioning compressors, stoves, dishwashers, etc. are typical remanufactured products.

Discarded products may also be reused in their original form but with a new function, for instance, old tires used as breakwaters.

#### 2.1.6.2 Recycling

Recycling is a process whereby the waste (broken glass, paper, cardboard, metal, plastics, etc.) becomes the raw material for an industrial process to manufacture new products of similar composition.

When recycling a product, both the original function and the original form are changed. For instance, used tires are cut to make shoe soles; old clothes and textiles are made into dusters and mops, stuffing for pillows, or remnants to be made up into bedspreads and rugs.

Although the environmental advantages of recycling are indisputable, it is important to bear in mind that waste in LAC is of low quality, and that the economic benefits that make recycling a sustainable option depend on the market demand.

There is a global trend to maximize refuse recycling as one of the solutions to the worldwide problem of waste disposal.

**If the waste recovery system is to be successful, there must be a market for reused or recycled materials. The system will not be feasible without a guaranteed outlet for its products.**

**Recycling is part of the solution, but it is not the solution.**

### *2.1.6.3 Energy and productive use*

A third level of recovery transforms waste into a new material or type of energy. The new material may be a recovered element or a relatively homogeneous substance, and these may be used as sources of energy (for example, combustible gas or biogas produced by anaerobic digestion of organic wastes and heat recovery from refuse incineration). It also involves the productive use and transformation of MSW into different products (land recovery by the construction of sanitary landfills, retaining walls made of used tires, and conversion of organic waste into compost).

### *2.1.7 Treatment*

In the integrated approach to solid waste management, the main objective of treatment is to reduce the health risks and pollution potential of the waste. The treatment solution that best suits the local technical, economic, social, and environmental conditions should, therefore, be selected. Composting, vermiculture, and incineration are the most common treatment methods. The latter has great impact on volume reduction.

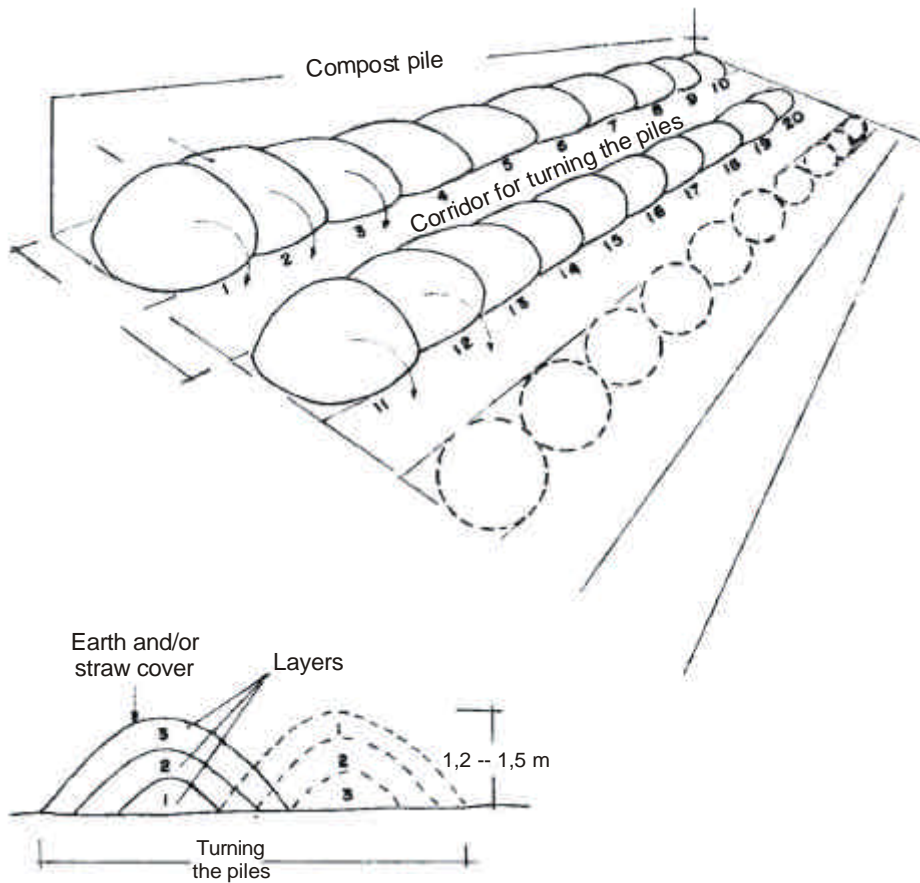
These methods leave residues that need to be disposed of in a sanitary landfill. This is why they cannot be considered final or definitive solutions.

#### *2.1.7.1 Composting*

Composting is the process of decomposition of organic waste by the bacteriological action of the microorganisms contained in the waste itself. The result of this process is known as “compost,” a product similar to humus, that acts as a soil conditioner rather than a fertilizer, and which can have a commercial value. However, since the commercial value is usually lower than the production cost, this system will need to be subsidized by the municipality.

Composting may benefit developing countries by permitting the recovery of a high percentage of organic matter contained in MSW. Besides, composting calls for organic matter to be separated from the rest of the solid waste, which is a good opportunity to start recycling other materials. However, before deciding whether or not to build a composting facility, a careful study should be made to confirm whether there is a potential market for the compost. Many such facilities worldwide have failed because they were unable to sell the product.





**Figure 2.3**  
**Manual processing of organic matter in compost piles to make compost**

In practice, composting has shown little success in LAC for the following reasons:

- ? Previous waste segregation is required; which increases costs, unless wastes with high organic content are collected selectively (such as wastes from restaurants, markets, etc.).
- ? Flexibility does not exist for the treatment of additional large quantities.
- ? The market for compost is unstable.
- ? Investment costs are high.
- ? Operation and maintenance costs of the composting facility are high.
- ? Skilled technicians are required to operate the facility.
- ? Transport expenses to rural areas are high.

Stacking solid waste from markets into piles manually is, however, recommended for small towns, since market waste is largely organic. The costs of distributing the product must be carefully considered, since they could increase the total production costs.

#### 2.1.7.2 *Vermiculture (earthworm farming)*

The cultivation of a particular earthworm (*Eisenia foetida*) using certain organic wastes as substratum or food (especially livestock dung and stubble from harvests) converts this resource into humus (soil conditioner) and protein (as animals feed and even for human consumption), provides a partial solution to the problem of waste disposal, and may produce economic benefits.

We must take care with these practices, since they are merely complementary alternatives in the integrated management of MSW and should in no way be regarded as a final solution.

**“The production of compost in Latin America and the Caribbean, using simplified processes such as piling, rotary biodigestors and, more recently, earthworm farming, is being abandoned due to its high cost and also because its promoters had promised the municipal authorities that there would be profits, whereas in fact the use of more environmentally-friendly alternatives has a cost. It is estimated that in the last 20 years no fewer than 30 compost plants have been purchased in the Region, some of which were never installed and the machinery was abandoned; another 15 closed down after only a few years because the municipalities stopped subsidizing them.”**

*Source: PAHO; BID. Diagnosis of municipal solid waste management in Latin America and the Caribbean. Washington DC, PAHO, 1998.*

#### 2.1.7.3 *Incineration*

Incineration converts MSW into inert material (cinder and ashes), and reduces it to 10% of its original volume. This reduction is obtained using special ovens with sufficient combustion air, turbulence, retention times, and adequate temperatures. Incomplete combustion, as in open-air burning, produces smoke, ashes, and bad odors.

The following points should be taken into account:

- ? A high initial investment is required.
- ? High operational costs are involved, usually beyond the reach of LAC towns.
- ? Skilled technicians are needed (and they are scarce in our Region).
- ? Operation and maintenance procedures are complex, involving many problems.
- ? Insufficient flexibility for the incineration of large additional quantities of waste.
- ? An auxiliary fuel is required owing to the high moisture content that results in low calorific power for the MSW of LAC countries, and this implies significantly higher treatment costs.
- ? Control equipment is required to prevent air pollution, since all incinerators release pollutants.

Incineration should, therefore, be discarded as a treatment system for the MSW of small towns and even in many large LAC cities. It should be suggested only when denaturation of hospital or other hazardous wastes is necessary.

**There are no magic facilities that will solve the problem of wastes and many generations will go by before the solution is found.**

### *2.1.8 Final disposal of MSW*

Final disposal is the last operational stage of any urban cleaning service.

**Nobody wants solid wastes. We cannot wish them away or hide them under paperwork and standards.**

#### *2.1.8.1 Inadequate final disposal practices*

Unacceptable final disposal practices include:

- ? Throwing refuse into watercourses, lakes, or seas.
- ? Disposal in open dumps.
- ? Open-air burning.
- ? Use of garbage as animal feed.

The risks of the above mentioned practices are:

- ? Throwing refuse into watercourses, lakes, or seas results in an ecological imbalance owing to the excessive increase of nutrients and organic load in the water.
- ? Disposal in open dumps results in acute public health problems owing to the proliferation of insects and rodents which are carriers of several disease agents and also because of the smoke caused by constant burning. All this contributes to the deterioration of the appearance of cities and natural landscapes.
- ? The use of raw waste to feed animals represents a high risk of disease transmission to humans, unless a strict sanitary control is in force. This kind of feeding may be allowed only when such food is cooked at 100 °C for 30 minutes.

Table 2.1 shows the common evolution of final disposal methods for MSW.

**Table 2.1**  
**Evolution of final disposal methods in cities of developing countries**

Alternative/situation	Description
Roadside disposal	This is common in areas where there is no waste collection service. The MSW is usually disposed of by its generators anywhere along the public highway or in a public dump.
Uncontrolled waste disposal in small local dumps	There is a primary collection service and incipient transport to a nearby site (usually within the city) where wastes are disposed of without any control.
Uncontrolled municipal dumping	There is primary and secondary collection. MSW is transferred and disposed of without control in a site on the outskirts of the city.
Controlled landfill	There is primary and secondary collection. MSW is transferred and disposed of with moderate control in a disposal site designed for that purpose and located on the outskirts of the city. The waste is buried regularly.
Sanitary landfill	The sanitary landfill is designed, built, and run according to sanitary and environmental engineering criteria. The site meets legal requirements and applies an environmental monitoring program. Environmental impacts are minimal and the population is not against the project.

*Source:* Adapted from "A Framework for the Disposal of Municipal Solid Waste in Developing Countries by Andrew Cotton, Mansoor Ali and Ken Westlake. Loughborough: WEDC; 1998.

### 2.1.8.2 Sanitary landfill

The final disposal method of virtually all municipal solid wastes is the sanitary landfill. This is the only accepted method since it is the only one that does not pose any public health hazard. Furthermore, it minimizes pollution and other negative environmental impacts. This important basic sanitation work will be described in detail in the following chapters.

### 2.1.9 Comparative costs of treatment and final disposal systems

Table 2.2 includes some figures relating to treatment and final disposal costs for a comparative analysis.

**Table 2.2**  
**Comparative costs of treatment and final disposal**

<b>Costs of treatment and disposal systems in landfills</b>		
<b>System</b>	<b>Investment cost US\$/ton installed</b>	<b>Operating cost US\$/ton (with amortization)</b>
Sanitary landfill - USA	-----	30 (ranging from 15 to 60)
Sanitary landfill - LAC (*)	5,000 to 15,000	6 (ranging from 3 to 10)
Composting	20,000 to 40,000	25 (ranging from 20 to 40)
Incineration - USA (**)	125,000 to 160,000	60 (ranging from 50 to 90)

*Source:* PAHO/WHO Guía para el manejo de residuos sólidos en ciudades pequeñas y zonas rurales. OPS/CEPIS. Serie Técnica 31. Lima, CEPIS/OPS, 1997.

(\*) Technical specifications of sanitary landfills are more stringent in the United StatesZ than in LAC, affecting costs.

(\*\*) Costs per ton are net after selling the energy. Gross cost is US\$ 90 per ton.

**Sanitary landfills are, so far, the MSW disposal technique best suited to the Region, from both the economic and technical standpoints.**

### 2.1.10 *Main characteristics of the urban cleaning service*

In developing countries, urban cleaning is one of the environmental health problems clamoring for greater attention on the part of governmental authorities and firmer commitment on the part of research institutions. Table 2.3 lists the characteristics that all urban cleaning services should have.

**Table 2.3**  
**Main characteristics of the urban cleaning service**

<b>Aspect</b>	<b>Description</b>
Technical	Simple implementation, operation and maintenance; use of local human resources and materials; covers the whole MSW process, from generation to final disposal.
Economic and financial	Investment, operation, maintenance, and management costs are affordable at the local level.
Institutional	Simple, dynamic management of the service.
Social	It fosters positive habits and discourages bad ones; it is participatory and promotes community organization.
Health	It can be included in a large-scale program for the prevention of infectious diseases.
Environmental	Negative impacts on soil, water, and air are minimized.
<i>Source:</i> Guía para el manejo de residuos sólidos en ciudades pequeñas y zonas rurales. Serie Técnica 31. Lima, CEPIS/OPS, 1997.	

### 2.1.11 *The urban cleaning service and its relationship with other basic sanitation services*

Basic sanitation refers to the supply of good quality drinking water, proper disposal of excreta, hygiene in the preparation of meals, cleanliness in the home, and the collection and final disposal of solid waste. Improvement in any one of these components is translated into positive health effects, but the combined improvement

in all of them is larger than the sum of each of the parts. Any integrated basic sanitation plan should include these ingredients and its effectiveness in achieving goals relating to health and well-being will depend on the success of each ingredient. Table 2.4 includes a figure (not drawn to scale) of the accumulated impact that all basic sanitation components have on the health of the population.

**Table 2.4**  
**Accumulated impact of the components of basic sanitation**

Basic sanitation components	Accumulated positive impact on the population's health and well-being				
Drinking water supply	■				
Proper disposal of excreta	■	■			
Food hygiene	■	■	■		
Personal and household hygiene	■	■	■	■	
Collection and final disposal of solid wastes	■	■	■	■	■

*Source:* Guía para el manejo de residuos sólidos en ciudades pequeñas y zonas rurales. Lima, CEPIS/OPS, 1997. Serie técnica 31.

## 2.2 What is integrated municipal solid waste management?

The integrated management of municipal solid wastes consists of a series of activities linked with the control of waste generation, segregation, presentation, storage, collection, hauling, sweeping, treatment, and final disposal. These activities must be carried out in such a way as to harmonize with the best principles of public health, economy, engineering, and aesthetics and also to meet public expectations.

### 2.2.1 Political and administrative management

#### 2.2.1.1 Responsibility of the local authority

Two of the indicators that reflect, at a glance, the health and life quality of a population, are the cleanliness and the beauty of their city.

It should be recalled that the mayor is the manager of a company called The Municipality, so he and his colleagues will be subject to the evaluation of the community. Also, the mayor's performance will almost certainly affect his future and the future of his political party.

Accordingly, the management and sanitary final disposal of MSW also reflect the quality of the local management and the commitment of its leaders, as well as the performance of the highest authority (the mayor). The quality of the urban cleaning service is an indicator to assess the municipal authorities' political purpose, management skills, and responsible attitude toward protection of public health, municipal workers' health, and the environment within their jurisdiction.

#### *2.2.1.2 Sustainability of the cleaning service*

Meager budgets have traditionally been allocated for the management, infrastructure, and equipment needed for the good operation and maintenance of solid waste management and disposal systems. However, the public is becoming increasingly demanding with regard to requested improvements, implying higher tariffs. And users are not aware or do not want to accept the fact that resources should come from their punctual payment of the service they have received.

The use of appropriate technology, combined with good planning and management can cut service costs, making it possible to charge a reasonable tariff that the users can afford, to ensure the self-financing of the service.

Sanitary and environmental education are becoming increasingly important if we are to raise community awareness about the problems caused by inadequate MSW management. Awareness is essential if there is to be a change of attitude that will enable people to understand the complexity of the problem and the requirements for a good collection, treatment, and final disposal system. It is also important that the public be made aware of the costs involved and the obligation of all citizens to pay for the urban cleaning service to ensure its sustainability. Sanitary and environmental education also encourage community involvement in source segregation and recovery.

**A clean city is the pride of its inhabitants.**



### *2.2.1.3 Environmental legislation and regulations*

Regulations regarding the environment and MSW are increasingly stringent. Adopting the standards of industrialized countries may actually be an obstacle to progress in MSW management in developing countries, when these standards do not adjust to local conditions.

The municipality is, by law, responsible for compliance with national environmental policies within its jurisdiction, including the provision of public cleaning services. Hence, the great importance of municipal management of the MSW generated in its territory.

**Existing European or American standards governing the location and construction of a sanitary landfill cannot be fully applied in developing countries. Particular local problems should be taken into account, including insufficient funds to be able to apply methods for the construction of an ideally safe landfill.**

### *2.2.2 Trends in MSW management*

Table 2.5 shows the trends in efficient and effective solutions for the MSW management problem. The scheme shows the order or hierarchy proposed for MSW management in industrialized and developing countries.

As may be seen, the trend in MSW management adopted in developed countries and recommended by the U.S. Environmental Protection Agency (EPA) is source reduction; followed, in the second place, by recycling; next comes incineration; and, finally, disposal in sanitary landfills. For developing countries, the same processes are presented in the same order, but instead of incineration (because of the high costs, unfeasible in these countries), treatment is proposed, since MSW in LAC countries contains a large percentage of organic matter. It is good to note that in both proposals the final disposal in sanitary landfills forms part of the strategy.

**Table 2.5**  
**Trends in the integrated management of MSW**

Developed countries	Developing countries
1. Source reduction	1. Source reduction
2. Recycling	2. Recycling
3. Incineration	3. Treatment
4. Sanitary landfill*	4. Sanitary landfill
<p>* Sanitary landfills are now being discouraged in some developed countries owing to the large extensions of land required and local environmental problems. The trend now is to build big sanitary landfills, known as regional sanitary landfills, which serve several urban conglomerates, where engineering principles are applied with important economies of scale.</p>	

Sanitary landfills are essential either as the only solution or as the final destination of the waste from other systems. This first step calls for the selection of appropriate sites to build sanitary landfills, from both the economic and social standpoints.

It is important to bear in mind that the different components of the integrated management of MSW should be interlinked in any program or system and should therefore have been selected for their ability to complement each other.

The sanitary landfill has the lowest rank in the integrated management of MSW because it represents the least desirable option for handling wastes; however, it is important to think about the following questions:

**What should be done with:**

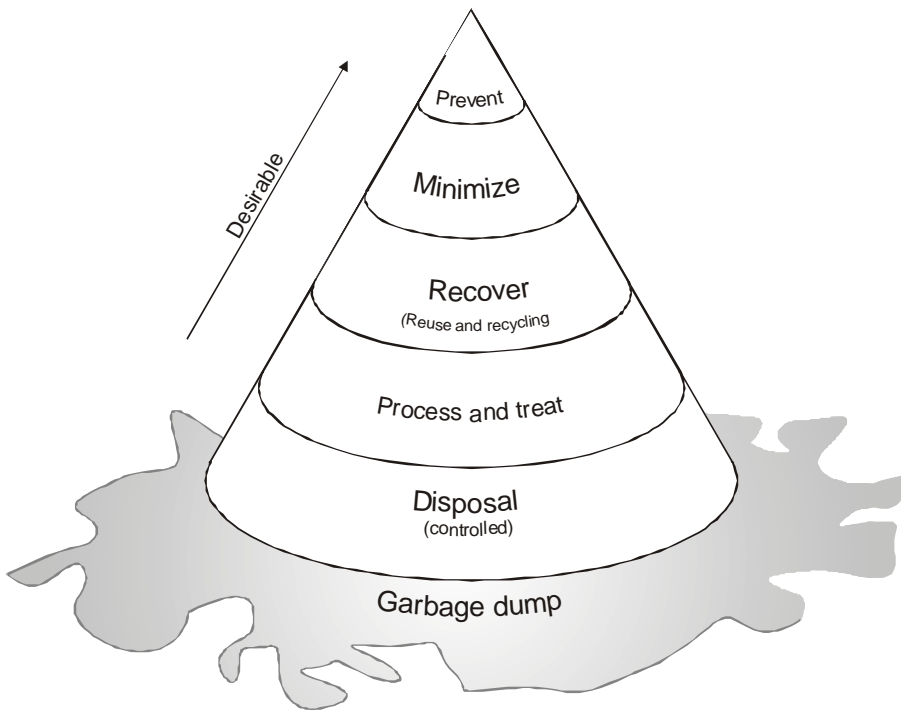
- ? those wastes that can be neither recycled nor given a different use?
- ? those remainders left after MSW have been segregated in a facility installed to separate materials?
- ? the remainders after solid wastes have been converted into other products or energy?

Safe, reliable and long-term disposal of waste should be an important component of the integrated management of MSW, especially because most of these materials can no longer be recovered for the production cycle. Hence, the sanitary landfill is the only acceptable alternative, which eliminates once and for all the practice of using “open dumps.”

**Regardless of the MSW treatment system adopted, it will always imply the existence of a sanitary landfill as a complement to its operation.**

In conclusion, the priority in MSW management with regard to treatment and final disposal, should be the construction of sanitary landfills, since it is urgent to minimize the health risks for the population, and put a halt to environmental pollution and the deterioration of natural resources. There can be no doubt that this is the most critical activity of the whole municipal urban cleaning service. (Figure 2.4).

**MSW sectoral plans should aim at eradicating open refuse dumps and graduating to cleaner processes.**

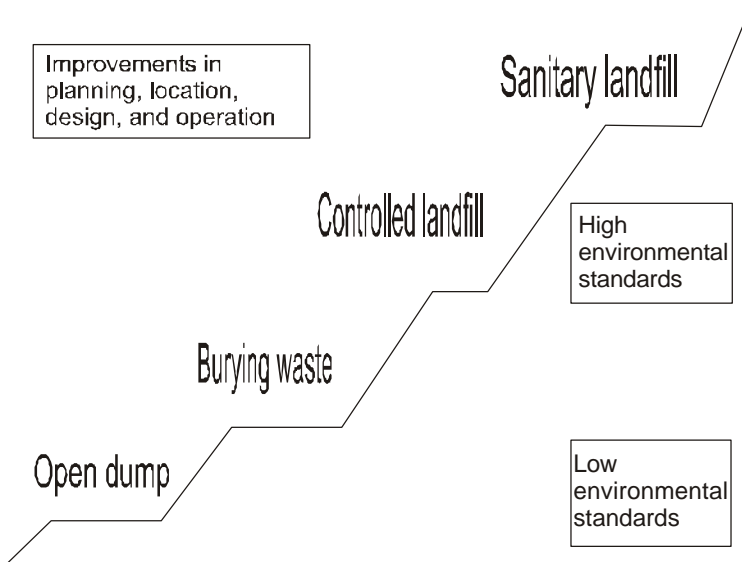


*Source:* Adapted from: World Bank. Planning guide for strategic municipal solid waste management in major cities in low-income countries. London, Environmental Resources Management, 1998. v.1.

**Figure 2.4**  
**Priorities in MSW management from the standpoints of public health and contamination**

**2.2.3 Process of continuous improvement in the final disposal of solid wastes**

The most common method used for the final disposal of MSW in the LAC Region is the open dump.



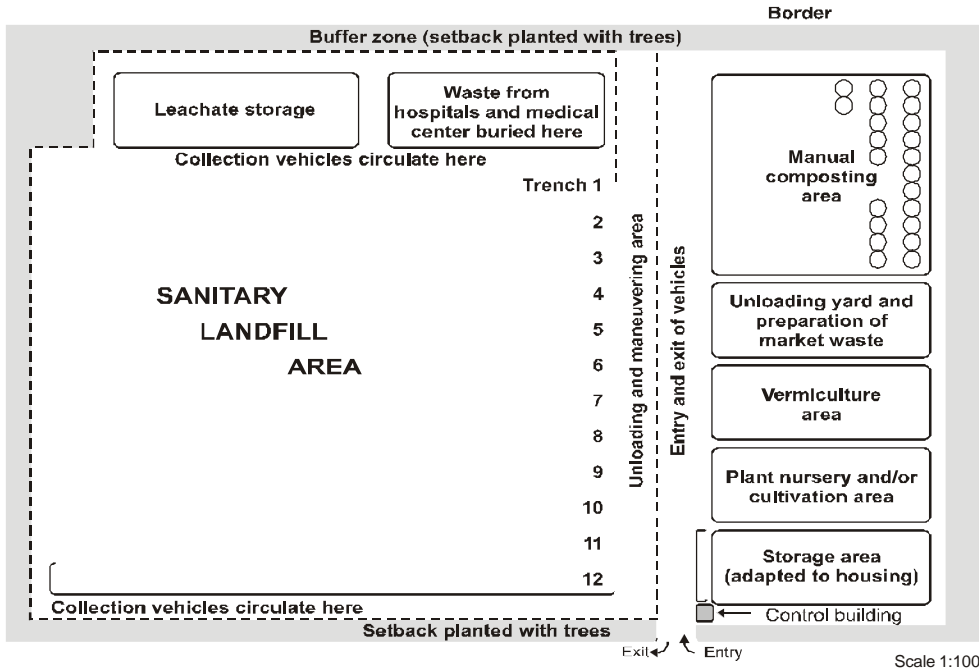
**Figure 2.5**  
**Evolution in the improvement of the final disposal of MSW<sup>1</sup>**

**2.2.4 Proposal for an integrated treatment and final disposal system**

A proposal that has been gaining ground in recent years, local conditions permitting, is that all the MSW-related activities be located at a single site: the sorting and collection of by-products recovered from MSW; the treatment of organic wastes by composting and vermiculture; final disposal in sanitary landfills; and incineration in special ovens for infectious waste or its disposal in a special cell.

These systems can, indeed, be concentrated in one area, as long as each one has its own infrastructure and none of them are neglected for the sake of economic profits only. Figure 2.6 shows a plan view of this proposal for an integrated system of MSW treatment and final disposal.

<sup>1</sup> This concept was introduced with the Environmental Action Program in the European Union (1977-1981) and has been reviewed and adapted since then.



Source: Adapted from: World Bank. Planning guide for strategic municipal solid waste management in major cities in low-income countries. London, Environmental Resources Management, 1998. v. 1.

**Figure 2.6**  
**Plan of an integrated system of MSW treatment and final disposal**



### **3. THE SANITARY LANDFILL**





### 3.1 What is a garbage dump or open dump?

The garbage “dump” is one of man’s oldest methods for getting rid of the waste matter resulting from his different activities. The place where solid waste is thrown without any attempt at sorting or treatment is called a dump. This site usually functions without technical criteria in a recharging area near a body of water, a natural drainage, etc. It has no sanitary control, nor are measures taken to prevent environmental contamination; the air, water and soil in the vicinity are impacted by gases released, leached liquids, burning and smoke, dust, and nauseating odors.

Open dumps are the breeding ground and habitat of harmful fauna that transmit many diseases. Dogs, cattle, pigs and other animals found at the dumps are a hazard for the health and safety of the local inhabitants, in particular for the families of the scavengers who survive under subhuman conditions on or near the garbage heaps.

The segregation of byproducts of the waste encourages the rapid growth of businesses dedicated to the resale and illegal trading of these materials. This, in turn, causes the depreciation of adjacent areas and buildings; it also produces filth, an increase in air contamination, and lack of safety because of the type of persons who frequent such places.

Nowadays it is considered irresponsible toward present and future generations, as well as contrary to sustainable development, for a municipality to dispose of its waste in open dumps.



**Figure 3.1**  
**Garbage in an open dump**

### **3.2 What is a sanitary landfill?**

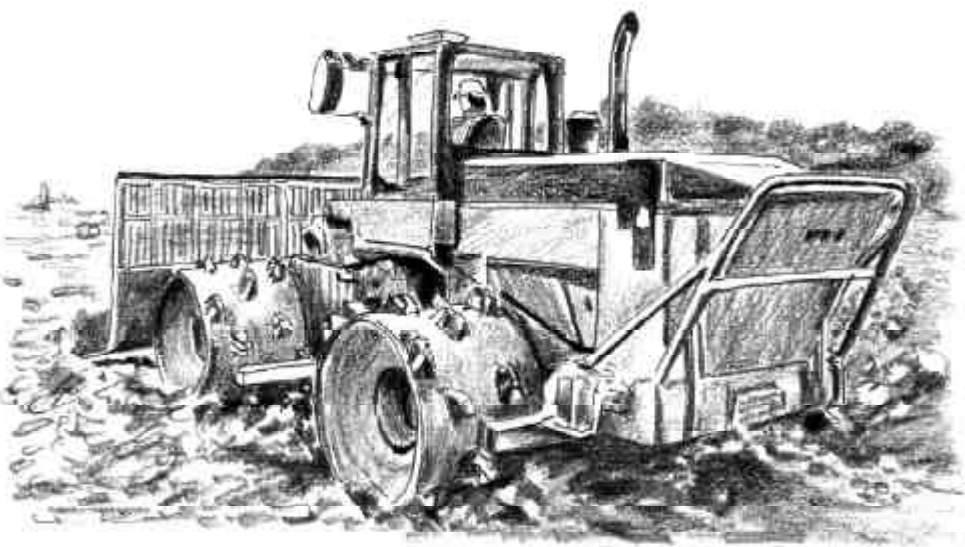
The sanitary landfill is a technique for the final disposal of solid waste in the ground that causes no nuisance or danger to public health or safety; neither does it harm the environment during its operation or after its closure. This technique uses engineering principles to confine the waste to as small an area as possible, covering it daily with layers of earth and compacting it to reduce its volume. In addition, it anticipates the problems that could be caused by the liquids and gases produced by the decomposition of organic matter.

The sanitary landfill emerged just under a century ago in the United States as the result of experiments employing heavy equipment to compact and cover waste; since then, this term has been used to refer to the site in which waste is first deposited and then covered at the end of each working day.

A modern sanitary landfill can be defined as a facility designed and operated as a basic sanitation project that has sufficiently safe elements of control, and the success of which lies in the selection of the suitable site, its design, and of course, its effective and efficient operation and control.

#### ***3.2.1 Types of sanitary landfill***

For the final disposal of municipal solid waste, three types of sanitary landfills could be proposed, as follows:



**Figure 3.2**  
**Sanitary landfill operated with heavy equipment**

### *3.2.1.1 Mechanized sanitary landfill*

The mechanized sanitary landfill is designed for large cities and populations that produce more than 40 tons of waste daily. This is an ambitious task, and it calls for quite a complex engineering project that goes beyond operating with heavy equipment. It involves researching into the quantity and type of waste, planning, site selection, the amount of land, the design and execution of the fill, the infrastructure required for receiving the waste and for the control of operations, the amount and management of the investments, and the operating and maintenance costs.

To operate this type of sanitary landfill, a solid waste compactor is required, as well as specialized earth-moving equipment: track-type tractor, backhoe, loader, dump truck, etc. (Figure 3.2)

### *3.2.1.2 Semi-mechanized sanitary landfill*

When a town needs to dispose of 16 - 40 tons daily of MSW in the sanitary landfill, it is advisable to use heavy machinery to support the manual labor, to ensure that the garbage will be thoroughly compacted, and the fill banks properly stabilized, thereby prolonging the useful life of the landfill. A farm tractor adapted with bulldozer or blade and with a scraper or roller for compacting could be suitable for operating this "semi-mechanized" landfill (Figure 3.3).

In Mexico, after 18 months of studies, tests and experiments, the former Secretariat for Urban Development and Ecology concluded that: "Using an adapted 31 HP tractor, and with the help of one laborer, we require only 8 hours of work to confine the waste generated by towns of up to 80,000 inhabitants, or approximately 40 t/d of garbage, in a sanitary landfill."<sup>2</sup>

Previous experience shows that it is necessary to use earth-moving equipment (track-type tractors or backhoes) permanently when the sanitary landfill receives more than 40 t/d of MSW. In the LAC Region, this is generally equivalent to towns with more than 40,000 inhabitants.

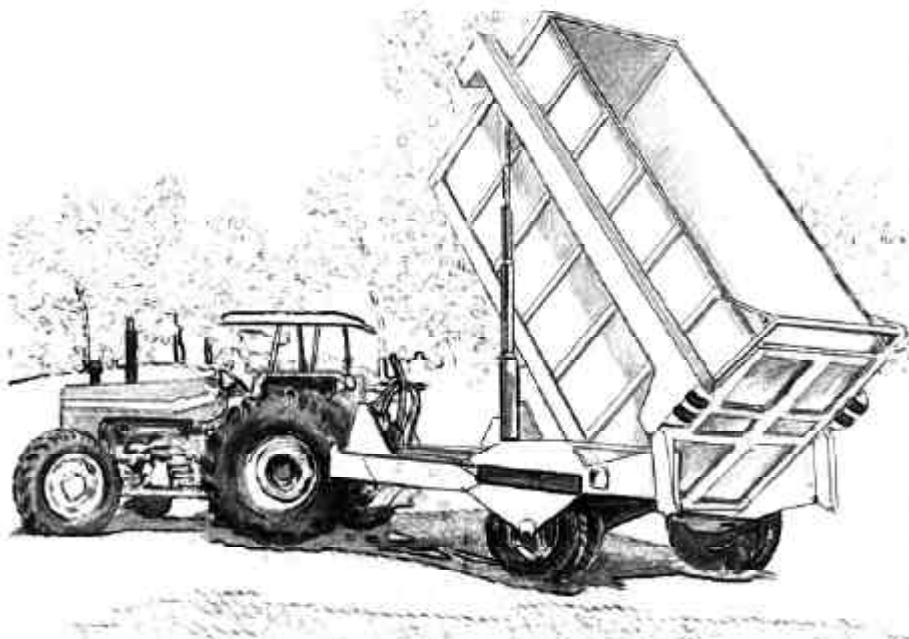
Thanks to its versatility, the farm tractor can be used to provide the waste collection service, or at least to support the regular service, if it is coupled to a hydraulic dumping trailer of some 6 to 8 m<sup>3</sup> capacity or a compaction unit, depending on the needs and resources of the locality (Figure 3.4). The municipality can occasionally

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<sup>2</sup> State Program for the Control of Municipal Solid Wastes. Secretariat for Urban Development and Ecology. Government of the State of Hidalgo, Mexico. July 1985.



**Figure 3.3**  
**Farm tractor adapted for sanitary landfill operations**



**Figure 3.4**  
**Trailer coupled to a farm tractor for the collection of garbage**

use this same equipment to carry out other public works in the city, thereby profiting to the full from the investment made.

### *3.2.1.3 Manual sanitary landfill*

This is an adaptation of the sanitary landfill project for small communities which, in view of the quantity and type of waste produced —less than 15 t/d— and their precarious economic situation, cannot afford to buy heavy equipment because of its high operating and maintenance costs.

The term “manual” refers to the fact that the task of compacting and confining the waste can be carried out by a team of laborers using hand tools.

### *3.2.2 Construction methods for a sanitary landfill*

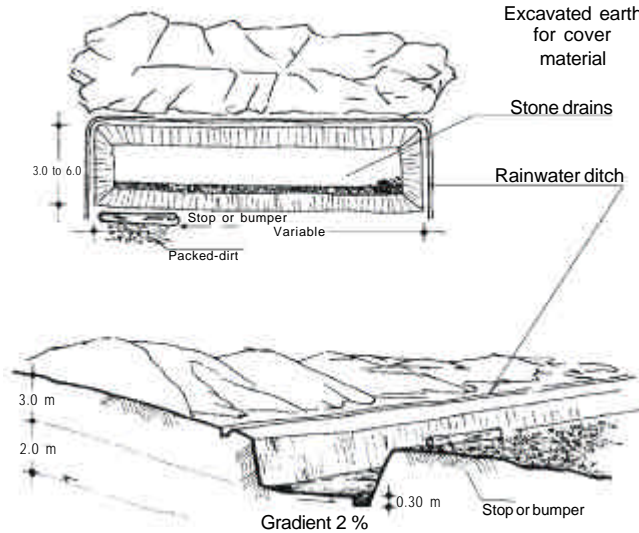
The construction method and subsequent operation of a sanitary landfill are mainly determined by the topography of the terrain, although they also depend on the type of soil and the depth of the water table. There are two basic ways of making a sanitary landfill.

#### *3.2.2.1 Trench method*

This method is used in flat regions and consists of periodically digging trenches two or three meters deep with a backhoe or a track-type tractor. Some trenches have been dug as deep as 7 m. The solid waste is placed and spread in the trench, later to be compacted and covered with the excavated soil.

Special care should be taken during rainy periods, since water can flood the trenches. To prevent this, drainage ditches should be dug around the perimeter to divert the waters, and internal drainage can also be provided for the trenches. In extreme cases a roof can be erected over them, or the accumulated water can be pumped out. The slopes or walls should be cut corresponding to the settling angle of the excavated soil.

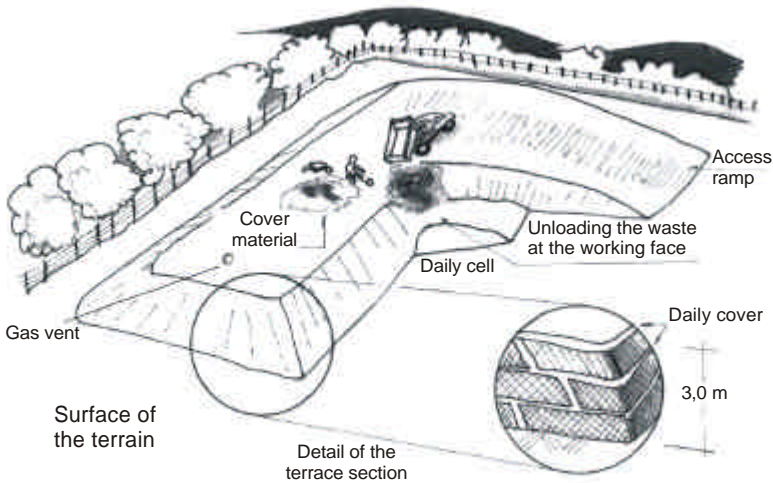
The digging of trenches demands favorable conditions with regard to the depth of the water table as well as to the type of soil. Terrain with a high water table or one close to the surface is not appropriate because of the risk of contamination of the aquifer. Rocky terrain is not suitable either, because it is difficult to dig (Figure 3.5).



**Figure 3.5**  
**Trench method for making a sanitary landfill**

**3.2.2.2 Area method**

In relatively flat areas where it may not be feasible to dig pits or trenches to bury the waste, it can be deposited directly on the original ground, which should be raised several meters after the terrain has been made waterproof. In these cases the

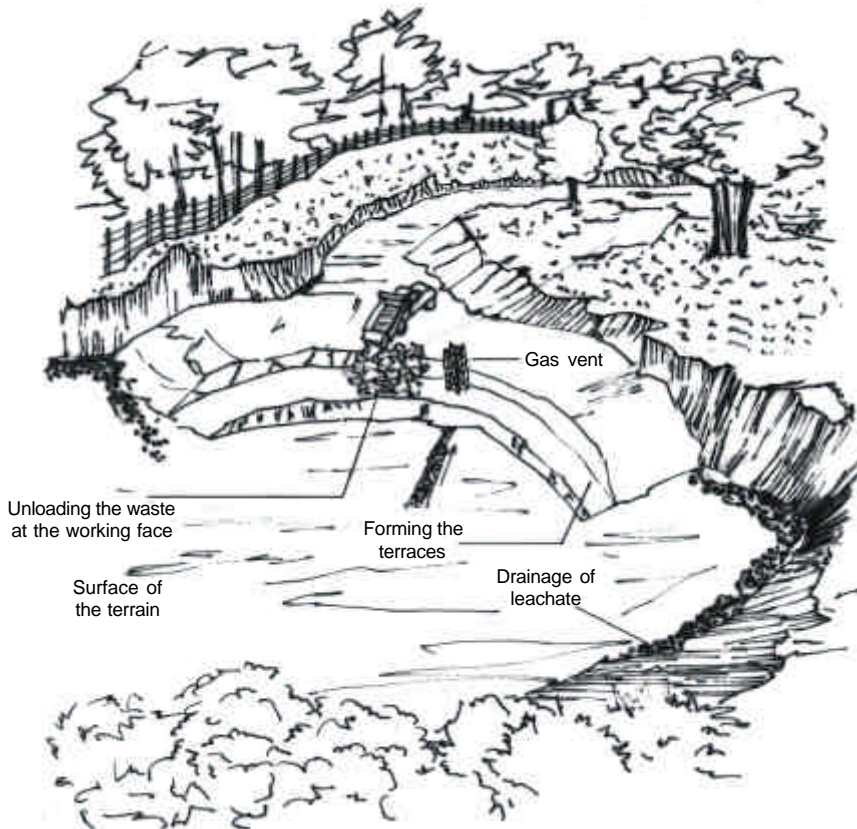


**Figure 3.6**  
**Area method for making a sanitary landfill**

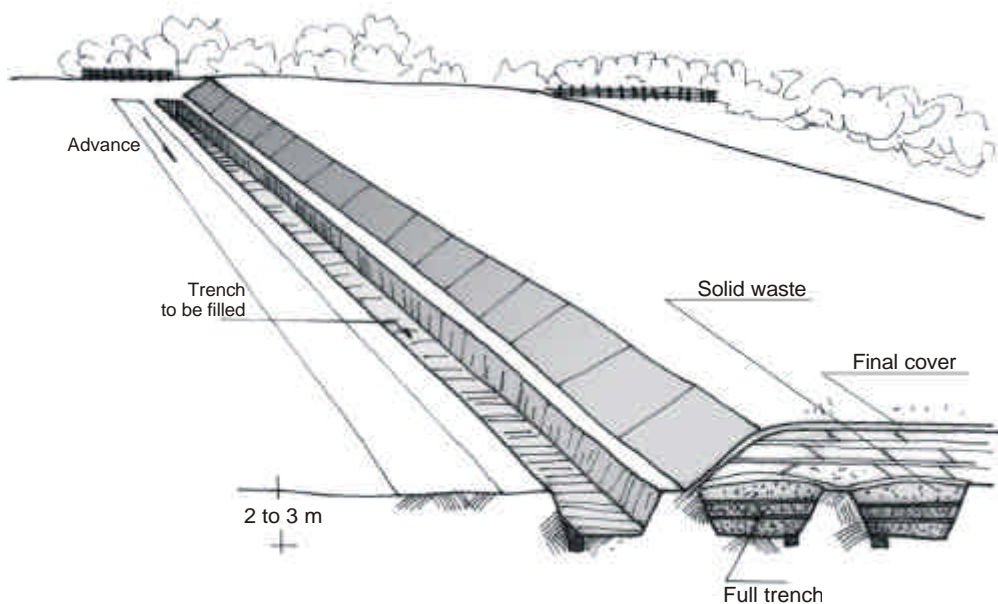
cover material will have to be brought from other places or, if possible, extracted from the surface layer. The pits are made with a gentle slope to prevent landslides and ensure greater stability as the landfill rises (Figure 3.6).

The area method can also be used to fill natural depressions or abandoned quarries that are several meters deep. The cover earth is excavated from the sides of the terrain or from a nearby site in order to avoid or reduce the haulage expense. The operation of unloading and construction of the cells should begin from the bottom up (Figure 3.7).

The landfill is made supporting the cells on the natural slope of the terrain, that is, the waste is unloaded at the toe or base of the slope, where it is spread and packed against it, and it is covered daily with a layer of soil. This activity is repeated as the operation continues, advancing over the site, maintaining a gentle slope of some 18.4 to 26.5 degrees, that is, a vertical/horizontal ratio of 1:3 to 1:2, respectively, and of 1 to 2 degrees on the surface, that is, a 2 to 3.5% grade.



**Figure 3.7**  
**Area method for filling depressions**



**Figure 3.8**  
**Combination of both methods to construct a sanitary landfill**

### 3.2.2.3 *Combination of both methods*

Since these two methods of constructing sanitary landfills use similar operating techniques, it is possible to combine them to make full use of the site and the cover material, and to obtain better results (Figure 3.8).

**Every city or town should have a sanitary landfill of its own or permission to use that of a neighboring municipality to dispose of its MSW. Otherwise, the irresponsible practice of throwing garbage on an open dump will continue.**

### 3.2.3 *Advantages and disadvantages of a sanitary landfill*

Table 3.1 summarizes the principal advantages and disadvantages of the sanitary landfill.



**Table 3.1**  
**Advantages and disadvantages of the sanitary landfill**

Advantages	Disadvantages
1. The initial capital investment is lower than that required to establish incineration plants or composting facilities for waste treatment.	1. The acquisition of the terrain is often a problem due to local inhabitants' opposition to the selected site (known as the NIMBY phenomenon: Not In My Back Yard) for various reasons: <ul style="list-style-type: none"> <li>. Lack of knowledge of the sanitary landfill technique.</li> <li>. The term sanitary landfill is associated with the open dump.</li> <li>. Citizens' evident distrust of local administrations that do not guarantee the quality or the sustainability of the work.</li> <li>. Legal problems regarding land registration.</li> </ul>
2. It has lower operating and maintenance expenses than treatment methods.	2. The rapid process of urban growth that limits the amount of land available and makes it more expensive, causing the sanitary landfill to be located at a distance from the town.
3. A sanitary landfill is a complete and definitive method, given its capacity to receive every kind of MSW.	3. The vulnerability of the quality of operation of the landfill and the high risk of its becoming an open dump, mainly because of a lack of political decision on the part of local governments to invest the necessary funds for its correct operation and maintenance.
4. It creates employment for unskilled labor, which is available in abundance in developing countries.	4. The finished landfill is not recommended for building homes, schools, etc.
5. Methane gas can be collected in sanitary landfills that receive more than 500 t/day, and this gas can be an alternative source of energy for some cities.	5. The restriction against building heavy infrastructure because of settling and sinking after the landfill is finished.
6. Its location can be as close to the urban area as the existence of available sites permits, which reduces hauling costs and facilitates supervision by the community.	6. It is necessary to monitor the site after closure of the sanitary landfill, not only to check for negative environmental impacts, but also to prevent undue use of the site by the inhabitants.
7. It allows lands considered unproductive or marginal to be recuperated, making them useful for constructing parks, recreational facilities, green areas, etc.	7. It can cause a long term environmental impact if the necessary precautions are not taken in the selection of the site and if mitigation measures are not applied. In the case of large sanitary landfills, it is advisable to analyze the effects of vehicular traffic, in particular the trucks carrying the waste on the roads that converge on the site and that produce dust, noise and windblown litter. In the immediate neighborhood the impact is produced by the liquids, gases and bad odors that can emanate from the landfill.
8. A sanitary landfill can start operating in a short time as a waste elimination method.	8. The properties or lands surrounding the sanitary landfill may be devalued.
9. It is considered flexible because it can receive greater additional quantities of waste with a small increase in personnel.	9. Usually it cannot receive hazardous waste.

### **3.2.4 Future use of the sanitary landfill**

The future use or “end use” of a sanitary landfill depends on several factors: the climate, location with respect to the urban area, its distance from inhabited areas, surface area, and construction characteristics. These “construction characteristics” refer to the final layout of the landfill, the height and degree of compacting, and also—an important factor—the economic capacity of the town’s inhabitants.

The site of a closed sanitary landfill is ideal for developing scenic and social programs such as a park, a sports field or a green area. Fortunately, the LAC Region already has several instances of such sites that have been successfully transformed into parks and recreational areas in Mexico City, Santiago, Buenos Aires, and other cities.

The landfill surface is not recommended for buildings, houses, schools, or any other heavy infrastructure, because it does not have the capacity to support heavy structures; besides, there could be problems due to sinking and the production of gases.

To re-create the natural landscape, grass and plants with short roots should be planted. In many cases, after the final earth cover has been applied, grass grows back spontaneously.

## **3.3 Reactions that take place inside a sanitary landfill**

### **3.3.1 Physical, chemical, and biological changes**

The MSW deposited in a sanitary landfill undergoes a series of physical, chemical, and biological changes that are simultaneous and interrelated. These changes are described below to give an idea of the internal processes that take place when the wastes are confined.

**Physical changes.** The most important physical changes are those associated with the compacting of the MSW, the migration of gases within and outside the sanitary landfill, the intake of water and the movement of liquids in the interior and toward the substratum, and settling caused by the consolidation and decomposition of the organic matter present in the waste.

The migration of gases is of particular importance for the operational and maintenance control of the system. For example, when biogas is trapped, internal pressure can cause cracking of the cover and fissures. This condition allows rainwater

to penetrate inside the sanitary landfill. This water, in turn, causes a greater production of gases and leaching, contributing to differential sinking and settling at the surface and the destabilization of the fill banks due to the greater weight of the mass of wastes.

**Chemical reactions.** Chemical reactions that occur within the sanitary landfill and also in open garbage dumps include the dissolving and suspension of matter and products of biological conversion in the liquids that filter through the mass of MSW, the evaporation of chemical compounds and water, the adsorption of volatile organic compounds, the dehalogenation and decomposition of organic compounds, and the reactions of oxidation-reduction that affect the dissolving of metals and metallic salts. (The significance of the decomposition of organic products is that these materials can be transported out of the sanitary landfill or out of the garbage dump with the leachates).

**Biological reactions.** The most important biological reactions that occur in sanitary landfills are carried out by aerobic and anaerobic microorganisms, and are associated with the organic part of the MSW, which produces gases and leachates. The process of decomposition starts with the presence of oxygen (aerobic phase); once the waste is covered, the oxygen starts to be consumed by biological activity. During this phase the principal product is carbon dioxide. Once the oxygen is consumed, decomposition takes place without it (anaerobic phase): at this stage the organic matter is transformed into carbon dioxide, methane, and traces of ammonia and hydrogen sulfide.

### *3.3.2 Generation of liquids and gases*

Almost all solid waste suffers a certain degree of decomposition, but it is the organic component that undergoes the greatest changes. The byproducts of decomposition include liquids, gases and solids.

**Leached or percolated liquid.** The natural decomposition or putrefaction of garbage produces a foul-smelling black liquid, known as leached or percolated liquid, that looks like domestic water waste, but much more concentrated.

Rainwater filtering through the layers of waste increases its volume in a far greater proportion than does the moisture of the MSW. It is therefore important to intercept the water and divert it to prevent an increase in leaching; otherwise there could be problems in the operation of the landfill and contamination in the water courses, sources of water, and neighboring wells.

**Gases.** A sanitary landfill behaves like an anaerobic digester. In addition to producing liquids, the natural decomposition or putrefaction of the MSW produces

gases and other compounds. The decomposition of organic matter by action of microorganisms present in the medium has two stages: aerobic and anaerobic.

During the *aerobic* stage the oxygen that is present in the air contained in the interstices of the mass of buried waste is rapidly consumed.

The *anaerobic* stage, on the contrary, is the one that predominates in the sanitary landfill because the air does not pass through it and there is no circulation of oxygen; thus appreciable quantities of methane ( $\text{CH}_4$ ) and carbon dioxide ( $\text{CO}_2$ ) are produced, as well as traces of foul-smelling gases, such as hydrogen sulfide ( $\text{H}_2\text{S}$ ), ammonia ( $\text{NH}_3$ ), and mercaptans.

Methane gas deserves the greatest attention because, although it is odorless and colorless, it is inflammable and explosive if it is concentrated in the air in a proportion of 5 to 15% in volume; gases have a tendency to accumulate in empty spaces inside a landfill and take advantage of any fissure in the terrain or permeability in the cover to leak out. When methane gas accumulates inside the landfill and migrates to adjacent areas, there is a risk of explosion. It is therefore recommended that there be adequate venting of this gas. However, in small landfills this is not a significant problem.

### **3.3.3 Differential sinking and settling**

In the sanitary landfill, sinking (uniform settling or faults) occurs. This is the easiest problem to spot, and also the easiest to control with good compaction. Differential settling also occurs at the surface, and in time this gives rise to depressions and cracks of different sizes, causing ponding of water and an increase of leachates and gases. These problems depend on the layout and height of the landfill, the type of waste buried, the degree of compaction, and volume of rainfall in the area.

## **3.4 Basic principles of a sanitary landfill**

The following basic practices for the construction, operation, and maintenance of a sanitary landfill should be emphasized:

- ? Constant supervision during the construction, to make sure that a high level of quality is maintained in the building of the landfill infrastructure and in the routine daily operations of unloading the waste, covering it, and compacting the cell to keep the landfill in an optimal condition. This means appointing one person to be responsible for its operation and maintenance.
- ? Diversion of runoff waters to prevent as far as possible their filtering into the sanitary landfill

- ? Verifying the height of the daily cell to reduce problems of sinking and ensure greater stability. The daily cell is the construction unit of the sanitary landfill. See 5.11.
- ? Daily covering with a layer of 0.10 to 0.20 m of soil or similar cover material.
- ? Compacting the MSW with layers 0.20 to 0.30 m thick and final compaction when the whole cell is covered with soil. The success of the daily work largely depends on this task, since in the long term it enables a greater density to be achieved and prolongs the useful life of the site.
- ? Achieving greater density (specific gravity) since this is more advisable from the economic and environmental points of view.
- ? Control and drainage of percolated liquids and gases to maintain ideal operating conditions and protect the environment.
- ? The final cover, some 0.40 to 0.60 m thick, is installed using the same methodology as for the daily cover; the final earth cover must be capable of producing and sustaining vegetation for the integration of the closed site into the natural landscape.

#### **3.4.1 Importance of the cover**

The daily covering of the waste and the final covering of the sanitary landfill with soil is of vital importance for the success of this work. The sanitary landfill has to carry out the following functions:

- ? Minimize the presence and proliferation of flies and birds.
- ? Prevent the entry and proliferation of rodents.
- ? Prevent fires and smoke.
- ? Reduce bad odors.
- ? Reduce the intake of rainwater into the garbage.
- ? Direct gases toward the vents to evacuate them from the sanitary landfill.
- ? Have an aesthetically acceptable appearance.
- ? Serve as a basis for internal access roads.
- ? Allow the growth of vegetation.

**One of the differences between a sanitary landfill and an open dump is the utilization of cover material (earth) to confine the waste at the end of each working day, thereby effectively separating the garbage from the external environment.**



## **4. THE MANUAL SANITARY LANDFILL**





#### 4.1 Why a manual sanitary landfill?

The manual sanitary landfill is a technically and economically feasible alternative, benefiting urban and rural populations of less than 30,000 inhabitants who have no way of acquiring the heavy equipment they would need for constructing and operating a conventional sanitary landfill. This is also a good alternative for the marginal areas of some cities.

**Populations that have settled on the outskirts of large cities are usually affected by the presence of garbage dumps and they usually lack a refuse collection service.**

This manual operation technique requires heavy equipment only to prepare the site, that is, for the construction of the internal road, the preparation of the supporting base or the digging of trenches and the extraction of cover material in accordance with the progress made and the fill method. The rest of the work can be carried out by the laborers without heavy machinery, which means that small communities with scanty resources—unable to acquire and maintain a track-type tractor or a backhoe—are able to dispose hygienically of the small amount of waste they produce, employing unskilled labor.

A sanitary landfill can serve two or more towns, and can eventually become a regional solution, that is, able to offer the service of final disposal of MSW to several nearby towns. In this context, small municipalities should evaluate the technical, economic, social and environmental desirability of taking their wastes to a regional sanitary landfill or to the neighboring municipality, or installing one of their own.

The manual sanitary landfill is adequate for towns that produce up to 15 tons of MSW per day. However, a careful analysis of the local conditions should be made in each region, since the site characteristics, the availability of cover material, the climate, the cost of labor, etc., may be such that the use of heavy equipment will, after all, be the preferred option for the construction and operation of the sanitary landfill, either temporarily or permanently.

The operation of a manual sanitary landfill that receives more than 15 tons per day of waste can become quite complicated, since it requires a larger number of workers, above all for the spreading and compacting processes and for the extraction and hauling of the cover material. In these cases the manual operation will certainly need the support of at least one farm tractor, as explained in the section on semi-mechanized landfills (Chapter 3, point 3.2.1.2).

#### 4.2 Is a small town justified in having a track-type tractor for operating a sanitary landfill?

To demonstrate that a small town is not justified in having a track-type tractor to operate a sanitary landfill, we present the following example (adapted from Héctor Collazos “*Relleno sanitario manual*,” Revista Acodal 87, 1979):

We will take two imaginary towns with the following characteristics:

Town	Number of inhabitants	Per capita production of solid waste kg/cap/day
A	250,000	0.5
B	30,000	0.4

For comparative purposes, let us assume that in each of the two towns a small 100 HP (D4) track-type tractor is used to operate a sanitary landfill with the following characteristics:

- ? Distance transported                      30 m
- ? Angledozer
- ? Return speed                                4 km/hr
- ? Productivity corrected for efficiency with garbage and earth in sanitary landfills

Material	Productivity of the equipment* (m <sup>3</sup> / hour)
? Waste	37
? Earth	14

\* The values are general and are presented as a guide for the calculation. The productivity in each region can be consulted with the equipment suppliers.

The above information enables us to determine the capacity of the equipment with the quantity of waste received from each town:

*Solution*1. *Waste generation*

$$\text{Waste generation} = \text{Population (inhab.)} * \text{ppc (kg/cap./day)} / 1000 = (\text{ton/day})$$

$$? \quad \text{Town A} = 250,000 \text{ inhab.} * 0.5 \text{ kg/cap./day} = 125 \text{ t/day}$$

$$? \quad \text{Town B} = 30,000 \text{ inhab.} * 0.4 \text{ kg/cap./day} = 12 \text{ t/day}$$

2. *Garbage collection* (6 days a week, from Monday to Saturday)

$$? \quad \text{Town A} = 125 \text{ t/day} * 7/6 = 145.8 \text{ t/day}$$

$$? \quad \text{Town B} = 12 \text{ t/day} * 7/6 = 14 \text{ t/day}$$

3. *Volume of garbage* (for a density of 0,6 t/ m<sup>3</sup> recently compacted)

$$? \quad \text{Town A} = \frac{145.8 \text{ t/day}}{0.6 \text{ t/ m}^3} = 243.1 \text{ m}^3/\text{day}$$

$$? \quad \text{Town B} = \frac{14 \text{ t/day}}{0.6 \text{ t/ m}^3} = 23.3 \text{ m}^3/\text{day}$$

4. *Cover material* (estimated to be 20% of the recently compacted garbage)

$$? \quad \text{Town A} = 243.1 \text{ m}^3/\text{day} * 0.2 = 48.6 \text{ m}^3 \text{ of soil/day}$$

$$? \quad \text{Town B} = 23.3 \text{ m}^3/\text{day} * 0.2 = 4.7 \text{ m}^3 \text{ of soil/day}$$

5. *Time during which the track-type tractor is in use* (in an 8-hour day)**Town A**

$$\text{Garbage} = \frac{243.1 \text{ m}^3/\text{day}}{37 \text{ m}^3/\text{hour}} = 6.57 \text{ hours/day}$$

$$\text{Earth} = \frac{48.6 \text{ m}^3/\text{day}}{14 \text{ m}^3/\text{hour}} = 3.47 \text{ hours/day}$$

	<b>10.04 hours/day</b>
<b>Total</b>	

**Town B**

$$\text{Garbage} = \frac{23.3 \text{ m}^3/\text{day}}{37 \text{ m}^3/\text{hour}} = 0.63 \text{ hours/day}$$

$$\text{Earth} = \frac{4.7 \text{ m}^3/\text{day}}{14 \text{ m}^3/\text{hour}} = 0.33 \text{ hours/day}$$

$$\text{Total} \qquad \qquad \qquad \underline{\underline{0.96 \text{ hours/day}}}$$

The calculations show that a city of 250,000 inhabitants requires a track-type tractor to work a full day (8 hours/day), and even to work overtime, but that this equipment is in no way justified for towns of 30,000 or fewer inhabitants

There can be no doubt, then, that the manual sanitary landfill is a viable option for small towns. The employment of laborers can provide an economic solution to the problem of final waste disposal in these small communities.

**4.3 Planning**

A manual sanitary landfill, although a small project, is still an engineering project in which potential future problems are prevented by careful planning to cover all stages, from the conception and design of the work to its construction, operation and closure.

The initial planning will set the bases for the different activities to be carried out. This phase consists of the evaluation of site selection criteria and of the different alternatives for the location, design, construction, operation, maintenance and monitoring of the sanitary landfill. The planning also provides essential basic information: the beneficiary population; the origin, quantity and quality of the MSW; the future use of the site once the landfill is completed; the resources for its financing; and the consultancy of a competent professional.

The planning should include a public information campaign to explain the advantages and disadvantages of a sanitary landfill and the importance of closing down the open garbage dump. Gaining public support has to be a major goal of local governments interested in executing this basic sanitation project, since without this backing it is unlikely that they will be able to carry out the project or ensure an efficient operation and maintenance.

The local administration as well as the community at large should bear in mind that a manual sanitary landfill, like any other basic sanitation project, requires funds to finance the site selection studies, the design, the construction, and the initial operation phase. It must be realized that throughout the entire service life of the landfill, the municipal administration, or whoever operates the system, will have to include in its budget the item of landfill operation and maintenance.

It is essential that the population be made aware of the benefits of eradicating the municipal garbage dump and constructing a sanitary landfill, and of the cost of this project. If the community is willing to pay, the sustainability of (1) a good public cleaning service and (2) the operation and maintenance of the landfill are guaranteed.

**Every user of the service, every producer of MSW, must pay the affordable tariff established by the municipality if the latter is to provide a good urban cleaning service, which, without a doubt, will help improve the quality of life of the whole population.**

#### 4.4 Site selection

For the selection of the site, preference should be given to places where the operations of the sanitary landfill will lead to an improvement in the terrain; this will greatly reduce any possibility of operational problems in the future.

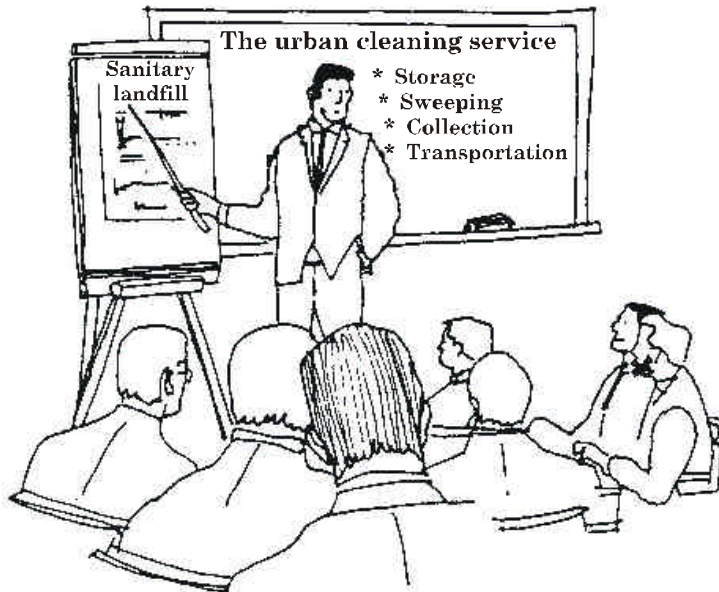
Only very rarely will a terrain meet all the ideal requirements for the construction of a sanitary landfill. The site with the best characteristics should be selected, and the technical and economic resources available should be used to analyze the drawbacks.

For the successful construction of a sanitary landfill, the following points must be taken into account:

##### 4.4.1 *Participation of local authorities and inhabitants*

###### ? *Participation of local authorities*

The site should be selected in coordination with the environmental and health authorities, and, of course, the local planning department (Figure 4.1).



**Figure 4.1**  
**The project is presented to the local authorities**

For presenting the sanitary landfill project to the authorities it is recommended that the following steps be taken:

**First**, the sanitary engineer, environmental engineer or technician in sanitation and a delegate from the local government (director of the planning department, public works, etc.) will determine what sites are available and appropriate for the construction of a manual sanitary landfill. Important tools will be maps of the city, topographical plans, aerial photos, and even the new Geographic Information Systems (GIS).

**Second**, the engineer or specialist technician—with the help of the geologist's analysis of the terrain and the soil characteristics— will prepare a report giving the order of eligibility of the possible sites pre-selected for the construction of the sanitary landfill. It is recommended that some calculations and preliminary designs be included, with an estimate of the useful life of the landfill and the cost of the works.

**Third**, the final decision will be subordinated to administrative and political considerations, and public opinion will be taken into account. The project should be submitted to the city council or assembly for their approval. If the land is not municipal property, the mayor will seek the authorization of the council to enter

into the necessary negotiations and make the budgetary transfers for the purchase of the land and the construction of the landfill with its various support facilities.

**Fourth**, the final tasks are to order the topographical survey (in those cases where it is considered necessary), prepare calculations and definitive designs for the sanitary landfill, estimate expenses, seek financing, and proceed with the project execution.

#### ? *Participation of the inhabitants*

From the beginning of the selection process the public should be given the opportunity to participate, comment on the proposals made, and raise objections when necessary. In all cases it is imperative to ensure the support of the different sectors of the population during the stages of selection, design, construction, operation, maintenance and end use of the landfill.

This citizen participation aspect is very important. The people often confuse a sanitary landfill with an open dump. It is a good idea to design and conduct an educational campaign emphasizing environmental health as a means of protecting personal health and preventing pollution. The campaign can involve local schools, community associations, cultural institutions, popular clubs, non-governmental organizations, etc. Also recommended are the use of the mass media and even the local parish priest to support this campaign.

The proposal to build a sanitary landfill to solve the waste disposal problem may encounter opposition or outright rejection if the local inhabitants do not participate in programs of sanitary education and negotiation processes<sup>3</sup> directed by the local government and environmental institutions. Local governments must make every effort to help the people understand that the problem of waste disposal is a complex one, and it is not going to be solved by their dumping the garbage somewhere on the outskirts of their neighborhood; also, for the population to accept the project, they will have to be persuaded that treatment systems are not a final solution, but rather they are complementary to the sanitary landfill.

#### **4.4.2 Technical aspects**

The engineer or specialist technician should take into account the following factors:

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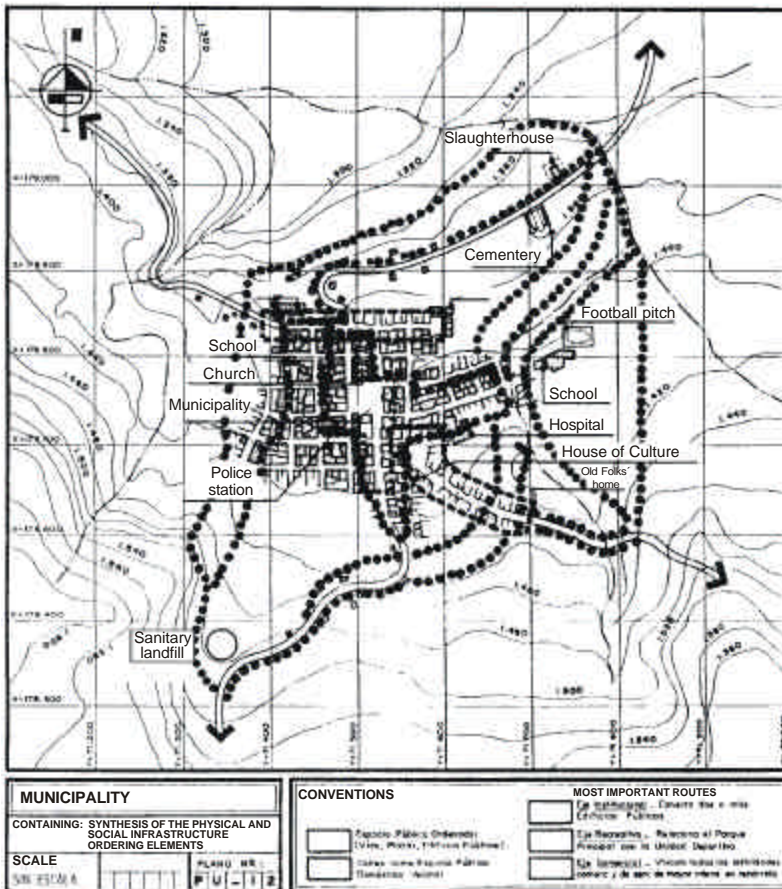
<sup>3</sup> Negotiation with the people living in the vicinity of the new sanitary landfill can cover the construction of basic infrastructure, compensatory works to cover community needs, the lowering of the urban cleaning tariff, etc.

? **Land-use plan or land regulating plan**

It is essential that those responsible for site selection consult the land-use plan or regulating plan of the municipality for information such as the delineation of the urban perimeter, the growth tendency, areas of future expansion, and the areas where the construction of sanitary landfills would be permitted according to the land usage approved by the city council.

? **Location**

It is advisable that the sanitary landfill be located in the direction or line of growth of the town development; however, in order to avoid disputes with the population, ideally this place would start to be populated once the useful life of the landfill has come to an end, so that the new community will have the benefit of a park or green area.



**Figure 4.2**  
**Locating the sanitary landfill near the urban area**



Special care must be taken in selecting sites on land where there may be archeological zones or special protected areas, which implies consultation with the National Institute of Culture or other pertinent authority to obtain permission. Landfills should not be constructed on land under high tension lines.

From the point of view of the urban cleaning service, the importance of the site location is its distance from the urban center (main square) and the time it will take the collection vehicle to arrive at its final destination, because on that depends the number of trips per day that it can make with loads of waste. This has repercussions on the coverage of the collection service and the cost of waste haulage. Ideally, the site should not be more than 30 minutes round trip from the center of town (Figure 4.2).

The nearer the landfill, the more effective will be its surveillance and supervision by the community, which will thus be able to assess the quality of its operation and maintenance. Once its useful life is over, the closed landfill site will be used by the community as proposed in the initial project.

**The sanitary landfill should be as close as possible to the urban area, especially in a small municipality.**

It should be noted that there is no consensus about a minimum distance between a landfill and a populated area that will guarantee the absence of risks to health and the environment. A great deal depends on the availability of suitable sites, the topography, the quantity and quality of waste to be disposed of, the useful life of the site, and, above all, the type of infrastructure the landfill will have in order to prevent or mitigate negative effects.

Although defining a distance does play a role in the reduction of possible risk or nuisance factors, such a definition cannot be definitive. The greatest obstacle to agreement on a distance is the perception of some technicians and neighbors of the site who believe that this type of facility should be constructed as far away as possible. They argue that it could end up as a simple open dump due to the fact that local governments do not always invest in the necessary infrastructure, nor do they guarantee the quality of the operation once the unloading of MSW has started on the site. One of the causes of this distrust lies in the continuous changes of local administrations and, consequently, of local government priorities. The NIMBY syndrome is a clear reflection of this.

Some specialists recommend that the borders of a sanitary landfill site be traced at a minimum distance of 200 m from the nearest residential area; however, in the case of a manual sanitary landfill—which is very small—the distance could be much

less. In any case, at the time of making this decision about a specific project, it is advisable to analyze the variables noted above, in particular the conditions of the soil and the environment. It must not be forgotten that each case is unique and merits an evaluation of its own.

It should also be pointed out that there are even experiences of large sanitary landfills constructed in the middle of a city without any serious health risks or negative environmental impacts having arisen, thanks to the fact that their construction, operation, and maintenance have been managed with due responsibility.

#### **4.4.3 Preliminary analysis**

Field visits will be made jointly with the local health and environmental authorities. For these visits it is advisable to have the urban maps of the region, on a scale of 1:10,000 or 1:25,000, so that possible sites can be evaluated in relation to the principal roads entering and leaving the urban area, the nearest watercourses, and the distribution of soils typical of the region.

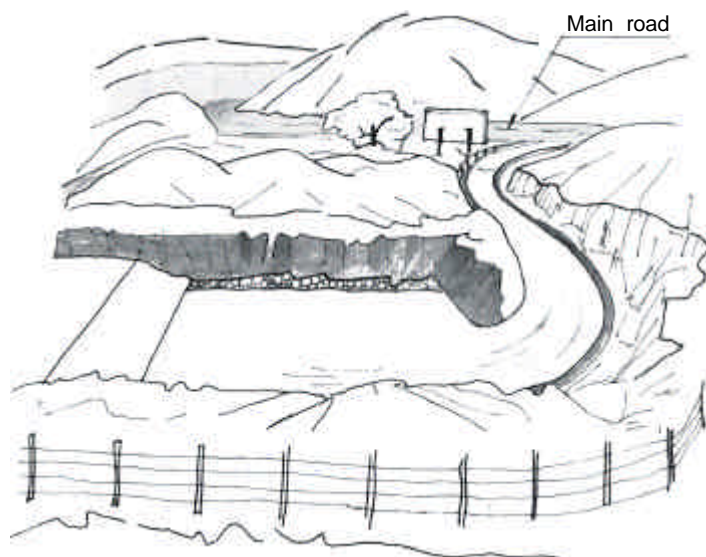
Once back in the local planning office, the project designers will consult the land-use plan to verify land uses and restrictions, and locate on the maps the future urban expansion zones. The compatibility of the most promising sites with the requirements for the sanitary landfill eventually to be constructed in the area is analyzed at this stage.

#### **4.4.4 Field research**

The best sites visited will be researched in greater detail. For example, it will be necessary to find out whether there are drinking water wells in the area, and to determine soil characteristics and the level of the water table; in addition, landmarks, geographical features, water sources, roads and important constructions will be identified.

An urban map on a scale of 1:2,000 or 1:5,000 will show these details and make it easier to weigh up the advantages and disadvantages of each site, and to make the preliminary calculations on the useful service life and costs. This information will be submitted to the local authorities for their consideration, since it is they who will make the final decision.

Remember that one of the first decisions to be made refers to the integration of the MSW treatment and final disposal systems, which will obviously influence the location and size of the site. However, in this case the selection criteria for the construction of the landfill will be the determining factors. These criteria are:



**Figure 4.3**  
The sanitary landfill is located close to a main road

? *Access roads*

The site should be close to a main road for easy access and to keep down the costs of hauling the MSW and constructing the internal penetration road. These roads should permit easy, safe, and rapid entry of the collection vehicles at all times of the year (Figure 4.3).

**For the construction of manual sanitary landfills, in view of the small amount and variety of MSW that will be disposed of (Chapter 5, point 5.1.3), exceptions can be made to the requirement of making the site impermeable.**

**In other words, it is considered unnecessary to waterproof the terrain in the following cases: in areas where there is little rainfall (the coast of Chile and southern Peru) or the rainfall rarely exceeds 300 mm/year; in places where the climate is very dry or solar radiation is high and where the little moisture contained in the waste is easily lost through evaporation (the Atlantic coast of Colombia); in places with landfills already built where there is no apparent production of leachates or biogas or where the depth of the water table is greater than 30 m.**

### ? *Hydrogeological conditions*

Before negotiating the purchase of the land it is important to analyze the type of soil on which the sanitary landfill will be constructed. It should be impermeable, clayey soil, otherwise it must be made impermeable with a layer of compacted clay 0.30 m thick or, as a last resort, with a geomembrane of PVC (polyvinyl chloride) or high density polyethylene. In some cases it is advisable to test the permeability of the soil that will serve as a base for the future landfill in order to prevent the contamination of the aquifer (see Annex 1).

The above is possible since, if there is no water in the waste, the process of bacterial decomposition is very slow (if it occurs at all) so only very small quantities of leached liquid and biogas are produced, and these are retained in the interior of the landfill. It should be recalled that the field capacity of the cover soil and the waste also have an influence in preventing liquids from being released, especially when the compaction in these manual landfills is considered weak. (Chapter 5, point 5.91)

It is also necessary to evaluate the depth of the water-bearing stratum or groundwater. A distance of at least 1.0 m between the water table and the solid waste is recommended when there is silty clayey soil.

**The ideal site, that is, one that meets all the requirements for the construction of a sanitary landfill, does not exist; in practice, it will be necessary to choose the best of several alternatives, after giving due consideration to the conditions of each locality.**

### ? *Useful life of the site*

It is desirable that the selected site will be large enough for a minimum of five years' use, to justify the management, and the expenses of preparation and infrastructure works. However, this does not mean that if sites with a smaller capacity are available, they should be rejected as a matter of course. These small lots often serve to install pilot projects that will gain the trust of the inhabitants, with a view to later acceding to larger sites with a longer useful life.

Table 4.2 illustrates the area of land required for the construction of a manual sanitary landfill for a small population, based on the following data: the daily per capita production of MSW, the density of compaction of the landfill, the volume of the cover material, the depth or height of the landfill, and the additional areas for



? ***Cover material***

The site should preferably have abundant cover material that can be easily extracted and has high clay content, because clay has low permeability and a high capacity to absorb contaminants. If there is not much clayey soil at the site, a nearby source must be found that guarantees a permanent supply in sufficient quantities so that the cost of moving it to the site is not too high. If no such source is found, it will be better to reject this site because it runs the risk of becoming an open dump.

? ***Conservation of natural resources***

The site should be located downstream from any intake structure where water is extracted for human consumption, and from surface water sources in general. Ideally it should be in an isolated area, of little commercial value, in a marginal zone or wasteland, where the landfill will not have a high contamination potential.

? ***Climate conditions***

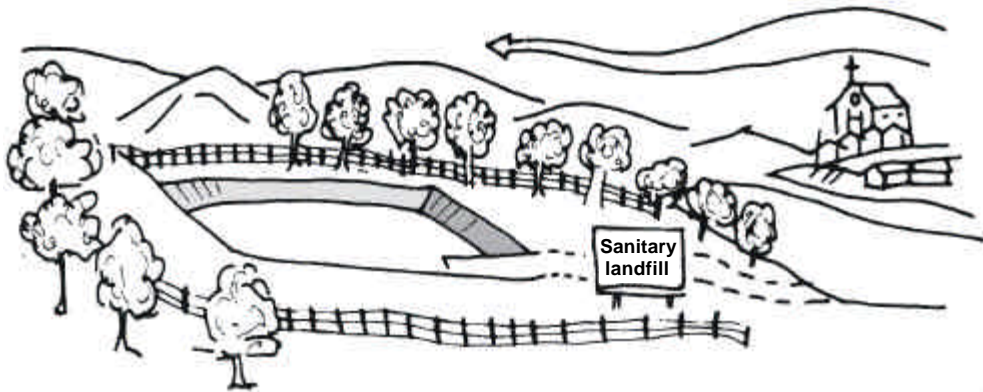
The direction of the prevailing wind is important because of the nuisance caused by the unloading of waste, extraction of soil, and covering; papers and other light material in the waste are blown by the wind, dust is raised, and the wind can also carry noxious odors to neighboring areas. Thus, the sanitary landfill should be located downwind from the urban area; otherwise, to counteract this nuisance trees and thick vegetation should be planted all around the landfill. The vegetation, in addition, acts as a screen to prevent the neighbors and passers-by from observing the MSW disposal operations and gives a more aesthetic appearance to the site.

Rain is another vitally important factor; it is recommended that the records of rainfall and dry periods be obtained, in order to estimate the amount of water that falls on the area under study. National meteorological institutions or water and sewerage service companies can provide this information. Even when rainfall is expressed in mm/year, it is advisable to consult the monthly records of several years for the sizing of the perimeter drains and the leachate collection and disposal system.

? ***Ownership of the land***

Work should start on a sanitary landfill project only when certain conditions are in place: when the municipality or town council has in its possession the legal document of land ownership; when the project has been authorized by the pertinent authorities; and also when it has been accepted by the majority of the community members, with awareness of its future use.

**Legal ownership of the land is a fundamental requisite before a start can be made on the construction of the infrastructure and operation of the sanitary landfill.**



**Figure 4.4**  
**Direction of the prevailing wind**

**? Cost of the land and of the infrastructure works**

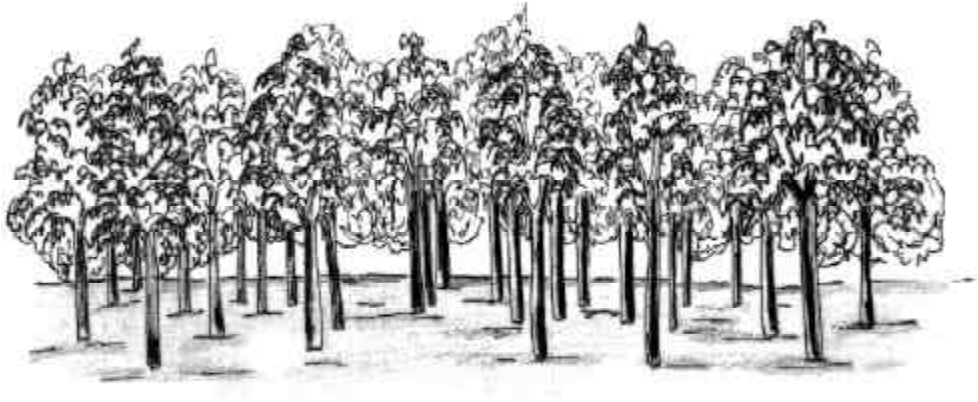
Once the most appropriate sites have been pre-selected for the construction of the sanitary landfill, the priority is to find out who owns the property, whether it is for sale, or whether it can be negotiated, and —most important— the value of the land. It often happens that the owner will want to speculate with its value when he finds out about the municipality’s interest in purchasing the land. The mayor could resort to the legal remedy of “declaration of public purpose,” in which case the land will be valued at the rate recorded in the official land registers.

Another aspect for consideration is the cost of the infrastructure for entering and preparing the terrain and making it ready to receive the town’s waste. It is always advisable to calculate the value of the works and compare it with the funds the municipality has at its disposal, to ensure that the project will not be abandoned in the future for lack of funds. If the investment required is too high and it appears to be beyond the reach of the municipality, it is better to look for another site.

#### **4.5 End use of the site**

In every sanitary landfill project the use that the site will be given once its service life is over should be considered from the outset, with plans to integrate it into the natural environment, transforming it into a green area, sports area, garden, nursery or forest. In the case of the manual sanitary landfill, the end use is limited by the size of the site—which rarely exceeds two or three hectares—the low degree of compaction, proximity to the town, and the cost of the transformation process.

A good strategy for presenting the project is to submit the engineering design plans together with the artistic landscape design for the site once its useful life is over and, if possible, a scale model, because the three-dimensional forms are more easily understood, especially by the local inhabitants.



**Figure 4.5**  
**End use of the manual sanitary landfill**

**Site selection is just as important for small towns, or even more so.**

#### **4.6 Schedule of activities**

Table 4.3 is a sample guide for scheduling the activities and works leading to the installation of a manual sanitary landfill.



**Table 4.3**  
**Schedule of activities for the process of installing a sanitary landfill**

<b>Activity</b>	<b>month 1</b>	<b>month 2</b>	<b>month 3</b>	<b>month 4</b>	<b>month 5</b>	<b>month 6</b>
? <b>Preliminary measures</b>						
? Local authorities take the decision						
? Sanitary education program for the inhabitants						
? Consultation with financial institutions						
? <b>Identification of the site and its surroundings</b>						
? Presentation of alternatives to the local authorities						
? Selection of the site and negotiation						
? Legalization of land ownership (official registration)						
? Topographical survey and preparation of the plan						
? <b>Studies and design (including budget)</b>						
? Presentation to the authorities and the community						
? Obtaining of loan for the investment						
? <b>Preparation of the land</b>						
? Clearing and cleaning						
? Preparation of the support soil						
? Cutting of slopes						
? <b>Construction of the peripheral infrastructure</b>						
? Access road to the site						
? Rainwater drainage						
? Diversion and isolation of possible water courses						
? <b>Construction of the landfill infrastructure</b>						
? Internal roads						
? Peripheral and internal rainwater drainage						
? Drainage of leached or percolated liquid						
? Drainage of gases						
? <b>Auxiliary constructions</b>						
? Perimeter fence						
? Planting of trees around the perimeter						
? Control building (with sanitary facilities)						
? Site identification board						
? Monitoring wells						
? <b>Closure of local dump(s)</b>						
? Extermination of rodents and arthropods						
? Covering with soil and packing						
? Sealing of the dump						
? Press releases and board informing of closure						
? <b>Beginning of the operation of the manual sanitary landfill</b>						

## **4.7 Basic project**

One of the basic tools for the successful development of a manual sanitary landfill project or an integrated system for treatment and final disposal of MSW is a topographical survey of the terrain, which produces a plan summarizing the extension of the land and differences in height; another tool is the set of plans<sup>4</sup> with the design and the details of the project.

### **4.7.1 Topographical survey**

Once the site has been selected and the land acquired by the municipality or town council, a topographical survey will be commissioned, requesting a plan with the original terrain at a scale of 1:250, 1:500, with the elevations represented by contour lines for each meter, dimensioned every five meters. The boundary, the identification of neighboring lands, the location of the main road, the access road, the natural drainage, the location of the material bank and other special features can be shown on this plan.

If there are no personnel trained for this activity, the municipality can hire a topographer with the assistance of the specialist technician or request this service of the Ministry of Health or Public Works or the regional branches of these ministries.

In very small communities where it is impossible to have topographic equipment, such as the transit or precision levels to determine the area of the land and its volumetric capacity, the measurements can be made with a measuring tape and hand level. In extreme cases of simpler projects, a hose-pipe is sufficient, because these works do not require greater precision.

### **4.7.2 Design of the sanitary landfill**

The design is the material expression of the concept of the landfill project. Its purpose is to guide the project and plan its construction; it is a tangible document that can be presented to the municipal authorities or town council and the community when promoting the project and seeking funds for it.

The basic design will show the delineation of the total area of the site and of the terrain to be filled. It will indicate the method of construction, the origin of the cover earth, and the layout of the infrastructure works. In addition, the project specifications will include the calculation of the useful life of the landfill, its end use, and the global estimated cost of the project.

---

<sup>4</sup> Plans are technical drawings used to present the details of the existing site conditions and features, as well as the proposal for developing the project works, and the location and details of the infrastructure.

### **4.7.3 Project details**

The design should be presented in a maximum of 10 to 12 plans (in compliance with the technical standards of each country) that include at least the plan layout and the various profiles of the project, such as:

- ? configuration of the original terrain and the delineation of the total area
- ? initial preparation of the terrain and layout of the infrastructure works and support facilities
- ? details of the access roads, principal drainage, and support facilities
- ? the order of the construction process to orient the operation of the landfill
- ? partial landfill layouts as the work progresses (by the first year, the third year, etc.); and the final landfill layout, including the landscaping process.

To make this document easier to read, the details regarding certain stages, namely, study of basic information, calculations, and design of the landfill and its infrastructure, will be presented in Chapter 5. The subsequent chapters describe the site preparation and the infrastructure work necessary for receiving the MSW, as well as the sequence of construction, operation and maintenance required.

## 4.8 Graphs of the steps necessary for design, construction and operation

### 4.8.1 Field studies and design



1. Identification of the site to be filled and its surroundings



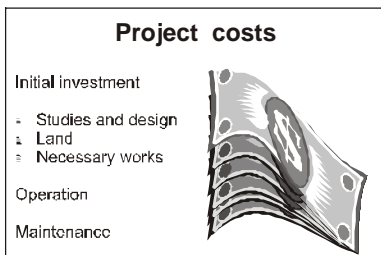
2. Analysis of the hydrogeological conditions



3. Topographical survey



4. Preparation of the design



5. Cost analysis



6. Presentation of the project to the Authorities

**Figures 4.6**  
**Field studies and design**

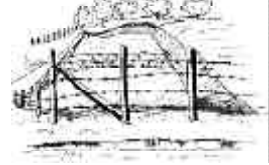
4.8.2 Preparation of the site and construction of the works



1. Clearing and cleaning



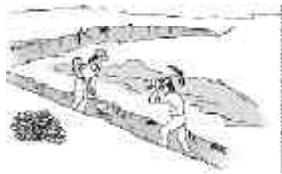
2. Construction of the direct access road



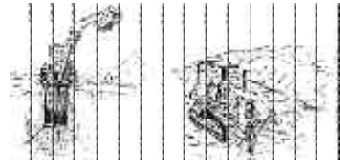
3. Sealing of the site



4. Planting of trees around the perimeter



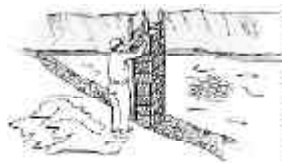
5. Construction of the peripheral drainage



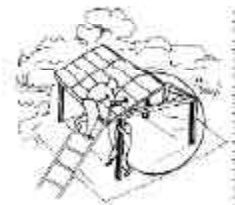
6. Preparation of the support soil



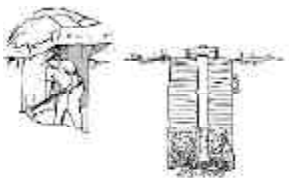
7. Construction of internal drainage



8. Preparation of gas drainage



9. Construction of the control building and sanitary facilities



10. Excavation of monitoring wells



11. Design and location of the site identification board



12. Visits with the leaders of the neighboring community

**Figures 4.7**  
**Preparation of the site and construction of works**

**4.8.3 Operation and maintenance**



1. Acquisition of tools



2. Purchase of safety equipment for the workers



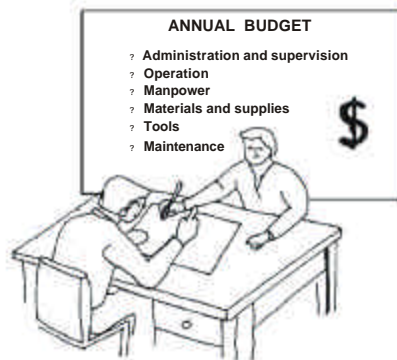
3. Beginning of landfill operation



4. Closure of the dump(s)



5. Permanent maintenance



6. Preparation of the annual budget

**Figures 4.8**  
**Operation and maintenance**

## **5. DESIGN OF A MANUAL SANTARY LANDFILL**





Once the land ownership has been legally registered, the studies and designs of the sanitary landfill and its infrastructure can be commissioned. For these studies, the project engineer or contractor will need to gather the basic information and make one or several field trips to become acquainted with the terrain.

When evaluating the site, the technician will take with him the topographic plan, which should contain the original description of the terrain (heights and depressions), a graph or table indicating the amounts of waste accumulated and the estimated volume of earth to be used as cover material for the next 5 to 10 years. The field visit is important in order to identify the fill area and its surroundings, as well as to locate the works for the infrastructure and support facilities, such as the access road, drainage system, maneuvering yard, and control building. At this stage the method of landfill, the source of the cover material, the distribution and design of the waste embankments are also evaluated in order finally to begin defining the sequence of construction.

## **5.1 Basic information**

### **5.1.1 Demographic aspects**

#### **? *Population***

The project designer needs to know the number of inhabitants and the rate of population growth in order to determine the amounts of MSW to be disposed of. It should be noted that there is a difference between rural and urban production of waste. Rural MSW will make fewer demands since it is not plentiful, although it is more difficult to collect. On the other hand, urban production is more problematic for reasons of concentration, increase in population, and technological and urban development. Urban waste production thus merits special attention.

#### **? *Population projection***

It is of the utmost importance to estimate the future population of the community, at least for the following five to ten years, in order to calculate the quantity of MSW to be disposed of daily and annually during the useful life of the sanitary landfill. Table 5.1 supplies basic information in this respect.

The population growth can be estimated by mathematical methods, or by entering census data in a graph and making an extrapolation of the resulting curve.

The following is an example of the mathematical method relating to geometric growth, that is, to biological populations in expansion, for which a growth rate is assumed to be constant. The equation is:

$$P_f = P_o (1 + r)^n \quad [5-1]$$

where:

- P<sub>f</sub> = Future population
- P<sub>o</sub> = Present population
- r = Rate of population growth
- n = (t<sub>final</sub> – t<sub>initial</sub>) interval in years
- t = time variable (in years)

However, it is recommended that the results obtained be compared with those of other methods of projection.

### **5.1.2 Production of MSW in small towns**

With reference to the generation and composition of the wastes to be managed in small communities, the residential sector is predominantly used for the calculation of waste production, all other activities being so incipient that they do not appreciably affect the total quantity of MSW, except for the waste from markets, and also from visitors in places where there are tourist attractions.

In any case, when a system of collection, treatment and final disposal of waste is required, the amounts of waste produced by the population need to be estimated. With a view to saving funds, we suggest using indirect methods for these analyses, as described below.

#### **? *Per capita production***

The per capita production of MSW can be estimated globally thus:

$$ppc = \frac{DSr \text{ en una semana}}{Pop \times 7 \times Cov} \quad [5-2]$$

where :

- $ppc$  = Production per capita per day (kg/cap/day)  
 $DSr$  = Quantity of MSW collected in one week (kg/wk)<sup>5</sup>  
 $Pop$  = Total population (inhab)  
 $7$  = Days of the week  
 $Cov$  = Coverage of the urban cleaning service (%)

The coverage of the service is the product of dividing the population served by the total population:

$$\text{Coverage of the service (\%)} = \frac{\text{Population served (inhab)}}{\text{Total population (inhab)}} \quad [5-3]$$

The amount of MSW produced can also be linked with the number of homes, that is, kg/home/day, since the garbage is produced per home. This method has the additional advantage of facilitating the counting of households.

MSW sampling in some small towns and rural and marginal areas in LAC countries, for the characteristics analyzed in this publication, has revealed that the  $ppc$  ranges from 0.2 to 0.6 kg/cap/day. These figures are typical of such communities, and they are worth noting or keeping in mind, because in most cases exhaustive sampling is not warranted.

In tourist resorts or destinations, the production of MSW can increase significantly during vacation periods, making its management and disposal somewhat more complicated.

In some rural communities, for example in the Amazon jungle or in agricultural areas, the production per capita of MSW can reach values ranging from 0.6 to 1.2 kg/cap/day.

### ? **Total production**

Once the total production of MSW is known, decisions can be made regarding the most suitable collection equipment, the number of workers, routes, frequency of collection, the area needed for treatment and final disposal, costs, and the tariff to be paid for the service.

<sup>5</sup> For calculation purposes, it is recommended to take as a minimum the production and collection data of a whole week, since the figures vary according to the different activities of the population. If possible, the amount of waste should be determined by weighing all the collection trucks for one week, or estimating their load volume.

Total MSW production is found by the following equation (cf. Annex 4, example 1):

$$DS_d = \text{Pop} \times \text{ppc} \quad [5-4]$$

where:

$DS_d$  = Quantity of MSW produced per day (kg/day)

$Pop$  = Total population (inhabitants)

$ppc$  = Production per capita (kg/inhab.-day)

### ? *Projection of the total production*

The annual production of MSW should be estimated from projections of the population and production per capita.

As already mentioned in this chapter, the projection of the population can be calculated mathematically, but for the growth of the  $ppc$  it is difficult to obtain figures that give an idea of annual variation. Nevertheless, to obviate this point and with the certainty that the production indices increase with development and urban and commercial growth, it is recommended that the total per capita production (Table 5.1) for each year be calculated with an annual increase of 0.5 to 1 %.

### 5.1.3 *Characteristics of MSW in small towns*

The most important parameters we need to know for the proper management of the MSW produced in a town are the production figures and specific features of the waste (origin, physical composition, and density).

#### ? *Origin*

Municipal Solid Waste in urban areas of small towns can be classified according to its origin: residential, commercial, industrial, sweepings from roads and public areas, market and institutional (Table 5.2).

#### a) *Residential sector*

Residential garbage, or domestic solid waste, is composed mainly of paper, cardboard, cans, plastics, glass, rags, and organic matter.

In studies carried out on the production of garbage in small towns (fewer than 40,000 inhabitants), no great differences have been found between the different socioeconomic strata of the population.

**Table 5.1**  
**Volume and area required for the sanitary landfill**

Year	Population (inhab.)	ppc kg/cap/day	Quantity of solid wastes			Volume (m <sup>3</sup> )					Area required (m <sup>2</sup> )					
			Daily (kg/day)	Annual t/year	Accumulated (t)	Compacted solid wastes		Cover material m <sup>3</sup>	Stabilized solid wastes	Sanitary landfill		Fill A <sub>R</sub>	Total A <sub>T</sub>			
(1)	(2)	(3)	(4)	(5)	Daily (m <sup>3</sup> )	Annual (m <sup>3</sup> )	Daily (m <sup>3</sup> )	Annual (m <sup>3</sup> )	(m <sup>3</sup> /year)	(m <sup>3</sup> )	Accumulated	(11)	(12)	(13)	(14)	
0																
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																

(3) = (1) x (2)      Population x ppc

(6) = [(3) x 7/6] / D<sub>C</sub>      The solid wastes produced in one week are taken to the landfill on collection days, normally from Monday to Saturday (7 days of production / 6 days of collection)

(8) = (6) x 0.2      Cover material = from 20 to 25 % of the volume of compacted waste

(11) = (9) + (10)      The volume of the sanitary landfill V<sub>RS</sub> = cover material + volume of stabilized waste

(13) = (12) / H      Area to be filled A<sub>R</sub> = accumulated volume of the fill / H  
H = estimated height of the fill

(14) = (13) x F      Total area A<sub>T</sub> = area to be filled x F  
F = Factor for estimating the additional area (between 20 and 30 %)

**MANUAL SANITARY LANDFILL**

**DENSITY OF THE WASTE (kg/m<sup>3</sup>)**

D<sub>S</sub> : Loose      200 - 300  
D<sub>C</sub> : Compacted      400 - 500  
D<sub>F</sub> : Stabilized      500 - 600

**b) *Commercial sector***

With some exceptions (populations in border areas and tourist sites), there is not a high production of commercial MSW in small communities, because trade is so little developed that any commercial activity is usually conducted from the home.

The composition of the waste from commercial activity in these communities is similar to the residential waste, although packing materials predominate (paper, cardboard, glass, plastic, textiles and wood).

**c) *Industrial sector***

Industrial activity, if any, is usually of the artisan type, compatible with residential use; thus, industrial solid waste in small towns is not expected to have any unusual characteristics. Indeed, with very few exceptions, it is insignificant for the analysis of these small towns.

**d) *Marketplace***

The market area has a more clearly defined character, since this is where meat, fish, vegetables, fruit, groceries and other items are sold. A large proportion of the waste is organic, and only a very small part is packing material. Composting using manual methods could be recommended for this type of waste.

**e) *Sweepings from streets and public areas***

The service of street sweeping and cleaning of public areas —such as the principal park, the area around the marketplace, fairs and beaches— contributes to the production of wastes. These sweepings are mainly leaves, grass, fruit peel, in addition to papers, plastics, cans, glass, sticks, and a high content of earth.

**f) *Institutional sector***

In the case of special establishments such as schools, we can safely assume that the production of solid waste is relatively insignificant, and its composition is similar to that of the waste from the above-mentioned sectors.

The hospitals or medical centers in these small towns are usually classified as primary health care facilities, which are not very specialized and usually have a minimal number of beds, although in some cases they are of medium size. Consequently they do not have a significant effect on the total production of solid waste. Nevertheless, with regard to the type of waste they produce, the distinction must be made between

**Table 5.2**  
**Projection of the production and origin of municipal solid wastes**  
**(t/year)**

Year	Popu- tion inhabi- tants	ppc Average total kg/cap/day	Residen- tial	Comer- mercial	Mar- ket	Indus- trial	Sweep- ings	Others	Total
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
Total									

the waste that is classified as being of residential origin (cleaning, cooking, common garbage); and the waste resulting from their specific activities, which are potentially infectious: sharp instruments and material used for treatment, viscera from surgery, etc., all of which are classified as “biological-infectious waste.” For this type of waste, special management, treatment, and final disposal are suggested.

In the medical center, this waste should be separated and presented in closed red polyethylene bags. Care should be taken not to spill the contents of these bags. Collection personnel must not come into contact with the contents, even if they are wearing gloves and protective clothing. The treatment and final disposal of infectious wastes can be by incineration and/or burial in a special pit within the establishment. In the latter case, this pit should be of clayey soil, and its bottom should be at least 1.0 m from the water table in order to prevent contact with the water. For further details, see Annex 6.

If infectious wastes are collected by the municipality, appropriate protection measures should be taken. Their final disposal can be in the manual sanitary landfill, preferably placing them in a special cell as soon as they arrive, similar to that indicated

in Annex 6 or, if not available, at the toe of the slope or in the lower part of the cell, to be immediately covered with soil and the rest of the solid waste.

? ***Physical and chemical composition***

Typical of the physical composition of MSW in Latin America and the Caribbean is its high percentage of organic matter (50 to 70% of the total waste), which translates into a greater moisture content with values between 35 and 55%; the rest is paper, cardboard, glass, metals, plastics and inert material, among others.

**The municipal solid wastes of small communities do not have significant differences in their physical composition such as to warrant the expense of exhaustive studies, so they can usually be assimilated as domestic wastes.**

The physical composition of the MSW of these small towns is important for evaluating the feasibility of setting up recycling and treatment programs, since the chemical composition needs little attention and the final disposal method is the sanitary landfill technique, which seeks to minimize the production of leachates.

? ***Density***

The density or weight per volume of the MSW is another important parameter for the design of the final waste disposal system. In the LAC Region there are values of between 200 and 300 kg/m<sup>3</sup> for loose waste, that is, garbage in the trashcan; these values are higher than those in industrialized countries.

In order to calculate the dimensions of the daily cell and the volume of the landfill, the following densities can be estimated.

**Table 5.3**  
**Density of daily cell design and manual sanitary landfill**

Design	Density kg/m <sup>3</sup>
? Daily cell (waste recently compacted manually)	400 - 500
? Volume of the fill (waste stabilized in the manual landfill)	500 - 600



These densities are reached by homogeneous compaction, and in the measure that the fill is stabilized, all of which has an effect on the stability and useful life of the site.

The increase in the density of the manual sanitary landfill is achieved in particular by the following means:

- ? Manual tamping, with daily use of the roller or the hand tampers.
- ? The transit of the collection vehicle over the already filled cells.
- ? The segregation and recovery of paper, cardboard, plastic, glass, scrap metal, wood and other voluminous materials. With the practice of recycling, less MSW will be disposed of in the landfill, so the site life will be prolonged.
- ? Other mechanisms that increase the density of the solid wastes are: the process of decomposition of the organic matter, and the weight of the upper layers or cells themselves pressing down on the lower ones and, obviously, reducing their volume.

#### **5.1.4 Site characteristics**

The geology and specific features of the soil of the terrain are among the most important factors to be considered when selecting the site. Thanks to these data, information can be obtained about possible displacement of water filtration and potential contamination of surface and ground waters. The soil study is also used for evaluating the stability of the site and the location and quality of the bank of cover material.

There can be no question that these analyses are of great importance in sanitary landfill projects for large cities, and should be a basic requirement in any study; but in the case of very small communities it is not necessary to be too rigorous, as already mentioned, considering the small scale of the works and the type of waste produced. As far as possible the services of a geologist or other professional with knowledge of these matters should be sought.

Field studies for towns with a population of 5,000 or less can consist of simple percolation tests and soil analyses only.

The following is a brief description of the principal parameters that should be taken into account in the analysis and evaluation of any terrain:

- ? *Type of soil:* a sanitary landfill should be located preferably on a terrain of sandy-silty-clayey soils (loamy coarse sand, predominantly clayey loam); also suitable are silty-clayey soils (heavy predominantly silty, predominantly silty clayey, light clayey silty) and clayey-silty ones (heavy clayey silty and clayey).

It is better to avoid sandy silty soils (predominantly sandy) because they are very permeable.

- ? *Soil permeability:* the greater or lesser ease with which water seeps through a soil. The permeability coefficient (k) is an indicator of the greater or lesser difficulty with which a soil resists seepage of water through its pores. In other words, it is the speed with which the water crosses different types of soil.

To illustrate these parameters better, we present Figure 5.1, which shows the type of soil and its relation to the permeability coefficient.

**Permeability coefficient k (cm/s)  
(Logarithmic Scale)**

k (cm/s)	10 <sup>2</sup>	10 <sup>1</sup>	1.0	10 <sup>-1</sup>	10 <sup>-2</sup>	10 <sup>-3</sup>	10 <sup>-4</sup>	10 <sup>-5</sup>	10 <sup>-6</sup>	10 <sup>-7</sup>	10 <sup>-8</sup>	10
Drainage	Good						Bad		Practically impermeable			
<b>Sanitary landfill</b>	Extremely bad									Good		
Type of soil	Coarse gravel	Clean sand, sand mixed with gravel			Very fine sand, organic and inorganic soils, mix of sandy silt and clay				Impermeable soil, for example: homogeneous clay under the weathering area			
		Impermeable soil, for example: homogeneous clay under the weathering area										

Source. Adapted from CETESB. Industrial solid wastes. 2<sup>nd</sup> enlarged edition. São Paulo, 1993, p. 91.

**Figure 5.1  
Relation between the type of soil, the permeability coefficient, and its acceptability for drainage and sanitary landfill**

The permeability coefficient (k) of soils can be determined in the field, if it is desired to know with certainty whether or not a sanitary landfill can be constructed there (Annex 1).

- ? *Depth of the water table:* the height of the water table or the dominant height of the groundwater level. Preference will be given to well drained land, where the water table is more than one meter deep the whole year round. Poorly

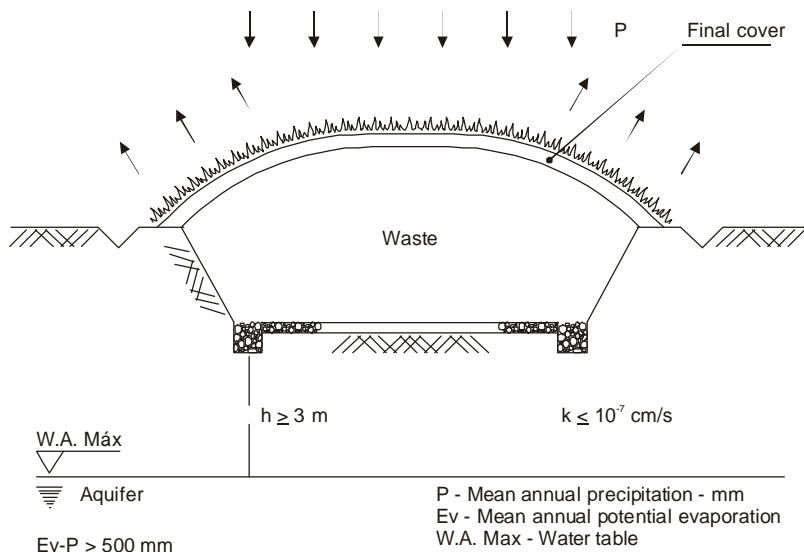
drained land—that is, sites where the water table is less than one meter down for most of the year— will have to be drained artificially. It is better to discard sites such as these, especially those that are prone to prolonged flooding.

- ? *Availability of cover material:* flat land with a silty clayey soil and a water table deep enough to prevent contamination of groundwater by the disposal of wastes can offer a good quantity of cover material, especially if the trench method is selected. On the other hand, if the land has sandy soil or a shallow water table (less than one meter deep), it will first be necessary to waterproof the terrain and then bring the cover material from elsewhere, which would greatly increase costs; this kind of site should therefore be rejected.

Land with depressions and gently rolling terrain can be good sources of cover material when the terrain is leveled and cuts made in the sides of the depressions.

### 5.1.5 Climate conditions

Rain, evaporation, temperature, and wind direction are the most relevant climatic data to be gathered to work out the design specifications for the sanitary landfill infrastructure and also to gain a better knowledge of the conditions for the construction in general (Figure 5.2).



Source: Adapted from: CETESB. Industrial solid wastes . 2<sup>nd</sup> enlarged edition. São Paulo, 1993. p.91.

**Figure 5.2**  
**Favorable climatic and hydrological conditions**

In Chapter 4, point 4.4 (site selection), reference was made to the need to investigate the wind direction, and above all, the records of rainfall in the area for the design of the different drainage systems for water and leachate.

### **5.1.6 Identification of standards in force**

Another aspect not to be overlooked by the designer of a sanitary landfill is the need to consult with the standards currently in force for the design and construction of the landfill and infrastructure works, and also for the issue of environmental impact (constraints on the project in order to prevent or mitigate possible negative effects from the construction and operation of the landfill).

Nevertheless in the case of a manual sanitary landfill, the local governments and environmental and health authorities should bear in mind that it is a small sanitation project and not a large-scale city project. In the LAC Region it often happens that the officials of surveillance and control agencies—who are either unaware or dismissive of the enormous differences between these two types of projects—merely supply the consultant or technician in charge of the studies and designs with the same terms of reference that have been drawn up for large metropolitan sanitary landfills. This effectively brings to a halt the execution of the manual sanitary landfill from lack of resources and even of information.

**“The adoption of the standards of industrialized countries can be an obstacle against improving the processes in developing countries, or even prevent progress in the management of MSW unless such standards are adapted to local conditions.”**

## **5.2 Calculation of the necessary volume**

The spatial requirements for the sanitary landfill are governed by:

- ? The total production of MSW
- ? The coverage of collection (The critical design condition is to receive 100% of the waste produced.)
- ? The density of the stabilized MSW in the manual sanitary landfill
- ? The amount of cover material (20-25%) in the compacted volume of MSW

### 5.2.1 Volume of solid waste

With the first two parameters we have the daily and annual volume of compacted and stabilized MSW that must be disposed of (Table 5.1, columns 6, 8 and 10, respectively), namely:

$$V_{\text{daily}} = \frac{DS_p}{D_{\text{msw}}} \quad [5-5]$$

$$V_{\text{compacted annually}} = V_{\text{daily}} \times 365 \quad [5-6]$$

where:

- $V_{\text{daily}}$  = Volume of MSW to be disposed of in one day ( $\text{m}^3/\text{day}$ )
- $V_{\text{annual}}$  = Volume of MSW in one year ( $\text{m}^3/\text{year}$ )
- $DS_p$  = Quantity of MSW produced ( $\text{kg}/\text{day}$ )
- 365 = Equivalent to one year (days)
- $D_{\text{msw}}$  = Density of the recently compacted MSW ( $400\text{-}500 \text{ kg}/\text{m}^3$ ) and of the stabilized landfill ( $500\text{-}600 \text{ kg}/\text{m}^3$ )

### 5.2.2 Volume of the cover material (column 9)

$$c.m = V_{\text{compacted annually}} \times (0.20 \text{ or } 0.25) \quad [5-7]$$

where:

- $c.m$  = cover material equivalent to 20 or 25% of the volume of the recently compacted wastes

### 5.2.3 Volume of the sanitary landfill

With the results obtained from the equations [5-6] and [5-7] the volume of the sanitary landfill for the first year can be calculated thus:

$$V_{\text{SL}} = V_{\text{stabilized annually}} + c.m \quad [5-8]$$

where :

- $V_{\text{SL}}$  = Volume of the sanitary landfill ( $\text{m}^3/\text{year}$ )
- $c.m$  = cover material (20 to 25 % of the recently compacted volume of MSW)

The data obtained are entered in Table 5.1, column 11. To find the total volume occupied during the useful life of the site, the following equation is applied:

$$V_{SLul} = \sum_{i=1}^n V_{SL} \quad [5-9]$$

where :

$$\begin{aligned} V_{SLul} &= \text{Volume of the sanitary landfill during its useful life (m}^3\text{)} \\ n &= \text{Number of years} \end{aligned}$$

which would be the data that appear in Table 5.1, column 12, that is, the amounts accumulated annually.

### 5.3 Calculation of the required area

Once the volume is obtained, the area required for the construction of the sanitary landfill can be estimated with the depth or height the landfill would have. This can be found only if one has a good general idea of the topography.

The manual sanitary landfill should be projected for a minimum of five years and a maximum of ten. However, sometimes it is necessary to design it for less than five years in view of the difficulty of finding available land. The duration of the landfill is called the *useful life or design period*.

The area required for the construction of a manual sanitary landfill depends mainly on factors such as:

- ? Quantity of MSW to be disposed of
- ? Quantity of cover material
- ? Compaction density of the MSW
- ? Depth or height of the sanitary landfill
- ? Additional areas for support facilities

From equation 5-8 we can estimate the area requirements thus: (Table 5.1, column 13)

$$A_{SL} = \frac{V_{SL}}{h_{LS}} \quad [5-10]$$

where:

$$\begin{aligned} V_{SL} &= \text{Volume of the sanitary landfill (m}^3\text{/year)} \\ A_{SL} &= \text{Area to be filled successively (m}^2\text{)} \\ h_{SL} &= \text{Mean height or depth of the sanitary landfill (m)} \end{aligned}$$

and the total area required (Table 5.1, column 14) will be:

$$A_T = F \times A_{SL} \quad [5-11]$$

where :

$$\begin{aligned} A_T &= \text{Total area required (m}^2\text{)} \\ F &= \text{Factor of increase in the additional area required for penetration roads, border setback areas, control building and sanitary facilities, maneuvering yard, etc. This is between 20 and 40\% of the area to be filled.} \end{aligned}$$

The parameters mentioned for the calculation of the volume of the sanitary landfill are included in Table 5.1 The area for each alternative site will be estimated when the average depth of the fill is known (see Annex 4, example 2).

## 5.4 Design of slopes

### 5.4.1 Earthworks

Sanitary landfills for urban wastes are engineering works built in the ground, and many of their structures —or parts of them— are earthen.

Among the principal works of a landfill are: the construction of embankments or containment dikes, the construction of berms, the excavation of trenches, the excavation of drainage canals, the construction of dirt roads, and of layers of compacted soil for waterproofing or protection.

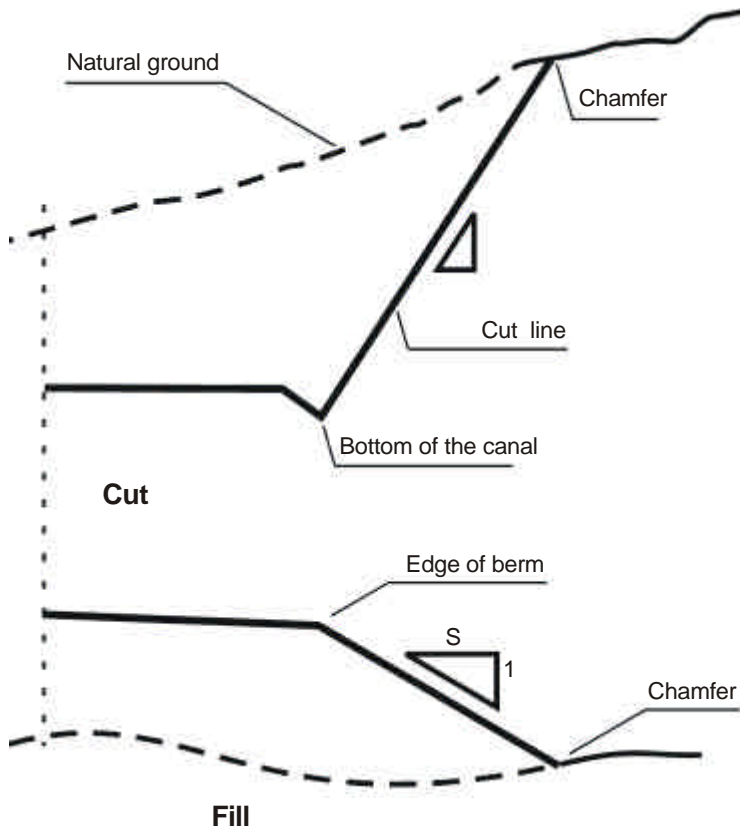
In the construction and operation stages, one of the most important aspects to be taken into account for manual sanitary landfills is the stability of the earth slopes and of the fill banks.

### 5.4.2 Designation of slopes

The surface that defines the grading laterally is called the slope. In cuts, the slope is included between the chamfer and the bottom of the channel. In embankments,

the slope is included between the chamfer (foot of the embankment) and the edge of the berm (Figure 5.3).

The convention used to designate the slope is in the form of “S” units horizontally by one unit vertically.



**Figure 5.3**  
**Designation of slopes**

### 5.4.3 *Design of slopes*

#### ? *Slopes in cut*

Taking into account that for the construction of a manual sanitary landfill it is recommended that the terrain be of a relatively impermeable material (fine sand mixed with silt, clay) and that the heights of the cut (H) be less than 5 m, it can be established as a standard that stability studies are not required in order to define the most appropriate slope.



For a low cut a single slope can be recommended; for greater heights two different slopes could be necessary; in some cases the construction of intermediate berms or banquettes will be suggested (Figure 5.4).

The following guide, based on the experience of several countries, will be useful for the definition of cut slopes (Table 5.3).

**Table 5.4**  
**Slopes recommended in cut**

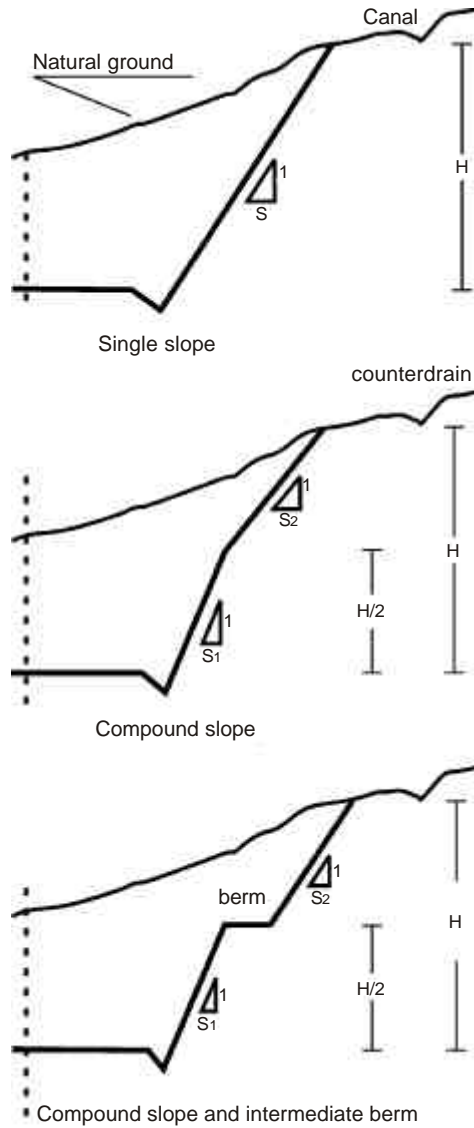
Type of material	Recommendable slope S height of the cut H (m) up to 5 m	Observations
1. Silty sands and compact silts	1/2	$k = 10^{-7}$ cm/s. Level 1:1 the more weathered upper part. In the case of easily eroded materials, the slope should be 1:1
2. Silty sands and non-compact silts	1/4	$k = 10^{-7}$ cm/s impermeable counterdrain (intercepting ditch at the top of a slope). Level to 1.5:1 in the most weathered part.
3. Silty sands and very compact silts	1/4	$k = 10^{-7}$ cm/s. Level the loose upper part.
4. Not very sandy clays, firm and homogeneous	1/2	$k = 10^{-8}$ cm/s. Level 1:1 the weathered part. If there is a flow of water, build subdrainage.
5. Bland, expansive clays	1	$k = 10^{-8}$ cm/s

*Source.* Taken and adapted from Secretariat of Public Works, Department of Antioquia, Colombia.

### ? *Slopes of embankments*

In embankments, because of the control over the extraction, selection and placing of the material that forms the landfill (fill in soil), the value commonly used in slopes is 1.5:1.

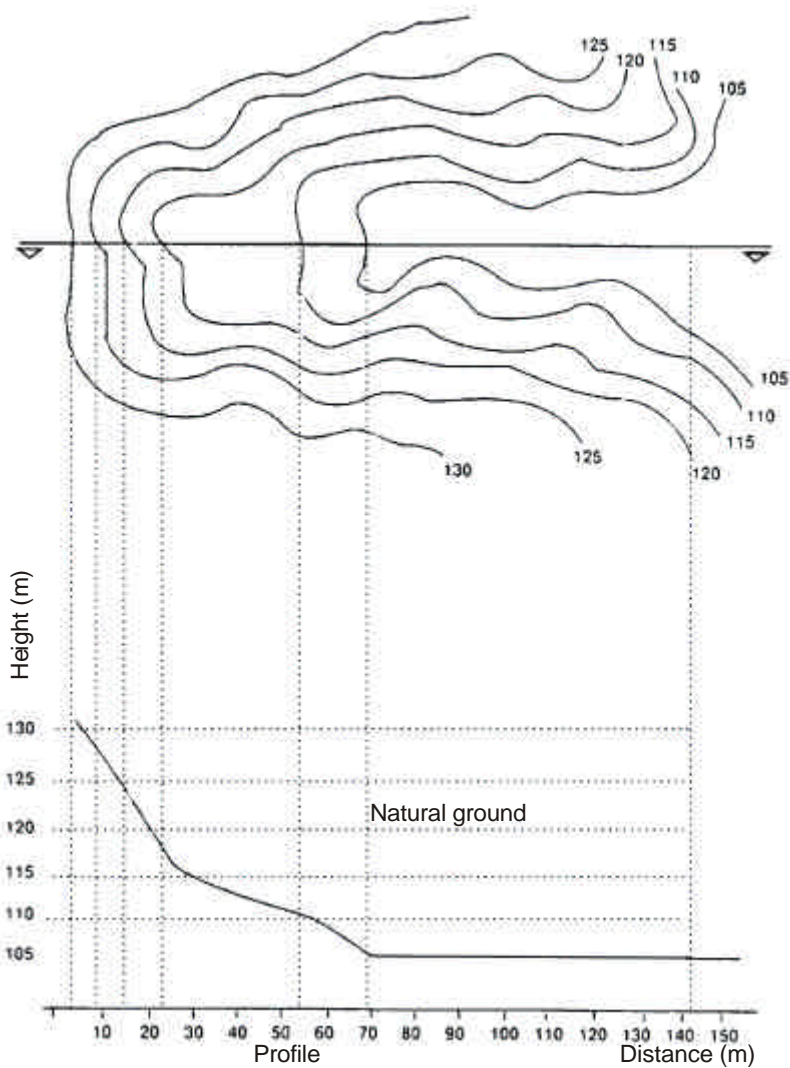
With regard to the slopes of waste for forming embankments in the manual sanitary landfill, 2:1 or 3:1 is recommended. Stability is guaranteed by good manual compaction of the wastes and the construction of compound slopes with an intermediate berm.



**Figure 5.4**  
**Slopes in cut**

### 5.5 Selection of the fill method

As already mentioned, the design of the sanitary landfill depends on the method adopted —trench, area or a combination of the two— whichever is the best suited to the topographical conditions of the site, the soil characteristics, and the depth of the water table.

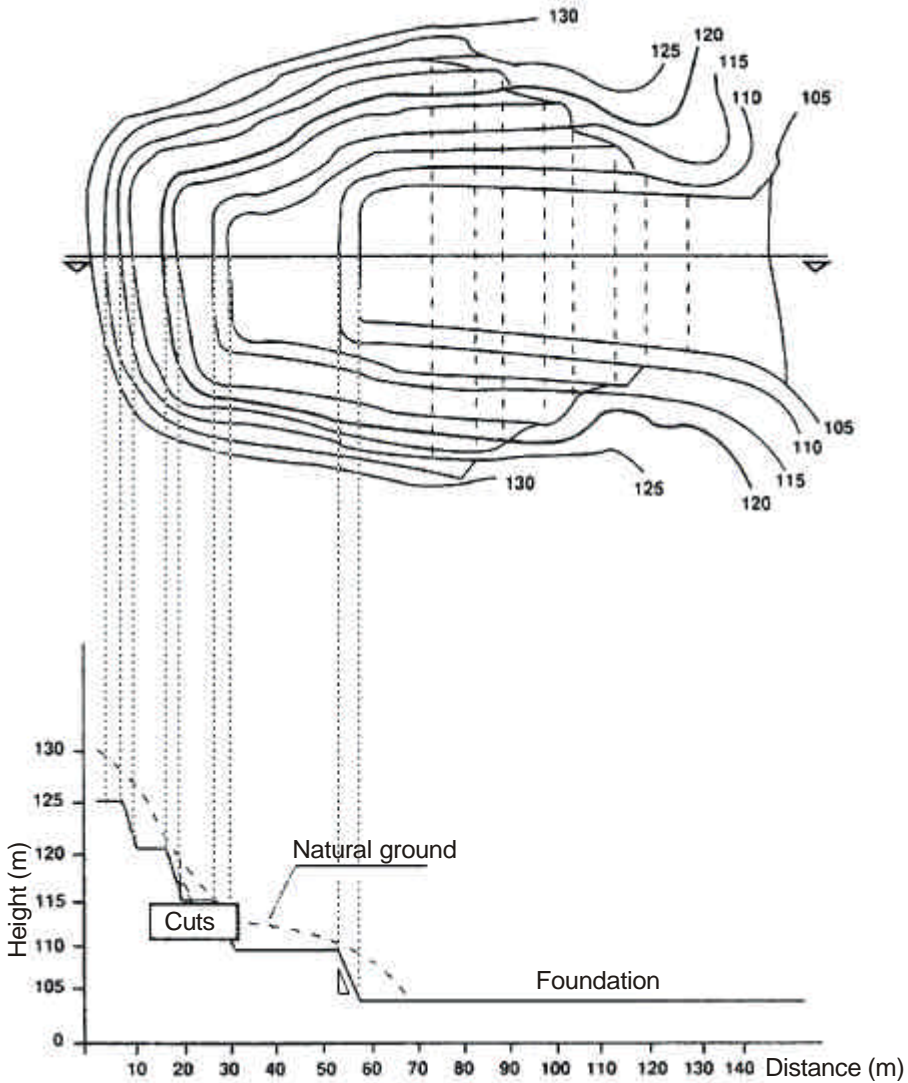


**Figure 5.5**  
**Layout of the original terrain**

The design should present a series of plans that will be followed in the construction of the sanitary landfill:

? *Layout of the original terrain*

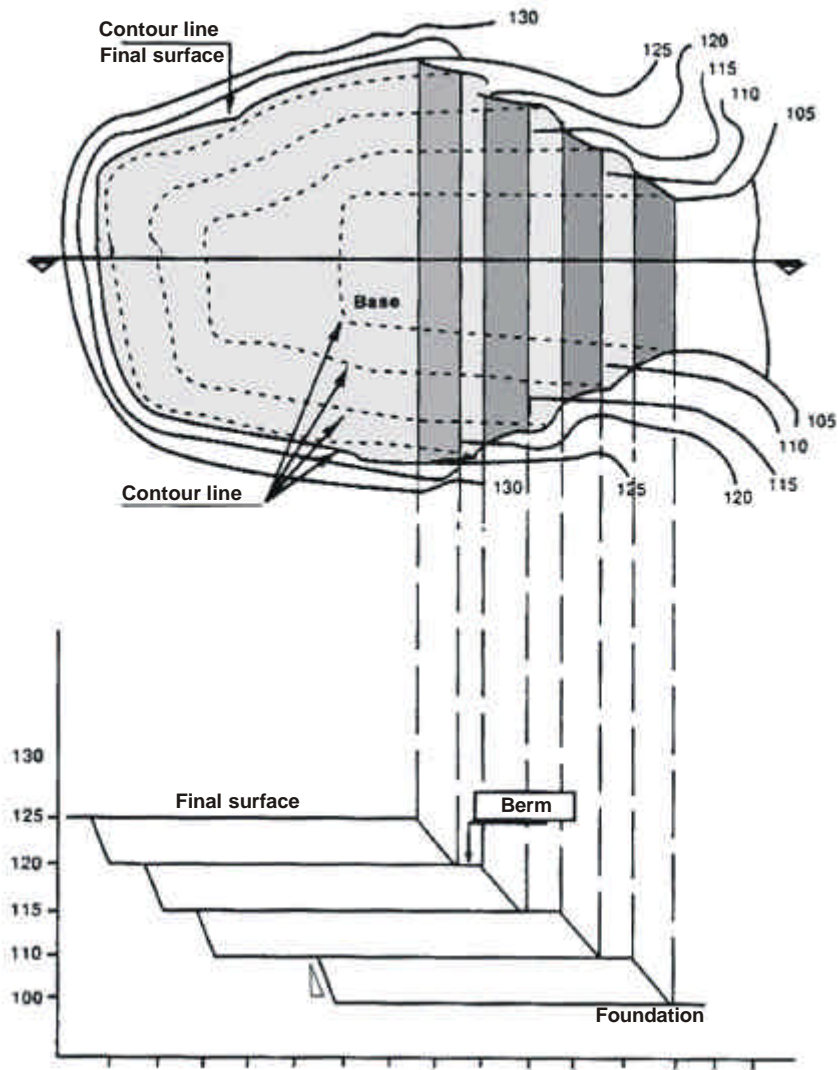
The layout of the original terrain is obtained from the topographical survey of the site of the future sanitary landfill. This information is necessary for the project calculations and design (Figure 5.5).



**Figure 5.6**  
**Initial layout of the foundation**

? *Initial layout of the foundation or base material*

The selected site will usually need to be prepared for construction of the necessary infrastructure and to give an adequate support base to the sanitary landfill, as well as to obtain the cover material on-site. These changes are presented in a topographic plan that will be used to guide the builder in the earth movement (Figure 5.6).



**Figure 5.7**  
**Final layout of the sanitary landfill**

? *Final layout of the landfill*

This is the layout of the site once its useful life is over. It is important to include this in a topographic plan in order to show the maximum levels that the landfills will reach as anticipated by the project designer (Figure 5.7).

? *Partial layouts of the landfill*

A partial landfill layout shows the progress of the construction and serves as a guide to the constructor for the corresponding controls. There may be more than one of these plans drawn at different stages of the project.

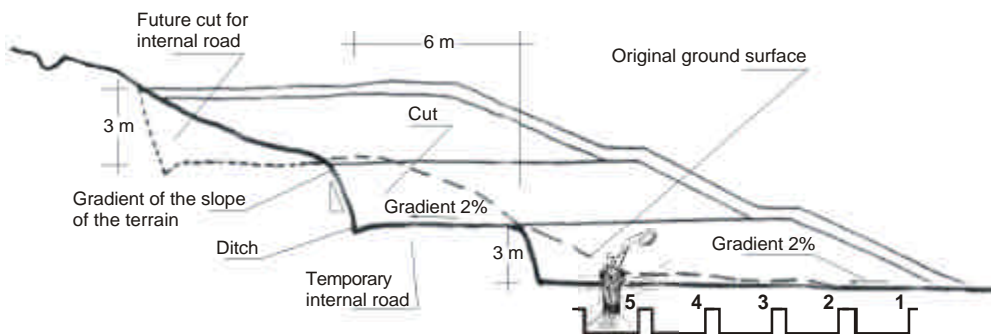
**5.5.1 Ditch or trench method**

Since small towns usually do not have a track-type tractor or a backhoe, it is recommended that this equipment be rented or borrowed for the periodic excavation of the trenches (which should have a useful life of 60 to 90 days), thus avoiding the constant use of the machinery. For this to be a feasible option, the excavation of the trenches should be planned for the whole year, to coincide with the availability of the equipment. The rental costs should be included in the general budget.

Before the period of useful life of the trench is over, the equipment for excavating the next trench should be in place, to ensure the final sanitary disposal of the MSW and protect the environment. Otherwise, the service will be interrupted and the site runs the risk of becoming an open dump.

? *Advice on trench location*

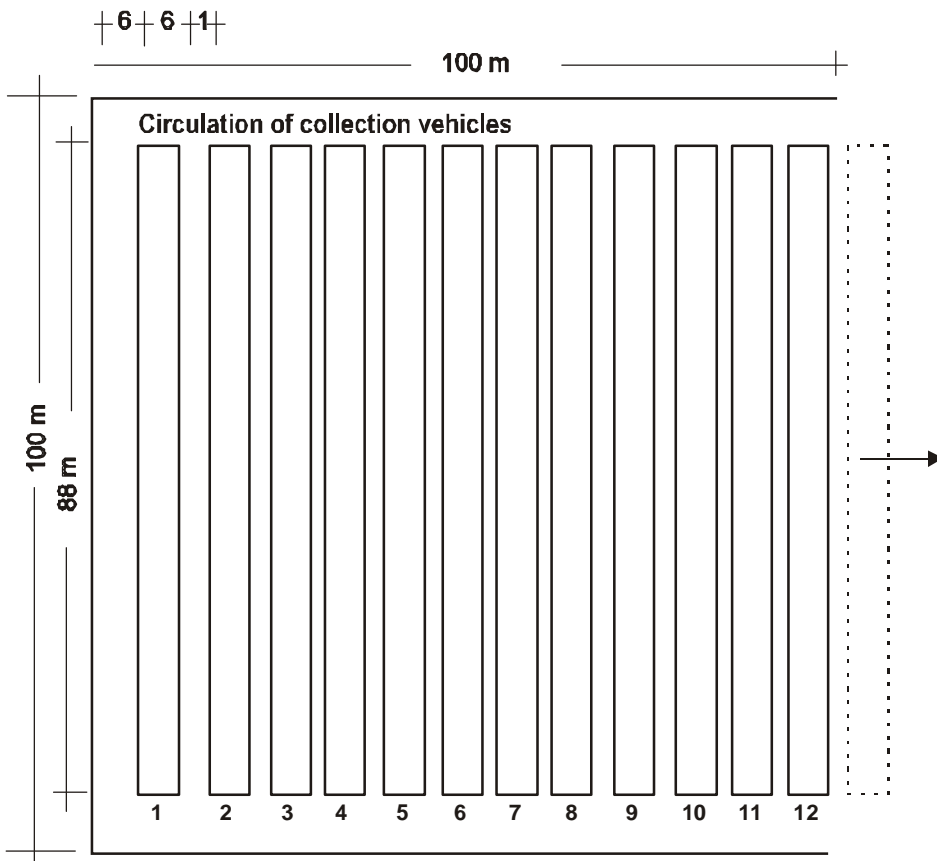
In the case of uneven land —for example, gradients of 5% in several directions— if optimal use is to be made of the terrain to facilitate the excavations,



**Figure 5.8**  
**Trench location, excavation process over time, and combination with the area method**

the trenches should be dug following the contour lines. This will ensure a more effective management of the excavated earth, both for stockpiling it to one side of the trench and for its subsequent use as cover material. It is advisable to start opening the trenches at the lowest point of the site and to ascend progressively as the lower trenches are filled (Figure 5.8).

In view of the difficulty of acquiring new sites, it is recommended that this trench method of operation be combined with the area method, that is, raising the terrain some meters above the original ground level. In this way it will be possible to take advantage of the surplus soil for daily cover material and for the final covering of this new stage of the landfill. Surplus earth can sometimes be used to make a kind of screen around the site to block visibility from the outside (Chapter 6, number 6.4.2).



**Figure 5.9**  
Distribution of trenches in the site

**A land-use program for the excavation of trenches over time and a program for the management of the surplus soil, which can be up to 50%, are fundamental for successful landfill management.**

? *Trench excavation volume*

The excavation volume and the time the machinery will be required are calculated from the useful life of the trench using the following equation (see Annex 4, example 3):

$$V_z = \frac{t \times DSr \times c.m}{D_{msw}} \quad [5-12]$$

where :

- $V_z$  = Volume of the trench (m<sup>3</sup>)
- $t$  = Time of useful life (days)
- $DSr$  = Quantity of MSW collected (kg/day)
- $c.m$  = Cover material (20 - 25% of the compacted volume)
- $D_{msw}$  = Density of the MSW in the landfill (kg/m<sup>3</sup>)

? *Dimensions of the trench*

For the effects of manual operation, the dimensions of the trench will be limited by:

- ? The depth of the trench, which should be from two to four meters depending on: the water table level; the type of soil; type of equipment; and excavation costs.
- ? The width of the trench, which should be from three to six meters (the width of the equipment). This is advisable in order to avoid long-distance hauling of the waste and cover material, thereby improving work output. Thus, the operation can be planned leaving one side for the accumulation of soil and the other for the unloading of the MSW. Depending on the degree of compaction and on the climate, the surface of a finished trench can be used for the unloading of wastes.
- ? The length depends on the duration time or useful life of the trench. Thus:

$$l = \frac{V_z}{a \times h_z} \quad [5-13]$$



where :

- l = Length of the trench (m)
- $V_z$  = Volume of the trench ( $m^3$ )
- w = Width (m)
- $h_z$  = Depth (m)

? ***Machinery time***

The time required for the excavation of the trench and movement of earth in general will depend a great deal on soil type, the type and power of the machine, its traction system (wheels or tracks), and the skill of the driver (see Annex 4, example 3).

$$t_{exc} = \frac{V_z}{R \times J} \quad [5-14]$$

where:

- $t_{exc}$  = Machinery time for the excavation of the trench (days)
- $V_z$  = Volume of the trench ( $m^3$ )
- R = Excavation output of the heavy equipment ( $m^3$ /hour)
- J = Daily work day (hours/day)

? ***Useful life of the site***

From Table 5.1, column 13, we can find the area required only if the average depth of the sanitary landfill is known. However, in practice we find we need to calculate the useful life of the site (see Annex 4, example 4).

In the trench method, once the volume has been calculated, we assume a factor for the additional areas (separation between trenches<sup>6</sup>, circulation roads, isolation, etc.) and then the number of trenches that can be excavated at the site is estimated. Thus:

$$n = \frac{A_t}{F \times A_z} \quad [5-15]$$

---

<sup>6</sup> A separation of one meter between trenches is recommended, for greater stability. This separation depends on the type of soil and the shape of the trench (square or trapezoid), among other factors.

where :

$n$	=	Number of trenches
$A_t$	=	Total area of the terrain (m <sup>2</sup> )
$F$	=	Factor for additional areas of 1.2 to 1.4 (20 - 40%)
$A_z$	=	Area of the trench (m <sup>2</sup> )

Therefore the useful life will be found by:

$$L_u = (t_z \times n) / 365 \quad [5-16]$$

where :

$L_u$	=	Useful life of the terrain (years)
$t_z$	=	Service time of the trench (days)

### 5.5.2 Area method

As already mentioned, the area method is used for constructing the sanitary landfill on the surface of the land or for filling depressions. Point 5.6 describes methods for evaluating the volumetric capacity of the site.

## 5.6 Calculation of the volumetric capacity of the site<sup>7</sup>

The volumetric capacity of the site is the total volume of the terrain available for receiving and storing waste and the cover material, that together make up the sanitary landfill. In other words, it is the volume between the surface of the foundation and the final surface of the landfill, for which it is indispensable to determine the volumetric capacity of the terrain.

There are two main methods for carrying out this type of calculation:

- ? Long, narrow volumes
- ? Volumes of great extension (in both directions)

### 5.6.1 Very long volumes (around an axis)

The field work in this category of determining volumes usually includes the obtaining of cross- sections at regular intervals all along the axis of the project

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<sup>7</sup> Taken and adapted from IRVINE, William. *Topography. Areas and Volumes.* McGraw Hill. Chapter 15. 1975

(polygonal). First the areas of these sections are calculated and then, using Simpson’s rule for volumes or the prismoid rule, the volume of the material to be removed or placed can be calculated.

**Method 1. Calculation of the volume by Simpson’s rule**

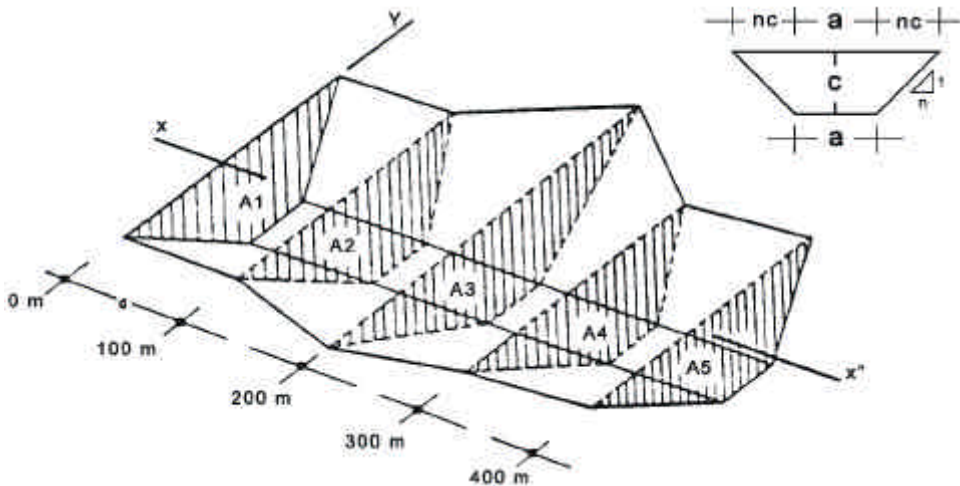
Once the area of the different sections has been calculated, the volume of the material in the cut or fill can be found by means of Simpson’s rule, which is the same as that used for areas, although the areas of the sections replace the ordinates in the equation (Figure 5.10 and Annex 4, example 5).

$$Volume = \frac{d}{3} [A_1 + A_5 + 2 \times A_3 + 4 (A_2 + A_4)] \text{ m}^3 \quad [5-17]$$

If “M” is the mean section, the volume by the Simpson’s rule will be:

$$Volume = \frac{1}{3} (d / 2) [A_1 + A_2 + 2 (cero) + 4 M] \quad [5-18]$$

$$Volume = \frac{d}{6} [A_1 + A_2 + 4M] \quad [5-19]$$



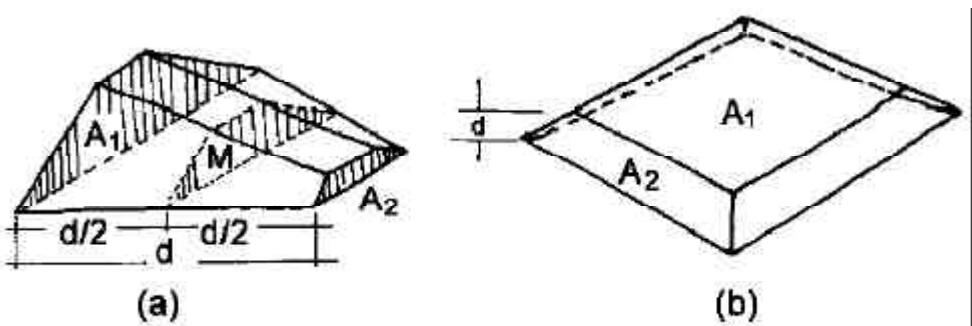
**Figure 5.10**  
Longitudinal volume around an axis

Equation [5-19] represents the prismoid rule, which can be used to find the volume of any prismoid, providing that the area of the middle cross-section is known (Annex 4, example 6).

Note: the area “M” is *not* the average of areas  $A_1$  and  $A_2$

**Method 2. Calculation of the volume by the prismoid rule**

A prismoid is defined as a solid that has two flat, parallel faces of regular or irregular shape, joined by flat or warped surfaces, on which can be drawn lines from one of the parallel faces to the other. Some examples of prismoids are shown in Figure 5.11, the equation of which is equivalent to [5-19].



**Figure 5.11  
Prismoids**

In order to find the volume by Simpson’s rule, it is necessary to divide the figure in such a way as to give a number of equidistant sections: three is the least number that fulfills this condition.

**Method 3. Volume from the outer areas**

From the axis of the landfill project and from the leveling of a terrain by strips, the volume between two consecutive cross-sections can be calculated, multiplying the average of the areas of the sections by the distance that separates them (for greater accuracy, 20 m stretches are recommended). (Figure 5.12).

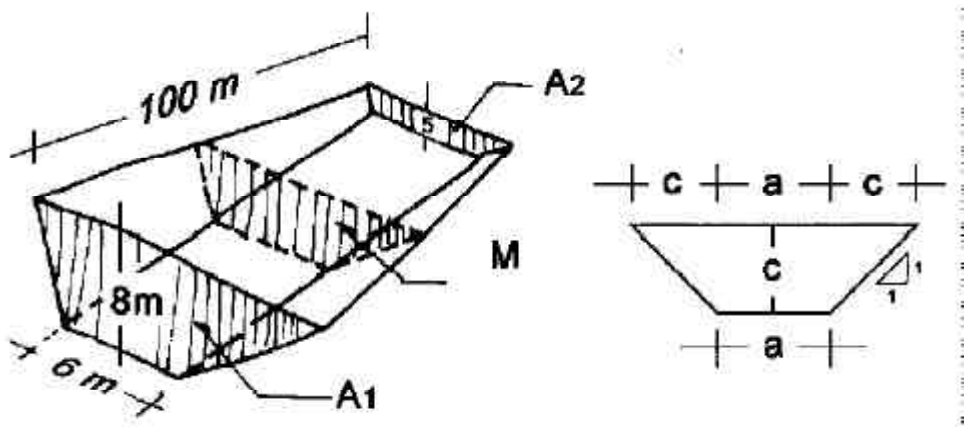
The volume between sections  $A_1$  and  $A_2$  is found by:

$$\text{Volume} = \frac{(A_1 + A_2) \times d}{2} \quad [5-20]$$

where :

$A_1$  and  $A_2$  = Areas of the cross-sections ( $\text{m}^2$ )  
 $d$  = Distance between sections  $A_1$  and  $A_2$

This formula will be more precise in the measure that  $A_1$  and  $A_2$  tend to be equal. The accuracy of this method is usually more than sufficient, since it is assumed that the terrain will be leveled uniformly between the two sections, even though it is known that the real volume is somewhat different (Annex 4, example 7).



**Figure 5.12**  
**Volume of a trench**

### 5.6.2 Volumes of great extension

#### *Method 1. Mesh*

When trying to find the volume of a site of great extension and little depth, the field work consists of covering the foundation surface area with a squared mesh and finding the levels of its vertices. The total volume can be calculated as the sum of volumes of all the prismsoids that have as transverse area one square of the mesh and as height the distance to the final surface of the fill. This height will be given by the average of the distances between the surface of the final outlay of the landfill and the

vertices of the square. That is, if the elevations of the vertices of a square are  $e_1, e_2, e_3$  and  $e_4$ , the height of the final surface is  $e_f$  and the area of each square of the mesh is  $A$ . Thus, the volume would be:

$$V_i = A(e_f - (e_1 + e_2 + e_3 + e_4)/4) \quad [5-21]$$

The smaller the squares of the mesh, the greater will be the degree of precision obtained (Annex 4, example 8).

**Method 2. From the contour lines**

This method consists of finding the existing capacity between the horizontal planes of the terrain. The areas of the intersections of these planes with those of the terrain are calculated and multiplied, after taking their average, by the difference in height that separates them. Using equation 5-20 we find:

$$V = \frac{(A_1 + A_2)}{2} \cdot h \quad [5-22]$$

where:

- $V$  = Volume between two contour lines ( $m^3$ )
- $A_1$  and  $A_2$  = Areas of the horizontal planes ( $m^2$ )
- $h$  = Difference in height between the planes (m)

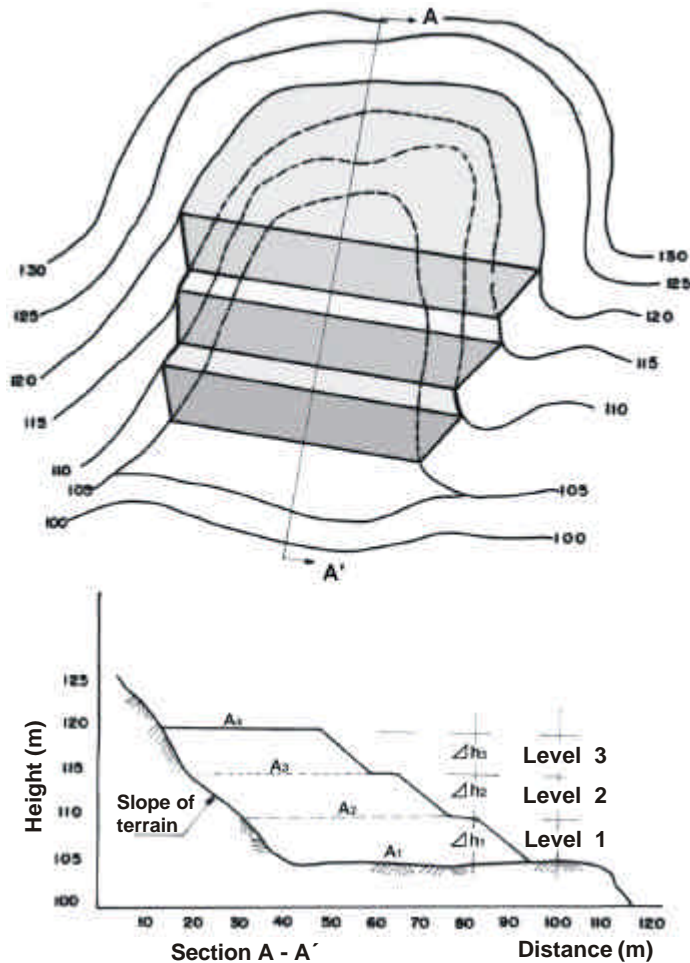
The smaller the increment  $h$ , the greater will be the precision of the method. In addition, it will be easier to use if the topographical survey is available with contour lines at every meter and if a planimeter is used for the calculation of the areas. This is the method most commonly used for large sanitary landfills.

Therefore the volumetric capacity of the site is generally obtained by the following equation:

$$V = \frac{(A_1 + A_2)}{2} \cdot h_1 + \frac{(A_2 + A_3)}{2} \cdot h_2 + \frac{(A_4 + A_5)}{2} \cdot h_3 + \dots [5-23]$$

When the areas taken are equidistant:

$$V = \frac{h}{2} \left( A_1 + 2 \sum_{i=2}^{n-1} A_i + A_n \right) \quad [5-24]$$



**Figure 5.13**  
**Plan and section of a terrain**

When the contour lines are widely separated, if it is desired to obtain a certain degree of precision in the calculation of the volume, the prismoid formula can be used. On applying this formula the planes of the contour lines should be considered to divide the depression into a series of prismoids. The volume of each one of them can be found by the successive application of the prismoid rule or, in favorable cases, directly using Simpson's rule.

On using the prismoid formula the areas of three curves are taken at once and the center one is used as the middle cross-section. The precision of the result depends above all on the difference of level between the curves. In general, the smaller the interval, the more accurately the volume can be calculated.

### 5.7 Calculation of the useful life

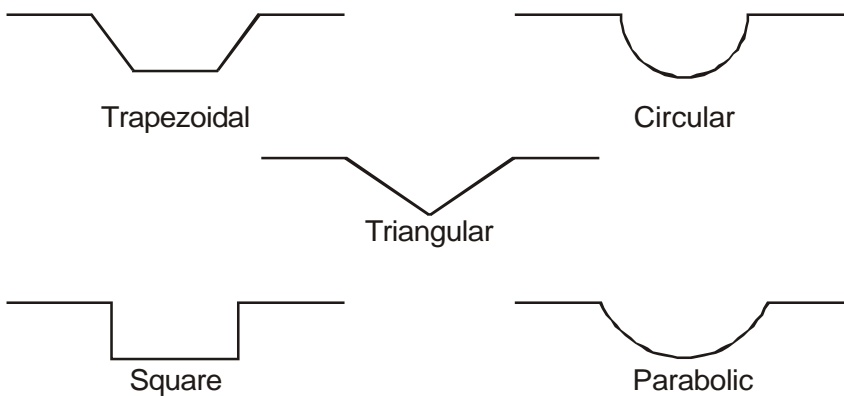
The volume of the landfill, that is, the volume between the initial and final layouts of the site, calculated by either of the above methods, will give the total volume available. Table 5.3 facilitates the collection of this information. The calculation of the useful life can be estimated thus:

The total available volume of the site is compared with the values in Table 5.1, column 12 (the accumulated volumes of the landfill) to find the same value or one slightly higher. Column 0 of the same line will indicate the number of years equivalent to the useful life of the landfill.

### 5.8 Design of a canal to divert surface water runoff

It is important to study the local rainfall figures to decide on the characteristics of the perimeter drainage system and necessary works. By diverting runoff water, we minimize leachate production and the potential for groundwater contamination.

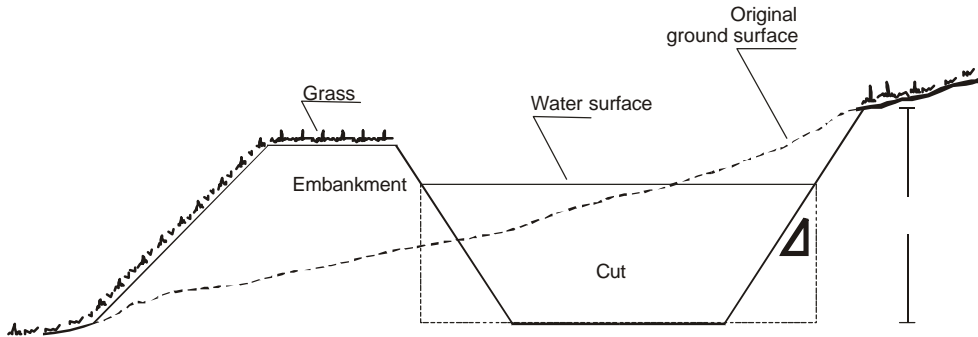
The rainwater that falls on areas adjacent to the sanitary landfill often drains onto it, hampering the landfill operation. A perimeter ditch around the sanitary landfill for the collection and diversion of rainwater runoff is, therefore, an essential element of the landfill infrastructure, which will contribute to reducing the volume of leachate and improving operating conditions. The ditch, trapezoidal in shape, should be constructed in earth or cement-soil; its dimensions will be determined taking into account the local rainfall figures, the tributary area, soil characteristics, vegetation, and the gradient of the terrain (Figure 5.14).



**Figure 5.14**  
Cross-sections of drainage ditches for runoff waters



For a small drainage area a ditch with the dimensions of Figure 5.15 is recommended.



**Figure 5.15**  
**Detail of the cross-section of a trapezoidal canal**

If greater precision is required owing to the characteristics of the place, the flow contributed by the drainage area can be calculated using the rational method, and the dimensions of the drainage ditch according to the following equation:

$$Q_p = \frac{K_i \times A_d}{3,6 \times 10^6} \quad [5-25]$$

where:

- $Q_p$  = Flow that enters or maximum runoff [ $m^3/sec$ ]
- $K$  = Runoff coefficient
- $i$  = Intensity of rain for an equal period [ $mm/hour$ ]
- $A_d$  = Area of the drainage area [ $m^2$ ]
- $t_c$  = Concentration time [ $min$ ].

The drainage canal should be along the highest contour line reached by the border of the sanitary landfill and should guarantee a maximum speed of 0.5 m/s, which does not cause excessive erosion; the size of the canal section can be calculated using the following equation:

$$A = \frac{Q_p}{v} \quad [5-26]$$

where:

- A = Area of the trench section [m<sup>2</sup>]  
v = Maximum average velocity [m/sec]

Once the area of the section is found, the dimensions can be decided upon, based on the previous recommendations.

## 5.9 Leachate generation

### 5.9.1 Calculation of leachate generation

The volume of leachate in a sanitary landfill depends on the following factors:

- ? Rainfall in the landfill area
- ? Surface runoff and/or groundwater filtration
- ? Evapotranspiration.
- ? Natural moisture of the MSW
- ? Degree of compaction.
- ? Field capacity (Capacity of the soil and the MSW to retain moisture)

The volume of leachate depends basically on the rainfall. Leachate is produced not only by runoff but also by rainfall in the area of the landfill, which increases the quantity, either by direct precipitation on the waste deposited there or by increasing the amount of filtration through cracks in the terrain.

Owing to the different conditions of operation and location of each landfill, the expected rates can vary, so they will need to be calculated for each individual case.

Since it is difficult to obtain local climatologic information, the volume of leachate produced is often determined by using coefficients that correlate the previously mentioned factors.

The Swiss Method<sup>8</sup>, for example, enables us to make a simple, quick estimate of the flow of leachate or percolated liquid by using the equation:

$$Q = \frac{1}{t} P \times A \times K \quad [5-27]$$

---

<sup>8</sup> Adapted from: Lima, Luiz Mario Queiroz. Tratamento do lixo. São Paulo. Hemus. 1991.

where:

- Q = Mean flow of leachate (l/s)  
 P = Mean annual precipitation (mm/year)  
 A = Surface area of the landfill<sup>9</sup> (m<sup>2</sup>)  
 t = Number of seconds in a year (31,536,000 s/year)  
 K = Coefficient that depends on the degree of compaction of the waste, the recommended values of which are the following:

- ? For weakly compacted landfills with a specific gravity of 0.4 to 0.7 t/m<sup>3</sup>, the estimated production of leachate is between 25 and 50% (K = 0.25 to 0.50) of the mean annual precipitation for the landfill area.
- ? For strongly compacted landfills with a specific gravity  $\geq 0.7$  t/m<sup>3</sup>, the estimated production of leachate is between 15 and 25 % (K = 0.15 to 0.25) of the mean annual precipitation for the landfill area.

Observations made at several small landfills have confirmed that leachate generation occurs chiefly during rainy periods and for several days afterwards, and stops during dry periods. It would therefore be a good idea to use an adaptation of the above method to calculate leachate generation from precipitation during the rainy months and not during the whole year. This criterion is important when estimating the leachate drainage or storage system for manual sanitary landfills.

Therefore, it is suggested that in equation [5-27] the precipitation records used be those of the month of maximum rainfall, expressed in mm/month. This method will give a good approximation of the flow:

$$Q_{lm} = P_m \times A \times K \quad [5-28]$$

where:

- Q<sub>lm</sub> = Mean leachate flow generated (m<sup>3</sup>/month)  
 P = Maximum monthly precipitation (mm/month)  
 A = Surface area of the landfill<sup>9</sup> (m<sup>2</sup>)  
 K = Coefficient that depends on the degree of waste compaction  
 1 m = 10<sup>3</sup> mm

<sup>9</sup> It is important to note that the "area" is that in which the waste is deposited, that is, the area of the platforms or embankments, not the area of the whole landfill site. In other words, it is the area covered with waste.

### 5.9.2 Design of the leachate drainage system

The first recommendation, in view of the small surface area of manual sanitary landfills, it is to minimize the inflow of rain waters. In addition to controlling runoff waters by means of perimeter drainage ditches, it is also possible to prevent the rain from falling directly onto the fill banks or trenches by constructing a roof to keep the rain off, rather like an umbrella. In this way the amount of leachate tends to be null, thus preventing one of the biggest problems in this type of landfill, especially in rainy areas.

Secondly, it is advisable to construct a herringbone shaped system of storage for the leachate in the interior of the landfill, specifically in the base that will serve as support for each platform. The system can be connected.

**Preventing or minimizing the increase of leachates (thereby also preventing the contamination of the rainwater) is technically and environmentally better and far more economical than designing and installing artificial waterproofing systems, building drainage systems, or carrying out conventional treatment for these highly contaminated waters, especially in the case of small municipalities.**

#### ? *Volume of leachate*

If the above measures are not sufficient, the greatest possible quantity of leachate generated will be stored in ditches inside the sanitary landfill, as in a false bottom, and the rest will be stored in other ditches outside the landfill so that it can evaporate. More ditches will be dug progressively, as the need arises. The volume of leachate is estimated by the equation:

$$V = Q \times t \quad [5-29]$$

where:

- V = Volume of leachate to be stored (m<sup>3</sup>)
- Q = Mean flow of leachate (m<sup>3</sup>/month)
- t = Maximum number of consecutive months with rain (month)

### ? *Length of the system of ditches for leachates*

Once the flow is obtained, the dimensions of the system of ditches for storing leachate can be calculated, as indicated in the following equation. The ditches should have a width of at least 0.6 m and a depth of 1 m, providing that the water table is one meter farther down and the soil has the conditions of impermeability previously recommended.

$$l = V/a \quad [5-30]$$

where:

- $l$  = Length of the storage ditches (m)
- $V$  = Volume of leachate to be stored during periods of rain (m<sup>3</sup>)
- $a$  = Surface area of the ditch (m<sup>2</sup>)

## 5.10 Monitoring water quality

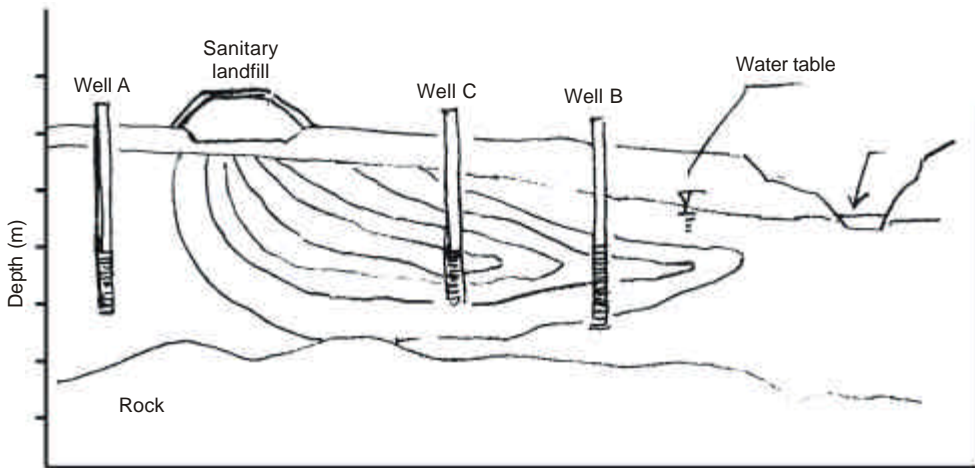
Before, during, and after the construction of the sanitary landfill it is important to take a series of measures to prevent potential risks to the quality of the environment.

Although it is a small project, a manual sanitary landfill must comply with certain environmental and safety standards, especially with regard to surface and underground waters. It would be advisable to install monitoring wells in order to prevent any risk of flooding.

We should not forget that a large portion of the MSW of small towns is of domestic origin, so the environmental demands and controls should also be in accordance with the size of the problem and the available resources. In addition, if there is a silty clayey soil, with a permeability coefficient of  $k < 10^{-7}$  cm/sec, and if the thickness of the soil above the water table is greater than 1 m, there is even less likelihood of contamination of groundwater.

### 5.10.1 *Location of the monitoring wells*

The monitoring wells should be situated at least 10, 20 and 50 m from the landfill area and from the exterior drainage of leachate; some three or four wells will be sufficient. For the collection of groundwater samples, if the water-bearing strata are near the surface (approximately 4 m down), these wells can be dug manually (Figure 5.17).



**Figure 5.16**  
**Location and characteristics of the water monitoring wells**

### **5.10.2 Parameters for the analysis of water and leachate**

Table 5.2 lists the most representative parameters for the analysis of the quality of groundwater, surface water, and leachate of a sanitary landfill.

The laboratory analyses of the samples of nearby ground and surface waters can be intensive during the early months and less frequent once constant values are recorded in the results.

### **5.11 Calculation of the daily cell**

The daily cell is made up of the MSW and the cover material. It is dimensioned with a view to economizing on soil, without damaging the cover, and with the purpose of offering a working face sufficient for the unloading and maneuvering of the collection vehicles.

The dimensions and the volume of the daily cell depend on factors such as:

- ? The quantity of MSW to be disposed of daily
- ? The degree of compaction.
- ? The cell height most comfortable for manual labor
- ? The working face necessary to enable the collection vehicles to discharge the MSW

**Table 5.5**  
**Parameters for measuring the quality of water and leachate**

Parameter	Surface Water	Ground-water	Leachate
pH	x	x	x
Biochemical oxygen demand (BOD) (mg/l)	x	x	x
Chemical oxygen demand (COD) (mg/l)	x	x	x
Temperature (°C)	x	x	x
Total iron (mg/l)	x	x	
Total organic carbon (TOC) (mg/l)			
Nitrates (mg/l)	x		x
Chlorides (mg/l)	x	x	x
Sulfates (mg/l)		x	x
Total colony count , (colonies/ml)	x	x	x
Conductivity, (umhos/cm)			x
Total suspended solids	x		x
Heavy metals (Hg, Cd, Pb, Cr, Fe, Zn, Cu, Ni)			x

A height between 1 and 1.5 m is recommended for the daily cell, because of the low degree of compaction achieved with a manual operation, and the need to provide greater mechanical stability to the construction of the embankments of the sanitary landfill. The advance and width of the cell will be calculated from the daily volume of compacted wastes, taking into account the limitations with regard to height, and maintaining a working face that is as narrow as possible, on the basis of equations [5-31] – [5-33].

#### 5.11.1 Quantity of MSW to be disposed of

For the design of the daily cell, the quantity of waste can be found in two ways:

From the quantity of garbage produced daily, that is,

$$DS_{sl} = DS_p \times (7/ d_w) \quad [5-31]$$

where :

- $DS_{sl}$  = Mean daily quantity of MSW in the sanitary landfill (kg/day)<sup>10</sup>  
 $DS_p$  = Quantity of MSW produced per day (kg/day)  
 $d_w$  = Work days in a week (normally  $d_w = 5$  or 6 days, and even less in smaller municipalities)

### 5.11.2 *Volume of the daily cell*

$$V_c = \frac{DS_{sl}}{D_{msw}} \times c.m \quad [5-32]$$

where :

- $V_c$  = Volume of the daily cell (m<sup>3</sup>)  
 $D_{msw}$  = Density of the MSW recently compacted in the manual sanitary landfill, 400-500 kg/m<sup>3</sup>  
 $c.m$  = Cover material (20-25%)

It should be noted that the density used for the recently compacted waste is less than that of the stabilized waste that is used for the calculation of the volume.

### 5.11.3 *Dimensions of the daily cell*

? *Area of the cell*

$$A_c = \frac{V_c}{h_c} \quad [5-33]$$

where:

- $A_c$  = Area of the cell (m<sup>2</sup>/day)  
 $V_c$  = Volume of the daily cell (m<sup>3</sup>)  
 $h_c$  = Height of the cell (m) – limit 1.0 m to 1.5 m. Flintoff reports heights of 1.5 to 2.0 m for manual sanitary landfills, whereby the cover material is reduced.

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<sup>10</sup> It should be considered that the daily volume of MSW will increase yearly and, consequently, so will the cell size, implying that it may be necessary to make an annual reassessment of the labor required.



**Table 5.6**  
**Volumetric capacity of the site for the sanitary landfill**

Embankment or platform	Elevation top (m)	Area (m <sup>2</sup> )		H (m)	Volumetric capacity (m <sup>3</sup> )			Useful life of each embankment (months)
		For each contour line	Average for the contour lines		Between contour lines	Accumulated volume	Cut (cover material)	
1								
2								
3								
4								
5								
<b>Total sanitary landfill</b>								

Total capacity of the terrain

\_\_\_\_\_ m<sup>3</sup>

Sanitary landfill volume = Total capacity of the terrain x 0,8

\_\_\_\_\_ m<sup>3</sup>

Cover material = 20-25% of the volume of compacted wastes

\_\_\_\_\_ m<sup>3</sup>

Quantity of MSW = MSW volume (m<sup>3</sup>) x stabilized density (t/m<sup>3</sup>)

\_\_\_\_\_ t

Total usefull life

\_\_\_\_\_ months

? *Length or advance of the cell (m)*

$$l = \frac{A_c}{w} \quad [5-34]$$

$w$  = Width, fixed according to the working face necessary for the collection vehicles to unload the waste (m). It should be noted that in small communities only one or two vehicles will be unloading at once, which will set the width between 3 and 6 m.

Since the slopes (perimeter) also have to be covered with earth, the relation of the width to the length of the cell that will require the least cover material would be that of a square. This means, therefore, the square root of the area of the cell:

$$w = l = \sqrt{A_c} \quad [5-35]$$

When this does not occur because the resulting width is too narrow for the vehicles to unload, the width is fixed first and then the advance is calculated, as explained with equation [5-33].

## 5.12 Calculation of labor

The labor necessary to form the daily cell depends on:

- ? The quantity of MSW to be disposed of
- ? The availability and type of cover material
- ? Number of work days at the landfill
- ? The duration of the working day
- ? Climate conditions
- ? The unloading of the waste at the working face according to distance
- ? The performance of the workers

The following is a guide for calculating the number of workers required in the manual sanitary landfill. A working day of eight hours is assumed, with an effective working time of six hours. These performances are under normal working conditions and can vary from place to place depending on factors previously described (Table 5.6).

**Table 5.7**  
**Calculation guide for estimating the number of workers required**

OPERATION	PERFORMANCES		Man/day
Movement of wastes	$\frac{\text{Solid waste (t/day)}}{(0,95^a \text{t/man} - \text{hour})}$	$\times \frac{1}{6 \text{ hours}}$	
Compaction of wastes	$\frac{\text{Surface area (m}^2\text{)}}{(20^a \text{m}^2/\text{man} - \text{hour})}$	$\times \frac{1}{6 \text{ hours}}$	
Earth movement	$\frac{\text{Earth m}^3}{(0,35 \text{ a } 0,70)^a \text{m}^3/\text{hora} - \text{hom.}}$	$\times \frac{1}{6 \text{ hours}}$	
Compaction of the cell	$\frac{\text{Surface area (m}^2\text{)}}{(20)^a \text{m}^2/\text{man} - \text{hour}}$	$\times \frac{1}{6 \text{ hours}}$	
	<b>(Total number of men)</b>		
(*) To be adapted to each region. Annex 4, example 11. Model for calculation to obtain performances.			

Flintoff reports the following requirements of labor from three sites, in which the sanitary landfills are operated manually (Table 5.7).

**Table 5.8**  
**Performances reported from other experiences**

Site	t/day	Performance
1	30	2 men /15 t/man-day
2	50	6 men /8 t/man-day
3	100	10 men /10 t/man-day

The densities of the wastes distributed in these places were between 250 and 400 kg/m<sup>3</sup>; thus, for a given tonnage, the volume to be managed could be similar to or greater than that in developing countries.

Table 5.8 indicates the probable scale of requirements for labor and cover material with a rate of waste production and density typical for Latin America.

**Table 5.9**  
**Probable labor requirements**

Population Inhab.	Volume (m <sup>3</sup> /day)				
	t/day (ppc=0.5 kg/cap/day)	Loose waste (330 kg/m <sup>3</sup> )	Compact waste (500 kg/m <sup>3</sup> )	Cover material m <sup>3</sup>	Men
20,000	10	30	20	4	4
50,000	25	75	50	10	10
100,000	50	150	100	20	19

In addition to the number of men who will carry out the work of construction of the landfill, another person is needed to direct and steer the operations in the manual sanitary landfill as supervisor. Taking into account that to have a professional trained in the management of MSW would be costly in some municipalities, an individual with the following characteristics can be hired:

- ? a technician with high school education, who knows how to do mathematical operations, or
- ? a health promoter who knows how to carry out mathematical operations and has some experience in the field.

It should be noted that the presence of the supervisor at the sanitary landfill is important during practically the whole workday in the early months. As he gains experience, his time present at the landfill can be reduced to two hours daily: one hour in the morning and another in the afternoon. He could spend the rest of the day supervising the urban cleaning service in general.

As a last resort this work of supervision can be carried out by the Head of Public Works of the municipality.

**The supervisor is very important!**

### **5.13 Landscaping project**

Another aspect of the manual sanitary landfill is its final landscaping, for aesthetic reasons, so that once its useful life is over it can be integrated into the natural environment and made to blend with its surroundings.

The final compacted cover of 0.4 to 0.6 m as a minimum and the drains for runoff waters and gases are essential for the vegetation on the landfill, which is restricted to species with short roots while the landfill is becoming stabilized.

The planting of bushes with short roots that do not pass through the cover is recommended, although it is also possible to plant in holes filled with fertilized soil and grass, in order to prevent erosion and the increase of leachate. Cover grass should be planted on finished areas of the landfill as each part becomes completed, rather than waiting until the whole surface of the platforms or fill banks is finished.

### **5.14 Analysis of environmental impacts**

Environmental impact analyses serve to anticipate the positive and negative effects that every sanitary landfill project has during its different stages: site selection, construction, operation, and closure.

The measurement of these impacts should be interdisciplinary and should be carried out on the natural components (water, soil and air), of the site and surrounding area as well as on the project-related economic and social variables.

Table 5.9 shows the main social and environmental aspects of the different stages of the sanitary landfill project.



## **6. SITE PREPARATION AND CONSTRUCTION OF THE INFRASTRUCTURE**





## 6.1 Site preparation

The terrain will need to be prepared for the construction of the basic landfill infrastructure with a view to receiving and disposing of MSW in an orderly way and with the least possible impact, as well as facilitating complementary works and a subsequent landscaping process.

The following works are of vital importance for the preparation of the site; they are simple, low-cost works that can be executed rapidly by the municipal workers, complying with sanitary requirements.

### 6.1.1 Clearing and cleaning

An area should be cleared to serve as the foundation or base material for the embankments that will form the landfill; it will sometimes be necessary to cut down trees and shrubs that would hinder landfill operations. This clearing will be done by stages as the project advances, to prevent soil erosion. (Figure 6.1).

### 6.1.2 Treatment of the base material

#### ? *Leveling*

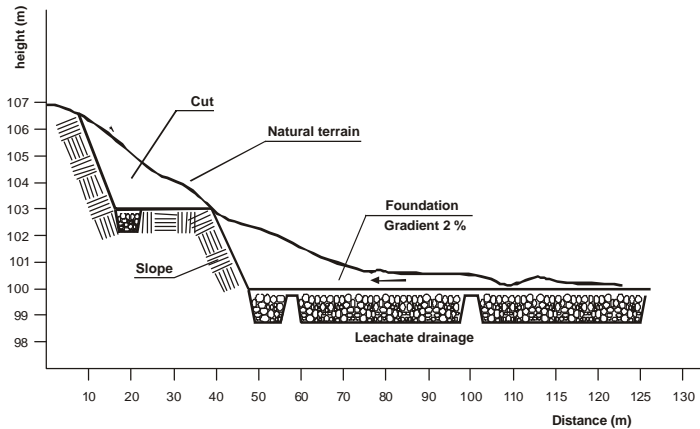
After the clearing, the landfill project continues with the removal of the first layers of soil, depending on the quantity of cover material available. It is sometimes



**Figure 6.1**  
Clearing and cleaning of the site

advantageous to leave the terrain intact, to take advantage of its capacity of absorption and filtration to remove contaminants from the leachate.

It is recommended that the surface of the base of the waste platforms have a negative gradient of 2 or 3% with respect to the bottom and side slopes, to guarantee the fast runoff of percolated liquids and their storage in the drainage ditches.

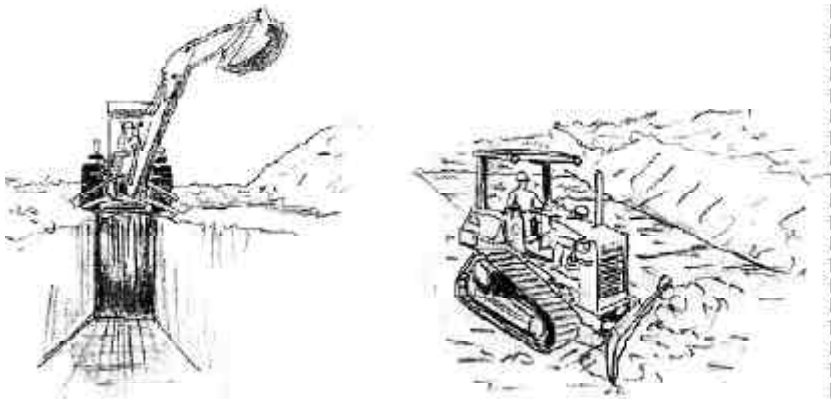


**Figure 6.2**  
**Gradient of the surface of the terrain or base of the landfill**

For the leveling of the base material and the cuts of the slopes it is recommended that the earth movement be done by stages during the site life; this will prevent the rain from eroding the terrain and carrying away the earth intended for use as cover material. The plant cover of the initial areas will need to be stored and conserved, since it will serve for the progressive landscaping of the site as the different areas of the landfill are completed.

For leveling the base material of the fill banks and excavating the trenches and ditches, heavy machinery should be used (track-type tractor and/or backhoe), because manual excavation is too inefficient. The same equipment will be used for the construction of the access road and the internal roads or the extraction and storage of cover material; the latter activity should preferably be carried out only in dry periods (Figure 6.3).

Through the Secretariat for Public Works, the municipal authority can request the machinery on loan or rent it from the central or regional government or even from a nearby municipality. One type of loan agreement could involve the municipal authority's commitment to pay for the fuel used as well as the wages and food for the operator for the number of days necessary.



**Figure 6.3**  
**Earth movement for site preparation**

The earth moving activities will not usually last more than one week, since the preparation of the land for a manual sanitary landfill is done in stages.

One of the greatest difficulties in small towns, besides the acquisition of the land for the sanitary landfill, is the borrowing or renting of the heavy machinery for the initial earth moving to open the access road for the collection vehicle and prepare the base soil. Negotiating such a loan tests the management skills of the civil servant in charge of the administration.

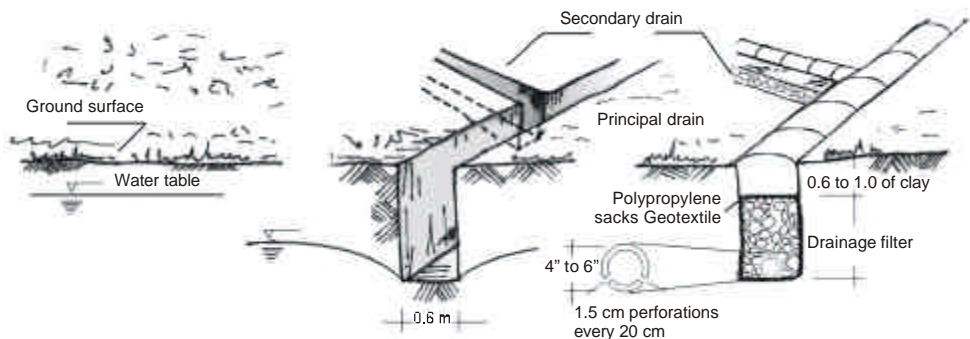
### ? *Drainage*

Avoid constructing the sanitary landfill “over” any small stream or spring of water.

When the only land available is waterlogged or swampy, it can be used to construct a manual sanitary landfill only if the water table is permanently lowered. This is done by using the following procedure (Figure 6.4):

- ? Dig one or several drainage ditches in the lowest part of the land, with the depth required in each case, until it is confirmed that the first levels of waste at the base of the site are at least 1.0 m. above the highest water level and that the soil is clayey.
- ? Set perforated concrete pipes in place and fill the ditches with stones and gravel, to act as a filter.
- ? Cover the stone and gravel drain with geotextile fabric or a similar material to prevent silting up. Polypropylene is appropriate, and can be obtained from used sacks.

- ? Place a layer of 0.3 to 0.6 m of compacted clayey matter over the material to ensure isolation between the upper surface of the drainage and the MSW to prevent possible contamination of the water.
- ? Be careful not to cross the leachate drainage system with the drainage ditch to lower the water level.



**Figure 6.4**  
**Drainage for land with a high water table**

### 6.1.3 Cuts and slopes of the site

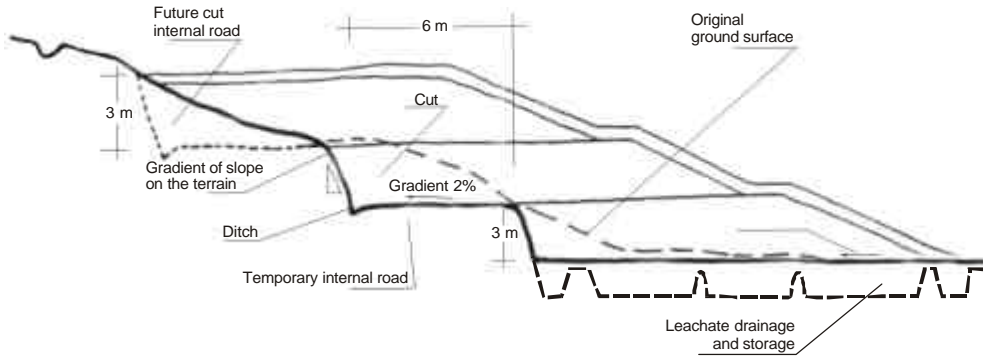
Because of the variations in the type and layout of the materials, it is indispensable to analyze the stability of the terrain to define the most appropriate slope. A good standard to establish in this reference is that for a cut of more than seven meters in height, a stability study should be made based on geotechnical principals. For lower heights, the slope can usually be determined from the classification of the rocks and soils and the consolidation of the cut materials.

For a low cut (less than five meters) a single slope is recommended; for greater heights it will be better to have two slopes; while in some cases the construction of intermediate berms or banquettes will be necessary (See Chapter 5, Figure 5.4, point 5.4.3).

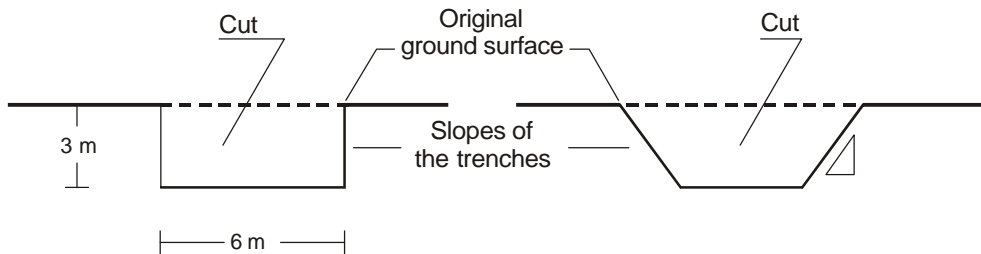
The slopes of the terrain are left in such a way that they will not cause erosion and can give good stability to the landfill. These can range from vertical to type 3:1 (horizontal:vertical), depending on the soil type.

The surface of the terraces or embankments should have a slope of 2% with regard to the interior slopes, in order to conduct the leachate waters to the drainage

**Area method**



**Trench Method**



**Figure 6.5**  
**Sections of the slopes and the foundation**

ditches and to prevent ponding when used as temporary access roads. This measure also contributes to landfill stability.

The ditches may be trapezoidal, square, or rectangular, depending on the soil conditions. The separation between them will be from 0.5 to 1 m, as required to ensure their stability while they remain empty (Figure 6.5).

**6.1.4 Infrastructure requirements and equipment for a sanitary landfill**

Table 6.1 will help to identify quickly the main infrastructure works and basic equipment for a sanitary landfill.

**Table 6.1**  
**Infrastructure and basic equipment for a sanitary landfill**

Aspect	Infrastructure/equipment	Usefulness
<b>1. Control of water pollution</b>	? Ditches for collection and diversion of surface runoff water.	Prevent surface water from penetrating into the site of the sanitary landfill, thereby reducing the generation of leachates <sup>2</sup> .
	? Drains for collection and evacuation of leachates.	Limit infiltration of leachates to groundwater and reduce the risk of surface discharge of leachates.
	? Leachate treatment plant or pumping station <sup>1</sup> .	Reduces the contaminating power of the leachate to dispose of it in a collection system.
	? Monitoring well.	Facilitates monitoring of the quality of groundwater to detect possible failures in the system.
<b>2. Control of odors and gases</b>	? Gas vents.	Permits the controlled evacuation of gases, preventing risks of fires, explosions, or release of gas in neighboring areas.
	? Spreading and compacting with appropriate machinery (com-pactor, tractor, etc.) or in the case of manual operations, roller and tampers.	This is the essence of the sanitary landfill method, which makes it possible to confine solid waste (Figure 7.3).
<b>3. Reduction of impact on the landscape</b>	? Perimeter fence, preferably using native vegetation.	Isolates and delimits the site; reduces spreading of odors; catches MSW blown by the wind.
<b>4. Labor safety and hygiene</b>	? Control building.	Helps to control the quantity and type of residues entering the site.
	? Storehouse, changing rooms, and washrooms.	Facilitates the hygiene of the workers and the storage of their working clothes, equipment, and tools.
	? Occupational safety and hygiene equipment (gloves, mask, etc.).	Protects the personnel from diseases and minimizes impacts of work accidents.

<sup>1</sup> *Leachate*: Liquid that filters through the solid waste picking up contaminants, and which can then travel to the surface or infiltrate toward deeper layers polluting the groundwater.

<sup>2</sup> The leachate can also be re-pumped (recirculated) to the same sanitary landfill so that this will act as a filter.

*Source*: Adapted from the methodology guide for drawing up MSW management plans for cities. OPS/CEPIS, 2000 (in edition).

## 6.2 Peripheral infrastructure

### 6.2.1 Access road

The manual sanitary landfill should be near an all-weather main public highway. It should be emphasized that the time spent hauling the waste from the populated area to the site of the sanitary landfill and making the return trip, is more important than the distance itself.

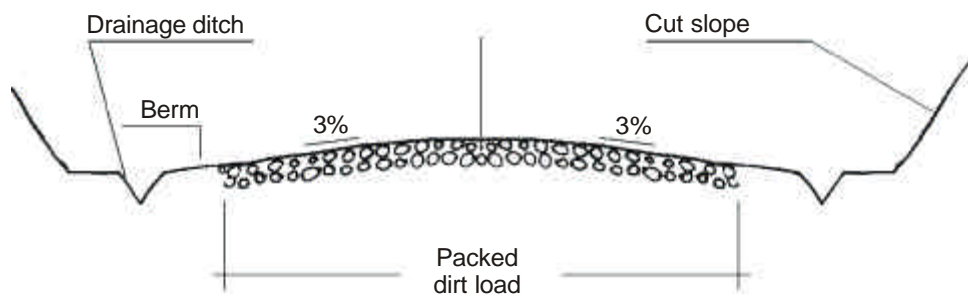
The internal access road should meet basic requirements for the easy and safe entry of the waste collection vehicle(s) at all times of the year.

For cases in which vehicular traffic is minimal, the access road can be a small four-meter-wide packed-dirt road, with good maintenance throughout the year. It is helpful to sprinkle the road with burned oil from time to time to prevent dust from accumulating (Figures 6.6 and 6.7).

The maximum gradient of this road can be 7% if the collection vehicle has to go uphill loaded, and 10% if the road is above the landfill, that is, if the vehicle will be traveling downhill to the working face when loaded. The same applies if more than one collection vehicles are used.

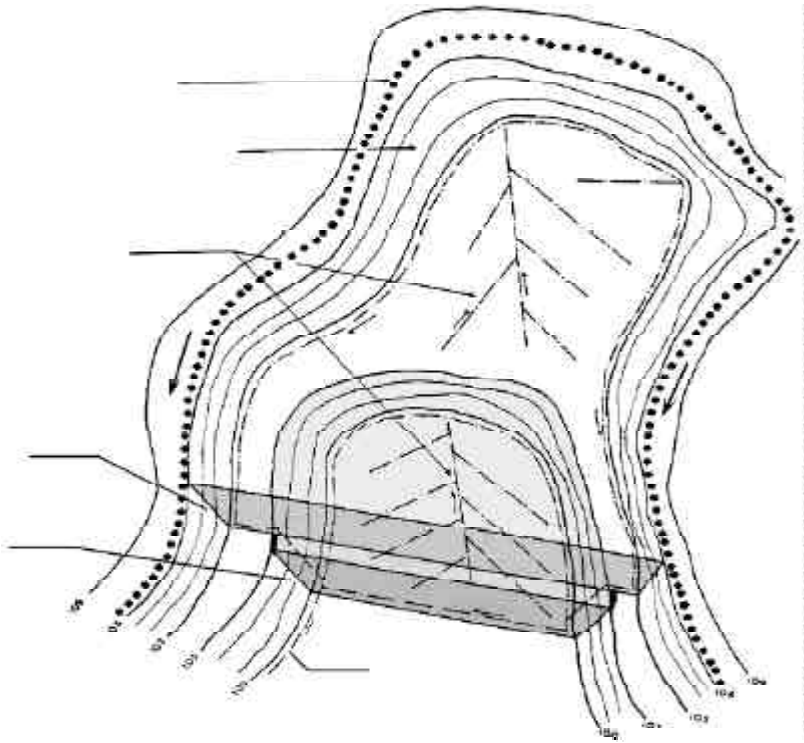
### 6.2.2 Peripheral drainage of rainwater

As soon as possible, any water sources or small veins of water existing in the landfill area should be diverted and channeled before the operation starts. Besides hampering the landfill operation, the passage of this water through the mass of wastes will contribute to an increase in the volume of leachate.



Source: (Adapted from Orth, Maria Helena de Andrade and Takeda, Kiyoshi: Aterros sanitários. (Sanitary Landfills). CETESB. Course on the Management of Solid Waste Systems.

**Figure 6.6**  
**Cut of the internal road of the landfill**



Source: (Adapted from Orth, Maria Helena de Andrade and Takeda, Kiyoshi: Aterros sanitários. (Sanitary Landfills). CETESB. Course on the Management of Solid Waste Systems.

**Figure 6.7**  
**Access road to the manual sanitary landfill**

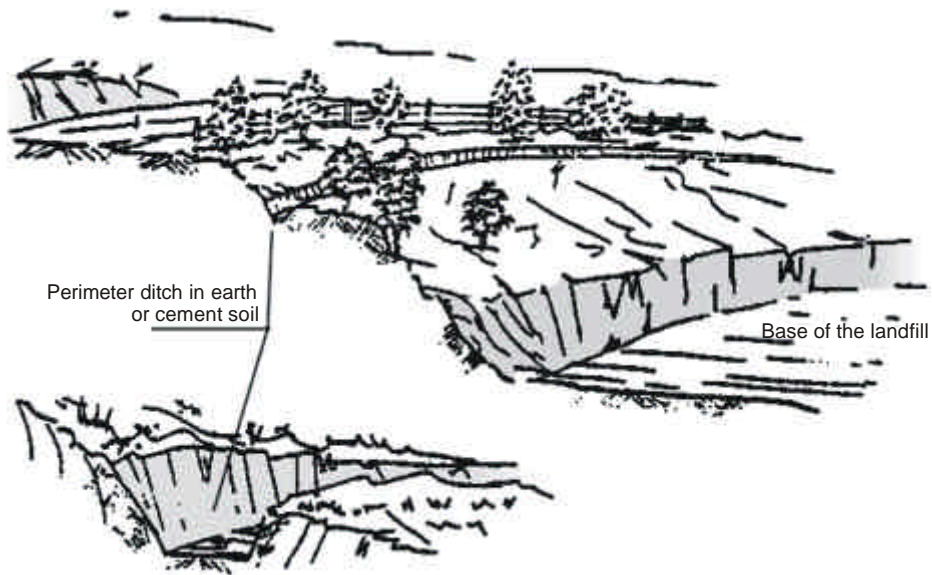
This interception and diversion of the surface rainwater runoff outside the landfill greatly helps to reduce the volume of leachate, thereby improving operating conditions. The canal or drainage ditch should always be constructed following the contour lines, to make for maximum speed without causing excessive erosion (Figure 6.8).

### **6.3 Infrastructure of the landfill**

#### **6.3.1 Leachate drainage and management**

Management of the percolated or leached liquid is one of the major problems in a sanitary landfill. Even if the landfill has peripheral canals that intercept and divert the runoff waters, the rain falling directly on the surface increases the volume of the leachate (Chapter 5, point 5.9). The following paragraphs describe some methods for alleviating this problem.





**Figure 6.8**  
**Perimeter drainage for runoff waters and leachate**

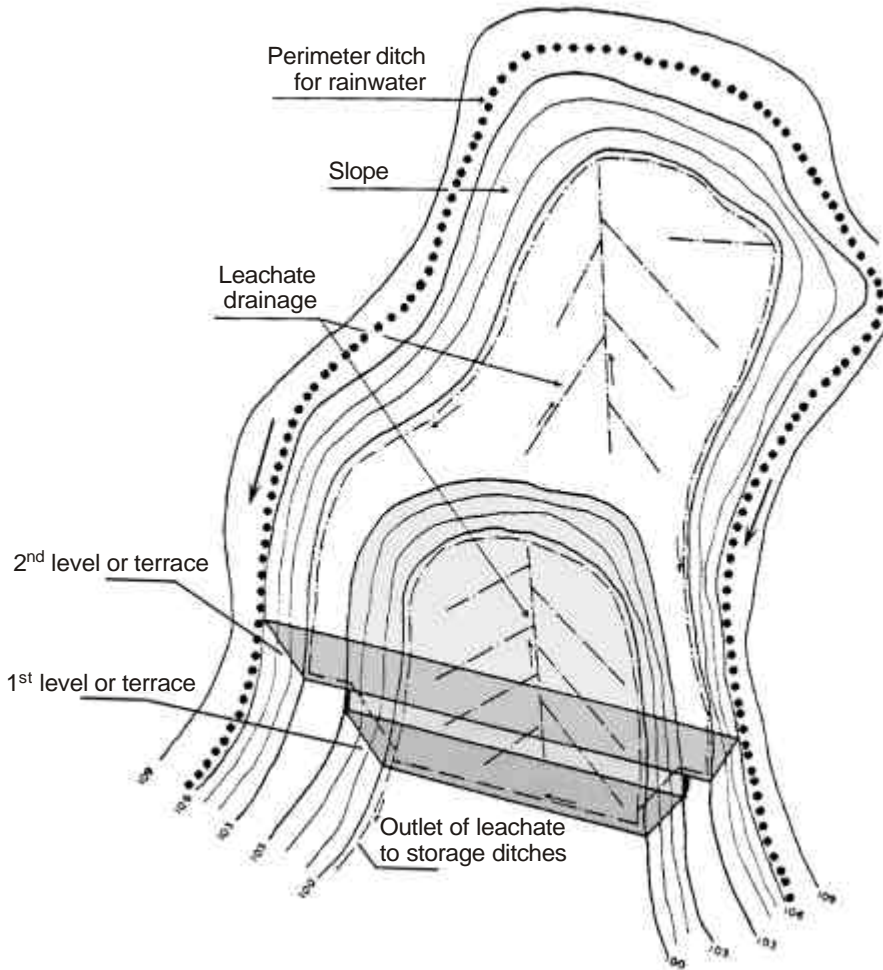
It is of utmost importance to build a drainage system that will serve as a base for the sanitary landfill before any waste is deposited; this system should retain the leachate inside the landfill for storage during an indefinite period. Such a system will largely reduce seepage to the exterior and remove the need for leachate treatment – which is very costly, complex process, and hardly feasible for small municipalities.

A more efficient solution is to build these drainage systems at the bases of all the interior and exterior slopes of the terraces or levels that make up the sanitary landfill. This prevents both runoff from the surface of the lower slopes of the fill banks, and interconnection with the vertical evacuation of gases.

#### *Construction of the internal leachate drainage system*

The system for the collection and storage of leachate consists of a horizontal network of stone ditches, interrupted with “screens” that are earthen walls of the terrain itself or mud-and-wood walls. One way of constructing the drains is as follows:

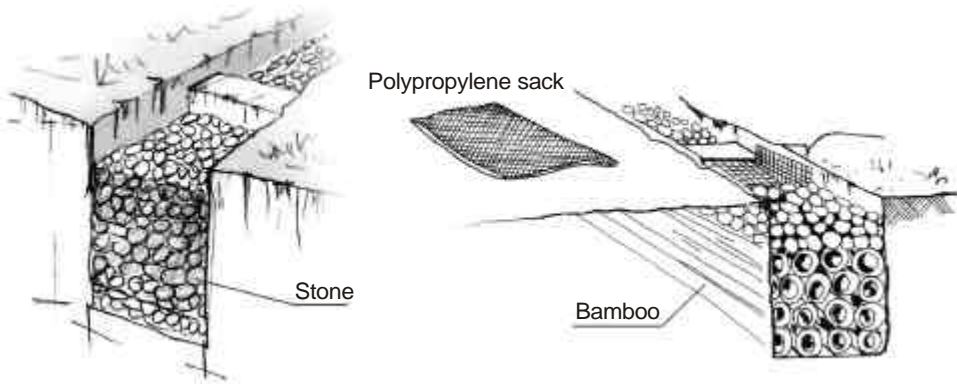
- ? The line along which the drainage will be located is drawn on the site. The layout can be similar to that of a sewerage system (e.g. herringbone) (Figure 6.9).
- ? The 0.6 m. by 1.0 m ditches of the principal drain are dug, and the earthen screens are installed at intervals of five or ten meters, with a width of 0.20 to



**Figure 6.9**  
**Layout of the leachate drainage system**

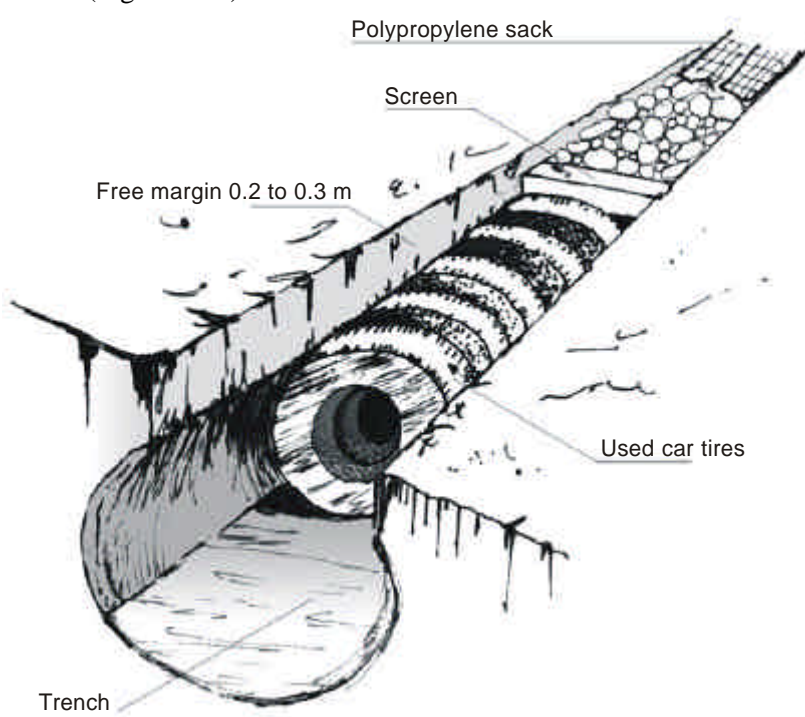
0.30 m., or else these small blocks of earth are simply left intact in the ditch. To ensure that the leachate will remain stored inside the landfill without overflowing the ditches, a free margin of some 0.30 m will be left between the screen and the ground surface level (Figure 6.10).

- ? For greater storage capacity, the ditches are filled with stones measuring 4 to 6 inches (not gravel). Once this has been done, it is advisable to place material over these stones that will permit the infiltration of the liquids and retain fine particles that might cause silting; as previously mentioned, polypropylene sacks can be used – or dry ferns, and even grass.
- ? Ditches made with used tires have a greater storage capacity for the percolated liquid; and at the same time this is a way of making use of bulky material



**Figure 6.10**  
**Details of the leachate storage ditches**

difficult to handle in the landfill. If used tires are not disposed of properly they can end up as a mosquito breeding ground. Once the tires have been buried vertically, one beside the other, a 0.20 a 0.30 m thick layer of stones is spread over them, and they are covered with polypropylene sacks or dry branches as in the previous case. The ditch will have a special conformation for reception of the tires. (Figure 6.11).



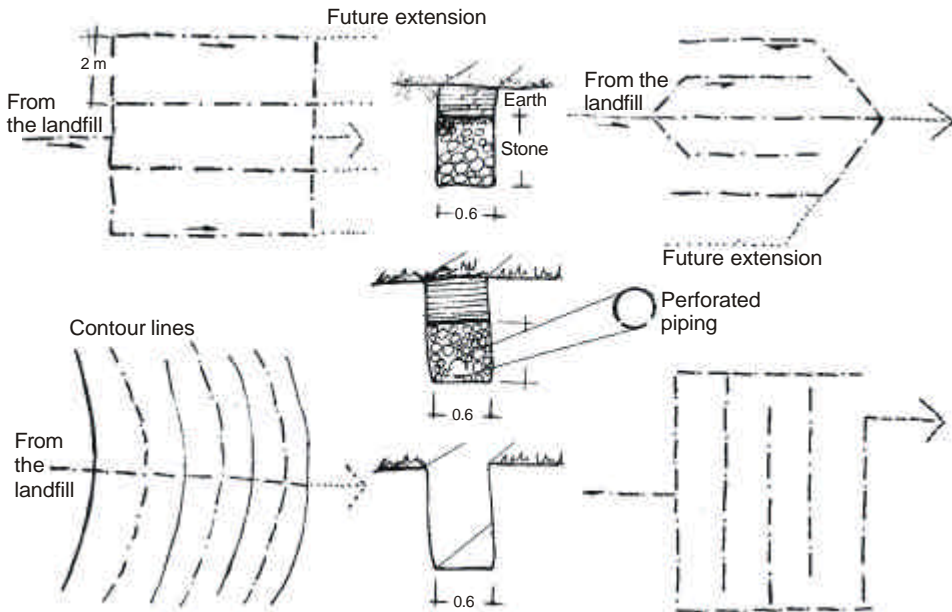
**Figure 6.11**  
**Leachate ditch ready for used tires to be installed**

- ? When there are long periods of rain and the quantity of leachate exceeds the landfill's internal storage capacity, the drainage ditches should be prolonged and, in addition, a network of drying ditches should be constructed outside the site that will make it possible to store this liquid during such times (Figure 6.12). (see Chapter 5, point 5.9.2).
  
- ? In these external drainage ditches, alternate stretches can be left empty of stones between one screen and another. This has several purposes, among which:
  - ? To estimate the volume of the leachate leaving the landfill.
  - ? To determine the amount of sediments and decide when the ditches will need to be cleaned

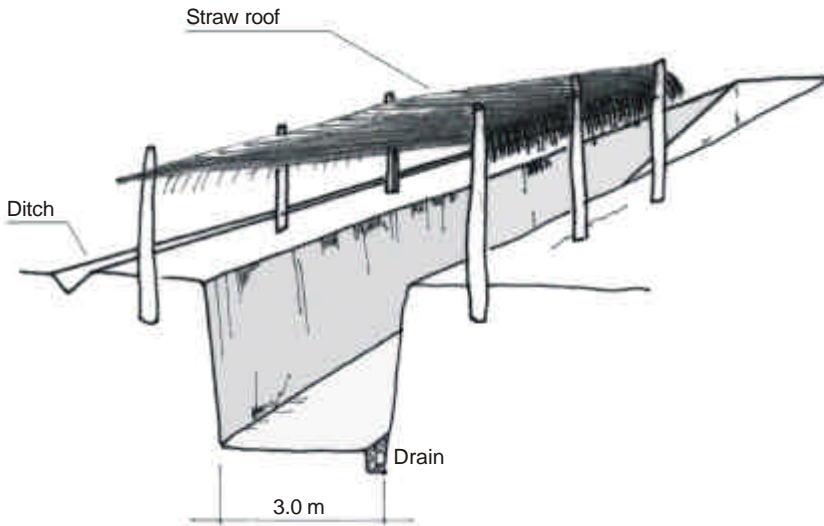
*Minimization of leachate in rainy regions*

In regions with extreme conditions of rainfall (more than 3,000 mm/year), the rain falling directly on the filled area can produce a large quantity of leachate that will exceed the storage capacity of the different landfills.

The most effective way of controlling the rain is to cover the whole surface area of the trenches or fill banks with a light roof made of palm, straw, or plastic



**Figure 6.12**  
**Network of external ditches for leachate storage**



**Figure 6.13**

**Light cover or roof to prevent rainwater from entering the landfill**

(similar to greenhouses); this will prevent the rain from falling directly on the finished areas and the working face. This method can reduce leachate generation by 90 to 95%. In some small landfills it could solve the leachate problem completely (Figure 6.12).

**Leachate control and storage**

- ? Overdimension the network of drainage ditches inside the sanitary landfill.
- ? Construct the landfill in such a way that there are narrow work areas. It is preferable to superimpose the cells one on top of the other, supporting them on the slope of the site and the finished cells; in other words, the landfill grows vertically instead of spreading over the site.
- ? Introduce as a daily routine the practice of covering finished cells and areas temporarily with plastic material. This will prevent rainwater from filtering through the waste and reduce the volume of leachate. Only a little amount of plastic material will be required, in view of the small area of the landfill and the work method. The plastic discarded from large greenhouses could be used.
- ? As soon as a landfill area is finished, the final cover is applied and made ready for immediate seeding with grass.

Usually, in regions where the annual rainfall does not exceed 300 mm and there is a canal to intercept and divert the rainwater, leachate is not a significant problem. However, it is still advisable to build smaller ditches for the internal storage of the small quantity of leachate generated by the moisture of the organic waste matter.

### ***6.3.2 Treatment of the leachate***

If we cover the areas filled with waste and the working face with a light roof of palm leaves, straw, or plastic, the rain will not get in to generate leachate. In this case, there will be no need for a costly treatment system which in any case is uncertain in these places.

**In landfills of small towns the generation of leachate must be prevented at all costs, but if despite everything a little is generated, it must be kept inside the sanitary landfill since it is not practical to treat it.**

It is important to have impermeable soil —otherwise it must be artificially waterproofed before the system of ditches is built to retain the leachate inside the landfill (cf. Chapter 4, point 4.4.4, on hydrogeological conditions)

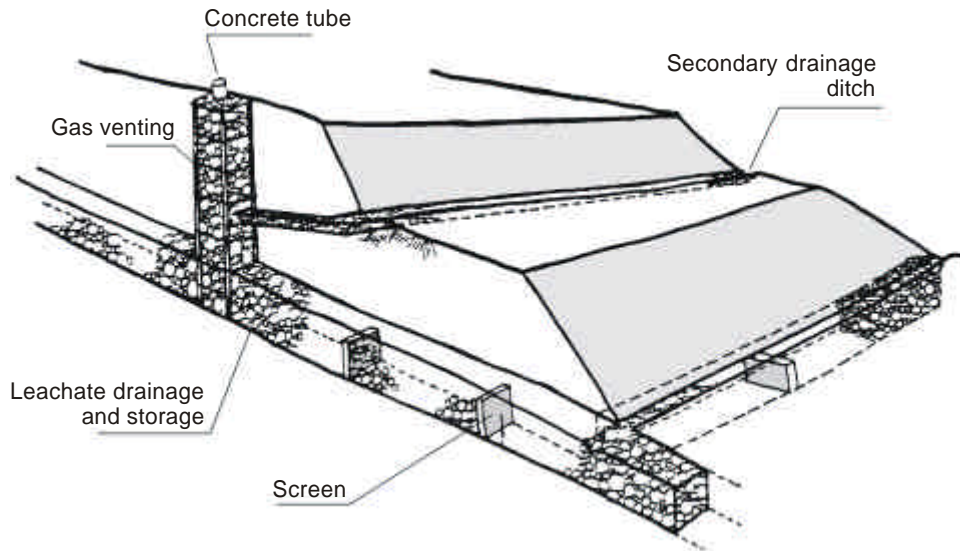
Another practice that minimizes the problem of leachate is to sow grass and plant small short-rooted shrubs as soon as each section of the sanitary landfill is completed —or in any case when the whole landfill has come to the end of its useful life. The grass and plants, suited to the conditions of the site, should be sown both on the finished surface and all around the filled sector; evapotranspiration can be very effective and in some cases even prevent the generation of leachate.

In extreme cases where leachate generation cannot be controlled, in view of the fact that the MSW of small communities is similar to domestic waste water in that it has a high percentage of biodegradable organic matter difficult to settle, biological treatment can be applied to improve the quality of this liquid as much as possible. Examples of treatment methods are percolating filters and stabilization ponds.

### ***6.3.3 Gas collection and venting***

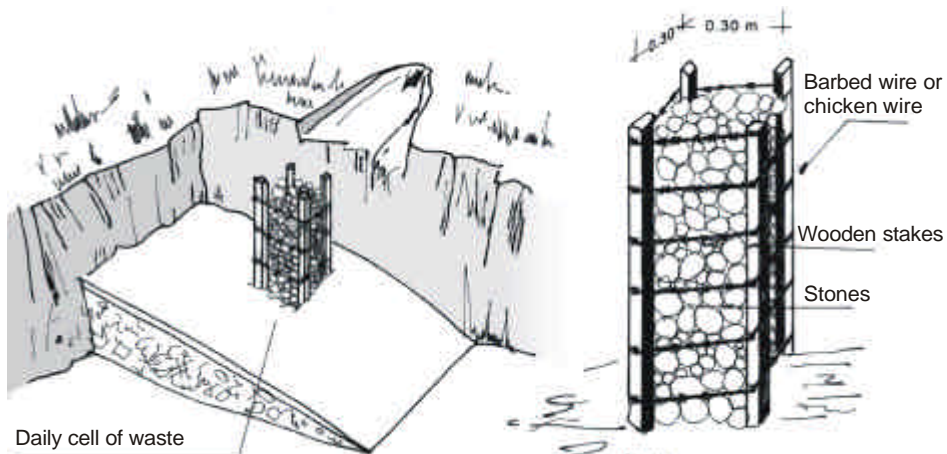
A gas venting system consists of stone-filled ditches or perforated concrete piping lined with stone that function as chimneys or vents, penetrating the whole landfill vertically. These vents are built to link with the leachate drainage at the bottom of the landfill, and they are projected to the surface, for more efficient drainage of both leachate and gases (Figure 6.13).





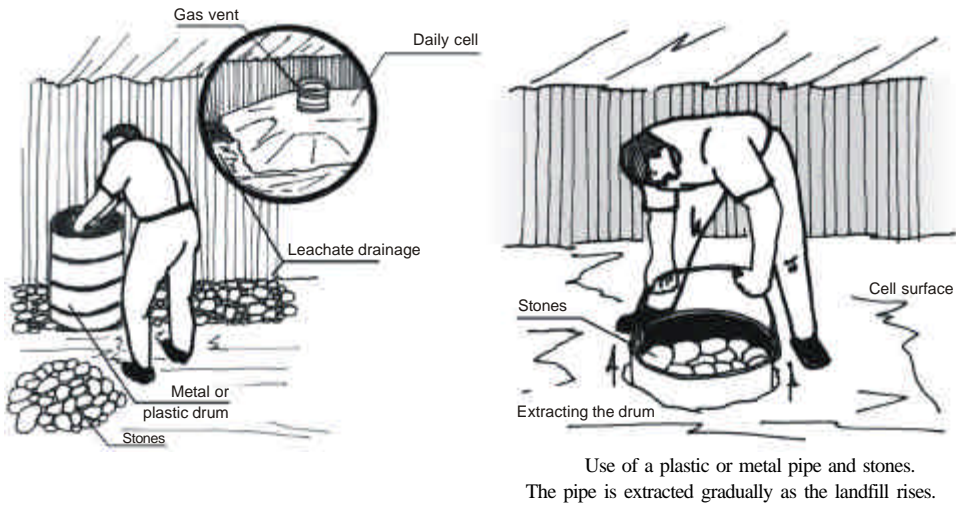
**Figure 6.14**  
**Interconnection of the systems for drainage of gases and leachate**

These vents are built vertically as the landfill advances, to ensure that the material around them is well compacted. It is recommended that each vent have a diameter of 0.30 to 0.50 m. and they be installed at 20 or 50 m. intervals, as determined by the technician (Figure 6.14 ).



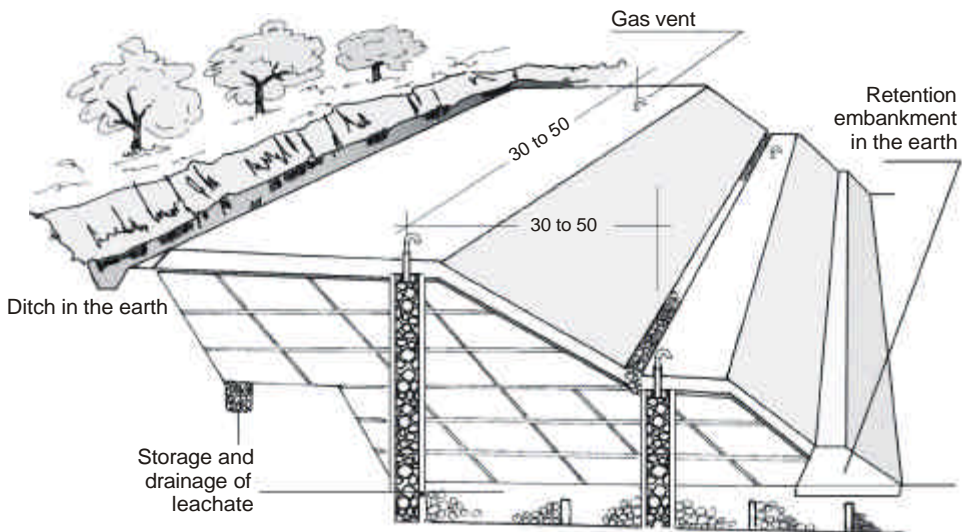
With wooden stakes, barbed wire, or chicken wire and stones

**Figure 6.15**  
**Construction of gas drains or vents**



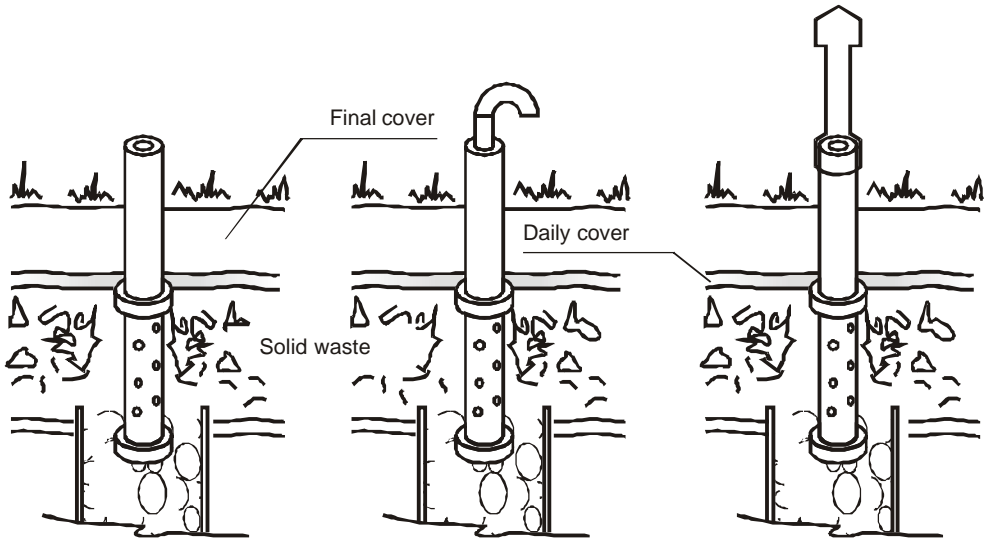
**Figure 6.16**  
**Details of construction of gas collection and venting system**

When the last cell is about to be completed, two concrete pipes are set in place. One of the pipes is perforated to facilitate the intake and drainage of gases. The second one is not perforated, to allow methane gas to be burned on exit; this burning eliminates the odors produced by other gases at the same time. To facilitate the burning of the methane, a metal pipe cap should be installed and a wick to light the gas as it comes out of the pipe. (Figure 6.19).

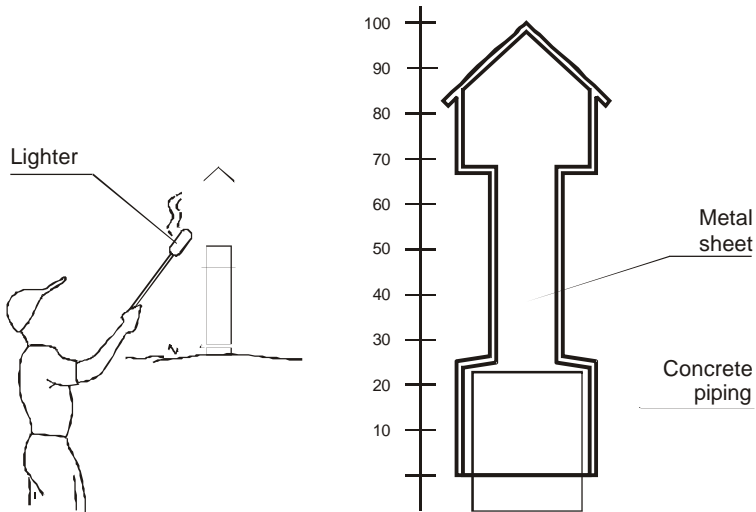


**Figure 6.17**  
**Layout of vents in the landfill**





**Figure 6.18**  
Proposals for the structure of final evacuation of gases from the landfill



**Figure 6.19**  
Metal pipe-cap and lighter flame for the protection of the gas vent and lighting of the gas as it is released, respectively

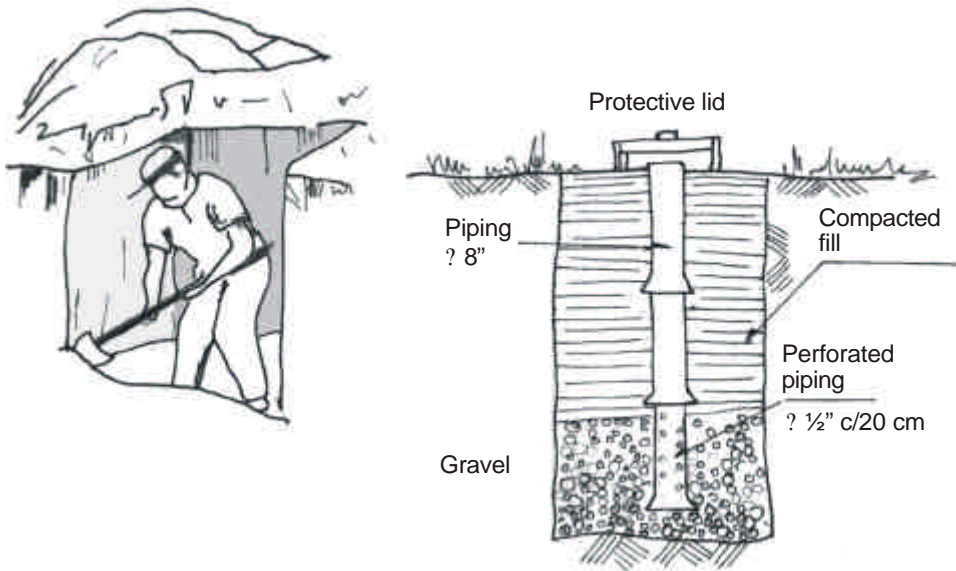
When piping is used, it should be lined with stone or gravel like a jacket, so that the solid wastes or the cover soil will not obstruct the perforations of the pipes (Figures 6.17 and 6.18).

### 6.3.4 *Monitoring wells*

As a result of the mechanisms of decomposition of solid wastes that occur in the landfill, liquids, gases, and intermediate products are generated. Some are retained in the site wells, while others can be carried and/or solubilized by the liquids that seep through the layers of earth and waste to reach water sources.

Therefore, although monitoring wells are not strictly necessary in small manual landfill projects, they are nevertheless recommended as a means of detecting the probable pollution of groundwater resulting from the construction of the sanitary landfill.

These wells can be dug manually and, depending on the type of soil, measures will be taken to prevent cave-ins during excavation. Once the water table has been found, granular material is placed at the bottom and an 8" diameter pipe is installed, wide enough to permit the entry of a plastic bottle or flask for the collection of water samples. When the piping has been installed, the rest of the well is filled with the excavated earth (Figure 6.20).



**Figure 6.20**  
**Construction process for a water monitoring well**

In places where the water table is more than 4 m deep, it is advisable to determine whether there is water below the landfill or identify the closest well that is working. Only then will samples be taken from those sources to assess any possible impact.

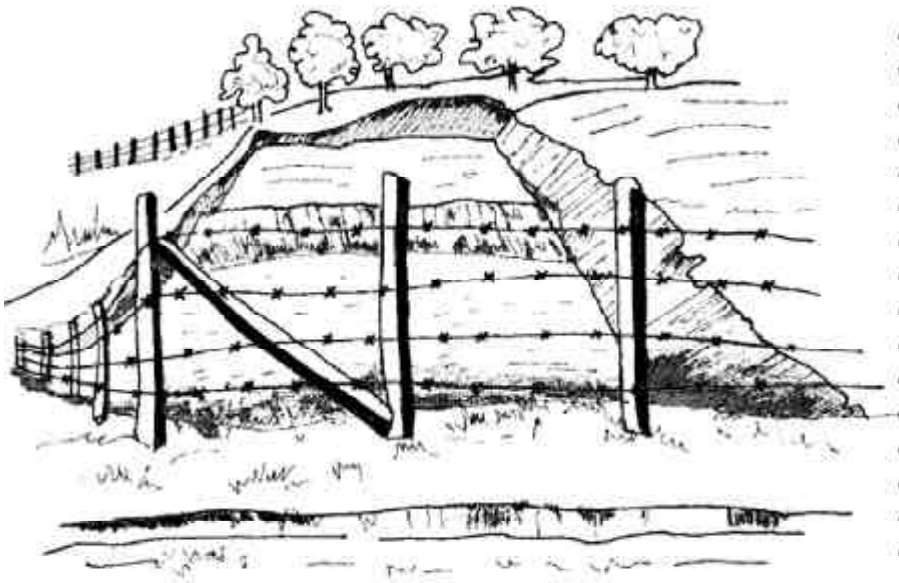
### **6.3.5 Internal roads and rainwater drainage**

At the planning stage, a study should be made of the internal circulation roads within the landfill, since there can be problems during the rainy season due to the continuous traffic of refuse collection trucks.

Although in a manual sanitary landfill the access road to the working face and control area can be made of stone and demolition rubble, it should always be kept dry and in a good condition if we are to prevent vehicles from getting stuck or turning over.

## **6.4 Support facilities**

The support facilities proposed are small and low-cost. They are designed in keeping with the anticipated service life of the sanitary landfill, always in a framework of maximum economy and labor-intensive work on all the landfill activities.



**Figure 6.21**  
**Perimeter fence**

### **6.4.1 Perimeter fence**

The site should be enclosed with a paddock fence 1.5 m high, made of five-strand wire (galvanized, caliber 12, with 10 barbs per linear meter), with an entry gate. The idea is to prevent cattle and other animals from wandering into the landfill, as this hinders the operation and destroys the waste cells, especially after the workers have gone home. The gate also restricts the entry of unauthorized people, thus enhancing the discipline and security of the landfill (Figure 6.21).

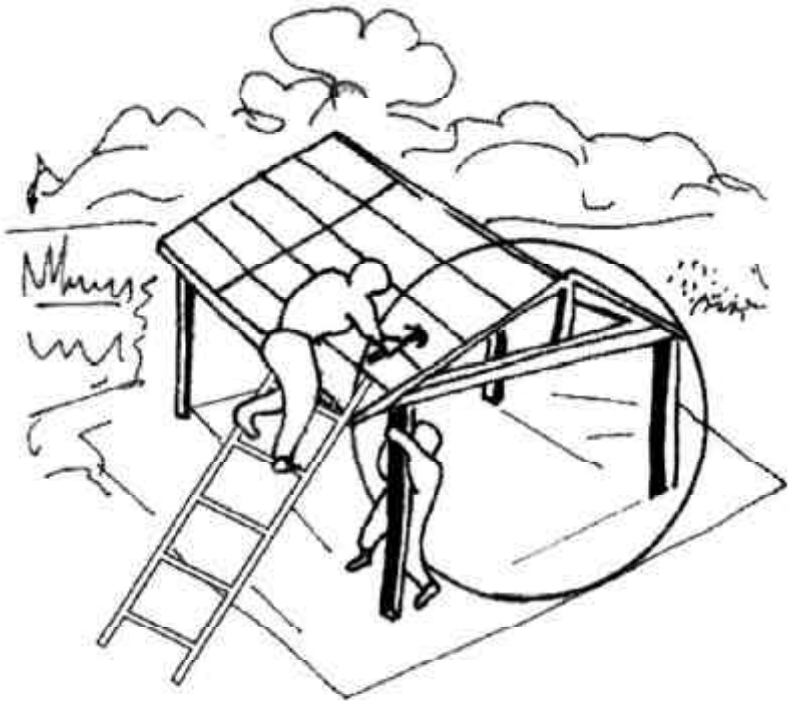
### **6.4.2 Buffer area and protection**

In many cases it will be necessary to leave a 5 to 20 m strip of land free between the site border and the area of waste embankments or trenches, to serve as a buffer zone that will mitigate any possible negative impact of the waste operations on neighboring properties. In this buffer area it is important to plant a hedge of shrubs and trees that will prevent neighbors and passers-by from seeing the MSW and the landfill operation. Surplus earth excavated from the trenches can sometimes be used to raise a screening berm for the same purpose.

This zone improves the aesthetics of the landfill and provides litter control by stopping blowing papers and plastic. For obvious reasons fast-growing trees and shrubs are suggested (pine, eucalyptus, laurel, bamboo, etc.) (Figure 6.22).



**Figure 6.22**  
**Planting trees in the perimeter buffer area**



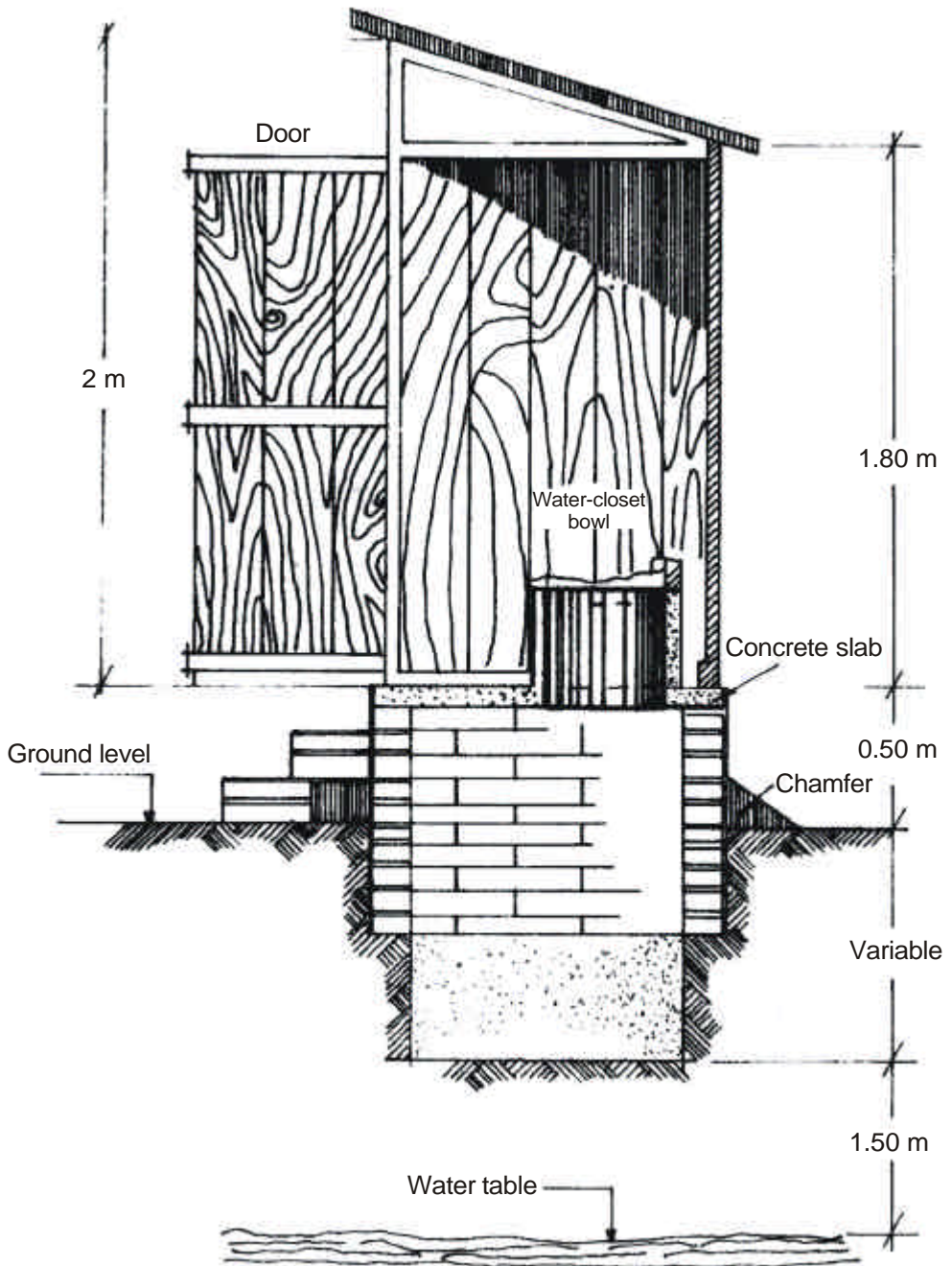
**Figure 6.23**  
**Control building and storage of materials**

### **6.4.3 Control building**

It is important to construct a control building with an approximate area of 12 to 15 m<sup>2</sup>. This will be a multi-use facility: checkpoint for entry control; storage place for small tools (roller, wheelbarrows, shovels, pickaxes, etc.); washrooms, changing rooms and lockers for the workers; a kitchen area where food can be heated up; shelter in the event of rain. This control building should have a table or desk and one or more chairs, so that the supervisor has a suitable place to update the records of activities.

A prefabricated hut can be used or a container can even be adapted for this purpose. The municipal administration could request these as a donation or loan (Figure 6.23).

In special cases it may be appropriate to construct a small rural house where one of the workers may live permanently with his family, and where the project tools can be kept, and even the excavated earth so that it can be used for cultivation in the future.



**Note:** This latrine is used when there is a shallow water table

**Figure 6.24**  
**Sanitary facilities**

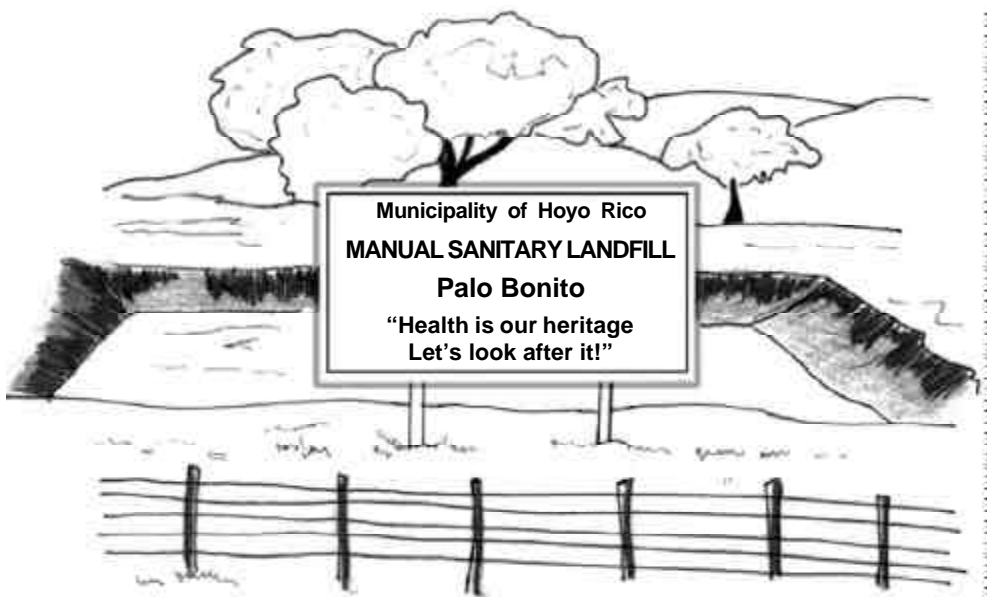
#### 6.4.4 Sanitary facilities

The landfill must have the necessary facilities to ensure the comfort and well-being of the workers. Water will have to be taken to the landfill for the workers' washrooms. In the dry season some of this water can be used to sprinkle on the surface of the landfill to improve compaction and prevent the accumulation of dust. A septic tank or latrine will also have to be constructed (Figure 6.23).

For the construction of the sanitary facilities, technical assistance can be requested from the health authorities.

#### 6.4.5 Maneuvering yard

There will need to be an area of some 200 m<sup>2</sup> (10x20) so that the collection vehicle(s) have plenty of room to maneuver and unload the waste at the working face.



Source: Mexico. Secretariat of Health and Assistance. Sanitary guidelines: water, housing, waste. Mexico, DF, 1980.

**Figure 6.25**  
**Identification board of the sanitary landfill**

#### **6.4.6 Site identification board**

An identification board should be put up at the sanitary landfill in process of construction so that the public will be able to identify the project.

The sign can be made of two sheets of zinc and a wooden framework, all undercoated first with anticorrosive paint, and then painted in the desired color. The sign will have the names of the municipality and of the sanitary landfill, a brief description of the project and a motto allusive to protection of the environment (Figure 6.25).

From the outset a name should be chosen for the sanitary landfill. This name will then be used on all the documents and correspondence referring to the project.



## **7. CONSTRUCTION, OPERATION AND MAINTENANCE**



## 7.1 Construction

Once the sanitary landfill has been designed, the next step is to execute the project. A good design is not sufficient: there has to be political-administrative willingness to allocate the necessary funds so that the project can be properly executed. Sound construction practices are even more important for a sanitary landfill than for other public works, because of the duration of the landfill operation and the permanent maintenance it requires.

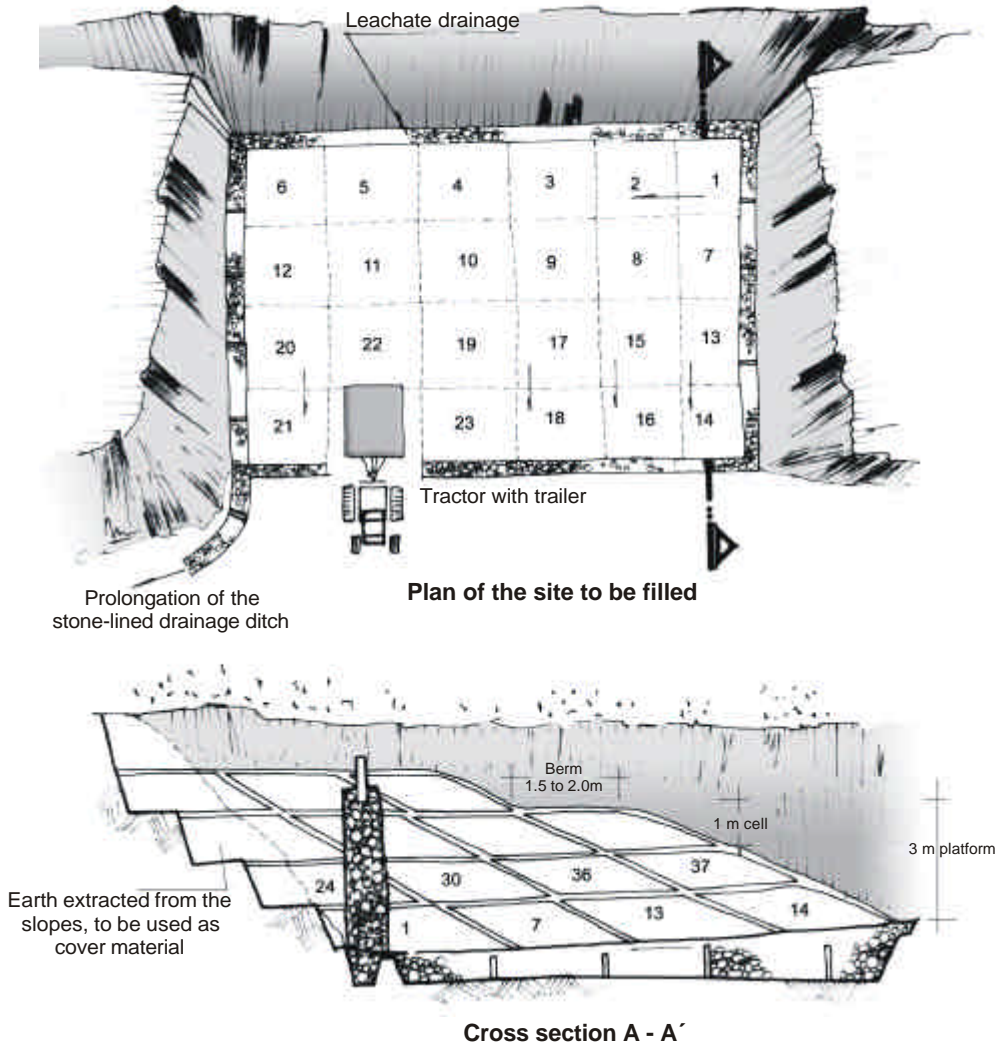
When planning the construction and advance of the sanitary landfill a series of drawings need to be available for consultation, namely: the project design, the general works location plan, modifications to the terrain (initial site layout), and details of infrastructure works. Also required are the plan and profiles of the trenches or fill banks, which indicate the form of excavation of the trenches and the layout of the fill of the embankments; these will be used to guide the partial and final layouts of the landfill. All these drawings indicate how the working face is to be programmed and how it will advance, calculating the volumes occupied and the heights in accordance with the design.

### 7.1.1 Method

The method of construction of a manual sanitary landfill depends mainly on the topography of the site, although it is also influenced by the type of soil and the depth of the water table.

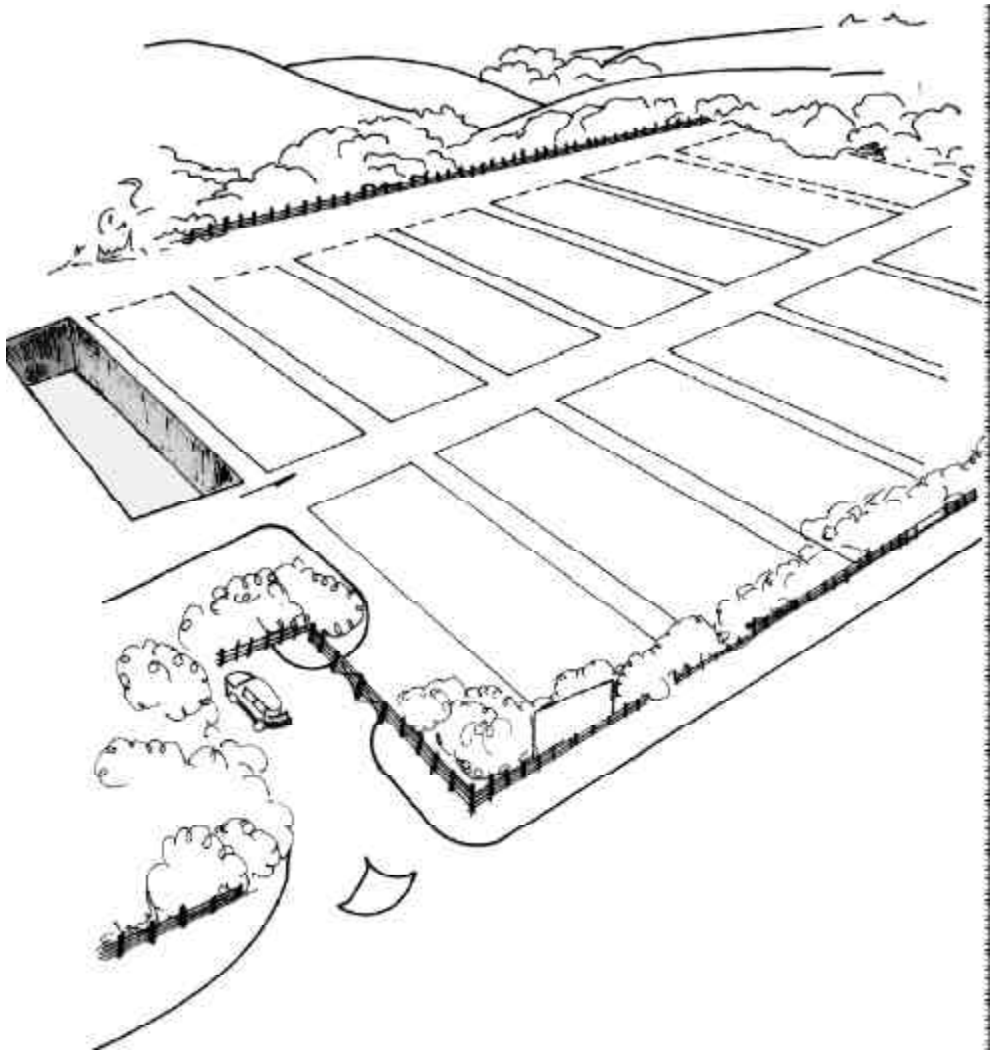
The area method is used on flat terrain, abandoned quarries, depressions, and low parts of ravines. The features of each individual site will determine whether it is possible to extract the cover soil from the site or whether it will have to be hauled from nearby places. The area method consists of depositing the wastes on the surface and laying them against the slope of the inclined terrain; they are then compacted in sloping layers to form the cell that will afterwards be covered with earth. The first cells are built at one end of the area to be filled and the work advances to its completion at the other end (Figure 7.1).

The trench method is used when the water table is deep and the gradients of the terrain are gentle. The trenches can be excavated with earthmoving equipment. This method consists of depositing the waste at one end of the ditch, placing it against the slope; the workers then spread and compact the waste in layers using masonry tools until a cell is formed which, at the end of the day, will be covered with the earth from the excavation.

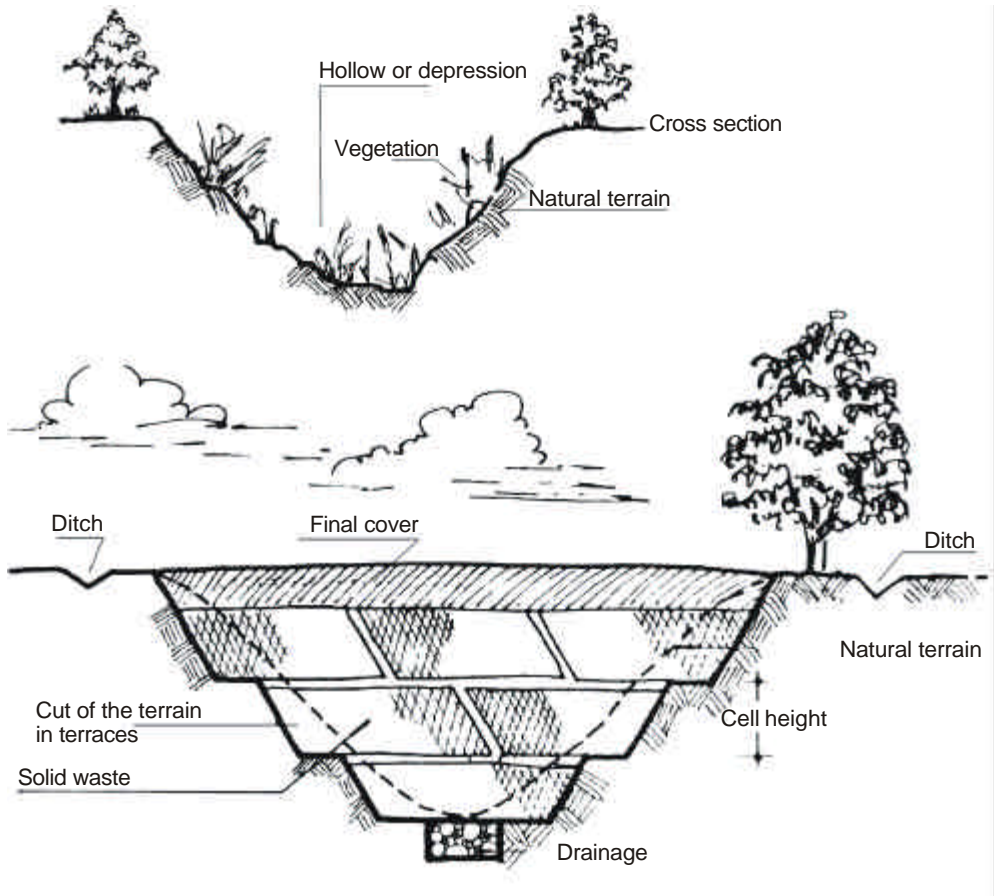


**Figure 7.1**  
**Location of the cells and progress of the landfill construction using the area method**

The two methods are used in combination when the geohydrological, topographical, and physical conditions of the site selected for the sanitary landfill are suitable. For example, the method used initially is the trench method and subsequently the operations continue in the higher part with the area method. This combined method is considered the most efficient one, since it permits savings in the hauling of cover material (providing this is present at the site) and increases the useful service life of the site. Figures 7.2 and 7.3 illustrate these methods.



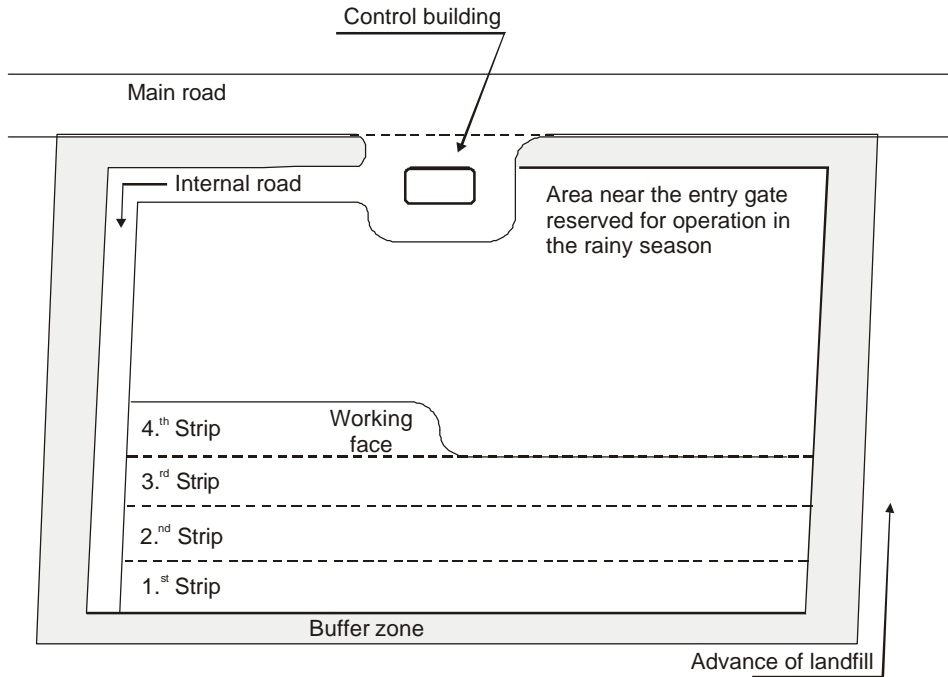
**Figure 7.2**  
**Trench method and start of the filling**



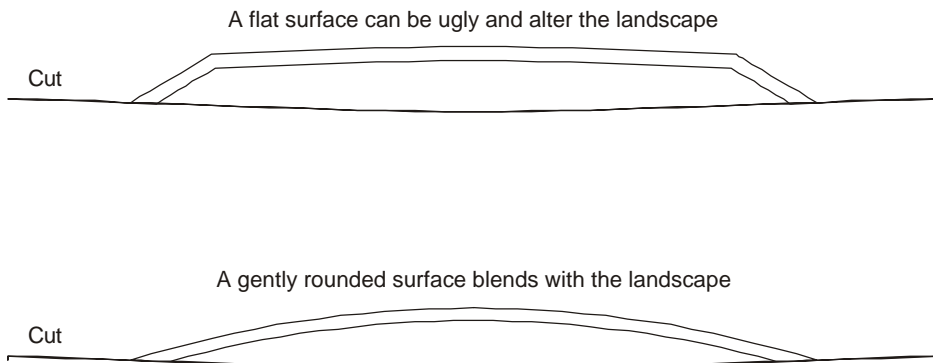
**Figure 7.3**  
**The area method in a natural hollow**

### **7.1.2 Plan for landfill construction**

The construction of the sanitary landfill should be planned in such a way that it is possible to control its progress based on its design and end use (Figures 7.4 to 7.8).



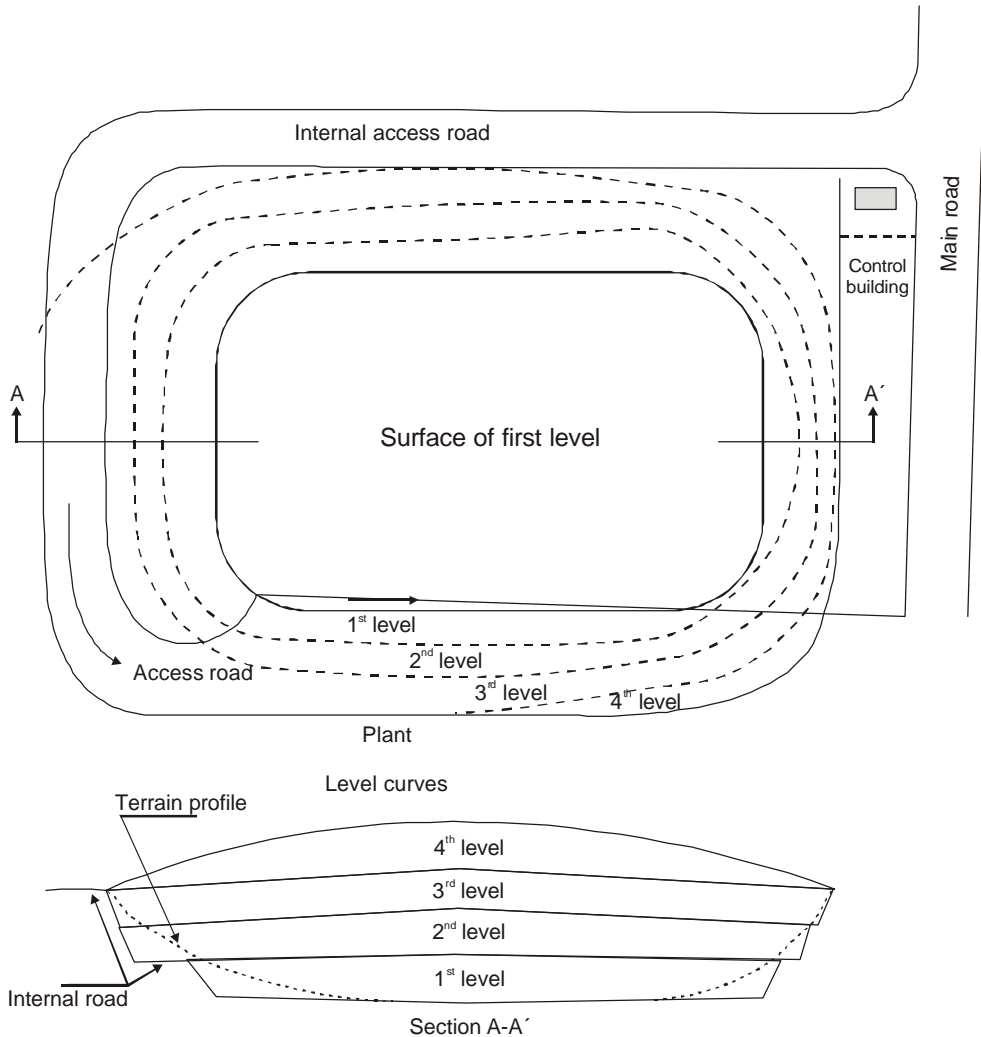
- Stages
1. Entry area - preparation with inert material.
  2. Setback area - tree-lined border.
  3. Internal road made with demolition debris.
  4. First strip waste covered.
  5. Strip-forming sequence.



Source: Flintoff, Frank. Management of solid wastes in developing countries. New Delhi, WHO, 1984.

**Figure 7.4**  
**Construction plan for a flat site**

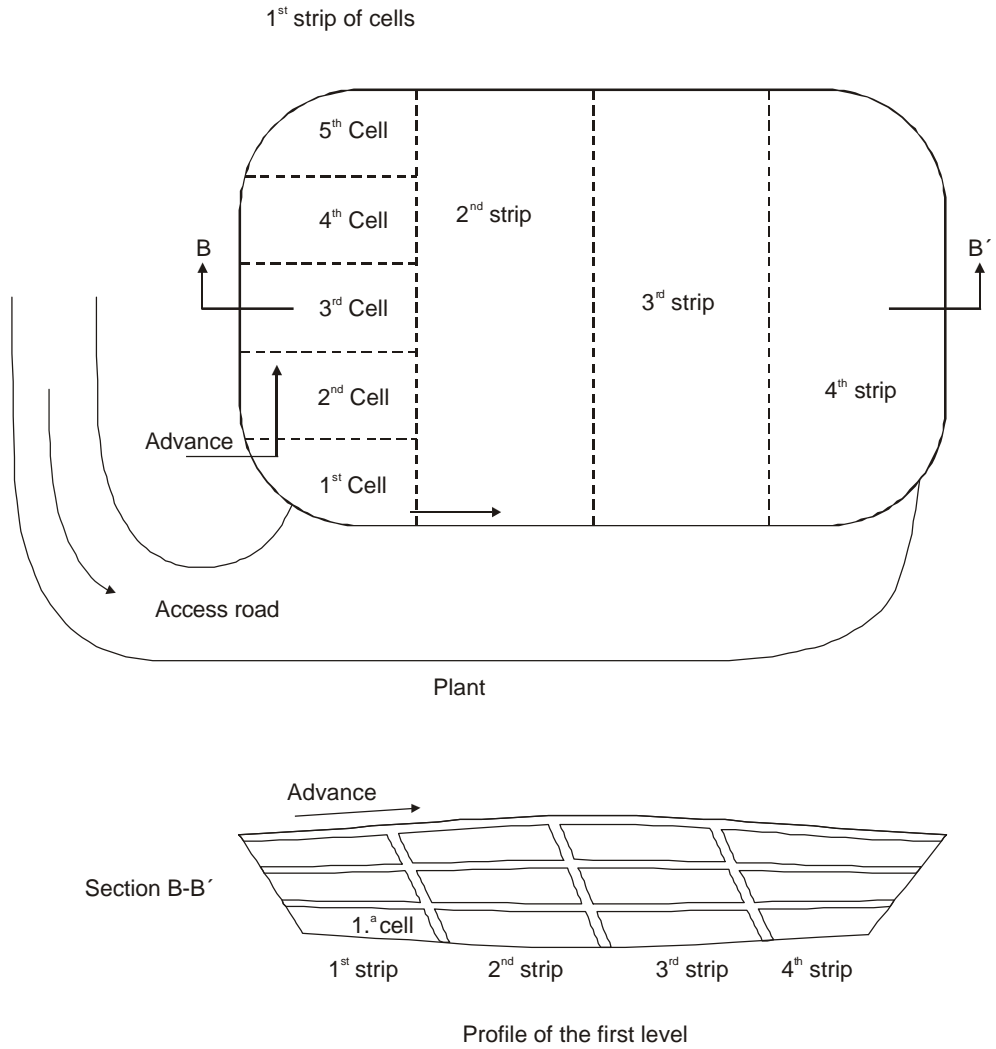
**The complexity of each project depends on the circumstances, the size, the funds, and the end use of the sanitary landfill.**



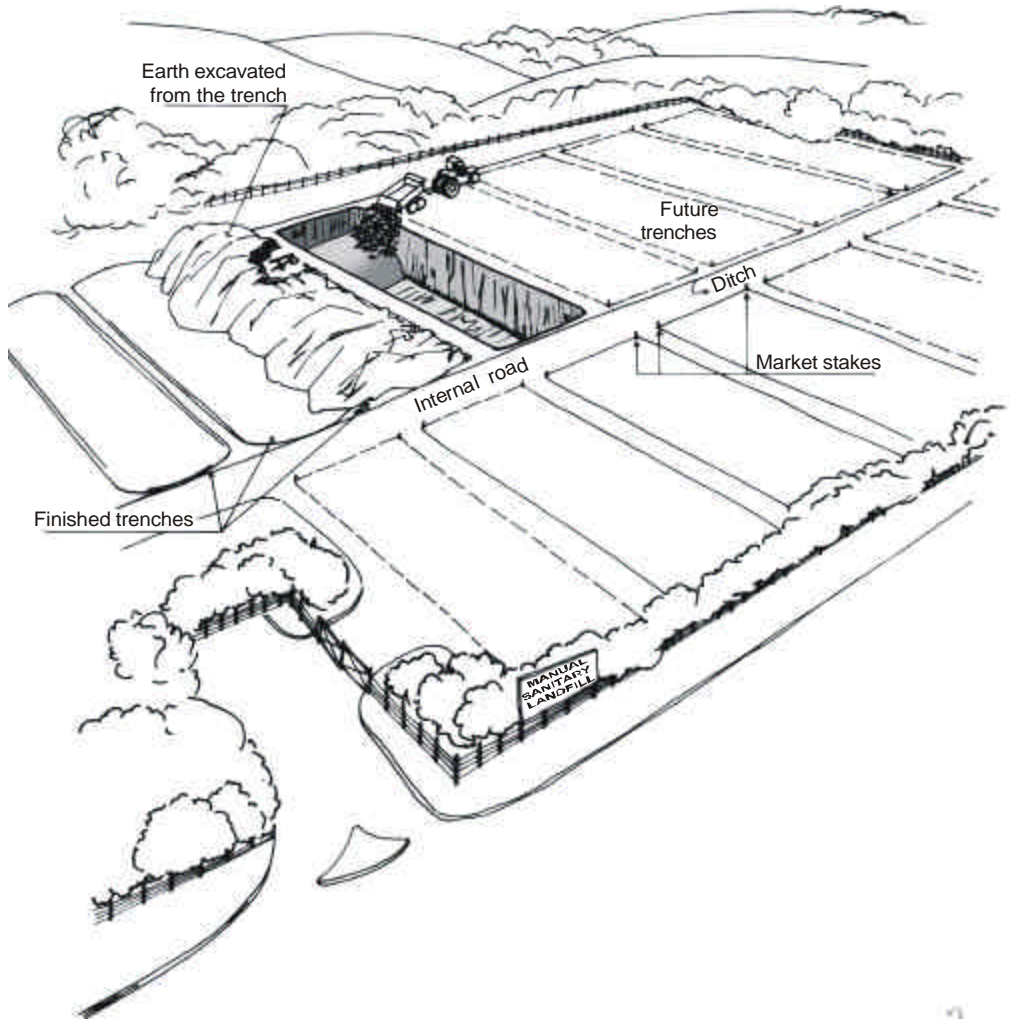
Source: Flintoff, Frank. *Management of solid wastes in developing countries*. New Delhi, WHO, 1984.

**Figure 7.5**  
**Construction plan for a deep quarry**



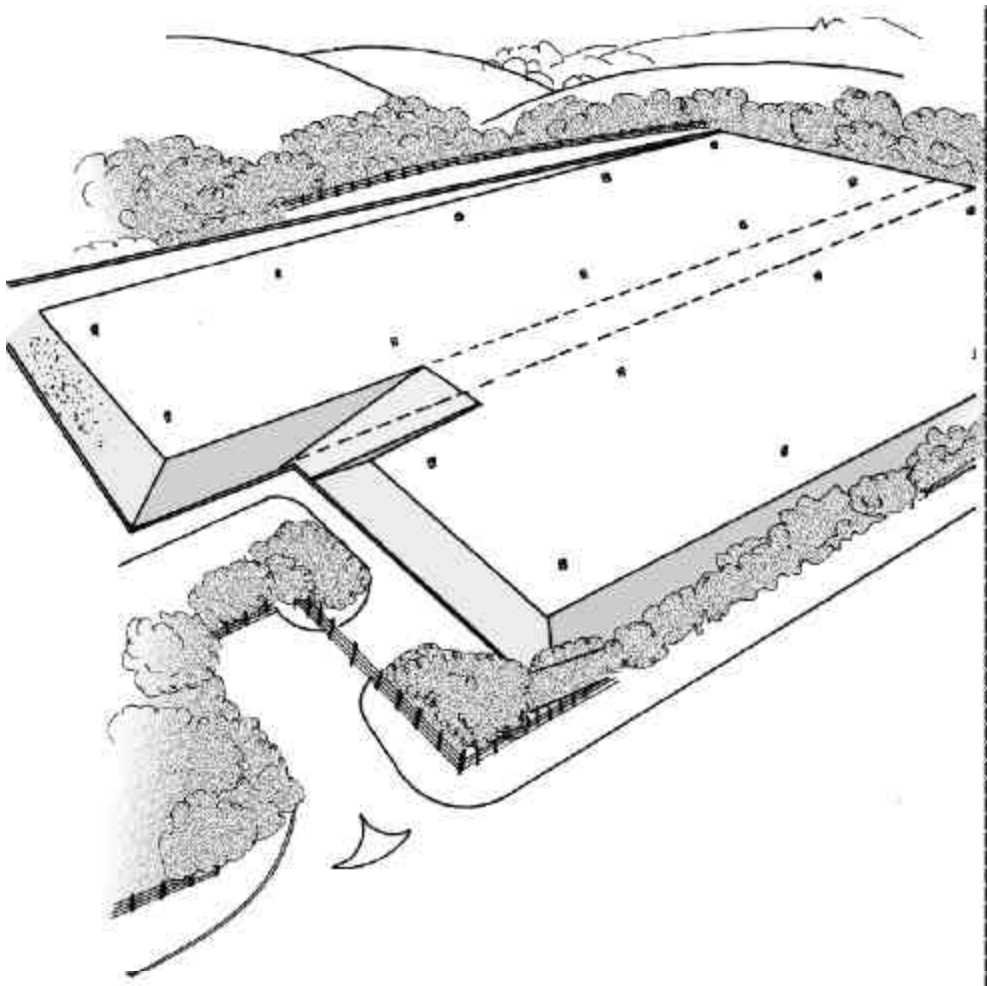


**Figure 7.6**  
**Formation of the landfill levels in the quarry**



*Source:* Orth, Maria Helena de Andrade and Takeda, Kiyoshi. Sanitary landfills. CETESB. Course on the Management of Solid Waste Systems.

**Figure 7.7**  
**Land management plan for the construction of the manual sanitary landfill using the trench method**

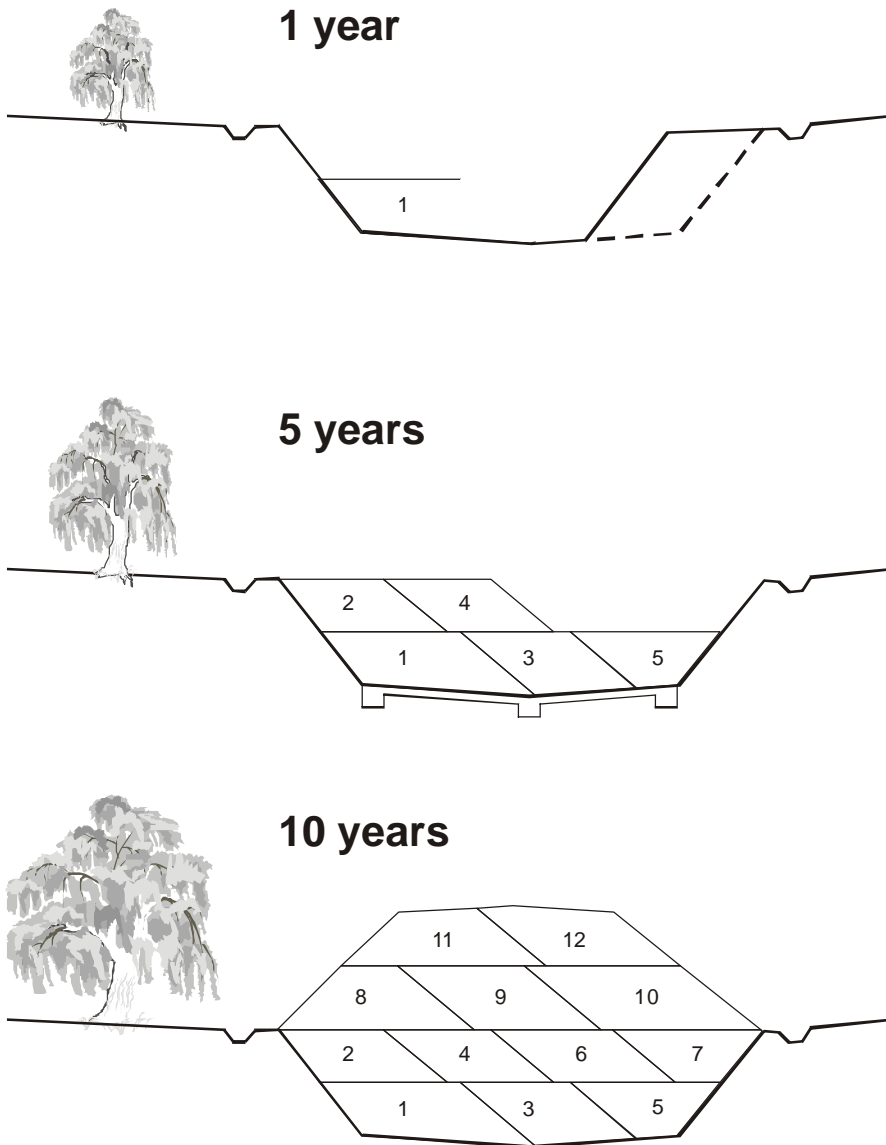


**Figure 7.8**  
**Completed sanitary landfill constructed combining the trench and area methods**

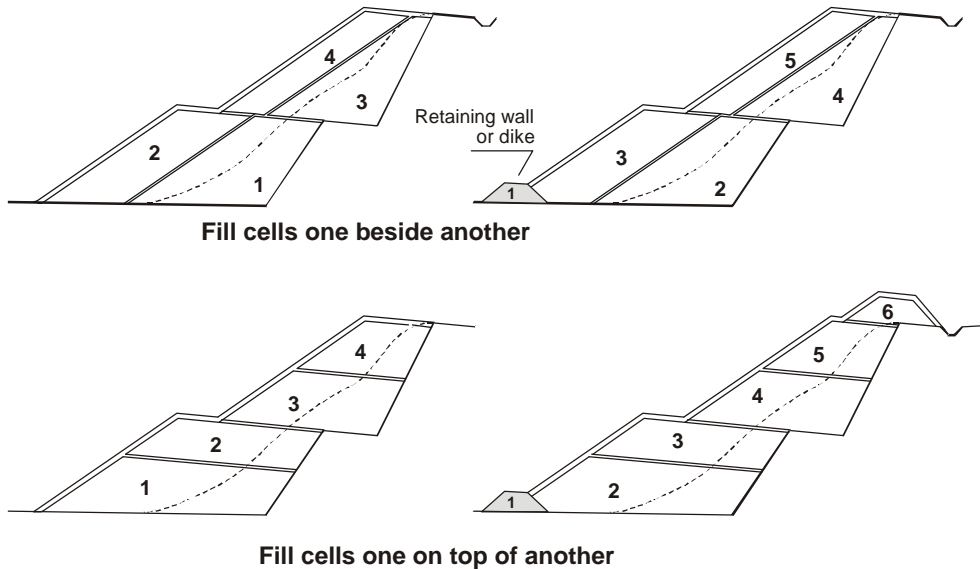
### ***7.1.3 Construction of embankments***

To ensure the stability of the manual sanitary landfill constructed with the area method, several terraces or embankments three meters in height should be constructed. They will each be made up of two or three 1.0 to 1.5 meter cells (Figures 7.9 and 7.10).

Each terrace will correspond to one stage of landfill construction. Between each pair of terraces a two to four meter wide berm or corridor is left to provide greater stability.



**Figure 7.9**  
Sequence of the construction of embankments for filling the site



**Figure 7.10**  
Types of sequence in the construction of embankments

#### 7.1.4 Construction of cells

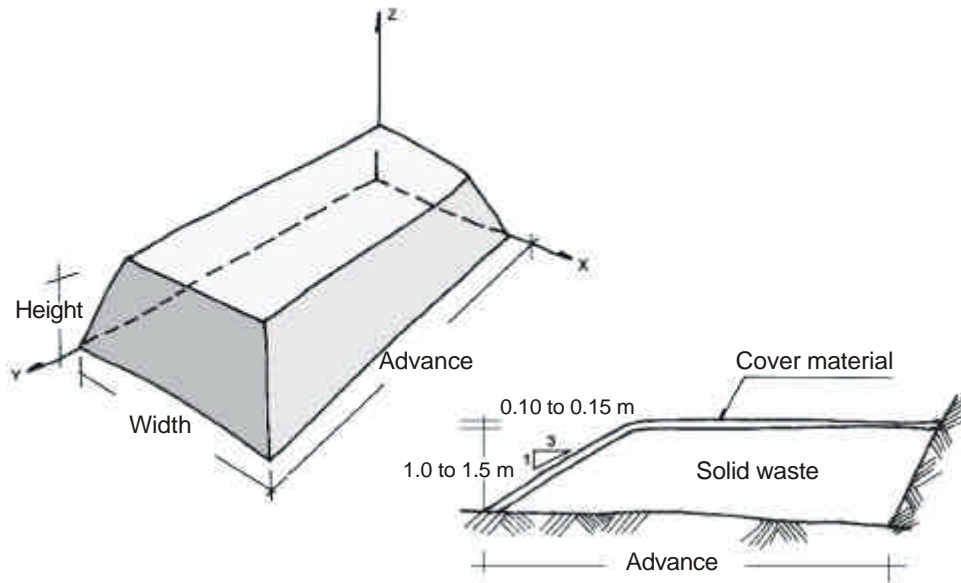
The daily cell is the basic construction unit of the sanitary landfill. It is made up of the amount of waste buried in one day and the earth needed to cover it.

##### ? *Dimensions*

The dimensions of the daily cell vary in each case and are defined, in theory, as a parallelepiped; the width is equivalent to the working face necessary so that the collection vehicles (usually not more than two) can unload the waste at the same time. The length (or “advance”) is defined by the amount of waste arriving at the landfill in one day; and the height is limited to one meter or a meter-and-a-half, to ensure greater compaction. In order to save earth, the cell should be square (Figure 7.11).

##### ? *Conformation of the typical daily cell*

The waste is unloaded at the working face; then the workers spread it over the surface of the land at the toe of the slope or of the cells that are already completed, in successive layers of 0.20 to 0.30 m; for this work they use forks (three-pronged),



**Figure 7.11**  
**Typical daily cell**

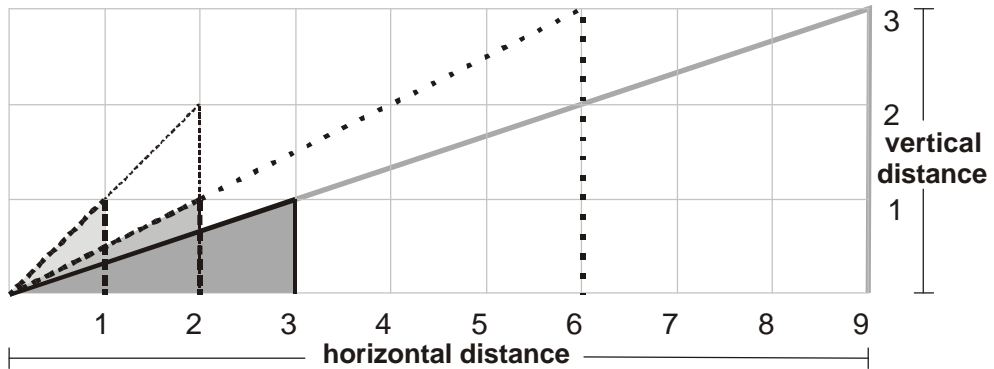
rakes (with eight or ten prongs) or picks, Next, the upper surface is leveled and compacted with the roller; and the lateral surfaces are compacted with hand tampers until a uniform surface is obtained.

$$\text{Gradient (\%)} = \frac{\text{Vertical}}{\text{horizontal}} = \frac{3}{6} = 0.5 = 50 \%$$

$$\text{Gradient} = \frac{3}{6} = \frac{1}{2} = 1 : 2$$

The material is spread and compacted in horizontal layers or sloping layers with a gradient of 3:1 or 2:1 (advance:height), which provides a better degree of compacting, better surface drainage, less consumption of soil, and better retention and stability of the landfill (Figure 7.12).

At the start of the landfill construction, containment must always be provided for the fill, by supporting each cell on the natural slope of the land or on the walls of the trench and, as the operation advances, on the completed cell.



**Figure 7.12**  
**Ways of representing the gradient of a site**

### ? *Covering the cell*

To complete the cell, it is covered with a 0.10 to 0.15 m layer of earth. This earth is spread with the help of hand trucks or wheelbarrows, shovels and hoes, and it is compacted with a roller and hand tampers, following the same procedure as for the waste. The daily cover keeps away insects, rodents, and scavenging birds, as well as burning and bad odors; it prevents water from entering the landfill and loose litter from blowing in the wind.

The cells should be covered daily after the entry of the last load of waste. At the end of the day, there should be no MSW uncovered, especially prior to the weekend.

There is no point in being choosy about the quality of the cover material for a manual sanitary landfill; the most accessible earth can be used. The main thing is to cover the waste. The amount of cover material necessary is  $1 \text{ m}^3$  of earth for each 4 or  $5 \text{ m}^3$  of MSW, that is, from 20 to 25% of the volume of the compacted waste.

The final cover will be 0.30 to 0.60 m thick, and it will be applied in two stages, using layers of 0.15 to 0.30 m. The second layer is placed after an interval of one month, to allow for the settlement produced in the surface of the first cover layer.

The following are some procedures for covering the landfill:

**Table 7.1**  
**Cover of the typical daily cell and of the sanitary landfill**

Cover material (earth)	Thickness of the layer of earth m	Ratio	
		Earth m <sup>3</sup>	Compacted MSW m <sup>3</sup>
Daily cell	0.10 to 0.15	1	4 to 5
End of landfill	0.30 to 0.60		

*Sanitary landfill — area type*

If the cover material is excavated on-site, the cost of moving the earth for covering the cells is minimal. This earth should be taken from the slopes of the site, forming terraces to prevent erosion, with the advantage that this will increase the site capacity and prolong its useful life. It is also a good idea to use surplus earth left over from excavations made for buildings in the urban area. This can be obtained by publicizing the fact that earth is needed at the landfill, or by making contact directly with local building firms. The haulage cost should be paid by the builders.

In the dry season, it is advisable to extract and accumulate earth for cover using a tractor or backdigger—in this way better yields are obtained. The earth can be stockpiled on top of a finished cell and from there it will be moved down to the cell that is yet to be finished.

In the rainy season, the opposite is true: accumulated material is lost by being swept away by rain, and the moisture it absorbs makes it heavier, and therefore more difficult to move. Under such circumstances it is advisable to extract only the amount of earth required for covering the cell.

*Sanitary landfill — trench type*

When using this method, there is a guaranteed supply of cover material from the excavation of the trench; it can be piled up at one side of the trench or on top of a trench that has already been filled.

? **Compaction**

This basic sanitation work has been designed to make use of local resources and local unskilled labor, so the forming of cells and compaction of the waste will be done manually with masonry tools.



The densities reached in a manual sanitary landfill are relatively low (400-500 kg/m<sup>3</sup>), but sufficient for the proposed purposes. Some of the main mechanisms influencing the compaction of MSW in a manual sanitary landfill are:

- ? The transit of the collection vehicles over the finished cells; so this should be more frequent during dry periods.
- ? The process of decomposition of the MSW, due to their high organic content.
- ? The weight of the upper cells themselves on the lower ones.
- ? The storage of cover material on the finished cells.

## 7.2 Operation

### 7.2.1 Plan of operations

The sanitary landfill is executed following a pre-established general plan of operations or with the guidance of an operations manual, which should be flexible enough for the supervisor to act on his own initiative when unexpected situations have to be dealt with, such as climate changes, or emergencies.

**As far as possible, all infrastructure works should be completed before any waste is unloaded in the new sanitary landfill.**

The waste and the cover material should be placed at the authorized working face only, and unlike the operation of a conventional landfill, which uses heavy equipment, it is recommended that the waste not be deposited in the lower part of the slope, but rather at the top of the finished cell, to facilitate the work and form the new cell in this way.

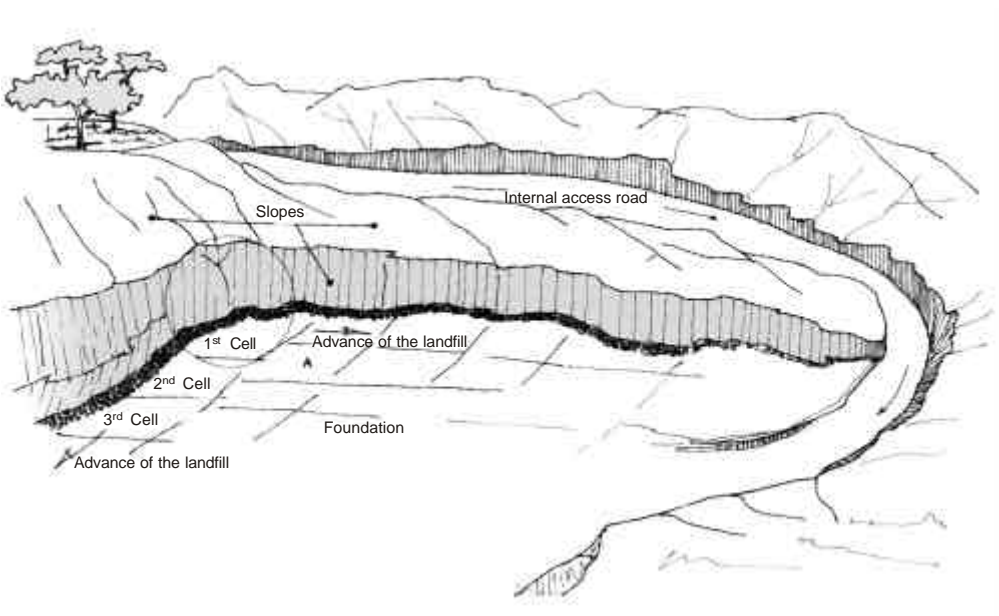
#### Steps for forming the first daily cells

- ? Mark out on the site the area to be occupied by the first cell that will receive the day's waste, with the dimensions estimated from the expected volume of waste entering the landfill site and the degree of compaction to be obtained.
- ? Unload the waste at the working face, in such a way that a single, small area remains uncovered during the day, and the waste will not need to be moved over long distances.

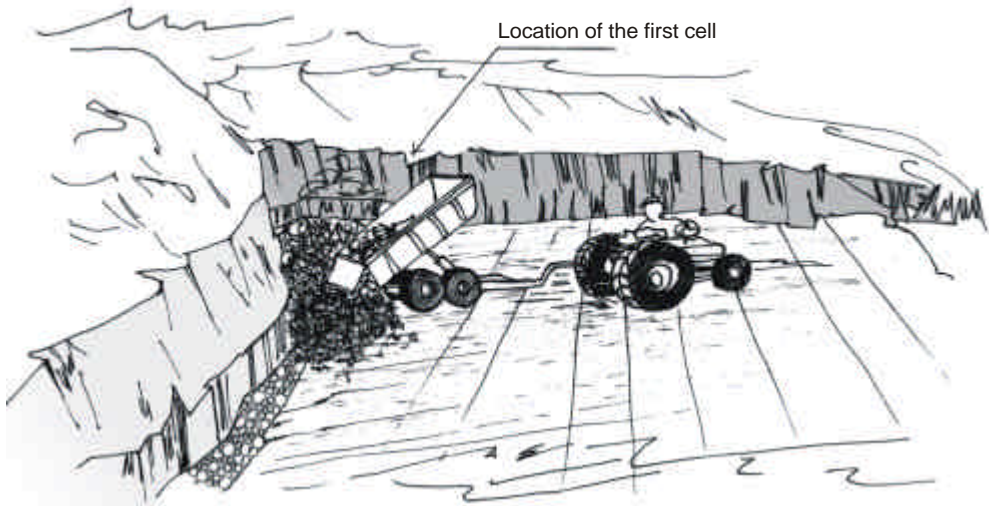
- ? Spread the waste in thin layers of 0.20 to 0.30 m and compact it manually to obtain a cell height of 1 to 1.5 m, forming a gentle gradient in the external slopes (per vertical c/m the horizontal advance will be 2 or 3 m).
- ? Cover the compacted waste completely with a layer of earth 0.1 to 0.15 m thick once the cell has reached maximum height.
- ? Compact the cell until a uniform surface is obtained at the end of the working day.

Once the first cell has been completed, the second can be constructed immediately beside or on top of it, always following the landfill construction plan. In dry periods it is recommended that the vehicles drive over the finished cells, to give greater compaction (Figures 7.13 to 7.36).

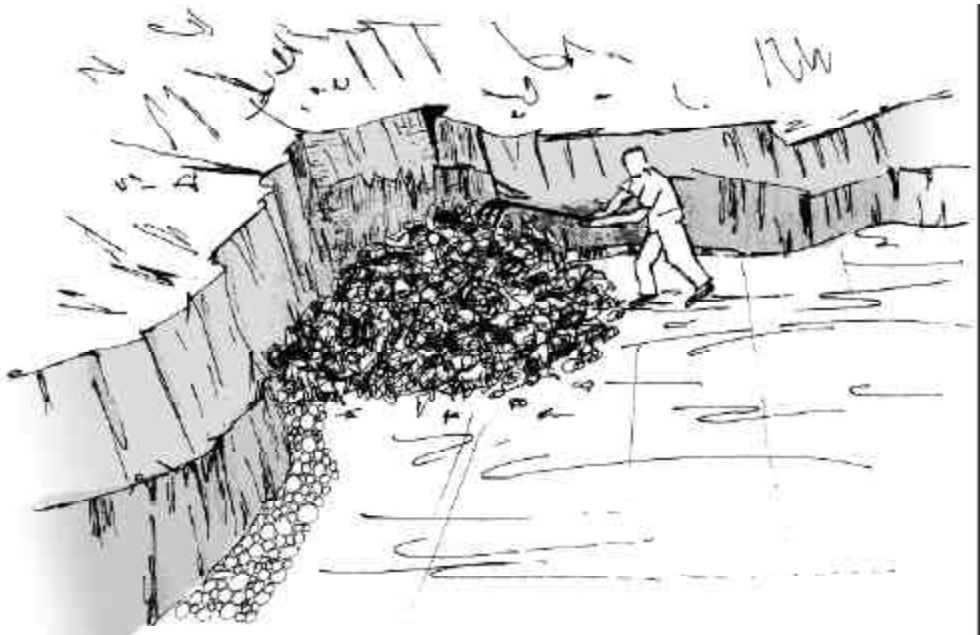
### **Landfill operation using the area method**



**Figure 7.13**  
**Terrain prepared for landfill construction**



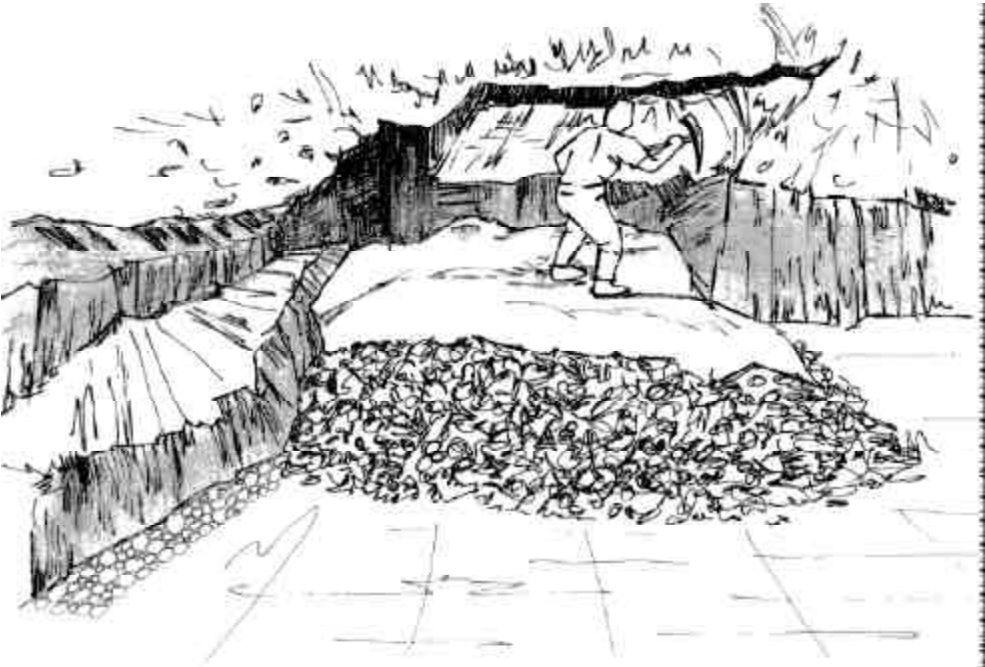
**Figure 7.14**  
**First discharge of MSW for formation of the daily cell**



**Figure 7.15**  
**Spreading MSW in the area delimited for the daily cell**



**Figure 7.16**  
**Compacting MSW with a hand tamper**



**Figure 7.17**  
**Extracting earth to cover the MSW**



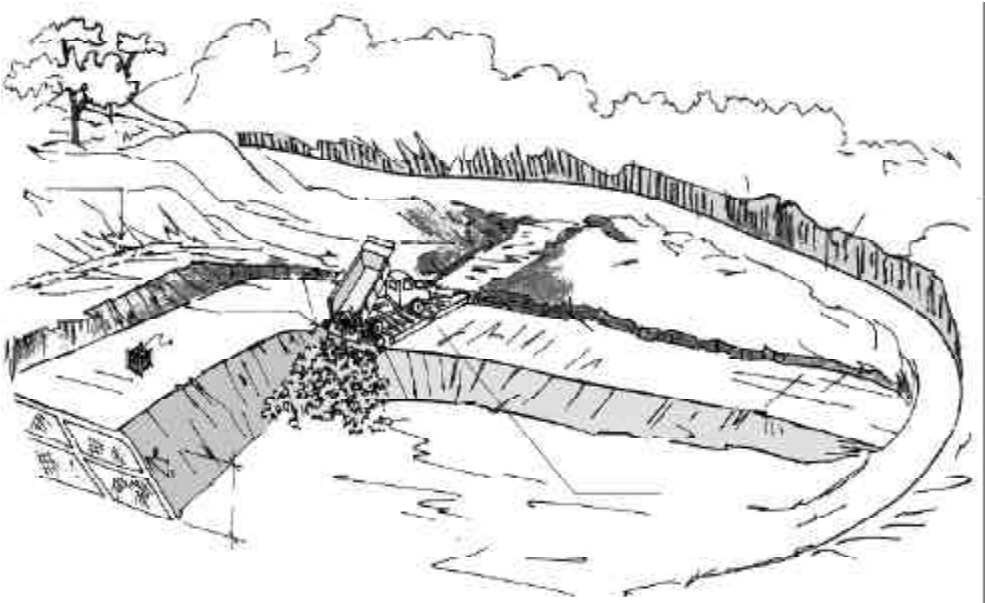
**Figure 7.18**  
**Covering MSW with earth**



**Figure 7.19**  
**Compaction of the first finished cell with roller and hand tamper**

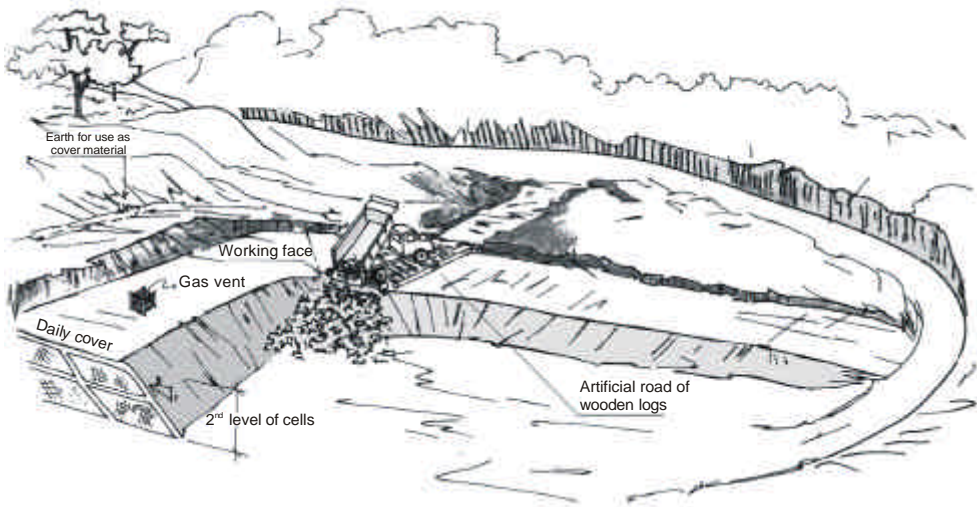


**Figure 7.20**  
**Compaction of the finished cell with roller and hand tamper**

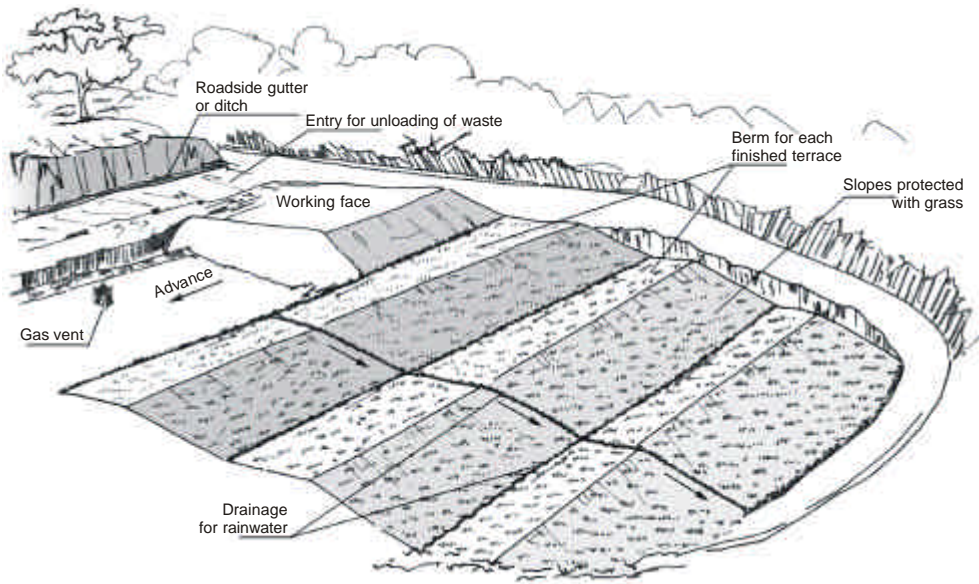


**Figure 7.21**  
**Construction of the second cell to one side of the first one**

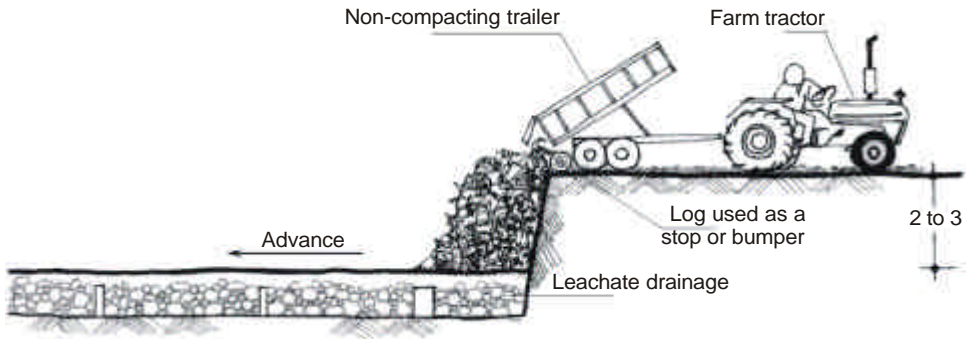




**Figure 7.22**  
**Construction of the first embankment or terrace of the landfill**

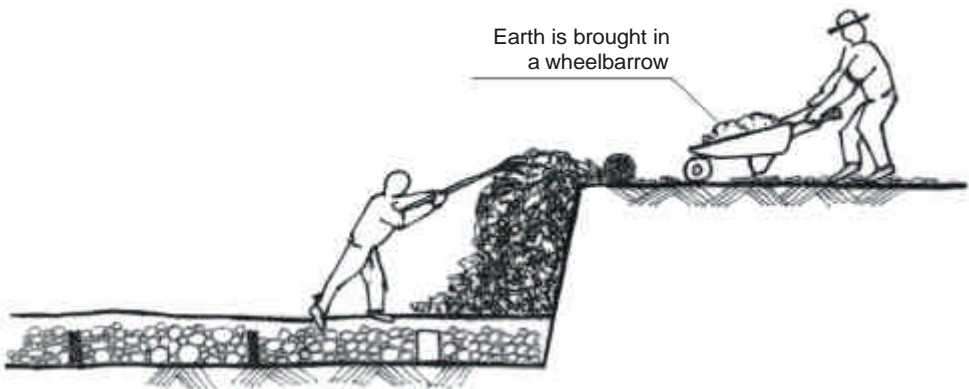


**Figure 7.23**  
**Final layout of the sanitary landfill**



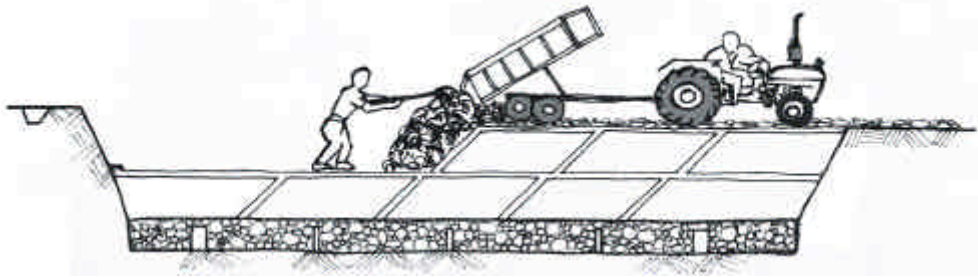
**Figure 7.24**  
**Process of filling a trench from one end**

**Landfill operation using the trench or ditch method**

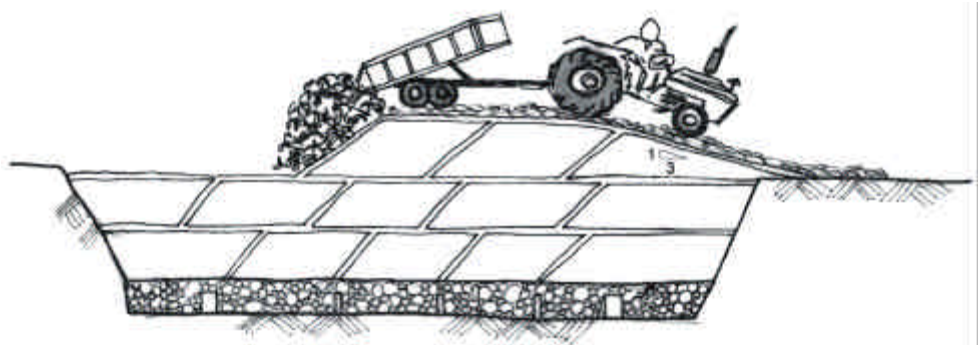


**Figure 7.25**  
**Unloading of the MSW and forming of the first cell**

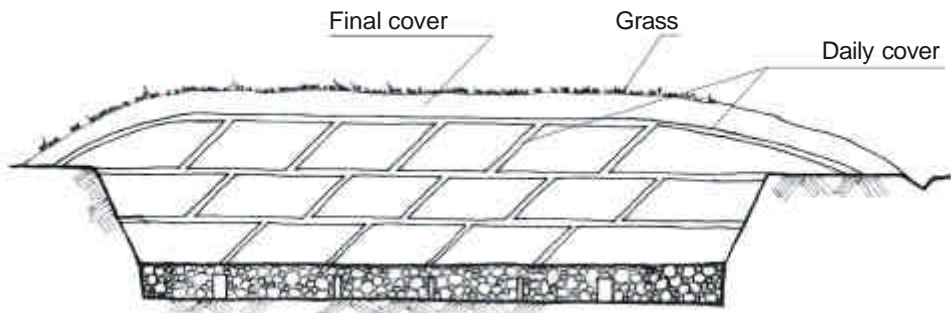




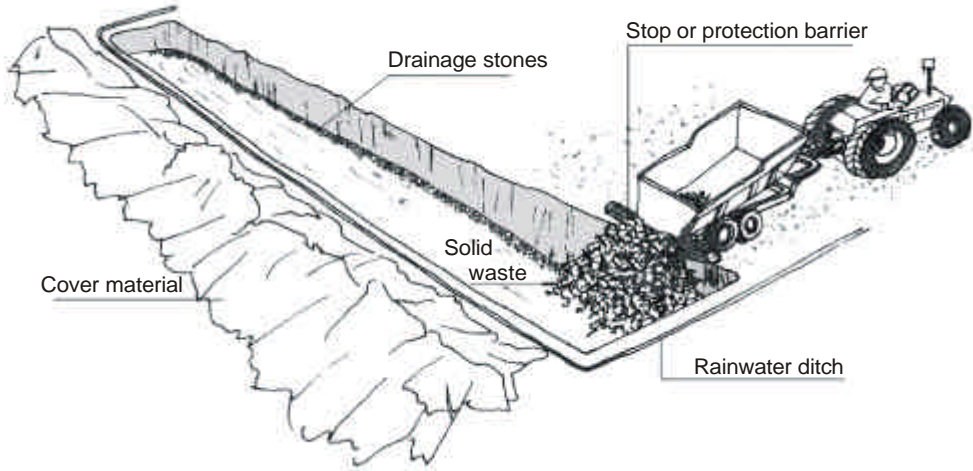
**Figure 7.26**  
The collection vehicle passes on top of the cell to unload fresh waste



**Figure 7.27**  
Forming of the upper layer of cells



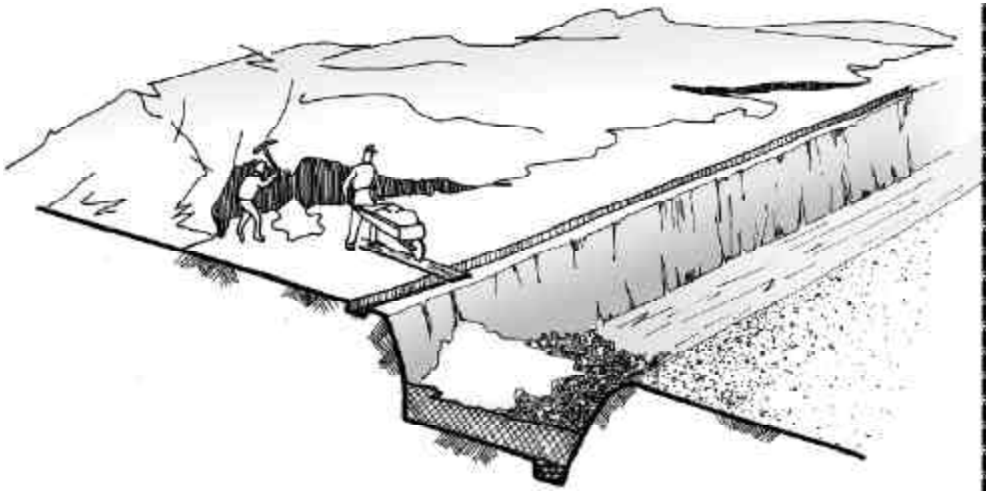
**Figure 7.28**  
Finished trench



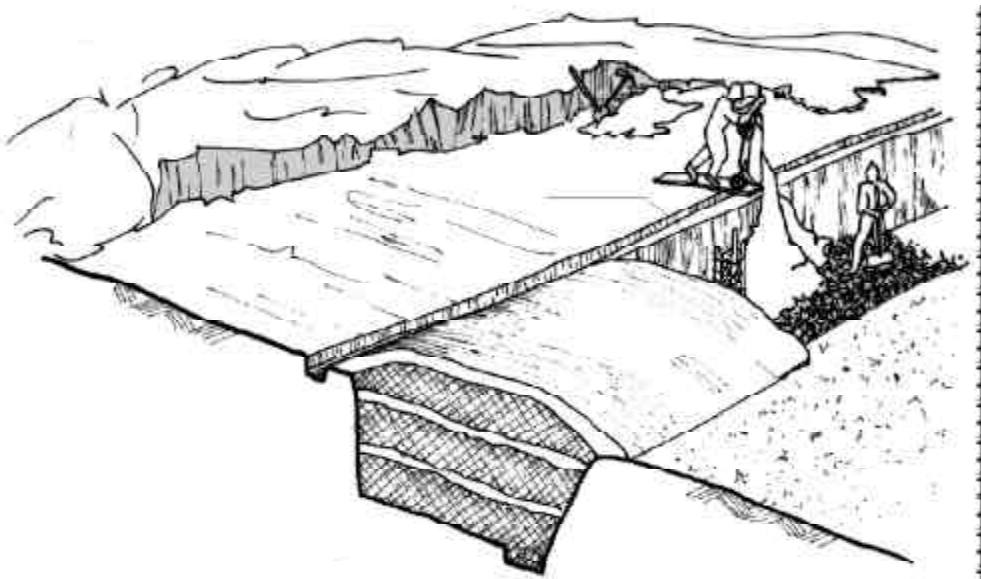
**Figure 7.29**  
**Unloading of MSW to one side of the trench**



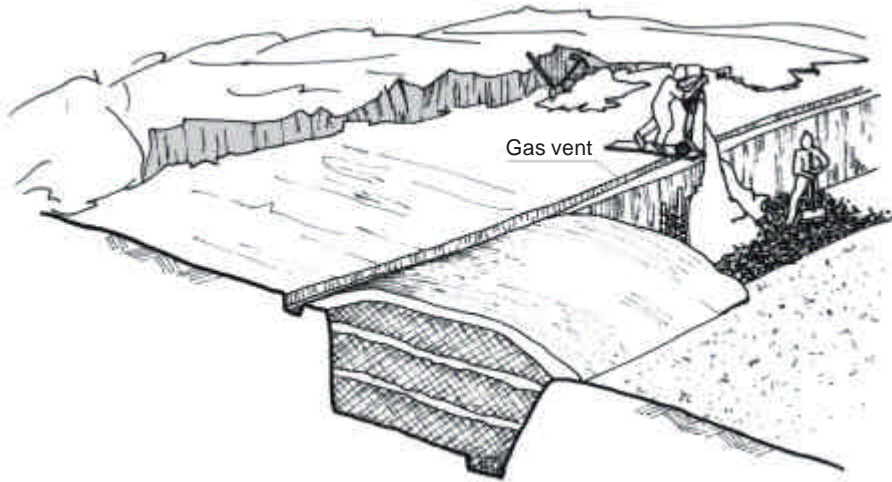
**Figure 7.30**  
**MSW is raked down into the trench and leveled**



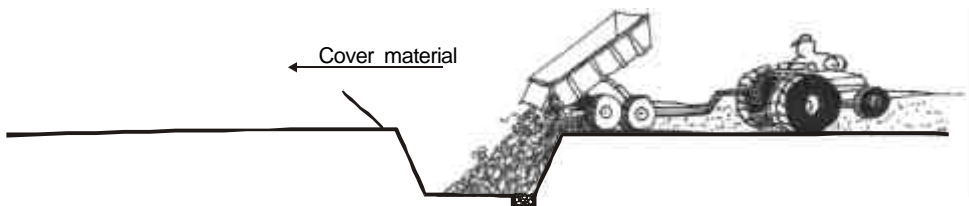
**Figure 7.31**  
**Earth hauling and covering of the waste**



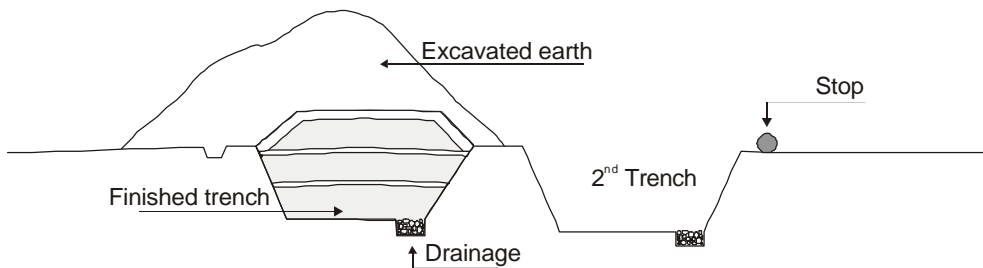
**Figure 7.32**  
**Manual compaction of the MSW in the trench**



**Figure 7.33**  
**Advance made filling the first trench**



**Figure 7.34**  
**Unloading of waste at the opposite side of the trench from that used for storage of the cover earth**



**Figure 7.35**  
**Sequence for filling the first two trenches**

### 7.2.2 Labor

The work at the sanitary landfill can be done by municipal workers or by a small construction firm (workers' cooperative) hired for the purpose; the number of workers needed depends on the amount of MSW to be buried, the climate conditions, and the method of operation of the landfill. There will have to be a person in charge or supervisor, who has the knowledge required for the operation and control of the landfill.

It is important that all the cleaning service personnel be trained in the practices of construction, operation and maintenance of the sanitary landfill, as well as in the whole process of MSW management, with emphasis on the importance of each task and the role they should play to make sure the work is well done.

### 7.2.3 Supervision

One of the most important elements at the sanitary landfill is the "boss" or supervisor, who will organize, direct, and monitor the operations; this person should be given the full support of the municipal administration.

If the manual sanitary landfill does not have good administration and supervision, sufficient funds, and effective technical maintenance, it will become an open dump.

**All administrators or supervisors should remember that a worker will give a much better performance if he is motivated and is given good working conditions.**

### 7.2.4 Work tools

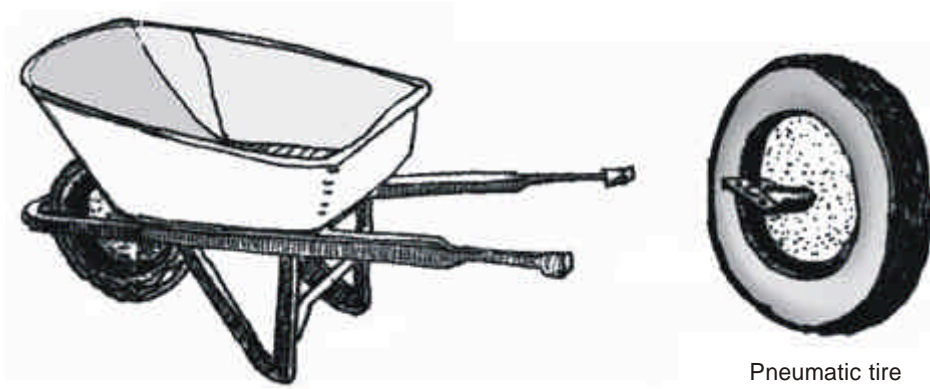
The equipment for operating a manual sanitary landfill is reduced to a series of masonry tools, such as: wheelbarrows or hand carts with pneumatic tires, shovels, pickaxes, hoes, iron bars, shears, wooden tampers, forks or rakes, picks and a compacting roller (Figures 7.36 to 7.40).

The quantity of tools required will depend on the number of workers, and this, in turn, depends on the amount of MSW to be buried in the landfill.

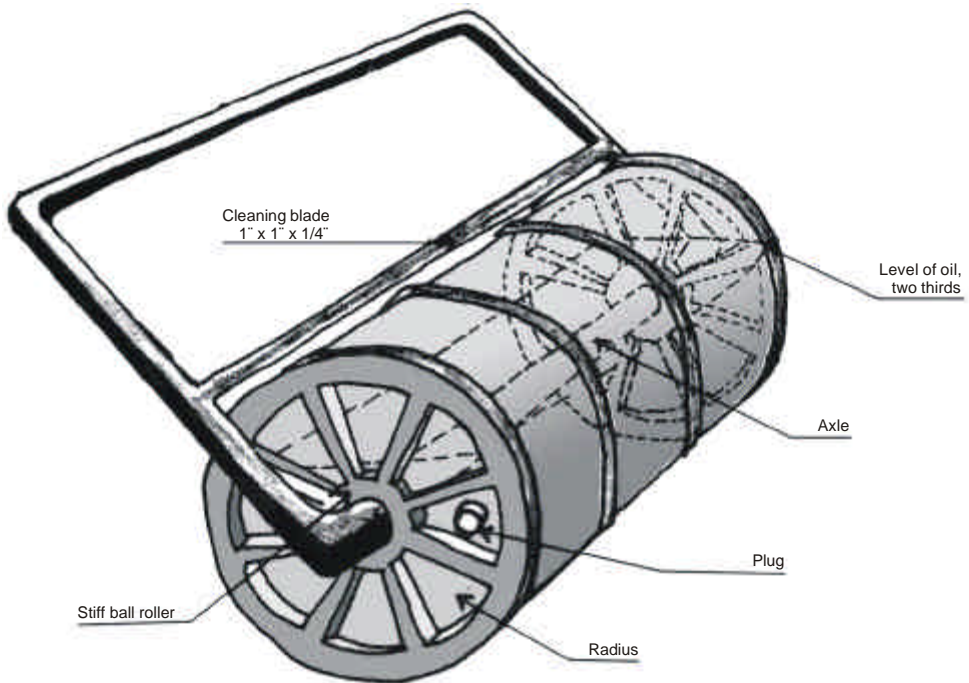
It is a good idea to place a line of wooden planks over the surface of the cells already constructed to make it easier to move the cover material or the waste in the wheelbarrows, especially during the rainy season, thereby improving the yields of the operation.



**Figure 7.36**  
**Work tools for the manual sanitary landfill**

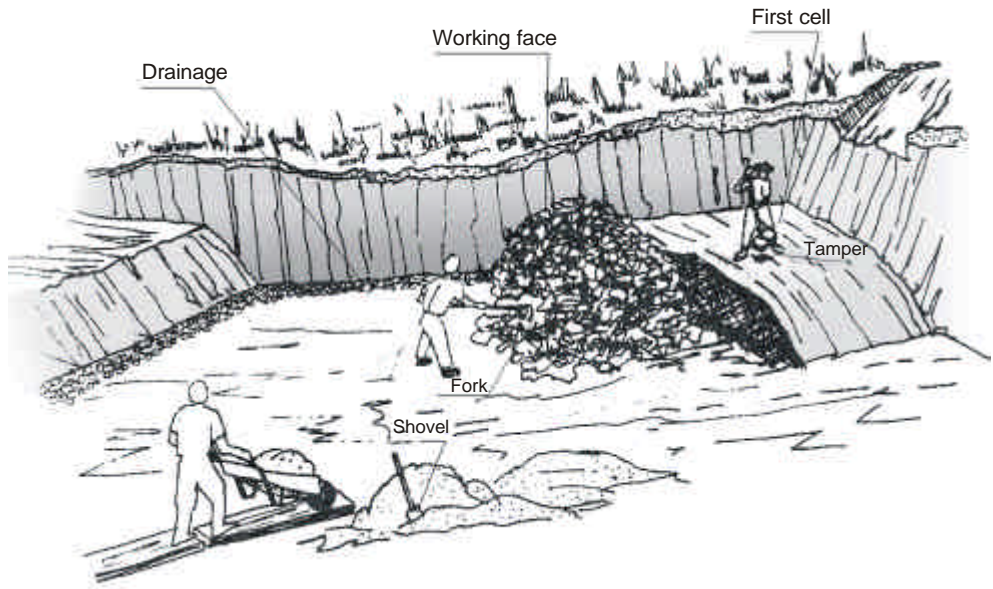


**Figure 7.37**  
**Wheelbarrow with pneumatic tires, 120-liter capacity**



**Figure 7.38**  
**55-gallon barrel adapted for use as a compacting roller**





**Figure 7.39**  
**Earth movement and formation of the daily cell**

### **7.2.5 Personal safety equipment**

Because of the type of work they do at the sanitary landfill, and their direct contact with the waste, the workers are exposed to accidents and to infectious and contagious diseases.

It is therefore important to protect the workers' safety and health by providing them with gloves, boots, caps or hats, dust masks, and at least two uniforms a year. Other factors to be taken into account are local customs and the weather (Figure 7.41).

### **7.2.6 Operation in the rainy season**

The most serious problems in landfill operation occur in rainy periods, namely:

- ? It is difficult for the collection vehicles to pass over the already formed cells, and the vehicles can get stuck because of the low density obtained with manual compaction.
- ? Difficulty in extracting and moving the cover material; and it is harder to form the cells in wet weather. These factors lead to lower performance on the part of the workers.



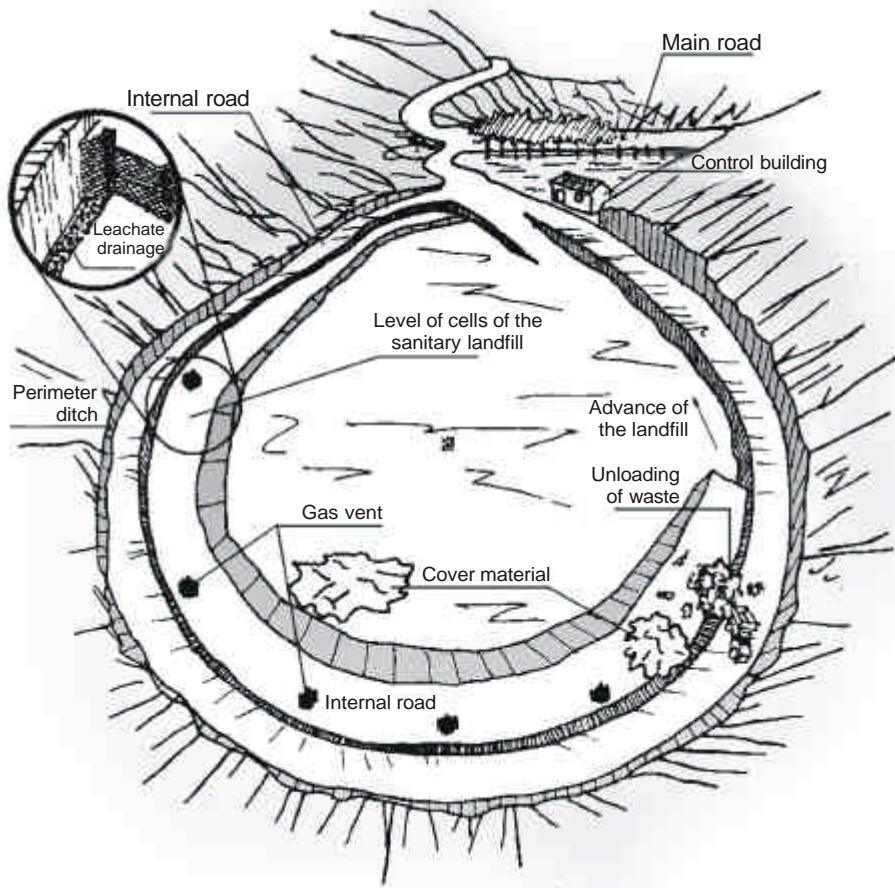


**Figure 7.40**  
**Safety equipment for the workers**

- ? The waste and cover material have to be unloaded on the terrace, leaving the forming and compaction of the cells pending. If the right measures are not taken in time, the dispersed waste and the presence of scavenging birds will detract from the appearance of the landfill.
- ? More leachate is produced, because of the rain falling directly on the filled areas.

The following precautions should therefore be taken:

- ? Cover the surface of the sanitary landfill totally or partially with a roof of palm leaves, plastic, or other local material.
- ? Reserve some areas in the places least affected by the rain, with access roads conserved, so that operations can continue under bad weather conditions.
- ? Construct an artificial road using wooden logs or small-sized rubble from constructions.
- ? Schedule earth movement (extraction of the cover material and excavation of trenches) for the dry periods. The only activity in the rainy season will be the waste disposal.
- ? The cells should routinely be covered with plastic material to prevent rainwater from seeping through the garbage.
- ? Keep the work areas narrow, supporting the cells on the slope of the site and superimposing three or more cells near the internal road so that the progress will be vertical rather than horizontal (Figure 7.42).
- ? For one or more days a week, reinforce the labor with an extra team of two or three workers, to keep the landfill in a good condition while the adverse factors remain in place.

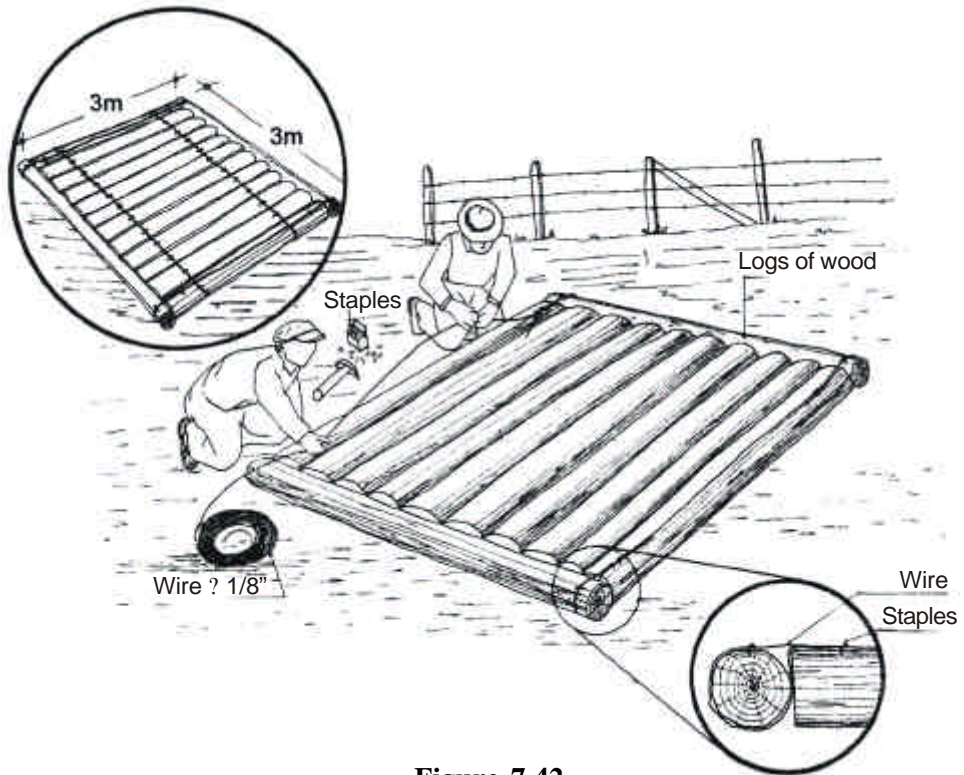


**Figure 7.41**  
**Reservation of areas and upward cell construction for operation in rainy periods**

*Construction of the artificial road:*

Build a timber road using 3-meter trunks tied together with a 1/8"-diameter wire. This road is constructed in modules 3 m long by 3 m wide, depending on the needs and the advance of the landfill. Once the access road is in place, it should be covered with gravel to prevent the vehicles from slipping on it. These timber roads should be built on site, and for this purpose the land must be well compacted and have good provisional drainage (Figures 7.43 and 7.44).

Rubble from the demolition of old buildings can be used to build and maintain some provisional internal roads in the landfill, especially on the waste platforms.



**Figure 7.42**  
**Details for making the timber road module**



**Figure 7.43**  
**Artificial road for the waste to reach the working face**

### **7.3 Maintenance**

#### **7.3.1 Tools**

Once the day's work is over, the tools should be put away clean. Any damaged tools must be repaired or replaced as soon as possible.

#### **7.3.2 External infrastructure and landfill infrastructure**

##### **? Access road and internal road**

The access road to the landfill and internal road to the working face, the rainwater drainage systems, and the finished surface of the landfill must be kept in good working condition.

The cost of giving maintenance to the access road and the internal road is lower than the cost of repairing damaged axles and suspension or other deterioration of the vehicle caused by the bad condition of the road or an overturn. It is therefore advisable to have boulders, demolition rubble, logs, and other implements at hand for road maintenance work. The working face should be kept tidy and free of loose litter.

##### **? Perimeter drainage**

The perimeter rainwater drainage system (ditches around the site and gutters beside the access road) should also be kept in good condition, as well as the surface of the landfill. As time goes by, these ditches become obstructed owing to the erosion of the earth slopes, material swept along in the rainy season, or litter blown by the wind (paper, plastic, etc.).

##### **? Loose litter**

It is important to keep the areas adjacent to the daily working face clean. When papers blown by the wind are allowed to accumulate, the landfill starts to look scruffy. At the end of the day's work, one of the workers should collect all such loose litter and deposit it where the daily cell is constructed. (Figure 7.45).

##### **? Drainage of the leachate.**

Because of the great quantity of fine material carried by the water that seeps into the landfill, the drainage system and internal and external storage ditches gradually silt up and can become blocked in time. It is hardly feasible to remove this material inside the landfill, but the external ditches can be cleared by extracting all the fine



**Figure 7.44**

**Collecting loose litter from the surface of the landfill and adjacent areas**

material silting them up, to renew their capacity of storage and evaporation. This material is deposited again in the landfill and can be used as cover material for the daily cell.

? ***Drainage of gas***

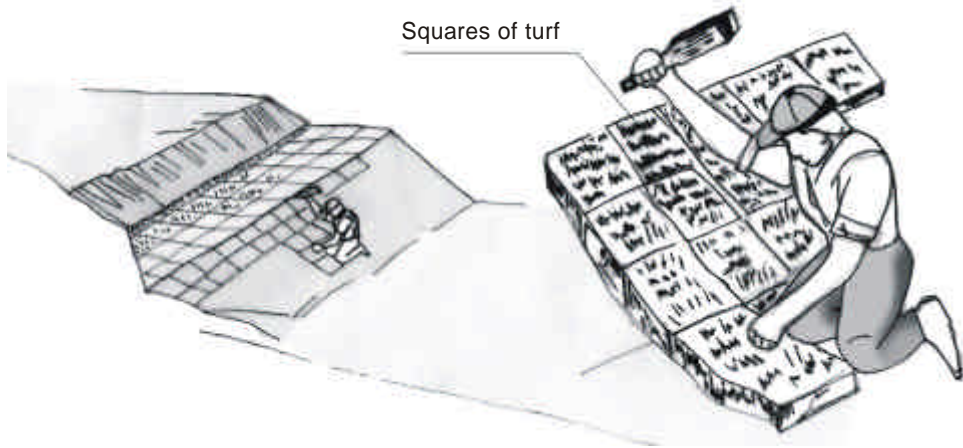
Landfill settlement and the vehicular traffic over the finished cells and embankments cause the gas vents to become deformed and bent, so it is necessary to make sure they are kept vertical as the level of the landfill rises, to prevent them from becoming obstructed or completely deteriorated.

? ***Facilities***

The infrastructure and other facilities, such as the enclosing fence, the site identification board, the control building, and the sanitary facilities, should be given good maintenance so as not to detract from the image of the landfill.

? ***Final cover and settlement***

The spreading of the final layers of cover material and the sowing of grass on the finished landfill, which will not be receiving any more waste, require great care because they contribute to the good working of the landfill and improve its aspect. It is a good idea to speed up the grass-sowing process by planting turf on at least 10% of the area so that the site will quickly blend in with the natural landscape (Figure 7.46).



**Figure 7.45**  
**Planting vegetation on the surface and slopes of the finished earthworks**

It is a well-known fact that as time goes by the MSW decomposes into gases and liquids, with the result that the cover earth and the moisture penetrate into the empty spaces of the landfill, causing it to settle. After two years, the settlement is greatly reduced, and it practically disappears after five years. Since this process is not uniform, depressions are produced in the surface of the landfill, and rainwater accumulates there. It must be made sure that the surface of the site is kept level and that it has good drainage, with a gradient of 2 to 3%.

The municipal administration or landfill management should make sure that once the useful life of the manual sanitary landfill is over, the final landscaping and all the maintenance required are provided, so that the site will be enjoyed by the community as intended at the beginning of the project. If this is not so, the affected population will probably reject the construction of new landfills, which would make it necessary to construct them farther away, thereby increasing the hauling costs and the costs of the public cleaning service in general.

At the end of the useful life of a sanitary landfill, a new site identification board or sign should be put up to inform all the neighboring population and passers-by that the landfill is out of service. After a prudent length of time in which the landfill has been successfully stabilized and turned into a recreational area or green area, it is recommended that a sign be put up with the information that the new project has been constructed on top of a closed sanitary landfill.

## **8. CLOSING THE MUNICIPAL GARBAGE DUMP**





The authorities have discovered, unfortunately too late, that it can be very difficult and costly to close sites that have been used as municipal dumps. Most of these dumps were opened and used without any technical, environmental, or social criteria, and with no control whatsoever.

The closure of the municipal garbage dump is usually neglected in the planning of the sanitary landfill. However, if the landfill is to be successful the municipal dumps will have to be closed, as well as any other sites where garbage is being dumped informally. To meet this objective, the necessary funds must be put aside, help must be given to the people who make their living from the dumps, and two basic goals must be kept in mind: first, that the site must be provided with minimal infrastructure to prevent future damage to the environment; and second, that the measures taken should be technical, practical, and inexpensive.

### **8.1 Informing the public of the closure**

The environmental and health authorities or the regulating institution, as well as the general public, in particular those living near the site, must be informed about the closure of the dump and the start of operations of the sanitary landfill. In these cases it is appropriate to do the following:

- ? Keep the municipal council informed, with the support of the health and environmental authorities, and even that of the parish priest; this is a good strategy to ensure the viability of the project.
- ? Prepare a program of sanitary and environmental education for the local schools, and a series of activities for the community at large on how important it is for their community and everyone in it to have the benefit of a good waste collection and final disposal service, pointing out the need for all the inhabitants to help maintain it by paying their urban cleaning service bills.
- ? Explain, through all the local mass media (newspapers, radio, newsletters, or, where appropriate, town-criers), that it is urgent to eradicate the irresponsible practice of throwing garbage into open dumps or rivers and streams, and emphasize the advantages of having a proper sanitary landfill.
- ? Inform the public that the open dumps have been closed and it is no longer permitted to throw garbage in those places. The sanctions that will be applied to people who infringe the rules and regulations established in this respect should be made public.
- ? Inform the public of the existence of the manual sanitary landfill to put an end to the practice of using the open dump.
- ? Request, and even demand, that the owners or managers of stores, warehouses, bars, canteens, etc., give their waste to the operator of the municipal collection

service or that they themselves take it to the sanitary landfill. In small communities these people usually hire third parties to take away the MSW produced in their establishments, and they do not care where the waste is deposited.

## **8.2 Steps and activities for closing the dump**

### **8.2.1 *Garbage scavengers***

In Latin American countries a large number of poor people find a source of income for their survival in the recovery of waste by-products. Although in communities distant from the great urban centers this phenomenon may not occur, since there is no market there for these materials, in the majority of municipalities it is a common phenomenon because of the high unemployment rate and extreme poverty in the Region.

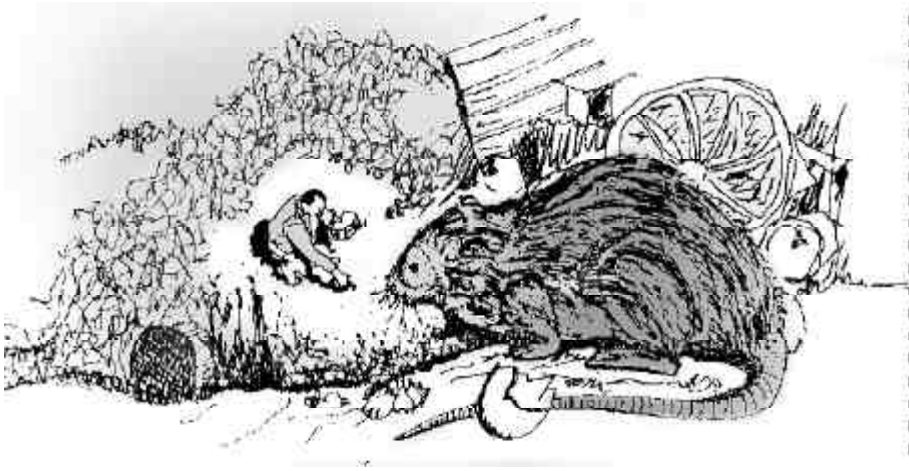
The individuals who work sorting waste at the municipal garbage dump survive under conditions of extreme poverty, and it is imperative to help them by all possible means to improve their living conditions. In this reference, the engineers and technicians will have to make way for experts in the social sciences (sociologists, social workers, and anthropologists), whose professional skills enable them to talk and coordinate with these people who, because of their low social condition, are usually suspicious of the rest of society and even resentful toward them.

One of the main strategies for helping them out of their state of marginality is to organize them in cooperatives and associations that are managed like companies; this enables them to be in a better position to negotiate terms with middlemen for the materials recovered or already sorted. They will also be able to offer other services depending on their original trades and the needs of the community.

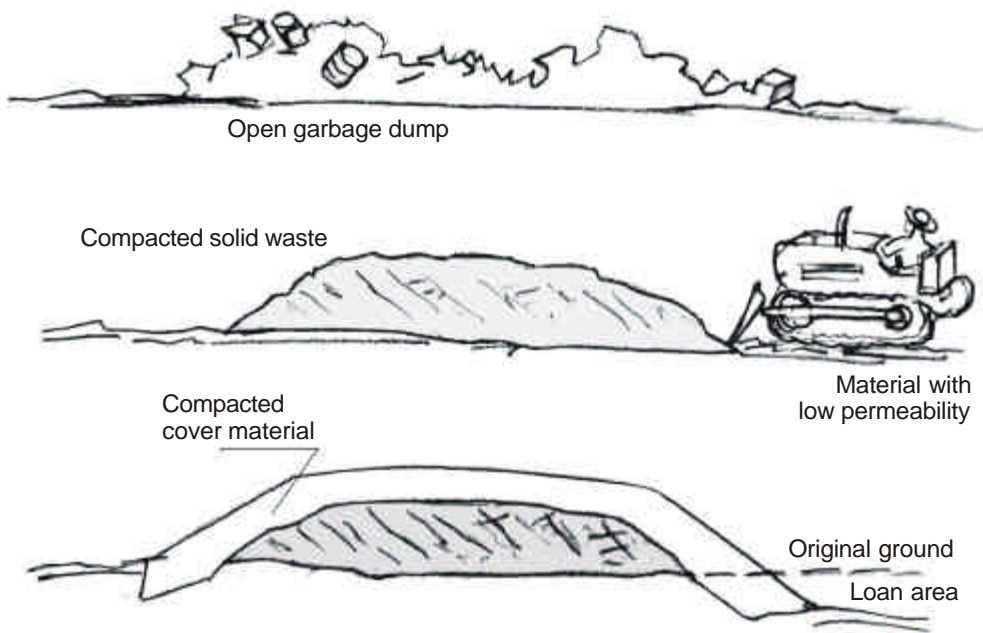
It cannot be stressed too much that a project for a sanitary landfill and closure of open dumps includes not only technical and economic aspects, but also social and environmental ones.

### **8.2.2 *Remedial measures***

To protect human health, and reduce the nuisance and the environmental impact caused by the MSW and its by-products in the neighboring community, a brief plan for the closure of open dumps should contain the following at least: a list of remedial activities; the final design of the dump layout, and the specification of the works, the equipment and personnel required; a work schedule; and the estimated costs. The following are the main jobs that can be done by municipal workers or other hired persons:

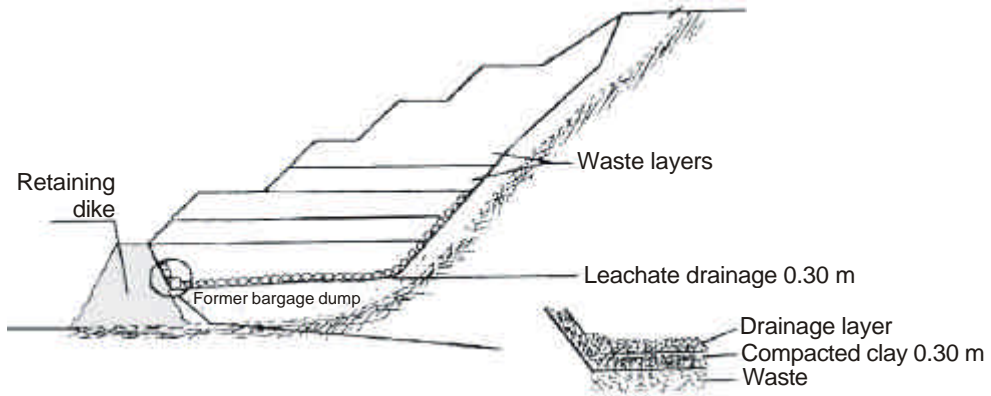


**Figure 8.1**  
**Extermination of rodents**



Source: Banco Mundial; PNUD; HABITAT. Desechos sólidos, sector privado/rellenos sanitarios. Quito, PGU, 1996.

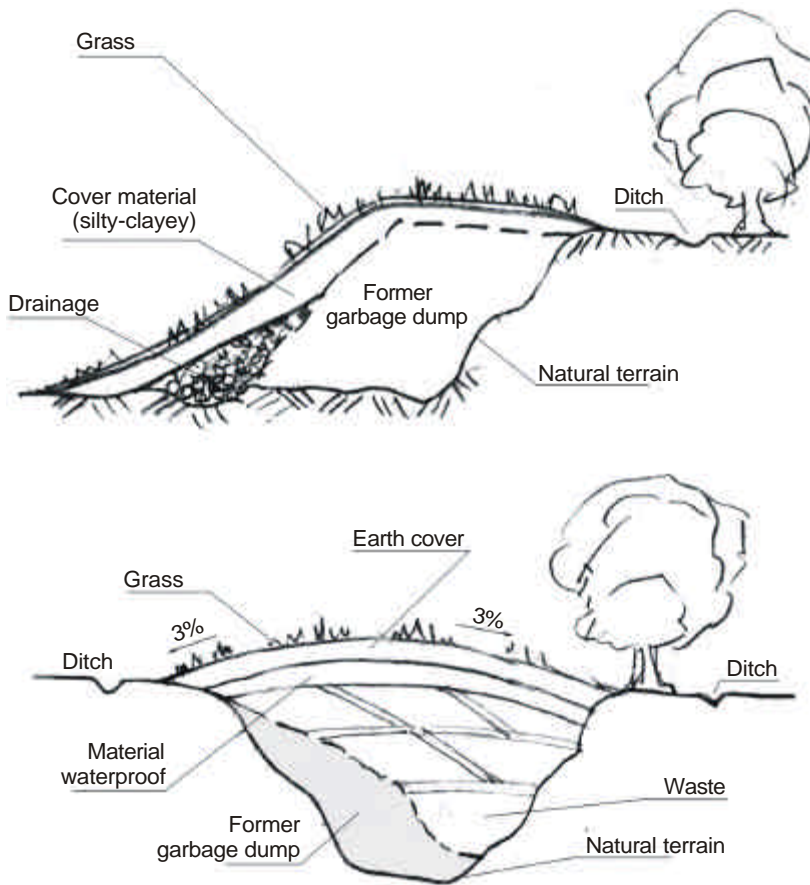
**Figure 8.2**  
**Steps for the final covering of a garbage dump**



Source: Banco Mundial; PNUD; HABITAT. Desechos sólidos, sector privado/rellenos sanitarios. Quito, PGU, 1996.

**Figure 8.3**  
**Containment and rehabilitation of a garbage dump**

- ? Put up a fence to restrict access of persons who might want to continue disposing of their MSW in the dump; and to prevent animals from entering.
- ? Set up a board, sign, or posters to inform the local population that the dump has been closed, indicating the location of the new site for disposal of MSW.
- ? Collect any loose litter scattered around the dump and place it with the mass of waste.
- ? Conduct a program to exterminate rodents and arthropods, for which the assistance of the health authorities and the environmental sanitation department will be requested. If this is not done, it is very likely that the vermin will move to neighboring homes in search of shelter and food (Figure 8.1).
- ? Complete the leveling and compacting of the surface and the slopes of the dump before unloading the cover earth. Ideally, the fill banks should have a gradient of 3:1 or 4:1 (horizontal:vertical) (Figure 8.2).
- ? It will sometimes be necessary to provide the mass of MSW with containment from the base of the slopes of the fill banks. This is done by constructing a wall of gabions or a small embankment of compacted earth. It is important to ensure that it is firmly anchored to the ground, to prevent overturning (Figure 8.3).
- ? Where justified, dig a series of 0.20 to 0.50 m wells and fill them with stones or gravel so that they can work as gas drains. As far as possible these wells should have the depth of the existing fill bank.
- ? Also, at the bottom of the embankments, excavate a longitudinal ditch at the toe of the slope and extend it a few meters. Any leachate generated can be stored here and it will evaporate during dry periods while the mass of waste is being stabilized.



Source: Adapted from Oeltzschner, H.; Mutz, D. Guidelines for an appropriate management of domestic sanitary landfill sites. Eschborn, GTZ, 1994.

**Figure 8.4**  
**Closure of a garbage dump**

- ? Put down baits for rodents and fumigate the site. Afterwards, cover with earth and compact the whole surface and the slopes of the dumps firmly with a 0.20 to 0.40 m thick layer for 8 to 15 days, forming a 3% gradient, to ensure good drainage of any rainwater falling on the surface.
- ? Install perimeter drainage to prevent infiltration of the surface water into the mass of MSW deposited there.
- ? Sow grass. This will give a better appearance to the site, reduce leachate formation, and prevent erosion. It will also be a clear sign to the local community that the garbage dump has finally come to an end.

### **8.3 End use of the closed dump**

The recommendation for closed garbage dumps in small communities is that they be turned into green areas with grass and short-rooted shrubs only, because of the lack of stability of the fill banks, which were not duly monitored during their construction.

## **9. ADMINISTRATIVE MANAGEMENT AND CONTROL**





## 9.1 Administrative management

If the sanitary landfill is to be constructed and operated following the specifications and recommendations of the project study or final report, good management is indispensable. Only if the landfill is properly managed can we be sure that the goals are being met. Since the final disposal of MSW is the last operational activity of the cleaning service, the landfill is the responsibility of the administrator of this public service. The person in charge is usually an official of the municipal office for cleaning or other public services or works. Nevertheless, the construction, operation and maintenance of a sanitary landfill can also be entrusted to a private operator.

The manager of the sanitary landfill should make public relations a priority both during its construction and after its closure, since public opinion plays a decisive role in promoting this basic sanitation work and its advantages.

**The administrator or person in charge of public cleaning should be aware of the operations of the urban cleaning service at all times and monitor the quality of the sanitary landfill.**

### 9.1.1 Resources

In small municipalities, one of the most common administrative problems is the absence of a plan for the supply of materials, on which depends the effectiveness of any good sanitary landfill construction, operation and maintenance project.

The administrator must therefore include the required resources in the design of the annual municipal budget. The budget should include the cost of the tools, spare parts, and other equipment required to work the sanitary landfill, as well as a heading of small expenditures for special situations and contingencies.

### 9.1.2 Supervision

To improve the quality of the cleaning service in small municipalities, it is advisable to hire a sanitation technician or promoter who will act as head or supervisor of public cleaning.

This person will be responsible for coordinating the operations of the sanitary landfill and the cleaning service, serving as liaison among the users, the workers, and the administration.

**If the manual sanitary landfill does not have good supervision for its operation and maintenance, or the necessary resources, it will very soon become an open dump.**

Some of the activities of the cleaning supervisor are listed below:

- ? Give instructions and assign tasks in accordance with the program defined by the directors for each part of the service (collection, hauling, and final disposal of the waste).
- ? Ensure the efficiency and quality of the service, planning the supply and maintenance of the materials, tools and equipment necessary for the efficient performance of the work.
- ? Apply the pertinent controls in the collection and hauling of the waste and at the sanitary landfill itself.
- ? Report periodically on the progress of the work and any anomalies that may arise.

**We must try to keep for the service those individuals who have received training in the different urban cleaning activities, especially in the construction and operation of the sanitary landfill; otherwise, the absence of trained personnel will translate into low efficiency and higher costs.**

### ***9.1.3 Health and safety of the workers***

The fact that the workers come into contact with MSW means that full attention must be given by the landfill manager to the protection of the health and safety of his personnel.

There are two main causes of risk: unsafe working conditions, and negligence on the part of the workers themselves.

The main unsafe working conditions are:

- ? Using their bare hands to collect the waste, which can produce cuts if the garbage contains broken glass or sharp objects.
- ? Working excessively long hours, which causes fatigue.
- ? Not having appropriate clothing or personal safety equipment.
- ? Not showering or washing at the end of the day's work.

- ? Having to eat at the working place without washing their hands with soap and water.

The most commonly found acts of negligence on the part of the worker include:

- ? Failure to use protective clothing or personal safety equipment.
- ? Drinking liquor during the working day, or coming to work drunk.
- ? Lifting heavy objects in the wrong way.
- ? Not taking care when the waste collection vehicle is unloading.
- ? Not giving good maintenance to the equipment and tools.
- ? Permitting the entry of people who have nothing to do with the sanitary landfill.
- ? Receiving wastes not included in the sanitary landfill project, which because of their hazardous nature can affect the workers and the local environment.
- ? Using their protective clothing or personal safety equipment outside the work site.
- ? Burning the MSW.
- ? Using the MSW to feed animals.
- ? Smoking while they work.

All unsafe conditions and the most common causes of work accidents to which the worker is exposed must be carefully identified, in order to find an appropriate solution.

Recommendations to minimize the problems mentioned above:

- ? Evaluate the most common causes of accidents and adopt preventive measures.
- ? Draw up safety standards, including instructions for the use of equipment.
- ? Provide the personnel with changing rooms and showers where they can shower and change their clothes after the day's work, so that they will not be carrying any kind of contamination to their homes.
- ? Set up a program of medical check-ups to identify, prevent, or treat possible diseases linked with their activity.
- ? Improve the quality of the equipment and tools.
- ? Provide the workers with basic personal safety equipment, such as: gloves, boots, cap or hat, and at least two uniforms per year.
- ? Keep a simple record of accidents and emergency situations, noting their causes, in order to prevent similar occurrences in the future.

**The supervisor will monitor compliance with safety standards on the job.**

**9.1.4 Indicators of productivity**

For successful management of the different activities, the manager of the cleaning service will need to analyze two basic aspects: costs and productivity.

In the case of the public cleaning service, certain indicators should be applied that will make it possible to establish productivity comparisons, and gauge the improvement achieved in the different tasks. The sanitary landfill, as a project

**Table 9.1**  
**Some indicators for the management and final disposal of municipal solid waste**

Indicator	Units
Coverage of collection service = $\frac{\text{Population served (inhab)}}{\text{Total population (inhab)}} \times 100$	%
1. Total production of MSW = Population (inhab) x per capita production (kg/cap/day)	kg/day
2. Percentage of financing of the sanitary landfill = $\frac{\text{Initial investment for the sanitary landfill}}{\text{Total municipal budget}} \times 100$	%
3. Coverage of final disposal = $\frac{\text{tons disposed of in the sanitary landfill}}{\text{tons collected}} \times 100$	%
4. Volume or weight of MSW received daily at the sanitary landfill	m <sup>3</sup> /t
5. Workers' efficiency in final disposal = $\frac{\text{tons disposed of in the sanitary landfill} \times \text{day}}{\text{number of workers at the landfill}} \times 100$	t/man-day
6. Cost of final disposal = $\frac{\text{cost of operation of the sanitary landfill} \times \text{year}}{\text{tons disposed of} \times \text{year}} \times 100$	\$/t
7. Cost of capital per ton of waste = estimate in column (g) of Table 9.1	\$/t
8. Total unit cost of the landfill TUC = formula [9-10]	\$/year

permanently under construction and permanently in operation, also needs a set of indicators as an administrative tool for assessing productivity and costs and to make sure that the best possible use is being made of the resources available.

A series of measures and controls will need to be applied to detect failures, apply remedial measures, and assess the effectiveness of such measures, in order to reach optimum productivity and provide a good service at the lowest possible cost.

Table 9.1 shows some indicators helpful in the direction and administration of a sanitary landfill.

## **9.2 Controls of the sanitary landfill**

No matter how small the manual sanitary landfill may be, MSW management is very important in any community, so it needs to be assessed periodically to ensure that it is operating under the best possible conditions.

### ***9.2.1 Control of the construction***

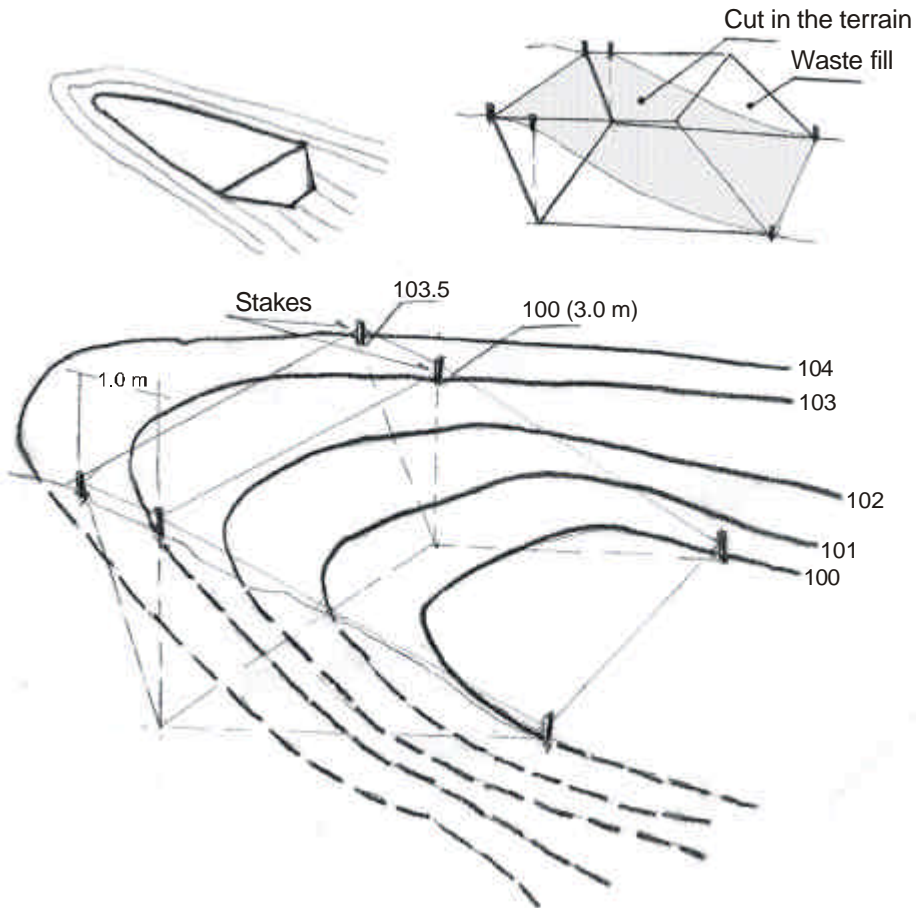
It is important to maintain the alignment and height of the platforms as well as the levels indicated for the cell heights, which can be controlled from the project design drawing or by simple observation with the help of stakes at the site. The gradients of the slopes should provide the stability required depending on the site topography (Figure 9.1).

### ***9.2.2 Control of operations***

- ? Entry of MSW and earth.
- ? Quantity (estimated weight and volume).
- ? Origin (sector of the urban area).
- ? Type of waste (domestic, commercial, market, etc.).
- ? Type of transportation (compactor, dump truck, horse-drawn cart, etc.).

MSW not authorized by the management or administration of the manual sanitary landfill will not be received.

- ? Vehicles and visitors entering the site.
- ? Schedule of working hours of the employed workers.
- ? Maintenance of tools.
- ? Unusual occurrences (collection vehicle getting stuck, fire, downpours of rain etc.).



**Figure 9.1**  
**Stakes at the site to control the construction of the fill banks**

To keep a record of the tools and implements supplied to the workers, Table 9.2 can serve as a guide.

### **9.2.3 Control of costs**

One of the aspects that municipal administrators tend to neglect is the collection and analysis of data on the productivity and costs of the cleaning service. This is a

**Each worker is responsible for the tools and implements he uses on the job.**

serious omission because the cleaning service is a subsidy that often devours a large portion of the municipality's limited budget.

It must therefore be stressed that it is very important to gather this type of information, both during the investment stage and during the construction, operation, and maintenance, since the analysis of this information will point us in the direction of maximum productivity with greater savings.

The amount invested by a municipality in the manual sanitary landfill fluctuates between 10 and 20% of the overall budget for public cleaning, so in practice the costs of this work are not so high as many local administrators believe.

**It is essential to keep separate accounts of each municipal public service and, as far as possible, of each activity corresponding to urban cleaning. In this way the value of the cleaning tariff can be calculated based on the real costs. This is vital to guarantee the economic solvency, the quality, and the sustainability of this service.**

#### *Factors for estimating operating costs*

- ? Operation and maintenance (personnel, infrastructure, maintenance of equipment, tools, support facilities, etc.).
- ? Tools (procurement and replacement).
- ? Hauling of cover material.
- ? Rental of equipment for preparing the site, opening the access road, and excavating ditches.
- ? Stones, wire, construction materials, water.
- ? Indirect costs (administration, supervision, etc.).

**All users of the urban cleaning service should pay a tariff in keeping with their socioeconomic level. This service should not be free under any circumstances.**

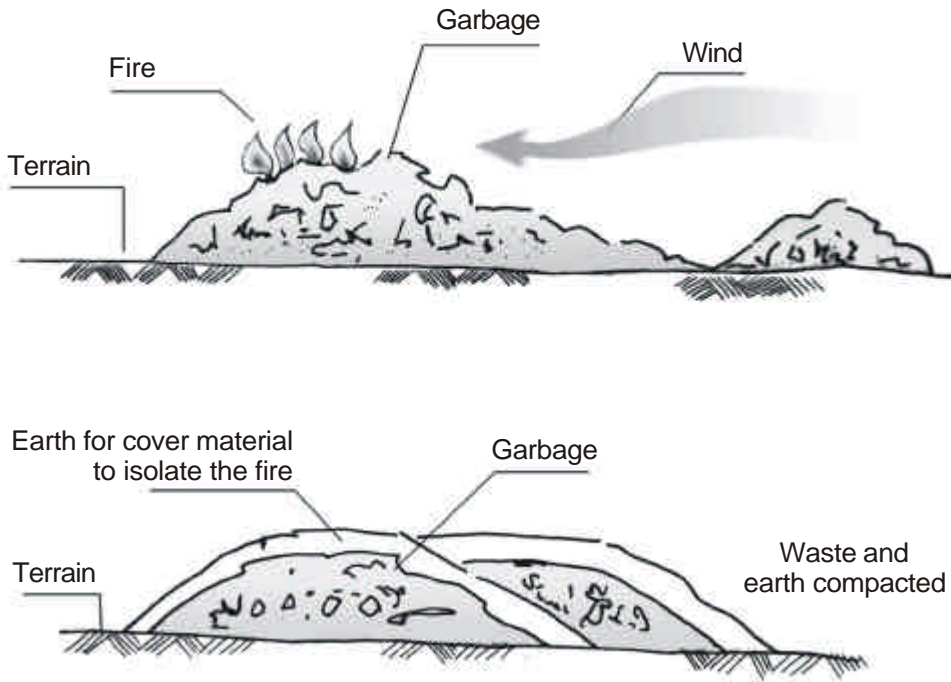
#### **9.2.4 Control of the environment**

- ? **Quality control of groundwater and surface waters.** It is advisable to set up a water quality sampling program. The samples can be collected monthly and, if possible, before and during operation, and one year after the useful life of the

landfill has come to an end. If after the first year of operation it is confirmed that there is no contamination, the sampling frequency may be reduced, or sampling may be suspended altogether. The parameters to be analyzed will be those indicated by the local or regional authorities in charge of monitoring water pollution (cf. Chapter 5, point 5.10.2).

- ? **Release of gases.** The gas vents or chimneys must be permanently observed to make sure they are working correctly.
- ? **Harmony with the natural landscape.** The sanitary landfill should have a good appearance so that it will not spoil the local scenery.
- ? **Control of burning and fires.** At the sanitary landfill the burning of combustible materials such as paper, cardboard, plastics, rubber, or any other element must be avoided, since this can cause fires, besides spoiling the look of the landfill. Fires should be extinguished with earth. (Figure 9.2).

It should be recalled that the decomposition of the waste produces methane, which is a combustible gas, and when fire is lit near gas vents and leachate drains, or if people smoke in such places, there can be serious accidents.



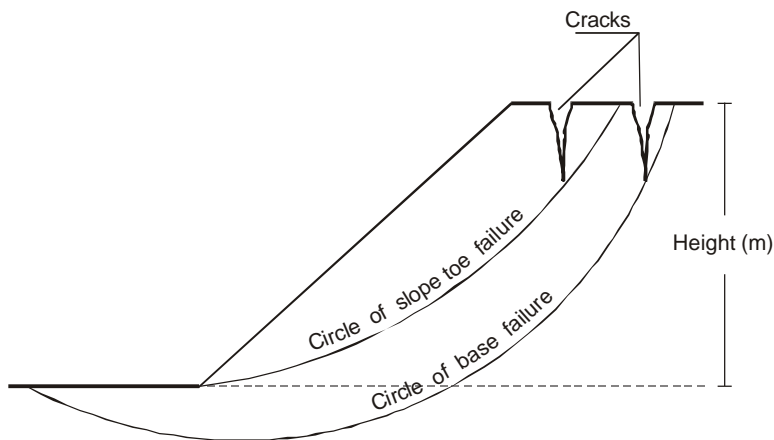
**Figure 9.2**  
**Controlling fires**





**Figure 9.3**  
**Control of vectors of sanitary interest**

- ? **Control of insects, rodents, and birds.** Insecticides or rodenticides contaminate the environment and eventually lead these vermin to develop greater resistance to the chemical agents, which in the long term makes it difficult to control them. For these reasons, the use of such products must be minimal and only those authorized by the health sector should be used. The best way to control these vectors is to cover them with earth (Figure 9.3).

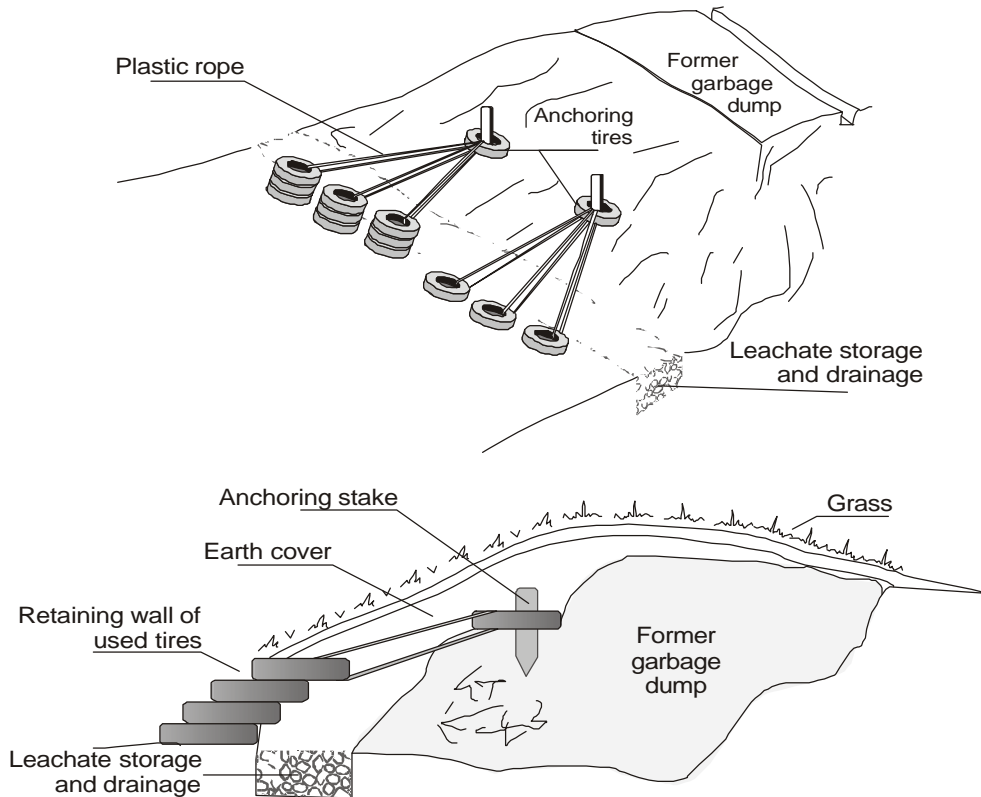


*Source:* Mexico. Subsecretaría de Desarrollo Urbano y Vivienda. Manual para la rehabilitación y clausura de tiraderos a cielo abierto. Mexico, DF, 1996.

**Figure 9.4**  
**Identification of slope failures**

Flies and rodents usually arrive with the garbage in the waste collection vehicles, so it is recommended to fumigate and place rodenticides in the landfill area. The presence of these insects and rodents, as well as scavenger birds that feed off the waste and carrion, is an indicator of a lack of earth cover and poor quality in the maintenance of the sanitary landfill.

? **Control of slope stability.** The embankments made of the waste and the earth cover tend to move downward by the force of gravity, and this can be seen by simply observing the slopes (Figure 9.4). Therefore, if loss of cover is detected, or waste appears on the slope, if lumps are seen on the slope surface, or an advance of the fill bank at its lower base becomes apparent, this must be remedied by removing the loose material and proceeding to cover and compact the slope again. In some cases a wall of gabions can be used, or old tires tied together with plastic ropes, and also plants can be sown (Figure 9.5).



**Figure 9.5**  
**Controlling slope stability with car tires**

- ? ***Control of differential settlement and cover conditions.*** This activity will be carried as each embankment or trench is finished, or when the whole landfill has been completed, to identify any fault (slide) in the stability, or cracking or depressions on the surface. Depressions and cracks favor the accumulation of rainwater on the surface of the landfill and permit its infiltration, which contributes to generating leachate. If such situations are detected, the surface must be leveled and vegetation restored.

### 9.3 Cost analysis

As in any other design, an estimate or a budget should be presented as part of the basic information for the project. Costs are divided into investment costs and operating costs.

In the case of the investment costs, each concept or item will need to be linked with the useful service life (in this case, of the sanitary landfill), since the infrastructure works will be constructed for the design period.

#### 9.3.1 Investment costs

- ? Studies and designs (including site selection and topographic survey).
- ? Acquisition of the land.
- ? Preparation of the site and support facilities.
  - ? Clearing and cleaning.
  - ? Earth moving (machinery rental).
  - ? Internal and external access roads.
  - ? Perimeter drainage.
  - ? Drainage of leachate.
  - ? Enclosure of the site.
  - ? Perimeter fence of trees.
  - ? Control building.
  - ? Sanitary facilities.
  - ? Site identification board.
  - ? Others.
- ? Closure of open dumps.
  - ? Study and design.
  - ? Elimination of arthropods and rodents.
  - ? Machinery rental.
  - ? Purchase of earth (if none available at the site).
  - ? Covering and compacting of the site.
  - ? Sowing of plants.

### **9.3.2 Operation and maintenance costs**

- ? Labor.
- ? Tools.
- ? Safety equipment.
- ? Venting of gases and secondary drainage.
- ? Maintenance.
- ? Periodic adaptation of the site (roads, drainage systems, excavations, etc.).

### **9.3.3 Costs of final closure of the sanitary landfill**

- ? Final closure.
- ? Drainage systems.
- ? Grass or plant cover.
- ? Landscaping project.

## **9.4 Preparing the budget**

The project designer or person who has designed the landfill should first prepare an investment budget for submission to the mayor or to the institution in charge of the work. Table 9.3 lists in column (a) the investment items, and in columns (b) and (c) the costs for each one. The sum in column (c) will give the initial investment or capital necessary for starting the works. The project items are described below.

- ? **Studies and designs.** The preliminary studies and the executive project of the landfill will imply a series of costs for the municipality, which will vary depending whether an expert is hired or the project obtains the support of an institution that provides this type of technical assistance. In some cases, the municipality will pay only for per diem expenses or the topographic survey or other studies as required.
- ? **Acquisition of land.** The cost of the land is placed in column (b) if it is private land; if it is municipal land, the cost will be zero. Another possibility is that the land is rented, in which case the value in column (b) will be zero and the cost should be transferred to recurring costs or operating costs.
- ? **Site preparation and complementary works.** This item is estimated by quantifying the volumes of works of each of the components, such as: clearing and cleaning, earth moving, access roads, etc., which should be placed in column (b) of Table 9.4 (this is used as an auxiliary table to facilitate filling out Table 9.3). To estimate the quantities of works, the construction drawings are used,

**Table 9.2**  
**Investment costs**

ITEM (a)	Initial investment (US\$)		Unit costs of investment (US\$)					
	Partial (b)	Total (c)	Useful life (years) (d)	Annual costs (US\$/year) (e)	AAI <sup>1</sup> (US\$/year) (f)	Capital cost (US\$/year) (g)	Annual productivity (t/year) (h)	(i)
a) Studies and designs								
b) Acquisition of land								
c) Installation and preparatory works ? Clearing and cleaning ? Earth moving (equipment rental) ? Access roads ? Rainwater drainage ? Leachate drainage ? Gas drainage ? Fence and entry gate ? Tree planting ? Control building and storage ? Sanitary facilities ? Site identification board ? Others								
d) Acquisition of equipment and tools								
e) Closure of the municipal dump ? Studies and design ? Machinery rental / labor ? Sanitation (fumigation of site) ? Cover material ? Planting vegetation								
<b>Total</b>								

<sup>1</sup> Annual average interest (US\$/year), formula 9.3

mainly those similar to the one shown in Figures 5.4 and 5.5, as well as the detail drawings.

The units with which the volumes are usually measured have been placed in column (c), but these may be changed if necessary.

In column (d) the unit costs of the work are entered. These costs are usually known to local engineers, construction foremen, and other individuals involved in the construction of public or private works. Many secretariats, development corporations, etc., have catalogs of unit costs, which are periodically reviewed. If these data are not available, they will have to be calculated using manuals or manufacturers' data.

Finally, in column (e) of Table 9.4 the cost of each component is entered, which is the same as the product of columns (b) and (d). The costs obtained are placed in column (b) of Table 9.3.

- ? ***Closure of the open dump.*** Closing an open dump is relatively easy if the machinery and the cover material required are available. However, to estimate the quantities of works and prevent any harmful environmental impact or health risks, it is indispensable to draw up a plan for the subsequent use of the site. Table 9.4 will be used for this purpose. Additional items may be added to it if necessary.

Finally, once Table 9.4 has been completed, the results are transferred to Table 9.3, where the sum of column (c) will give the initial investment that will need to be obtained. This investment could be obtained through a loan which, inevitably, would include interest.

#### ***9.4.1 Estimation of the unit costs of investment***

First, the unit costs of investment are calculated (including interest), and these are then added to the total costs of the sanitary landfill, and to the calculation of the tariff that the user will have to be charged. For this it is necessary to calculate the annual or hourly cost and afterwards the unit cost according to the production or productivity, that is:

$$C_n = \frac{C \text{ total}}{n} \quad [9-1]$$

**Table 9.3**  
**Cost of opening the landfill and closing the open dump**

Item (a)	Quantity of works (b)	Unit (c)	Unit cost (US\$/unit) (d)	Cost (US\$) (e)
a) Opening the landfill				
? Clearing and cleaning		m <sup>2</sup>		
? Earth moving		m <sup>3</sup>		
? Access road		m		
? Rainwater drainage		m		
? Leachate drainage		m		
? Gas drainage		m		
? Fence		m		
? Entry gate		unit		
? Tree planting		m		
? Control building		m <sup>2</sup>		
? Sanitary facilities		unit		
? Site identification board		unit		
? Others		-		
b) Acquisition of equipment and tools		unit		
c) Closing the municipal dump				
? Studies and design		unit		
? Machinery rental / labor		hours		
? Sanitation (fumigation of the site)		unit		
? Cover material		m <sup>2</sup>		
? Planting vegetation		m <sup>2</sup>		
<b>Total</b>				

where:

- $C_n$  = Annual cost or hourly cost depending on units of n  
 $C_{total}$  = Total cost of the item  
n = Useful life of the work or the item (for example, from 5 to 10 years for a sanitary landfill)

For the unit cost:

$$C_n = \frac{C_n}{R} \quad [9-2]$$

where:

$$\begin{aligned} C_u &= \text{Unit cost (for landfills US\$ / t)} \\ R &= \text{Productivity for one year or per hour (e.g. for a 10t/day manual landfill working 300 days a year, it would be } 10 \times 300 = 3,000 \text{ t/year)} \end{aligned}$$

Table 9.3 shows the total costs in columns (b) and (c). The times “n” of the equation [9.1] appear in column (d) of the same table. Usually “n” coincides with useful life of the sanitary landfill; however, there are certain elements that could have a shorter duration. It is generally recommended to depreciate everything in the useful life of the landfill. The annual cost, also called annual depreciation, is calculated in column (e) using equation [9-1], that is, dividing column (c) by column (d).

Column (f) of Table 9.3 shows the annual average interest that allows the invested capital to be recovered. The interest can be calculated thus:

$$AAI = C_{total} \frac{(n + 1)}{2n} i \quad [9-3]$$

where:

$$\begin{aligned} AAI &= \text{Annual average interest (US\$/year)} \\ C_{total} &= \text{Total cost of the item} \\ n &= \text{Useful life of the item in years (useful life of the landfill)} \\ i &= \text{Annual interest} \end{aligned}$$

The sum of columns (e) and (f) gives column (g), that is, the annual cost of the capital. This can also be calculated directly from the total cost (d) and using the tables or the equations for capital recovery. In economic engineering books there are tables that give the capital recovery factor (CRF), based on the annual interest and useful service life. The following equations can also be used:

$$Cc = C_{total} (CRF) \quad [9-4]$$

$$CRF = \frac{i}{1 - \frac{1}{(1 + i)^n}} \quad [9-5]$$



where:

- $C_c$  = Cost of capital (US\$/year)  
 $C_{total}$  = Total cost (US\$)  
 $i$  = Annual interest on the loan or municipal bank interest (if the interest is 13%,  $i = 0.13$ )  
 $n$  = Useful life in years

Once the cost of the capital has been estimated using any of the above methods (column (g), Table 9.3), it is divided by the production or annual productivity R (see column 5, Table 5.1) to obtain the unit cost in column (i) of Table 9.3. It will be seen that the annual productivity—that is, the quantity of tons received by the landfill—will increase year by year, while the unit cost of capital will decrease annually. If the administration wishes to avoid this, a productivity factor R can be taken as the average for the whole useful life of the landfill.

#### 9.4.2 Estimation of the operating costs

The operating costs or recurring costs serve to estimate the annual budget required to run the sanitary landfill well and charge a fair tariff.

##### 9.4.2.1 Annual labor costs

The number of people working at the sanitary landfill will be calculated as indicated in Chapter 5, point 12. The productivities proposed there may be modified according to the specific experiences and conditions of each site:

$$A_{lc} = 12 N (Fsb S_m) + 12 P (Fsb S_s) \quad [9-6]$$

where:

- $A_{lc}$  = Annual labor cost (US\$/year)  
 $N$  = Number of workers at the landfill, as in point 5.12  
 $S_m$  = Local legal minimum wage (US\$ / month)  
 $F_{sb}$  = Factor of social benefits, usually between 1.4 and 2.0. This includes social security, pension fund, vacations, etc.  
 $P$  = Proportion of time or of the working day which the supervisor spends on the landfill (from 0.2 to 0.25 in small landfills)  
 $S_s$  = Monthly salary of the supervisor (US\$ / month)

#### 9.4.2.2 *Tools and safety equipment*

The quantity of tools used will depend on the volume of MSW entering the sanitary landfill. The tools are described in Chapter 7, point 7.2.4. They can last for about one year, although that will depend on the use they are given.

The safety equipment could consist of two or three uniforms per year, boots, goggles, masks, and gloves. The cost of these items will be calculated from local prices.

#### 9.4.2.3 *Drainage, roads, machinery, and others*

Each year the following will have to be evaluated from the drawings and project advance: cost of the drainage and roads needed; equipment rentals (hours-machine); and the materials and labor temporarily required for these works.

The sum of these three items will give us the annual operating cost or annual operating budget:

$$Aoc = Alc + Ct + Cm + Others \quad [9-7]$$

where:

$$\begin{aligned} Aoc &= \text{Annual operating cost (US\$/year)} \\ Alc &= \text{Annual labor cost (US\$/year)} \\ Ct &= \text{Annual cost of tools (US\$/year)} \\ Cm &= \text{Annual cost of machinery (US\$/year)} \\ Others &= \text{Other annual costs (US\$/year)} \end{aligned}$$

#### 9.4.2.4 *Unit operating costs*

The unit operating cost will be the previously calculated annual cost divided by the volume (in tons) buried during the year.

$$Uoc = \frac{Aoc}{R} \quad [9-8]$$

where:

$$\begin{aligned} Uoc &= \text{Unit operating cost (US\$/t)} \\ Aoc &= \text{Annual operating cost (US\$/year)} \\ R &= \text{Annual productivity (t/year)} \end{aligned}$$

### 9.2.3 Total costs and tariffs

#### 9.4.3.1 Total costs

The total annual costs and total unit costs would be:

$$Tac = Cn + Aoc \quad [9-9]$$

$$Tuc = Cu + Uoc \quad [9-10]$$

where:

$Tac$  = Total annual cost (US\$/year)

$Tuc$  = Total unit cost (US\$/t)

$Cn$  = Annual capital costs, by equation [9-1], (US\$/year)

$Cu$  = Unit capital costs, by equation [9-2], (US\$/t)

$Aoc$  = Annual operating costs, by equation [9-7], (US\$/year)

$Uoc$  = Unit operating costs, by equation [9-8], (US\$/t)

#### 9.4.3.2 Tariffs

The cost structure makes it possible to calculate the real value of the different activities of the urban cleaning service. In all cases, a realistic estimate of the degree of payment arrears and the percentage of the population who do not pay for the cleaning service is necessary. The tariffs to be applied vary according to the policies established by the municipality. They may be:

##### ? *Total recovery without cross subsidization*

Here the families pay the real cost of the service, regardless of their economic situation. The average monthly tariff would be:

$$Trt = \frac{Tac}{12 Fcs} \quad [9-11]$$

where:

$Trt$  = Total recovery tariff, monthly per family (US\$/fam-month)

$Tac$  = Total annual cost of the service, equation [9-9], (US\$/year)

$Fcs$  = Number of families with service in the town or community

? ***Total recovery with crossed subsidy.***

In this case the families with the highest income pay more and those with the lowest income pay less, but in such a way that the total revenue from tariffs covers the operating and investment costs (“Tac”). One way to achieve this is by linking the collection of the tariff with another service (preferably electricity, which has a wider coverage). The percentage that would have to be applied on the cost of the other service is obtained thus:

$$Inc = \frac{Tac}{Ios} (fcc) (100) \quad [9-12]$$

where:

- Inc* = Increase in the household tariff (%)
- Tac* = Annual costs of the cleaning service (US\$/year)
- Ios* = Annual income from household collection of the other service
- Fcc* = Factor of the cost of tariff collection, that is, the costs that should be charged by the other service for additional personnel, etc.

The other services nearly always include cross-subsidization. The collection for the cleaning service from industries and special centers would have to be made separately, especially in the case of the big generators and consumers of the other services. For example, industries that consume a great deal of electricity and produce little garbage would be affected if public cleaning were charged as a percentage of electric power consumption.

? ***Recovery of operating costs***

Municipalities have often obtained support or a subsidy to cover initial investments. In this case, the annual costs of the service would be the operating costs; consequently, in the equations [9-11] and [9-12] “Tac” would be substituted by “Aoc”.

The average tariffs of the population can also be calculated according to their production:

$$Tmf = \frac{30 (ppci) (Tuc) (N)}{1000} \quad [9-13]$$

where:

$Tmf$	=	Monthly family tariff for the “i” social stratum (US\$/month-family)
$ppc_i$	=	Production per capita in the “i” socioeconomic stratum (kg/cap/day)
$Tuc$	=	Total unit cost (\$/t) (can be substituted by “Aoc” if the service is subsidized)
$N$	=	Average number of persons per family.
30, 1000	=	Dimensional parameters in (day/month) and in (kg/t), respectively.

#### 9.4.4 Tariff collection

As indicated, the tariffs per item of the urban cleaning service and, in particular, of the sanitary landfill should be collected together with those of another service. The cost of the tariff collection service, which is added to the tariff for the waste collection and for the sanitary landfill, is usually 10 to 20% of the total tariff. An advantage of collecting payment in this way is that if the user has his electricity or water cut off for lack of payment, he will be far more concerned than if he is suspended from the waste collection service.

**On the invoices in which several public services are charged, it will be obligatory to indicate separately the amount for each of the services.**

#### 9.4.5 Failure to comply with payment of the tariff

As already mentioned, if the collection of the cleaning item is included in the invoice of another public service, non-compliance by the consumer or user can give rise to a sanction, such as the suspension of other services; otherwise it will be almost impossible to use coercive collection methods for the payment of the cleaning service only. Sanctions for failure to pay should be combined with promotional actions for the users who pay punctually.



# **GLOSSARY**





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- Aerobic.*** Relative to life or processes that can only occur in the presence of oxygen.
- Anaerobic.*** The condition under which no free oxygen exists. The requirement of the absence of air or oxygen for the degradation of organic matter.
- Berm.*** Space between the toe of the slope and the external slope of the embankment.
- Biodegradable.*** A quality of organic matter meaning that it can be metabolized by biological means.
- Biogas.*** Mixture of gases of low molecular weight (methane, carbon dioxide, etc.), that are the product of an anaerobic decomposition of organic matter.
- Carbon dioxide.*** A colorless gas, heavier than air, the formula of which is  $\text{CO}_2$ . It is highly soluble in water, where it forms corrosive weak acid solutions. Not flammable due to its anaerobic metabolism.
- Cell.*** Geometric conformation given to the MSW and to the cover material duly compacted by means of mechanical equipment or by the workers in a sanitary landfill.
- Commercial solid waste.*** The waste generated in commercial establishments (warehouses, hotels, restaurants, cafeterias and markets).
- Compaction.*** The action of compressing any matter in order to reduce the empty spaces in it. The purpose of compaction in the sanitary landfill is to reduce the volume occupied by the MSW to obtain greater stability and a longer useful life.
- Contaminant.*** Any element, matter, substance, compound, as well as any kind of thermal energy, ionizing radiation, vibration, or noise which, on being incorporated into, or acting upon, any element of the physical environment, alters or modifies its state and composition, or which affects flora, fauna or human health. Soil, air and water should be understood as physical environment.
- Control.*** Surveillance and application of the measures necessary for compliance with established regulations.
- Control building.*** The construction located at the main entrance to the sanitary landfill that serves as gatehouse and as a place to keep tools; it also houses the sanitary facilities.

**Cover material.** The surface layer of earth in each cell, the purpose of which is to isolate the waste from the external environment, control infiltration, and keep harmful fauna away.

**Cubature.** The determination of the volume of any material or space taking the cubic meter as a unit.

**Cut.** The action of lowering a material by mechanical or manual means, in this case the terrain where a sanitary landfill will be constructed.

**Degradable.** The quality certain substances or compounds have of gradually decomposing by physical, chemical or biological means.

**Density.** The mass or quantity of matter of MSW contained in a unit of volume.

**Design.** Drawing or outline of a work or figure. The term is applied to the basic project of the landfill.

**Domestic solid waste.** The waste that by its nature, composition, quantity, and volume is generated by activities carried out in homes or in any other establishment with similar characteristics.

**Drain.** A structure that serves to clear soils of excess moisture.

**Embankment.** The mass of earth that is used to fill a hole or that is raised to build a defense, a road or similar work.

**Environment.** The set of elements, either natural or man-made, that interact in a certain space and time.

**Environmental impact.** Modification of the environment caused by the action of man or of nature.

**Final disposal.** The definitive depositing of MSW at a site in appropriate conditions to prevent damage to the ecosystems.

**Flow.** Situation in which each particle of water moves in a direction parallel to that of any other.

**Garbage.** Garbage is understood to be all solid or semisolid waste (with the exception of human or animal excreta) that has no value either for those who produce it or for those who possess it. Included in the same definition are refuse, ashes,

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street sweepings, and wastes from industry, hospitals and markets, among others. It is a synonym for waste or solid waste.

**Generation or production.** The quantity of MSW originating from a source during a specific period.

**Gradient.** The slope of a terrain or any element, expressed as the ratio of the horizontal length to the vertical.

**Improvement.** Increase in quality.

**Industrial solid waste.** The waste generated by industrial activities, as a result of production processes.

**Institutional solid waste.** The waste generated in educational, governmental, military, penitentiary, and religious establishments; also in air, bus, river or maritime terminals, and in offices.

**Invoice for public services.** The bill that the municipality or provider of public services submits to the users for said services.

**Leachate.** The liquid produced mainly by rain filtering through the cover material and percolating through the layers of garbage, carrying significant concentrations of decomposing organic matter and other contaminants. Other factors that contribute to leachate generation are the moisture content typical of wastes, the water from decomposition, and the seepage of groundwater.

**Migration of biogas.** The movement of particles of biogas through and out of the sanitary landfill.

**Monitoring.** Sampling and a series of measurements to determine the changes in levels or concentrations of contaminants in a certain period and place. In a restricted sense, it is the periodic examination of levels of contamination in order to comply with standards or to evaluate the effectiveness of a control.

**Monitoring well.** The deep well made in a sanitary landfill to measure the quantity of biogas and the quality of the leachates generated there.

**Pathogenic solid waste.** Waste that because of its characteristics and composition could be a reservoir or vehicle of infection.

**Permeability.** The capacity of the soil to conduct or transport a liquid when it is in a gradient. It varies with the density of the soil, the degree of saturation, and the size of the particles.

**Precipitation.** Atmospheric water that falls to the ground in liquid or solid state (rain, snow or hail).

**Prevention.** Set of regulations and measures adopted in advance to prevent the deterioration of an element.

**Protection.** The group of policies and measures for preventing and controlling the deterioration of the environment as well as for improving it.

**Recovery.** The activity relating to obtaining secondary materials, by separation, unpacking, collecting or in any other way removing them from the rest of the MSW for the purpose of recycling them or reusing them.

**Recycling.** The process by which certain materials from the garbage are sorted, collected, classified, and stored in order to reincorporate them into the productive cycle as raw material.

**Reuse.** This is the return of a good or product to the economy to be used in the same way as before, with no change in its shape or nature.

**Runoff waters or runoff.** Water that does not penetrate the soil or that does so slowly and that runs on the surface of land after rain.

**Sanitation.** The control of all the factors of man's physical environment that have, or may have, a harmful effect on his physical development, health and survival.

**Separation of solid wastes.** The activity that facilitates the integrated management of the MSW, since it divides them into organic and inorganic, hazardous and non-hazardous.

**Slope.** The inclination of a dike, embankment or cut.

**Socioeconomic stratification.** The classification of the residential buildings in the jurisdiction of a municipality pursuant to factors and procedures determined by law.

**Subscriber.** The person or legal entity with whom a contract to receive a public service has been entered into.

**Subsidy.** The difference between what is paid for a good or service and its cost when this cost is greater than the payment received for it.

**Terraces.** The shaping of very steep slopes for the purpose of creating horizontal lots.

**Treatment.** The process of physical, chemical or biological transformation of the MSW to obtain sanitary and/or economic benefits and to reduce or eradicate their harmful effects on man and on the environment.

**Useful life.** The period during which the sanitary landfill will be apt for receiving waste continuously.

**User.** The person or legal entity benefiting from the provision of a public service, whether as the owner of a building where it is provided or as the direct recipient of this service.

**Vectors.** The living beings that intervene in the transmission of diseases by carrying them from a sick person or a reservoir to a healthy person.

**Vermiculture.** The farming of worms of the species *Eisenia foétida*, used in the production of animal feed and of humus for improving soils.

**Water table.** The depth of the groundwater level. This level descends in dry periods and rises in rainy seasons.



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# **APPENDICES**



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## APPENDIX A

### Percolation test<sup>1</sup>

#### A.1 *Underground exploration*

Underground exploration will have to be made in a given area. In some cases, the observation of cuts in roads, river terraces or excavations for buildings will yield useful information.

Records of wells or of the drilling of wells can also be used to obtain information about the groundwater level and substratum conditions. In some areas, the substrata vary widely over short distances, and drilling will have to be carried out at the site where the system is to be located.

#### A.2 *Test procedure*

The greater the porosity of the soil, the greater will be the risk of infiltration of leachate and possible contamination of groundwater. Terrains formed by large pores are not effective for retaining small particles, and those formed by very small pores are practically impermeable. In order to determine the area necessary for treatment systems, the following test should be performed (Figure A.1).

- A 30-centimeter-square pit will be dug to a depth to which the excavation will be made for the system of ditches for leachate storage and drainage (approximately 60 centimeters).
- It will be filled with water to saturation point for one hour.
- The water will be allowed to drain completely and the pit will be filled again immediately with clean water to a height of 15 centimeters (6 inches). The time it takes for the water level to go down the first 2.5 centimeters (one inch) should be noted, for which a ruler will be necessary, or the average can be taken of the time it took to go down 15 centimeters.

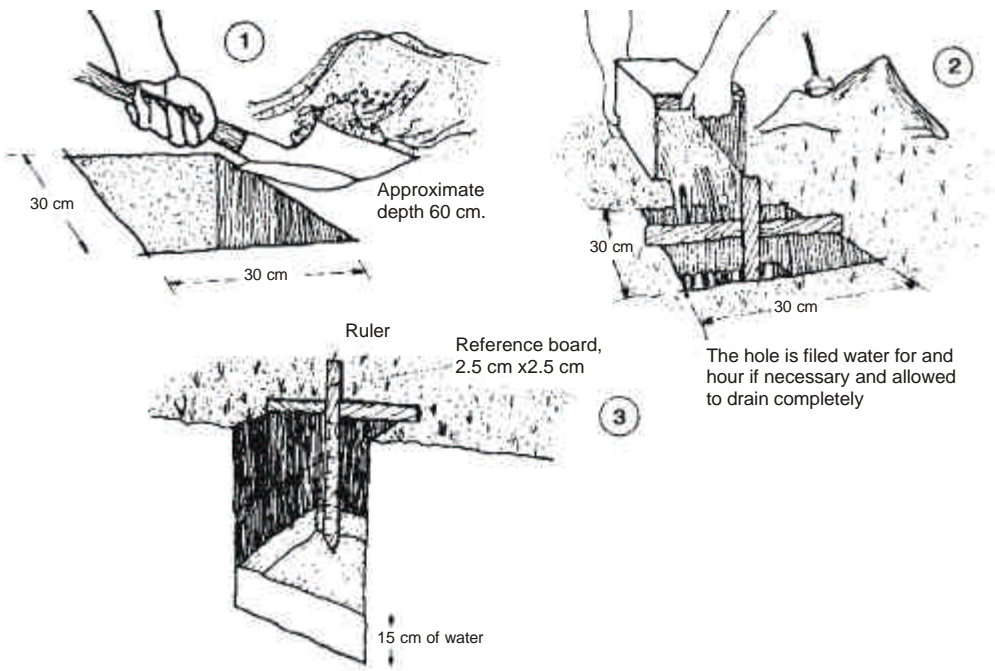
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<sup>1</sup> Taken and adapted from Empresas Públicas de Medellín. “Sistemas elementales para el manejo de aguas residuales, sector rural y semirural”. Revista, vol. 10, no. 2, April-June 1988. (“Elementary systems for waste management, in the rural and semi-rural sectors”).

For example, if during 30 minutes the water level descends 2 centimeters, the percolation rate will be  $30 \text{ min}/2 \text{ cm} = 15 \text{ min/cm} = 37.5 \text{ min}/2.5 \text{ cm}$ .

This rate of percolation is frequently expressed in min/2.5 cm because this is equivalent to min/inch and many tables and design standards are expressed in min/inch. It is clear, then, that a percolation rate in min/2.5 cm is equivalent to one in min/inch (table A.1).

- The rates of filtration found from the percolation test will be used to gauge the possibilities of the terrain in terms of suitability for solid waste disposal. After satisfactory tests, work will continue on the design of the sanitary landfill.



**Figure A.1**  
**Percolation test**

**Table A.1**  
**Porosity of the terrain according to the rates of filtration**

<b>Rate of filtration (time required for the water to descend 2.5 cm in minutes)</b>	<b>Porosity of the terrain Absorption of the terrain</b>	<b>Type of soil</b>
1 or less 2 3	Rapid absorption	Coarse sand or gravel
4 5	Medium absorption	Fine sand, predominantly sandy
10 15 30 <sup>a</sup>	Slow absorption	Predominantly clayey
45 50 60 <sup>b</sup> or more	Semi-permeable land  Impermeable terrain	  Compact clay

<sup>a</sup> If over 30 min/2.5 cm, the terrain is unsuitable for absorption wells.

<sup>b</sup> If the rate of percolation is greater than 60 min/2.5 cm, the terrain is unsuitable for treatment systems that use the soil as an absorption medium. The terrain is appropriate for the disposal of solid wastes in a sanitary landfill.





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## APPENDIX B

### Simplified soil analysis<sup>2</sup>

The observation and evaluation of the characteristics of the soil are very important when it is to be used as the base material for the disposal of solid wastes. It is possible that the soil characteristics may be such that they make the terrain unsuitable for the construction of a sanitary landfill, and costlier technical solutions will have to be resorted to.

The most important aspects for evaluating soil characteristics are discussed in the following pages.

#### ***B.1 Drillings***

The characteristics of a soil can be determined from drillings performed manually or with drilling equipment. From these drillings it will be possible to identify the different strata and soil types. It is better to carry out several drillings for a more representative picture of the soil. They should be deep enough to permit observation of the different strata.

The drillings should be done inside and outside the landfill supporting area; that is, the site where the trenches will be excavated or the embankments of waste and earth will be constructed, and the ditches for storage and evaporation of the leachates will be dug. Once the samples have been taken, the wells should be filled again with the same material, and the soil should be firmly compacted.

#### ***B.2 Soil texture***

Texture is perhaps the most important physical property of the soil because it has to do with the size, the distribution of size, and the continuity of the pores.

Soil texture is determined in the field by rubbing a moist sample of the soil between the thumb and forefinger. The texture of the soil depends on its composition. It can be:

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<sup>2</sup> Taken and adapted from Empresas Públicas de Medellín. "Sistemas elementales para el manejo de aguas residuales, sector rural y semirural". Revista, vol. 10, no. 2, April-June 1988.

<b>Texture</b>	<b>Principal component</b>
• Rough	Sands
• Silky	Silts and light clayey soils
• Sticky	Clays

After analyzing several samples, the experience gained in identifying the different textures makes laboratory analysis unnecessary, with the consequent significant savings in money and time, especially in isolated communities. To test the texture, a round soil sample 1 to 3 centimeters in diameter is moistened to a putty-like consistency.

If the sample is made too moist, it will become very sticky and difficult to work. Once the sample is moist, it should be crushed and squeezed between the fingers so that it starts to form a ribbon (figure B.1).

Table B.1 and Figure B.2 give a very general description of the appearance and feel of different soil textures.

Once the drilling is completed and the soil texture has been determined, the different layers should be marked and their thickness measured. With this information a chart can be made as shown in Table B.2.

### *B.3 Soil structure*

Soil structure has a significant influence in the control of leachates in the sanitary landfill. Soil structure refers mainly to the aggregation of particles of soil in groups that are separated by cracks or weak surfaces. The pores formed between the aggregates can modify the influence of the texture on the movement of water in the soil. In soils with many pores the movement of water is more rapid than in soils without structure, compact or massive. These latter have low percolation rates. Soil structure is summarized in Table B.3.

**Table B.1**  
**Texture properties of mineral soils**

Texture	Appearance and feel	
	Dry soil	Moist soil
Sandy	Breaks into single, rough-feeling grains. When pressed between the fingers, the mass disintegrates.	When squeezed between the fingers, it forms a ball that breaks when touched. Does not form a ribbon when rubbed between thumb and forefinger.
Predominantly sandy	Breaks easily. At first the texture appears soft, but when rubbed, a sandy feel predominates.	Forms a mass that permits careful manipulation without breaking. Does not form a ribbon when rubbed between thumb and forefinger.
Loamy (soils with characteristics of sand, silt, and clay)	The aggregates break under moderate pressure. The clods can be firm. When pulverized, this soil feels velvety, turning sandy when rubbed. When this soil is molded, it withstands careful manipulation	A mold or ball of loamy soil can be manipulated carefully without disintegrating. Has a slight tendency to form a ribbon when rubbed between thumb and forefinger. The rubbed surface is rough.
Predominantly silty	The aggregates are very firm, but can break under moderate pressure. The clods are firm to hard. When the soil is pulverized, it feels like flour.	A mold of predominantly silty soil can be manipulated without breaking. Has a tendency to form a ribbon when rubbed between thumb and forefinger. On being rubbed, the surface takes on a rippled appearance.
Predominantly clayey	Very firm and hard aggregates, very resistant to being broken by hand. When pulverized, the soil feels rough to the touch, due to the small aggregates that persist.	A mold of this soil withstands much manipulation without breaking. When rubbed between thumb and forefinger, it forms a ribbon the surface of which feels somewhat rough. The soil is plastic and sticky.
Clayey	Very hard aggregates, extremely hard molds or balls of the material, very resistant to being broken by hand. When pulverized, has an apparently sandy surface due to the persistence of small aggregates.	A mold or ball of this material withstands considerable manipulation without breaking. Forms a flexible ribbon when rubbed between thumb and forefinger and retains its plasticity when the stress is removed. The surface takes on a satiny, very soft feel when rubbed. Sticky when moist.

- Moistening the sample



- Molding



- Forming a ribbon



**Figure B.1**  
**Preparing the soil for a texture test**

*Dry sample*

*Moist sample*



*Sand*  
*Loose consistency*

*Does not form ribbon*



*Silts*  
*Moderately hard to hard consistency*

*Hardly forms ribbon*



*Clays*  
*Hard to very hard consistency*

*Forms ribbon*

**Figure B.2**  
**Determination of the texture of a soil by hand**  
**Appearance of textures**

**Table B.2**  
**Chart of the texture, structure and color of the soil from**  
**observations in a drilling**

Depth (m)	Texture	Structure	Color
0.0	Predominantly silty	Granular	Brown (coffee)
		Laminar	
1.0	Clayey-silty		From brown to yellowish- brown
2.0	Clayey	Blocky	
3.0	Clayey-sandy	Laminar	
4.0			

**Table B.3**  
**Degrees of soil structure**

Degree	Characteristics
Without structure (non-plastic if sand, plastic if massive)	No aggregation observed
Weak	Poorly formed and difficult to see. When manipulated, does not retain its shape.
Moderate	The aggregates are well-defined. Moderately durable when manipulated.
Strong	Well-defined aggregates. Very durable when manipulated.

#### ***B.4 Color of the soil***

Although the color is not an important property in itself, it is an indication of other, more important properties. For example, yellowish and reddish shades indicate that a soil has undergone severe weathering, since those colors are due to the iron oxides that have been formed. A dark brown color, between black and dark brown (coffee), often indicates the presence of organic matter. If during an excavation a

change of color is found, this is frequently an indication that a different soil stratum with different properties has been reached. Usually, color is the property of the soil most readily used for its identification by persons who do not have experience in soil mechanics. It is, indeed, a practical method for distinguishing soil characteristics. Soil colors are described visually with the help of color charts.

### **B.5 Hydraulic conductivity**

Hydraulic conductivity is the parameter used for determining how well a soil absorbs and percolates leachate. This capacity is measured with a percolation test (described in Appendix A). Although percolation tests have been widely criticized for their variability and lack of precision, in practice they are the only simple, inexpensive way to calculate hydraulic conductivity.

Table B.4 gives some very general figures and ranges for the permeability and percolation of soils.

**Table B.4**  
**Hydraulic characteristics of soil**

<b>Soil texture</b>	<b>Permeability cm/hour</b>	<b>Percolation min/2,5 cm</b>	<b>Observation</b>
Sand	> 15	< 10 <sup>a</sup>	Very permeable, unsuitable for constructing a sanitary landfill
Predominantly sandy Predominantly silty-porous Predominantly clayey-silty	0,5 to 15	10 to 45	Unsuitable for disposal of solid wastes
Clayey-compact Predominantly silty Predominantly clayey-silty	< 0,5	> 60	Impermeable, good for disposal of solid wastes

<sup>a</sup> Very permeable or permeable terrain is not suitable for the disposal of solid wastes.





## APPENDIX C

### Notions of scale drawings and topography

#### C.1 Scale drawings

A measurement ratio is used to draw real objects in their exact proportions at a reduced size to facilitate the work of the project engineers and construction engineers.

A scale drawing could be defined as the accurate representation of an object at a reduced size.

Different scales can be used to establish the proportional measurements for drawing the natural objects:

1:1	one to one	1:50	one to fifty
1:2	one to two	1:100	one to a hundred
1:5	one to five	1:200	one to two hundred
1:25	one to twenty-five	1:1000	one to a thousand

The first number is the unit, and the second one is the times by which it has been divided to give smaller proportional dimensions.

Examples:

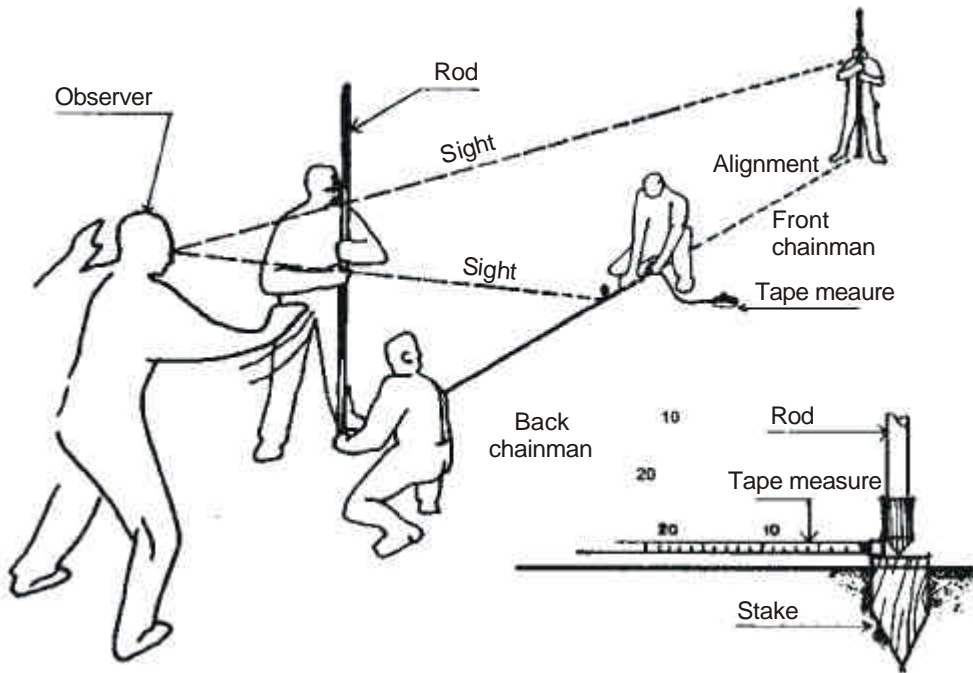
Scale	Each meter in the field equals	=	on the plan it is
1:20	1/20	0.05 m	5 cm
1:50	1/50	0.02 m	2 cm
1:100	1/100	0.01 m	1 cm

#### C.2 Tracing and measuring alignments<sup>3</sup>

- Stakes are placed at each end of the line to be measured, and on them are placed poles or rods.
- The observer stands behind one of the rods or poles, at a distance of approximately four meters, so that he sees the two poles merged into one.

<sup>3</sup> Mexico. Secretaría de Salubridad y Asistencia. Instructivo sanitario. Mexico, DF, Limusa, 1980.

- Then two “chainmen” will take the ends of the tape; the chainman at the back will place the beginning of the tape at the base of the first rod, and the front chainman will stretch the tape along the alignment fixed by the two poles, following the indications of the observer standing behind the first pole. The chainman at the front will take with him several wire hooks that he will place at the end of each tape so that, when making the next measurement, the back chainman will place there the end he is carrying (Figure C.1).



**Figure C.1**  
**Alignment**

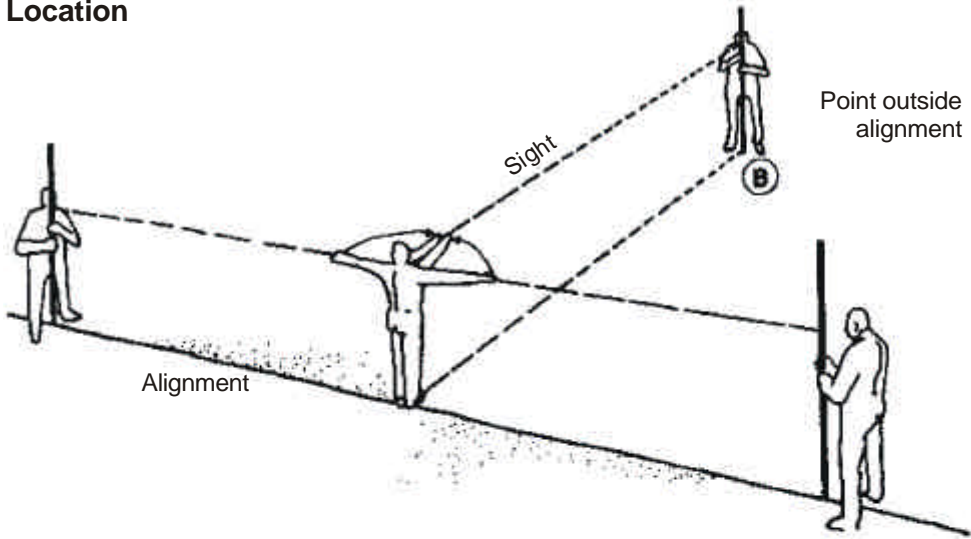
This operation is repeated as many times as necessary until the far end is reached.

### **C.3** *Tracing a perpendicular line from a point outside the alignment*<sup>4</sup>

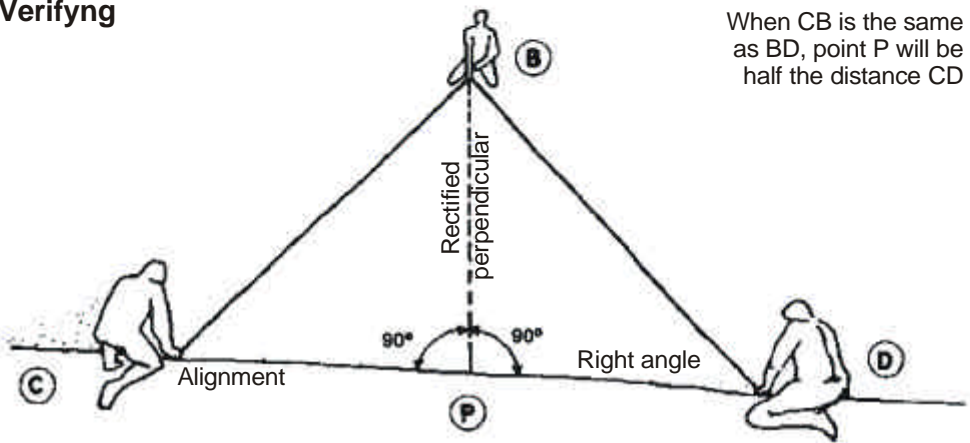
A person is placed on the alignment, facing the point where it is wished to trace the perpendicular, with both his arms extended, pointing towards each end of the

<sup>4</sup> Mexico. Secretaría de Salubridad y Asistencia. Instructivo sanitario. Mexico, DF, Limusa, 1980.

**Location**



**Verifying**



**Figure C.2**  
**Tracing a perpendicular**

alignment. Then he closes his arms and extends them straight forward. The desired point should be in the direction in which his arms are now pointing.

If a goniometer is available (Figure C.2), the observation is simply made through the slots.

**C.4** *Calculation of areas*<sup>5</sup>

The area of any figure can be calculated using:

- Field notes
- The plan drawn

*C.4.1 Areas deduced from field notes*

- *Using a tape measure*

Using a tape measure, the area is subdivided into triangles. The three sides of each triangle are measured and the area of each one is found using the equation:

$$\text{Area} = [s(s - a)(s - b)(s - c)]^{1/2}$$

Where:

s = semi-perimeter; that is:

$$s = \frac{a + b + c}{2}$$

a, b, c = sides of triangle

***Example 1:***

Figure C.3 shows a simple measurement with tape measure, partly composed of triangle PQR, whose sides measure:

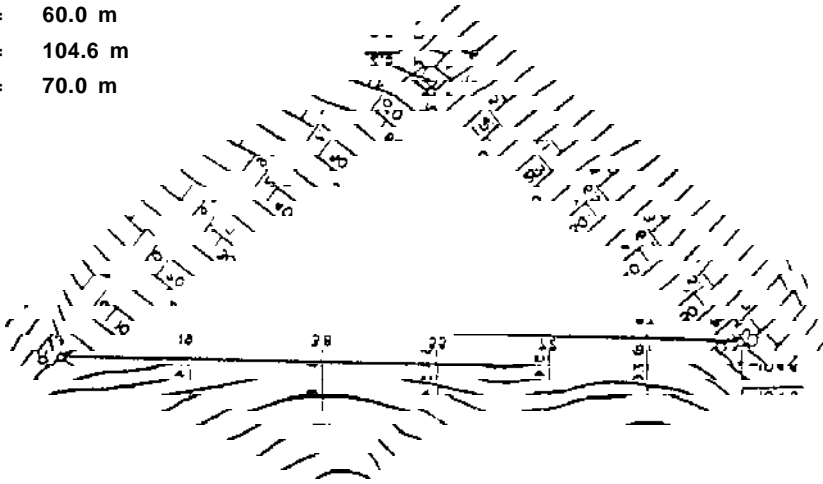
$$\begin{aligned} \text{PQ} &= 60.0 \text{ m} \\ \text{QR} &= 104.6 \text{ m} \\ \text{RP} &= 70.0 \text{ m} \end{aligned}$$

The area of PQR is found thus:

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<sup>5</sup> Adapted from: Irving, William. Topografía. Mexico, DF, McGraw Hill, 1975. Chapter 15.

- PQ = 60.0 m
- QR = 104.6 m
- RP = 70.0 m



**Figure C.3**  
**Measuring a terrain with a tape measure**

a. In triangle PQR:

PQ	=	r	=	60.0 m
QR	=	p	=	104.6 m
RP	=	q	=	70.0 m
				234.6 m

Perimeter of PQR = 234.6 m

hence, the semi-perimeter  $s = 117.3$  m

b.

$s - r$	=	57.3
$s - p$	=	12.7
$s - q$	=	47.3

Checking = 117.3 =  $s$

c. Area of triangle  $PQR = \sqrt{s(s-r)(s-p)(s-q)}$

$$= \sqrt{117.3 \times 57.3 \times 12.7 \times 47.3}$$

$$= 2,009.3 \text{ m}^2$$

The borders were found by diversions from the alignments.

In Figure C.3 the area between the line and the stream is made up of a series of triangles and trapeziums, whose areas can be calculated separately thus:

On the line RQ :

Area of triangle (1)	=	$\frac{1}{2} \times 19 \times 4$	=	38.0
Area of trapezium (2)	=	$\frac{1}{2} (4 + 8) \times (38 - 19)$	=	114.0
Area of trapezium (3)	=	$\frac{1}{2} (8 + 4.5) \times (55 - 38)$	=	106.25
Area of rectangle (4)	=	$4.5 \times (72 - 55)$	=	76.5
Area of trapezium (5)	=	$\frac{1}{2} (4.5 + 7) \times (87 - 72)$	=	86.25
Area of triangle (6)	=	$\frac{1}{2} (104.6 - 87) \times 7$	=	61.6
				482.6 m <sup>2</sup>

The area between the line PQ and the road is also made up of triangles and trapeziums. However, in this case, the diversions are at regular 10-meter intervals.

Calling each diversion Y, the area between any two consecutive diversions is calculated thus:

$$\text{Area between abscissa 20 and abscissa 30} = \frac{1}{2}(Y_{20} + Y_{30}) \times 10$$

Therefore:

$$\begin{aligned} \text{Total area} &= \frac{1}{2} (Y_0 + Y_{10}) \times 10 + \frac{1}{2} (Y_{10} + Y_{20}) \times 10 + \frac{1}{2} (Y_{20} + Y_{30}) \times 10 + \dots \\ &\quad + \frac{1}{2} (Y_{50} + Y_{60}) \times 10 \\ &= \frac{1}{2} \times 10 (Y_0 + Y_{10} + Y_{10} + Y_{20} + Y_{20} + Y_{30} + \dots + Y_{50} + Y_{60}) \\ &= \frac{1}{2} \times 10 (Y_0 + Y_{60} + 2Y_{10} + 2Y_{20} + 2Y_{30} + 2Y_{40} + 2Y_{50}) \\ &= 10 \left( \frac{Y_0 + Y_{60}}{2} + Y_{10} + Y_{20} + Y_{30} + Y_{40} + Y_{50} \right) \end{aligned}$$

This is the trapezium rule of the that is usually expressed thus:

Area = Width of the band x (average of the first and last diversions + the sum of the others)

d. In Figure C.3 the area is as follows:

$$\text{Area} = 10 \left( \frac{4 + 4}{2} + 4.5 + 5.1 + 6.5 + 6.3 + 5.1 \right) = 315.0 \text{ m}^2$$

The area can be found slightly more precisely with Simpson's rule, which may be expressed thus:

Area =  $\frac{1}{3}$  of the width of the bands (first + last diversions + double the sum of the odd diversions + four times the sum of the even diversions).

- Note :**
- (i) There has to be an odd number of diversions.
  - (ii) The diversions must occur at regular intervals.

Using Simpson's rule, the area between the line PQ and the road will be:

$$\begin{aligned}
 \text{Area} &= \frac{10}{3} [Y_o + Y_{60} + 2(Y_{20} + Y_{40}) + 4(Y_{10} + Y_{30} + Y_{50})] \\
 &= \frac{10}{3} [4 + 4 + 2(5.1 + 6.3) + 4(4.5 + 6.5 + 5.1)] \\
 &= \frac{10}{3} [8 + 2(11.4) + 4(16.1)] \\
 &= 317.3 \text{ m}^2
 \end{aligned}$$

- e. Finally, the area between the alignment RP and the woods is calculated. The area should be calculated with the trapezium rule, because there is an even number of diversions between R and P at regular intervals of 10 meters.

The area between abscissas 70 m and 74 m is calculated separately. The area between RP and the woods will be:

$$\begin{aligned}
 \text{Area} &= 10 \left( \frac{3 + 2.5}{2} + 8 + 10 + 9.5 + 9.2 + 7.1 + 4.5 \right) \\
 &= 510.5 + 5.0 \\
 &= 515.5 \text{ m}^2
 \end{aligned}$$

$$\begin{aligned}
 \text{Total area} &= 2.009.3 + 482.6 + 317.3 + 515.5 \\
 &= 3,324.7 \text{ m}^2
 \end{aligned}$$

**C.4.2 Calculation of the areas from the plan**

There are several methods for finding the area of a figure on a plan. The areas of contour lines can be measured with a planimeter, graphically, or using Simpson’s rule or the trapezium rule. These methods are described below, since they are easy to apply in these cases.

- *With a planimeter*

The area of any irregular figure can be found on a plan using the mechanical apparatus for measuring areas that is known as a planimeter.

- *With graph paper*

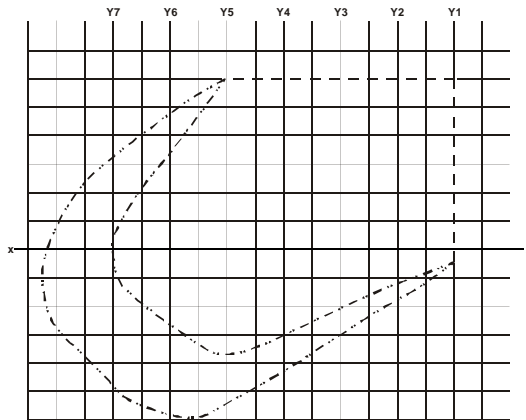
A sheet of transparent graph paper or millimetric paper is placed over the plan, and the squares are counted to deduce the area.

- *With Simpson’s rule or the trapezium rule*

The area is subdivided into a series of bands of the same width, the corresponding ordinates are measured, and one or the other rule is applied.

**Example 2:**

Figure C.4 shows an irregularly shaped area on a 1:500-scale plan. Calculate the area of the upper part of the landfill using the graph method, the Simpson’s rule and the trapezium rule.



**Figure C.4**  
**Calculation of area using the graph method**



**Solution***a. Graph method*

The transparent millimetric paper laid over the plan has squares measuring 5 millimeters per side and therefore each square represents an area on the ground of:

$$(5 \times 500) \text{ mm}^2 = 25 \times 0,25 \text{ m}^2 = 6.25 \text{ m}^2$$

$$\begin{aligned} \text{Area} &= (6.25 \times \text{number of squares}) \text{ m}^2 \\ &= 6.25 \times 89 \\ &= 556.25 \text{ m}^2 \end{aligned}$$

*b) Simpson's rule and the trapezium rule*

We take the straight line marked xx as the base line and every second vertical line of the graph paper as an ordinate Y – of which there will be seven in all ( $Y_1$  to  $Y_7$ ). The lengths of these ordinates, read on scale, are 16 m, 18.3 m, 20 m, 22.5 m, 23.8 m, 15.3 m and 0 m, and their separation is 5 m along the base line.

Using Simpson's rule:

$$\begin{aligned} \text{Area} &= \frac{5}{3} [16 + 0 + 2(20 + 23.8) + 4(18.3 + 22.5 + 15.3)] \\ &= 546.67 \text{ m}^2 \end{aligned}$$

Using the trapezium rule:

$$\text{Area} = 5 \left( \frac{16 + 0}{2} \right) + 18.3 + 20 + 22.5 + 23.8 + 15.3$$



## APPENDIX D

### Design of a manual sanitary landfill

#### Examples of calculations

##### *D.1 Example 1. Calculation of daily generation of waste*

Find the daily quantity of solid waste produced by the 40.000 inhabitants of a city whose production per capita is estimated at 0,5 kg/cap/day.

$$\begin{aligned} \text{SWd} &= \text{Pop} \times \text{ppc} \\ \text{SWd} &= 40,000 \times 0.5 = 20,000 \text{ kg/day} = 20 \text{ t/day} \end{aligned}$$

If the landfill is to operate six days a week, how much waste will have to be processed every working day?

$$\text{SWd working day} = \frac{7 \times 20}{6} = 23.3 \text{ t/day}$$

##### *D.2 Example 2. Calculation of required landfill volume*

The municipal administration of a city has a project to construct a sanitary landfill as a solution to the final disposal of its waste. The information needed prior to site selection is the amount of waste produced, required volume of the landfill, and the required area. The following information is available:

● Population in the urban area	30,000 inhabitants
● Population growth rate	2.6% per year
● Volume of solid waste collected in the collection vehicle	252 m <sup>3</sup> /week
● Coverage of the solid waste collection service	90%
● Density of the solid waste	
In the collection vehicle (not compacted)	300 kg/m <sup>3</sup>
Recently compacted at the manual sanitary landfill	450 kg/m <sup>3</sup>
Stabilized in the manual sanitary landfill	600 kg/m <sup>3</sup>

**Solution**

For easier handling of the information, Table D.1 will be used to summarize all the findings. The column numbers mentioned in this text therefore refer to Table D.1.

**D.2.1 Population projection**

Geometric growth will be adopted for the calculation of the population projection with a rate of 2.6% per year (equation 5-1), to estimate the needs of the next 10 years, column 1.

				<b>Year</b>
$P_f$	$= P_1 (1 + r)^n$	$=$		
$P_1$	$=$	$=$	30,000	1
$P_2$	$= 30,000 (1 + 0.026)^1$	$=$	30,800	2
$P_3$	$= 30,000 (1 + 0.026)^2$	$=$	31,580	3
....	$= \dots$	$=$	...	...
$P_{10}$	$= 30,000(1 + 0.026)^9$	$=$	37,796	10

**D.2.2 Production per capita**

Production per capita is estimated applying equation 5-2.

$$ppc = \frac{SW_{coll}/week}{Pop \times 7 \times Cov} = \frac{252m^3/week \times 300 \text{ kg/m}^3}{30,000 \text{ inhab} \times 7 \text{ days/week} \times 0.9}$$

$$ppc_1 = 0.4 \text{ kg/cap/day (first year)}$$

It is estimated that production per capita will rise 1% each year. So for the second and the third year it will be:

$$ppc_2 = ppc_1 + (1\%) = 0.4 \times (1.01)$$

$$ppc_2 = 0.404 \text{ kg/cap/day}$$

$$ppc_3 = ppc_2 + (1\%) = 0.404 \times (1.01)$$

$$ppc_3 = 0.408$$

and so on, to calculate the ppc for more years (column 2).

### D.2.3 Quantity of solid waste

The daily production is calculated using equation 5-4 (column 3).

$$s w_d = \text{Pop} \times \text{ppc} = 30,000 \times 0.4 \frac{\text{kg}}{\text{cap/day}}$$

$$s w_d = 12,000 \text{ kg/day}$$

The annual production is calculated multiplying the daily production of solid waste by the 365 days of the year (column 4).

$$SW_{\text{annual}} = \frac{12,000 \text{ kg}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} \times \frac{1 \text{ ton}}{1,000 \text{ kg}} = 4,380 \text{ t/year}$$

### D.2.4 Volume of solid waste

- Volume of annual waste, compacted (equation 5-6, column 8). With a density of 450 kg/m<sub>3</sub> due to the manual operation.

$$V_{\text{annual compacted}} = \frac{SW_{\text{annual}}}{W_{\text{msl}}} \times 365 = \frac{12,000 \text{ kg/day}}{450 \text{ kg/m}^3} \times 365 \text{ days/year} = 9,733 \text{ m}^3/\text{year}$$

- Volume of stabilized annual waste (equation 5-6, column 10). We take the estimated density of 600 kg/m<sub>3</sub> for the calculation of volume of the sanitary landfill.

$$V_{\text{annual stabilized}} = \frac{SW_{\text{annual}}}{W_{\text{msl}}} \times 365 = \frac{12,000 \text{ kg/day}}{600 \text{ kg/m}^3} \times 365 \text{ days/year} = 7,300 \text{ m}^3/\text{year}$$

- Volume of sanitary landfill stabilized. Comprising the stabilized solid waste and the cover material.
  - Cover material. The earth needed to cover the recently compacted waste, calculated as 20% of the volume of recently compacted waste (equation 5-7, column 9), thus:

$$cm = V_{\text{annual of compacted waste}} \times 0.2 = 7,300 \text{ m}^3/\text{year} \times 0.2 = 1,460 \text{ m}^3 \text{ of earth/year}$$

- **Volume of sanitary landfill (equation 5-8)**

$$V_{SL} = V_{\text{annual stabilized}} \times c.m = 7,300 \text{ m}^3/\text{year} + 1,947 = 9,247 \text{ m}^3/\text{year}$$

Note that column 10 presents the fill volume accumulated annually, which enables us to identify the useful life of the landfill by comparing it with the volumetric capacity of the site.

### **D.2.5 Calculation of the required area**

- **Calculation of the area to be filled.** Using equation 5-9, assuming an average depth of six meters, the area requirements will be:

In the first year

$$A_{SL} = \frac{V_{SL}}{h_{SL}} = \frac{9,247 \text{ m}^3/\text{year}}{6 \text{ m}} = 1,541 \text{ m}^2 \text{ (0.15 ha)}$$

In the third year

$$A_{SL} = \frac{28,763 \text{ m}^3}{6 \text{ m}} = 4,794 \text{ m}^2 \text{ (0.48 ha)}$$

In column 13 the area required for 2, 3, or more years will be seen, working from the data gathered in column 12.

- **Calculation of the total area.** An factor of increase (F) is used for the additional areas (column 14). In this case, a 30% increase is assumed. Thus:

For the first year

$$A_T = F \times A_{SL} = 1.30 \times 1,541 \text{ m}^2 = 2,003 \text{ m}^2 \text{ (0.2 ha)}^6$$

For three years of useful life:

$$A_T = 13 \times 4,794 \text{ m}^2 = 6,232 \text{ m}^2 \text{ (0.62 ha)}$$

---

<sup>6</sup> 1 ha = 10,000 m<sup>2</sup>.

**Table D.1**  
**Table to calculate the sanitary landfill volume and land required**

Year	Population (inhab.)	PPC kg/inhab-day	QUANTITY OF SOLID WASTE			VOLUME OF SOLID WASTES							REQUIRED AREA	
			Daily kg/day	Ton annual	Accu- mulated ton/year	Compacted			Stabilized Annual <sup>3</sup>	Sanitary landfill		Sanitary landfill <sup>2</sup>	Total area m <sup>2</sup>	
						Daily m <sup>3</sup>	c.m.* m <sup>3</sup> /day	Annual m <sup>3</sup>		c.m.* m <sup>3</sup> /año	(SW+c.m.*) Annual			Accu- mulated <sup>3</sup>
1	30,000	0.4	12,000	4,380	4,380	6	7	8	9	10	11	12	13	14
2	30,780	0.404	12,435	4,539	8,919	28	6	10,086	2,017	7,565	9,582	18,829	31,381	40,795
3	31,580	0.408	12,886	4,703	13,622	29	6	10,452	2,090	7,839	9,929	28,758	47,930	62,309
4	32,401	0.412	13,353	4,874	18,496	30	6	10,831	2,166	8,123	10,289	39,047	65,079	84,603
5	33,244	0.416	13,837	5,051	23,547	31	6	11,224	2,245	8,418	10,663	49,710	82,850	107,705
6	34,108	0.420	14,339	5,234	28,781	32	6	11,631	2,326	8,723	11,049	60,759	101,265	131,645
7	34,995	0.425	14,859	5,424	34,204	33	7	12,052	2,410	9,039	11,450	72,209	120,348	156,453
8	35,905	0.429	15,398	5,620	39,824	34	7	12,489	2,498	9,367	11,865	84,074	140,123	182,160
9	36,838	0.433	15,956	5,824	45,649	35	7	12,942	2,588	9,707	12,295	96,369	160,615	208,800
10	37,796	0.437	16,535	6,035	51,684	37	7	13,412	2,682	10,059	12,741	109,110	181,850	236,405

(6) Solid wastes produced during a week enter the SL in the «x» days of collection (7 days/x working days)

(7 and 9) Cover material

(11) Sanitary landfill volume = stabilized solid wastes + soil (20 a 25%).

(13)  $A_{SL} = V_{SL}/h$  ( $A_{SL}$  = Area to be filled)

(14)  $A_T = F \times A_{SL}$  F (Factor per additional area)

Area/inhab..... (m<sup>2</sup>/inhab.) current

\* c.m. = cover material

Waste density:

Loose <sup>3</sup>

Compacted <sup>3</sup>

Stabilized - 500 - 600 kg/m<sup>3</sup>

**D.3 Example 3. Calculation of the volume of a trench**

A municipality has a flat piece of land on which to construct a manual sanitary landfill using the trench method. To open the trenches, a backhoe will be rented which has a productivity of 14 m<sup>3</sup>/hour of cut.

- Find the volume of a trench and its dimensions for a duration of 60 days.
- For how many days should the machinery be rented?

**Basic information**

Population to be served	30,000 inhabitants
ppc	0.4 kg/cap/day
Coverage of waste collection service	90% of the population

**Solution**

- *Quantity of solid waste produced*

$$SW_p = \text{Pop} \times \text{ppc} = 30,000 \text{ inhab} \times \frac{0.4 \text{ kg}}{\text{cap/day}} = 12,000 \frac{\text{kg}}{\text{day}}$$

- *Quantity of solid waste collected*

$$SW_{\text{coll}} = SW_p \times \text{Cov} = 12,000 \frac{\text{kg}}{\text{day}} \times 0.90 = 10,800 \frac{\text{kg}}{\text{day}}$$

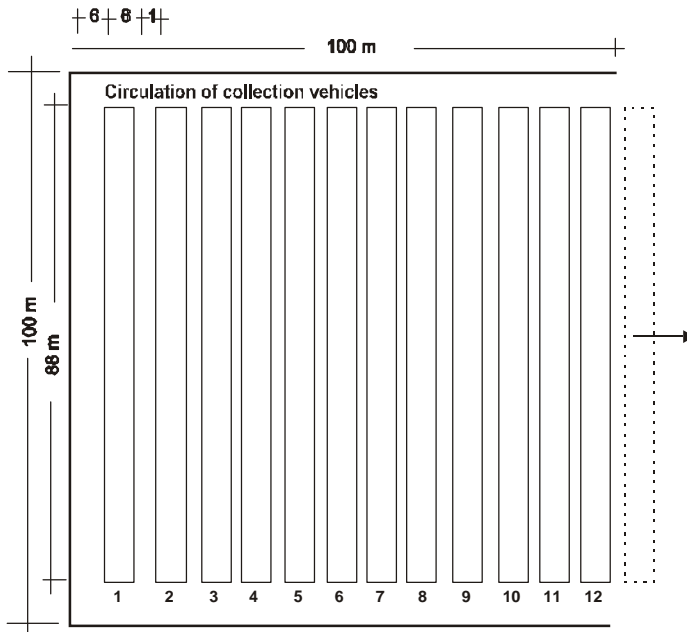
- *Volume of the trench*

If the cover material is estimated at 20%, the useful life at 60 days, and density at 500 kg/m<sup>3</sup>, then:

$$V_z = \frac{t \times SW_{\text{coll}} \times c.m.}{SW_{\text{msl}}} = \frac{60 \text{ days} \times 10,800 \text{ kg/day} \times 1.2}{500 \text{ kg/day}} = 1,555 \text{ m}^3$$

That is, to deposit the solid waste of one day, it will be necessary to excavate 1,555/60 = 26 m<sup>3</sup>





**Figure D.1**  
**Trench layout and distribution in the site**

- *Trench dimensions*

$$\begin{aligned}
 h_z &= \text{depth} &= & 3 \text{ m} \\
 w &= \text{width} &= & 6 \text{ m} \\
 l &= \text{length} &= & ?
 \end{aligned}$$

Therefore:

$$\begin{aligned}
 h_z &= 3 \text{ m} \\
 w &= 6 \text{ m} \\
 l &= 86 \text{ m}
 \end{aligned}$$

- *Machinery time*

$$t_{\text{exc}} = \frac{V_z}{R \times J} = \frac{1,555 \text{ m}^3}{14 \text{ m}^3/\text{hour} \times 8 \text{ hours/day}} = 13.9 = 14 \text{ days}$$

This means that to make the trench completely ready, fourteen days will be needed to excavate it. However, it should be noted that at least five days before the trench is filled, the equipment should be brought to the site to open a new one. Good

scheduling of the use of the machinery must be maintained, to ensure that the waste is disposed of without delay.

**D.4 Example 4. Calculation of the useful life of a trench landfill**

The site is relatively flat and has an area of 2.3 hectares. We need to find out how long the sanitary landfill will last if trenches like those calculated above are excavated, 86 meters long.

**Solution**

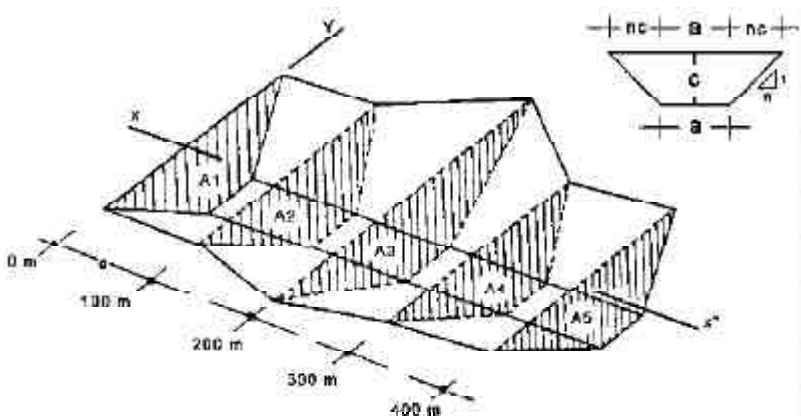
After reserving 0.3 hectares for complementary works, 2 hectares remains to be filled. Each trench has a one-meter separation from the next one: So,

Since each trench occupies 6 meters, plus a meter of separation—that is, a total of 7 meters—the number of trenches in one hectare will be:

$$\text{Number of trenches} = 100/7 = 14.2 \text{ or } 14$$

If each trench has a useful life of two months, the 14 trenches will last 2.4 years. The site should measure 2.5 hectares if it is to have the required useful life of five years.

The trench method can be combined with the area method to make full use of the land; that is, the sanitary landfill is raised some meters above the original ground level by constructing embankments of waste and earth, making use of the surplus earth from the excavation (80% in this example).



**Figure D.2**  
**Layout in a stretch of abandoned highway**

**Volume of an area method sanitary landfill**

**D.5 Example 5. Calculation of volume using Simpson’s rule**

Let us assume that there is a manual sanitary landfill project in a stretch of abandoned highway, with cuts similar to those shown in the figure. We will also assume that levels have been taken on transverse axes every 100 meters, with an average height of 8 meters.

The landfill will have a width of 6 meters at the bottom, a variable gradient in each stretch, and the following:

<b>Abscissa (m)</b>	<b>0</b>	<b>100</b>	<b>200</b>	<b>300</b>	<b>400</b>
Cross section (m <sup>2</sup> )	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>	A <sub>5</sub>
Gradient (n)	1:2	1:1	1:3	1:1	1:2
Average height at axis	8 m				

The largest base of the trapezium will be:

$$\begin{aligned} \text{Width of landfill surface} &= (w + nc + nc) \text{ meters} \\ \text{in each abscissa (w = 6)} &= [ 6 + 2 (nc) ] \text{ meters} \end{aligned}$$

Therefore, the area of the section in each abscissa (trapezium) will be:

$$= \frac{[ 6 + 2 (nc) ] + 6}{2} \times c = (6 + nc) \times c$$

Area at	0	=	(6 + 2 x 8) x 8	=	176 m <sup>2</sup>	A <sub>1</sub>
	100	=	(6 + 1 x 8) x 8	=	112 m <sup>2</sup>	A <sub>2</sub>
	200	=	(6 + 3 x 8) x 8	=	240 m <sup>2</sup>	A <sub>3</sub>
	300	=	(6 + 1 x 8) x 8	=	112 m <sup>2</sup>	A <sub>4</sub>
	400	=	(6 + 2 x 8) x 8	=	176 m <sup>2</sup>	A <sub>5</sub>

Applying Simpson’s rule (equation 5-17):

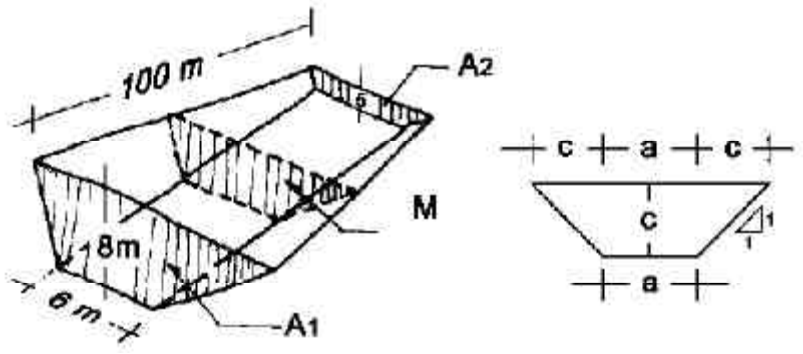
$$\text{Volume} = \frac{100}{3} [ 176 + 176 + 2 (240) + 4 (112 + 112) ] = 57,600 \text{ m}^3$$

**D.6 Example 6. Calculation of volume using the prismoid rule**

The Figure shows a manual sanitary landfill project in a large ditch, of which the following data are known:

- i. length of ditch 100 m
- ii. width of lower base 6 m
- iii. initial depth 8 m
- iv. final depth 5 m
- v. slopes 1:1

Calculate the volume of the landfill using the prismoidal formula:



**Figure D.3**  
**Sanitary landfill in a large ditch**

**Solution**

i. Section A<sub>1</sub>:

width of the base = 6m  
 total width = (6 + 2c) m  
 depth at axis c = 8m

Therefore, total width = (6 + 16) m = 22 m

ii. Section A<sub>2</sub>:

width of the base = 6m  
 total width = (6 + 2c)  
 depth of axis c = 5m

$$\text{Therefore, total width} = (6 + 10) \text{ m} = 16 \text{ m}$$

iii. Mid-Section  $M$ :

$$\begin{aligned} \text{width of the base} &= 6 \text{ m} \\ \text{total width} &= (6 + 2c) \text{ m} \\ \text{depth of axis } c &= \text{average depth in } A_1 \text{ and } A_2 \\ &= \frac{1}{2} (8 + 5) \text{ m} \\ &= 6.5 \text{ m} \end{aligned}$$

$$\text{Therefore, total width} = 6 + 13 \text{ m} = 19 \text{ m (average of the widths in } A_1 \text{ and } A_2)$$

iv. Area of the sections and trapeziums

$$\begin{aligned} A_1 &= \frac{1}{2} (6 + 22) \times 8 = 112 \text{ m}^2 \\ A_2 &= \frac{1}{2} (6 + 16) \times 5 = 55 \text{ m}^2 \\ M &= \frac{1}{2} (6 + 19) \times 6.5 = 81.25 \text{ m}^2 \end{aligned}$$

$$\text{v. Volume} = \frac{100}{6} [112 + 55 + 4(81.25)] = 8,200 \text{ m}^3$$

### D.7 Example 7. Volume from the extreme areas

Using the same data provided for the previous example, we have:

$$V = \frac{A_1 + A_2 \times d}{2} \text{ (m}^3\text{)}$$

$$\begin{aligned} A_1 &= 112 \text{ m}^2 \\ A_2 &= 55 \text{ m}^2 \\ d &= 100 \text{ m} \end{aligned}$$

Hence, the volume will be:

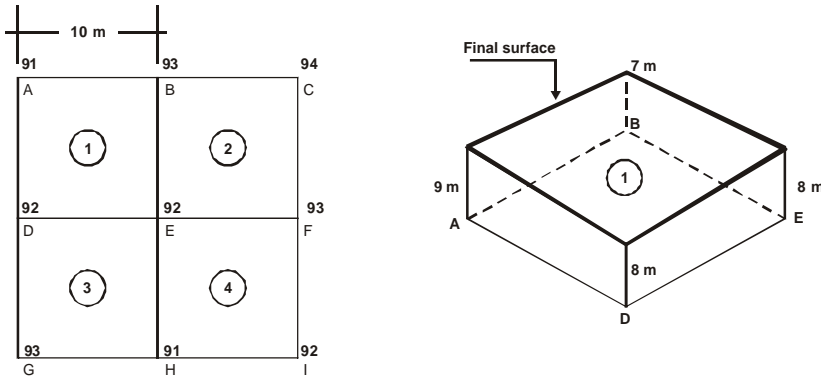
$$\text{Volume} = \frac{(112 + 55)}{2} \times 100 \text{ (m}^3\text{)} = 8,350 \text{ m}^3$$

Note that the result is approximate.

**D.8 Example 8. Volume calculated from a grid**

The Figure shows a small part of a grid. The area should be filled to the elevation of 100.0 meters to obtain the final surface. The slopes will be considered vertical.

The solid with its base in each square of the grid is a truncated vertical prism. That is, a prism whose bases are not parallel.



**Figure D.4**  
**Embankment in the form of a truncated vertical prism**

Volume of each prism = average height x area of the base

The average height of each truncated prism below the elevation 100.0 m is:

- prism 1 =  $(9 + 7 + 8 + 8) / 4 = 8 \text{ m}$
- prism 2 =  $(7 + 6 + 8 + 7) / 4 = 7 \text{ m}$
- prism 3 =  $(8 + 8 + 7 + 9) / 4 = 8 \text{ m}$
- prism 4 =  $(8 + 7 + 9 + 8) / 4 = 8 \text{ m}$

Area of the base of each truncated prism =  $10 \times 10 = 100 \text{ m}^2$

Therefore :

- Volume of 1 =  $100 \times 8 = 800 \text{ m}^3$
- 2 =  $100 \times 7 = 700 \text{ m}^3$
- 3 =  $100 \times 8 = 800 \text{ m}^3$
- 4 =  $100 \times 8 = 800 \text{ m}^3$
- Total available volume =  $3,100 \text{ m}^3$

The volume can also be found as follows:

$$\text{Volume} = \text{average height of the landfill} \times \text{total area}$$

The average height of the landfill is the average of the average heights of the prisms and not the mean of the heights at the bench marks.

$$\begin{aligned} \text{Average height of the landfill} &= (8 + 7 + 8 + 8) / 4 = 7.75 \text{ m} \\ \text{Total area} &= 20 \times 20 = 400 \text{ m}^2 \end{aligned}$$

where:

$$\text{Total volume} = 7.75 \times 400 = 3,100 \text{ m}^3$$

Point of the grid	Height to project level	Number of times used	Product
A	9	1	9
B	7	2	14
C	6	1	6
D	8	2	16
E	8	4	32
F	7	2	14
G	7	1	7
H	9	2	18
I	8	1	8
	<b>Addition</b>	<b>16</b>	<b>124</b>

Observing this process in detail, we see that level A was used only once to find the average height of the landfill, level B twice, and E four times in all. Consequently, the average height and the volume can be found in the simplest way tabulating the operations as in the previous Table.

The heights at the bench marks are tabulated in column 2 and the number of times used are tabulated in column 3; column 4 lists the products of the numbers of columns 2 and 3; the mean height is found dividing the sum of column 4 by that of column 3.

$$\begin{aligned} \text{Mean height of the landfill} &= 124 / 16 \text{ m} \\ &= 7.75 \text{ m as before} \end{aligned}$$

**D.9 Example 9. Volume found from contour lines**

The procedure consists of determining the existing capacity of the site, between the horizontal planes of the waste banks that can be built on the terrain, for which it is necessary to calculate the horizontal areas, obtain the average of the sum of the areas, and multiply them by the difference of height between the horizontal planes.

Therefore, the volume of the landfill is found by the equation:

$$V = \frac{1}{2} (A_0 + A_1) h + \frac{1}{2} (A_1 + A_2) h + \dots + \frac{1}{2} (A_{n-1} + A_n) h$$

$$V = \left\{ \frac{(A_0 + A_n)}{2} + A_1 + A_2 + \dots + A_{n-1} \right\} h$$

**Procedure:**

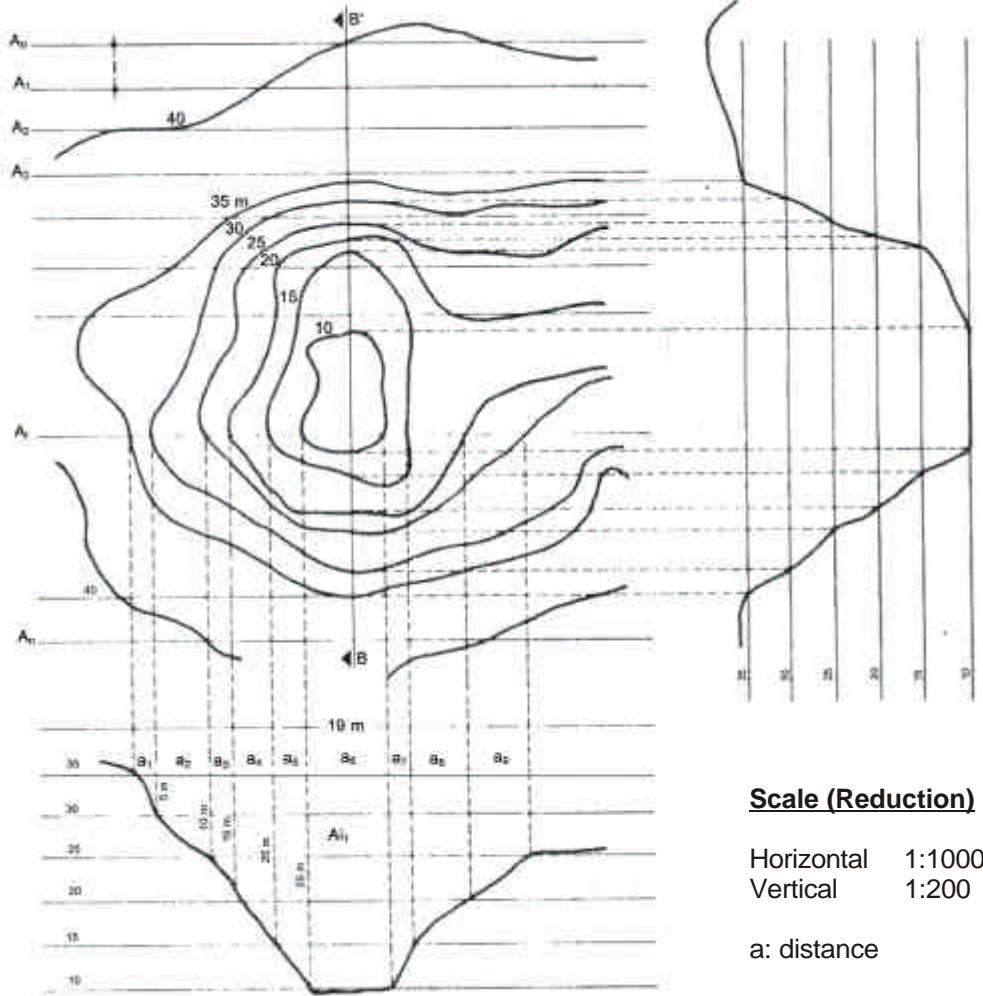
1. A plan of the site is drawn using a scale of 1:250, 1:500 or 1:1.000, depending on the size of the site, with the contour lines of each meter.
2. The topography of the site is drawn, after the initial preparation and the final topography of the sanitary landfill, making sure of the gradient of the surface (2 to 3%) to facilitate rainwater drainage.
3. A horizontal axis is traced at the appropriate point and then the terrain is cut with the horizontal planes  $A_0, A_1, A_2, A_3, \dots$  and  $A_n$ , with a height (h) between them. The recommended distance between the horizontal planes is 3, 5, 10 or 15 m, depending on the size of the site.
4. Areas  $A_0, A_1, A_2, A_3, \dots$  and  $A_n$ , are calculated, using the initial and final topography maps and the maps showing the advance of the landfill stages.
5. The volumetric capacity of the site is calculated, using equations 5-19, 5-20, 5-21 or 5-22, taking the areas calculated in point 4.

**D.10 Example 10. Calculation and design of the daily cell**

For the same population of 30,000 inhabitants, with a production of 12 t/day and a 90% coverage of the waste collection service, calculate and design the daily cell in the manual sanitary landfill, assuming that this operates six days a week.



**Original topography of the terrain**



Section Ai

$$A_{i_1} = \frac{1}{2}(0 + 5)a_1 + \frac{1}{2}(5 + 10)a_2 + \frac{1}{2}(10 + 15)a_3 + \frac{1}{2}(15 + 20)a_4$$

**Figure D.5**

**Plan and profiles of the terrain and landfill for calculation of the volume from the contour lines or horizontal planes**

**Solution**

- A. The amount of waste produced, which will go to the sanitary landfill is calculated using equation 5-31.

$$SW_{sl} = SW_p \times \frac{7}{x} = 12,000 \text{ kg/day} \times \frac{7}{6} = 14,000 \text{ kg/working day}$$

However, as we know, only 90% of the solid waste actually reaches the landfill.

So:

$$SW_{sl} = 14,000 \frac{\text{kg}}{\text{working day}} \times 0.90 = 12,600 \frac{\text{kg}}{\text{working day}}$$

- B. The volume of the daily cell is found with equation 5-32, bearing in mind that the cover material is 20% of the volume of the recently compacted waste, whose density in this case is estimated to be 450 kg/m<sup>3</sup>.

$$V_c = \frac{SW_{sl}}{D_{rsm}} \times c.m = \frac{12,600 \text{ kg/day}}{450 \text{ kg/day}} \times 1.20 = 33.6 \text{ m}^3/\text{working day}$$

- C. The dimensions of the cell are found in the example by fixing the height of the cell at one meter. So, the area will be equal to:

$$Ac = \frac{V_c}{hc} = \frac{33.6 \text{ m}^3}{1 \text{ m}} = 33.6 \text{ m}^2/\text{working day}$$

The length or advance of the cell will be subject to the normal variations in entry of waste, while the width, in this case, can be kept at 3 meters, which is a suitable width to enable the vehicle to discharge the waste:

$$l = \frac{Ac}{w} = \frac{33.6 \text{ m}^2}{3\text{m}} = 11.2 \text{ m/day}$$

Therefore:

$$l = 11.2 \text{ m}, a = 3 \text{ m}, hc = 1.0 \text{ m}$$

A square section can also be chosen:

$$l = 5.8 \text{ m}, a = 5.8 \text{ m}, hc = 1.0 \text{ m}$$

**D.11 Example 11. Calculation of labor**

For 12,600 kg/day, in each of the 6 days that the sanitary landfill is working, with a working day of 8 hours, considering 6 effective hours of work per day, how many workers will be required assuming the yields proposed in Chapter 5, point 5.12

**Solution**

Daily cell = Volume of solid waste + cover material (20%)

$$\text{Volume of SW} = \frac{12,600 \text{ kg/day}}{450 \text{ kg/m}^3} = 28 \text{ m}^3/\text{day}$$

$$\text{Volume of earth} = \frac{28 \text{ m}^3 \times 0.20}{\text{day}} = 5.6 \text{ m}^3/\text{day}$$

$$\text{Volume of daily cell} = (28 + 5.6) \text{ m}^3/\text{day} = 33.6 \text{ m}^3/\text{day} \text{ (hc} = 1.0 \text{ m)}$$

Now, according to the various operations and productivity figures we have:

<b>Operation</b>	<b>Productivity</b>	<b>Man/day</b>
Waste movement	$\frac{12.6 \text{ t/day}}{0.95 \text{ t/hr-man}} \times \frac{1}{6\text{hr}}$	2.21
Waste compaction	$\frac{33.6 \text{ m}^2}{20 \text{ m}^2/\text{hr-man}} \times \frac{1}{6\text{hr}}$	0.28
Earth movement	$\frac{5.6 \text{ m}^3}{0.37 \text{ m}^3/\text{hr-man}} \times \frac{1}{6\text{hr}}$	2.52
Cell compaction	$\frac{33.6\text{m}^2}{(20) \text{ m}^2/\text{hr-man}} \times \frac{1}{6\text{hr}}$	0.28
	<b>Total men</b>	<b>5.29</b>
<b>Sanitary landfill</b>	<b>12.6 t/day    5 men</b>	<b>2.5 t/man/day</b>

The above means that this sanitary landfill can be operated with a total of five workers (equal to a productivity of 2.5 t/man/day). As noted, the number of workers depends on how close the waste discharge point and the cover material discharge point are to the working face; it also depends on the climate (rainy season); and, naturally, on the quantity of waste received at the landfill.

It must not be forgotten that supervision plays a key role, both in the effective operation of the sanitary landfill and in the productivity of the workers.

### ***D.12 Example 12. Calculation of costs<sup>6</sup>***

We need to find out the investment, operating, and maintenance costs of a manual sanitary landfill, and also to establish the tariff for users. The sanitary landfill will receive 12 tons of waste daily, from Monday to Saturday, in a site estimated to have a useful life of 9 years. The following information is available for the analysis:

#### ***D.12.1 Investment cost (US\$)***

● Studies and designs (contract with consultant)	4,000
● Purchase of the land	8,000
● Site preparation and complementary works	7,000
Total investment costs	US\$ 19,000

#### ***D.12.2 Operating and maintenance expenses***

- ***Labor***

It has been determined that 4 workers are required, with a salary of US\$ 90.00/month each, and a benefits factor of 1.6; and 20% of the salary of a supervisor at US\$ 150/month.

- ***Other operating expenses***

Material (stone for drains, wire, tools) US\$ 300/year

Rental of track-type tractor (excavations and internal roads), 20 hours, twice a year at US\$20/hour.

### ***Solutions***

Solution to D.12.1 (Calculation of the unit cost of capital recovery [cu] for a period of 9 years, with interest of 20% p.a.):

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<sup>6</sup> Costs are calculated in US\$ dollars.

Using equations (9-4) and (9-5):

$$C_c = C_i (FRC) = C_t \frac{i}{1 - \frac{1}{(1+i)^9}}$$

$$C_c = 19,000 \times \frac{0.20}{1 - 1/(1.2)^9}$$

$$C_c = 19,000 \times 0.248079 = 4,713.5 \text{ US\$/year}$$

Annual productivity will be:

$$R = 313 \frac{\text{days}}{\text{year}} \times 12 \frac{\text{t}}{\text{day}} = 3,756 \frac{\text{t}}{\text{year}}$$

So:

$$(Cu) = \frac{\text{annual amount of capital recovery}}{\text{tons disposed of per year}} = \frac{4,713.5 \text{ US\$/year}}{3,756 \text{ t/year}} = 1.25 \text{ US\$/year}$$

Solution to D.12.2. Calculation of the unit cost of operating and maintenance (cuo):

#### D.12.2.1 Labor costs, equation (9-6)

● Direct	=	4 × 12 × 90 × 1.6	=	6,912 US\$/year
● Indirect	=	(1 × 12 × 150 × 1.6) × 0.2	=	576 US\$/year
Labor subtotal			=	<u>7,488 US\$/year</u>

#### D.12.2.2 Other operating expenses (Ch + Cm)

● Material and tools			=	310 US\$/year
● Equipment rental	=	(20 × 20) 2	=	800 US\$/year
Subtotal other operating expenses			=	<u>1,100 US\$/year</u>
Total operating and maintenance costs (Cao)			=	<u>8,588 US\$/year</u>

$$(Cuo) = \frac{\text{Total operating and maintenance costs}}{\text{Tons disposed of per year}} = \frac{8,588 \text{ US\$/year}}{3,756 \text{ t/year}} = 2.29 \text{ US\$/t}$$

The total unit cost will be:  $C_{ut} = 1.25 + 2.29 = \text{US\$ } 3.54 \text{ per ton.}$

### **D.12.3 Calculation of tariff**

#### *D.12.3.1 Tariff with recovery of capital, plus operating and maintenance costs*

Cost of providing the service, when a loan is received and the debt service has to be paid for out of tariff collection.

● Unit cost of recovery of capital per t	=	1.25 US\$/t
● Unit cost of operating and maintenance	=	2.29 US\$/t
Total to be recovered	=	<u>3.54 US\$/t</u>

$$\text{Amount of waste collected per month} = 12 \frac{\text{t}}{\text{day}} \times 26 \frac{\text{days}}{\text{month}} = 312 \frac{\text{t}}{\text{month}}$$

$$\text{Monthly cost for final disposal} = 312 \frac{\text{t}}{\text{month}} \times 3.54 \frac{\text{US\$}}{\text{t}} = 1,104.5 \frac{\text{US\$}}{\text{month}}$$

If every household (user) averages five members, who each produce 0.5 kg/day of waste, and bearing in mind that 12 t/day are collected 6 days a week, the daily production of waste is as follows:

$$\text{Daily production of waste} = 12,000 \times \frac{\text{kg}}{\text{day}} \times \frac{6}{7} = 10,250 \text{ kg/day}$$

Then, the number of users is:

$$\text{No. of users} = \frac{10,250 \text{ kg/day}}{0.5 \frac{\text{kg}}{\text{inhab/day}} \times 5 \frac{\text{inhab}}{\text{house}}} = 4,100 \text{ households (users)}$$

So:

$$\text{Monthly tariff per user} = \frac{1,104.5 \text{ US\$/month}}{4,100 \text{ users}} = 0.269 \text{ US\$/user/month}$$

#### *D.12.3.2 Tariff based on operating and maintenance costs*

The cost of providing the service, not including the debt service in the tariff (only the operating and maintenance costs are included):

$$\text{Unit cost of operating and maintenance} = 2.29 \text{ US\$/t}$$

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$$\text{Monthly cost of final disposal} = 312 \frac{\text{t}}{\text{month}} \times 2.29 \text{ US\$} = 714.5 \text{ US\$/month}$$

$$\text{Monthly tariff per user} = \frac{714.5 \text{ US\$/month}}{4,100 \text{ users}} = 0.174 \text{ US\$/user/month}$$

#### ***D.12.4 Municipality's annual budget allocation***

The municipal administration should allocate from its budget an annual sum of:

● Annual amount for debt repayment	=	4,713 US\$/year
● Operating and maintenance costs	=	<u>8,588 US\$/year</u>
Total annual allocation		13,301 US\$/year





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## APPENDIX E

### Problems resulting from inadequate solid waste management

#### Press Reports

Every now and again, the local and international press publish reports about diseases or epidemics, under surprising and disconcerting headlines. We tend to forget that non-sanitary conditions breed the vectors which cause these diseases. A selection of press articles are quoted below:

? *“El Heraldó”* – Mexico: “Garbage Piling Up In Residential Area”. Huixquilucan, Mexican State. In the middle of a residential area where a plot of land averages US\$350 per square meter, there is a huge garbage dump, with its foul odors, harmful vermin, and toxic fluids spilling out only a few meters away from the houses. Householders have to keep their doors and windows closed 24 hours a day. Saturday, September 27, 1997.

? *“El Heraldó”* – Mexico: “PAHO Decides To Intensify Its Fight Against Hantavirus”. Washington (Reuter). The Pan-American Health Organization has decided to intensify its fight against hantavirus (a non-curable disease), which is transmitted by mice and which has surfaced in Argentina, Chile and Paraguay [...]. “We are tremendously concerned”, stated Alex Figueroa, Chile’s Health Minister, where 27 persons have been infected by the virus, 14 of whom have died.

Since it first appeared in South America in 1992, there have been 122 cases of hantavirus pulmonary syndrome in Argentina, with a death toll of 48; and 35 cases in Paraguay, with 13 deaths, said PAHO. Brazil, Bolivia and Uruguay have reported sporadic cases. The hantavirus is carried in the rodents’ urine, saliva and excrement and it is transmitted to human beings through the air, normally in dust particles. Saturday, September 27, 1997.

? *“El Colombiano”* - Medellín, Colombia. “Mysterious Epidemics Sweep Through Latin America”. Miami. Editing Bureau (Reuter). Mosquitoes and rats have become the animals posing the greatest health hazards for people in Latin America, a wildlife-rich continent. This statement will seem strange to those who associate the region’s tropical jungles and savannas with pumas, tigers and poisonous snakes, but not to the hundreds of Latin Americans who suffer from inexplicable ailments involving hemorrhages and diarrhea, on a daily basis.

The latest outbreak of strange viral diseases of unknown origin occurred in Nicaragua, where an ailment produced by a yet to be identified virus (highly transmissible) has so far claimed the lives of at least 12 people. People affected by the disease show symptoms similar to those of hemorrhagic dengue: high fever, headaches, and muscle and joint pains, as well as rapid hemorrhaging [the disease is assumed to be transmitted by rodents].

*Three decades ago in Bolivia, it was also rats that carried the mortal Machupo virus, which left a death toll of approximately 100.*

? “Strange Outbreak In Peru”. In Peru, 137 persons in a remote village in northern Peru had to receive medical treatment this week, as they were affected by a strange epidemic outbreak. Bagua Province’s Director of the Territorial Health Unit reported that the disease, with symptoms including diarrhea, was located in the village of Tolopampa. “It is a rare epidemic outbreak. We fear that it may be a widespread viral infection [...], otherwise it could be para-typhoid”, explained the physician.

Last month, Venezuela and Colombia reported the outbreak of another strange hemorrhagic disease which produced high fever, and which turned out to be equine encephalitis, transmitted by the so-called “super-mosquito.” Dozens died from the disease, most of them children. Meanwhile, the *Aedes aegypti* mosquito continues to transmit dengue to thousands of people in countries near the Equator.

PAHO experts have linked the increase in unknown ailments with the invasion of jungle areas, dropping sanitation levels, and lower levels of investment in health in the region. October 29, 1995.

? “*El Herald*” - Mexico. “Two Cases Of Encephalitis Confirmed In Florida”. Melbourne (Reuter). Two cases of St. Louis encephalitis in human beings have been confirmed in the State of Florida, announced health officials in the United States [...]. Health authorities in the State of Florida, which obtains a large part of its revenues from tourism, issued a medical alert two months ago due to the threat of encephalitis, at a level similar to that of 1990. At that time, there were 226 persons infected, of whom 11 died. The alert was issued after it was discovered that several animals exposed to mosquitoes were affected by the disease [...]. Symptoms include fever, headache, tense neck muscles, dizziness, disorientation; and in the worst cases, death. Normally, this virus is first spotted in wild birds, and it is transmitted to human beings by mosquito bites. Saturday, September 27, 1997.

? “*El Tiempo*” - Bogota, Colombia. Geodatos. “What Is The Black Plague?” Plagues, responsible for more deaths during the past millennium than wars, continue to cause panic throughout the world. Thousands of people fled Surat, in India, when

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pneumonic plague affected this port city last September. Pneumonic plague, a highly contagious pulmonary infection, can kill a person within three days. Bubonic plague, slower and less mortal, attacks the body's lymphatic system. These two plagues devastated Europe in the 14<sup>th</sup> century.

The plague arrived in the Old World in 1347. In only five years it killed 25 million people. In those days it was known as the Black Death, because the victims' skin turned very dark. Originating in Asia, the Black Death killed 50 million Europeans up to 1771 [...]. Produced by the *Yersinia pestis* bacteria, the plague is frequently transmitted to human beings by fleas from infected rats.

In the United States an average of 15 cases occur every year, mostly in the Southwest, among the aboriginal inhabitants. But at least 50 people died during the last epidemic in India. [...] Originating in Yunnan, China, in 1855, the plague had reached Hong Kong by 1894. It took only six years for the plague to spread throughout the entire world, carried by merchant ships. National Geographic Society, 1994.

? “*El Colombiano*” - Medellín, Colombia: “The Rebellion Of The Rats”. Silent Invasion In Santafé de Bogotá. A small beast with dusky eyes, thick hair and very strong teeth is having the time of its life in Santafé de Bogotá. Rats are invading the city, especially places where the garbage collection service does not work as well as it should [...].

The proliferation of rats in certain areas of the city is mainly due to the fact that garbage is not picked up on time; and when it is, residents are not cooperating, because a few minutes later the streets are again filled with bags of trash. All of this is compounded by the sporadic garbage collectors who have turned empty lots and corners into garbage dumps, without the residents being able to do anything about it. [...] Situations involving rats attacking and disfiguring newborn babies are more common than many people may imagine. Between 60 and 100 attacks on human beings are reported each year only in the Capital District. Even so, the problem continues and is on the increase, because of the scanty cooperation of the public, who fail to understand that lack of proper hygiene and poor waste management are the main causes of the proliferation of large rodents in the city. Thursday, April 13, 1995.