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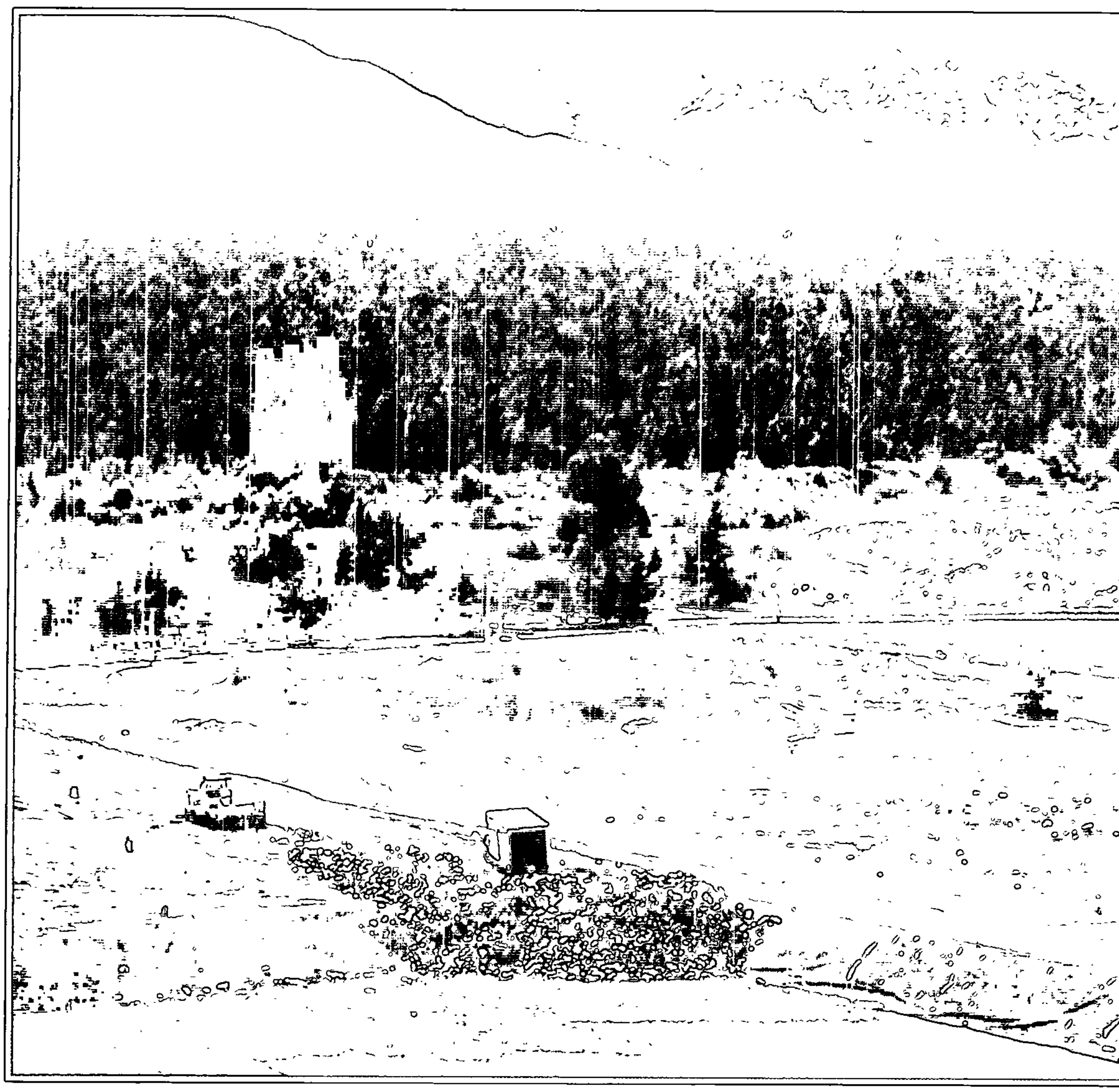
Solid Waste Landfills in Middle- and Lower-Income Countries

A Technical Guide to Planning, Design, and Operation



Philip Rushbrook
Michael Pugh

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Solid Waste Landfills in Middle- and Lower-Income Countries

A Technical Guide to Planning, Design, and Operation

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Foreword

Where will all the waste go? The conversion of the open dumps characteristic of many cities around the world to controlled and sanitary landfills is a critical step for protecting public health and the environment. As cities grow and produce more waste, and their waste collection systems become more efficient, open dumping becomes increasingly intolerable. This Guide serves as a tool for technical specialists in the solid waste management policy discourse to make gradual improvements in the short term by upgrading disposal of wastes at modest cost, while still providing acceptable levels of environmental protection. In the medium to long term, the target should be to achieve full sanitary landfilling together with comprehensive policies and programs to reduce waste generation and increase recycling when it is economically viable.

An informative summary aimed at nontechnical professionals, *Decision-Makers' Guide to Solid Waste Landfills,* was published in August, 1998. In this release of the full publication, the World Bank, the Swiss Agency for Development and Corporation (SDC), the World Health Organization Regional Office for Europe, and the Swiss Centre for Development Cooperation in Technology and Management (SKAT) hope to guide technical professionals with the planning, siting, design, and operational aspects of waste disposal. We must all cultivate the political will to stop open dumping, and promote an affordable and higher standard of waste disposal, while protecting human health and the environment.

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Abstract

The disposal of residual wastes to land is the ultimate end-point for any waste management system. It is a delusion to believe that the health and social problems posed by wastes come only from waste storage or collection activities. Unfortunately, open dumping is currently the world's most common disposal method. No amount of careful waste collection or treatment will reduce the hazards to health or the environment from disposal if the final resting place for waste is an uncontrolled dump. Development of disposal sites away from open dumping is a necessity.

To advance waste management systems in countries undergoing development, attention should also be paid to the improvement of waste landfills. Some aid assistance and loans for waste improvement schemes in the past have avoided doing this, perhaps in the belief that the prevailing disposal practices are too difficult to change. This Technical Guide seeks to demonstrate that, by encouraging small, continuous improvements in landfill siting, construction, and operation, the accumulative effect over time is the achievement of better operations. The Guide does not seek an immediate adoption of sanitary landfill practices. Instead, sanitary landfill is regarded as an eventual goal for which middle- and lower-income countries can plan during the course of several years.

Most existing guides on sanitary landfill focus on technologies and practices most suited to the conditions and regulations found in higher-income countries. These are often based on attaining extremely high levels of protection for aquifers, incorporating aesthetic concerns, high levels of leachate treatment, and controls to assure low noise and low gaseous emissions. The immediate adoption of some of these technologies and practices are beyond the technical and financial resources available in many middle- and lower-income countries.

The principle used in this Guide is "keep it simple." This axiom is considered at all stages in the development of a landfill (i.e., in its siting, design, operation, and aftercare). A common theme through the Guide is the emphasis on the practical ways landfills can evolve, as resources and confidence increase, from open dumps to "controlled" dumps to "engineered" landfills and perhaps, one day, to sanitary landfills. At each stage in this evolution, the level of environmental and health protection will also increase.

The Guide is targeted at senior waste management staff in local authorities in middle- and lower-income countries. Of necessity, it is written in a generalized way, in recognition that there are wide differences in climatic, cultural and political regimes around the world. These will have varying influences on the appropriateness of some of the approaches and techniques described for the better siting, design, operation, and aftercare of landfills.

Preface

Almost all human activities create waste in some form. Most individual items of waste, particularly wastes from homes and offices, are not themselves a direct threat for the public health. However, it is the way these wastes are (or are not) handled, stored, collected, and disposed that can pose risks to public health. It is the control of these risks that is addressed in most public health laws and regulations. Indeed, some of the earliest public health legislation related to the management of solid wastes in cities and the prohibition of their dumping in the streets.

In the nineteenth century, in those countries undergoing rapid industrialization, waste management was recognized for the first time as being a public health priority. Increased urbanization from industrial expansion meant that the improved removal of wastes from residential areas became a necessity. Left uncollected in residential areas, the considerable accumulations of putrescible material were easily accessible to disease-carrying rodents. Rats were implicated in the spread of bubonic plague in medieval times in Europe (and more recently in other parts of the world), as well as leptospirosis, salmonellosis, and lice-borne typhus. In lower-income countries, as well as poorer parts of middle-income nations, an estimated 30 to 50% of solid waste produced in urban areas is left uncollected. Some arboviral infections are associated with waste too, as well as habitat formation for breeding insects and mosquitoes. In tropical climates some flying insects are directly associated with the transmission of endemic diseases. Uncollected waste also blocks drainage channels and increases the health problems related to the ponding of stagnant water. In addition, accumulated wastes provide the ever-present hazard of physical injury to people coming into its close proximity, particularly children.

In general, clean and healthy living conditions in cities, towns, and villages cannot be achieved without reliable and regular waste collection and disposal. Much effort has been expended, rightly, in progressive cities and towns on improving urban collection services. It is now time to extend this attention to improve the standard of landfill disposal. Open dumping is neither safe nor hygienic. With more forethought it is no longer realistic to simply remove the health risks from waste from city streets and accumulate them in a nearby suburb or rural area.

Four categories of health effects can generally be identified from poorly designed and operated waste disposal sites:

1. Direct physical harm arising from collapses of unstable slopes of waste, explosions and fires, asphyxiation, and waste-related transport accidents or similar accidents.

2. Bacteriological and protozoal pathogens and similar infective agents arising from the biological contamination of wastes and their subsequent infective transmission to a host. Transmission routes via hand-to-mouth and hand-to-food-to-mouth are the most likely for waste workers and scavengers, while contamination of water supply or uptake through the food chain could affect the general public.
3. Similar transmission routes may apply to chemical contaminants from waste by affecting target organs or regulatory and control functions within the body. The chemical inducement of cancers is also a theoretical possibility.
4. The impact of chemical or microbiological contaminants on reproductive activities, notably stillbirth, low birth weights, or specific birth defects, are also known. There have also been incidents of health damage and death from exposure to dumped organic chemical compounds and, even, radioactive materials.

Disposal of residual wastes to land is inevitable. It is the ultimate end-point for any waste management system. However, waste landfills should be set up and operated properly, or municipal authorities and local populations will continue to live under the delusion that health problems from only waste collection have been addressed. Open dumping is the world's most common disposal method. No amount of careful collection or treating of waste will reduce the hazards to health and the environment from disposal if the final resting place for waste is an open dump. Open dumping is a generator of ill health.

This Technical Guide is one of a series of documents on solid waste management being produced as part of an informal inter-agency working group program on solid waste management in middle- and lower-income countries launched in April 1995.

It is the purpose of this Guide to explain to waste managers in middle- and lower-income countries that it is possible to develop a better disposal operation with the local resources available to them. Doing something better is better than doing nothing at all. Doing nothing will inevitable lead to avoidable health problems for someone. This cannot be right or honorable.

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Attention has also been given to incorporate relevant parts of a previous World Bank internal document on waste management in lower-income countries. Correspondingly, the work of Luis Diaz and his colleagues at CalRecovery Inc., California, USA is respectfully acknowledged.

Acknowledgments are also made to the external reviewers of the draft of this Guide listed below. Their insights and comments have enabled the Guide to be made relevant to more situations in middle- and lower - income countries.

Final acknowledgment is made to Binnie Black & Veatch for permitting the attachment of Mike Pugh to the WHO to assist in preparing extensive contributions to the waste and civil engineering aspects of the Guide.

In addition, a personal thanks is extended to René Kersauze, Catherine Mougenot, Gitte Andersen at the WHO Nancy Project Office, France, and Gabriela Boyer, World Bank, Washington DC, for their assistance in preparing the manuscript of the Guide and commenting on the contents of the draft versions.

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John Lucas and Howard Robinson, Aspinwall & Co, UK
Ole Hjelmar, VKI, Denmark

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Chapter 1 Introduction

1 INTRODUCTION

1.1 Purpose of the Technical Guide

Disposal of wastes to land is an inevitable component of every solid waste management system. No waste can be removed from its point of generation without there being a place for it to be taken. Even if facilities are provided for processing the waste, to recover materials or energy for instance, there will always be a need for land disposal of a residual proportion of the waste originally produced.

Providing adequate disposal facilities is a challenge faced by waste managers throughout the world. Often, the lack of such facilities is just one of a number of related deficiencies to be overcome in solid waste management, where problems in delivering a satisfactory service include

- inadequate residential waste storage facilities
- shortage of waste collection equipment (trucks and containers) caused by rapid increases in waste quantities
- inefficient waste collection and haulage due to inadequate forward planning and poor truck maintenance
- insufficient emphasis on waste minimization and realistic recycling opportunities
- unsanitary disposal practice with open dumping
- increasing difficulty in acquisition of land for disposal
- inadequate use and improper management of contractors or public sector labor
- inappropriate location of the landfill disposal site
- inadequate cost recovery
- inadequate forward (strategic) planning capability

The range of key issues that have to be tackled when seeking to improve solid waste management includes

- improving public health and environmental protection
- expansion of waste collection to areas not currently serviced and involvement of the private sector
- improvement of the organization, resources, and technical skills to achieve cost savings and efficiencies
- improvement of cost recovery from waste producers
- upgrading the standard of land disposal of waste to make landfills last longer, operate more safely, and reduce existing on-site problems

Each of these is crucial to the overall improvement of public health and the environment. However, ***this Guide is intended to respond chiefly to this last key issue,*** but inevitably will address related environmental, health, organizational, technical, and financial issues.

The other key issues are also being addressed in a series of guidance documents being prepared through an informal inter-agency working group program on solid waste management in middle- and lower-income countries. In addition, the World Health Organization Regional Office for

Europe has prepared a series of briefing papers on solid waste which provide further useful information on

- solid waste and health
- landfill
- waste incineration
- waste collection
- health care waste
- biological treatment of waste
- recycling
- waste minimization
- hazardous wastes

Many of the current problems with waste have come from increased urban population and waste generation, insufficient resources being available for solid waste management and the low professional status of waste management staff. Waste management is an important municipal service and requires high-caliber managers to make complex, authoritative decisions to ensure that a good quality, sustainable operation is achieved.

Most guides on sanitary landfilling are based on technologies and practices suited to the conditions and regulations found in high-income countries. These are often based on extremely high levels of protection for aquifers, incorporating aesthetics, low noise, low gaseous emissions, and high levels of leachate treatment. Many of these technologies and practices are beyond the financial resources of middle- and lower-income countries. This Guide presents practical approaches that should allow decisions to be taken on the siting, design, and operation of sanitary landfills which will provide more modest, but still acceptable levels of environmental protection at an affordable cost.

Protection of human health and the environment from risks and impacts associated with landfilled wastes may be achieved by a range of technological, operational and managerial interventions of varying complexity. However, it is generally the case, particularly in middle- and lower- income countries, that the higher the level of complexity of the intervention, the greater the risk of its failure. Priority should therefore be given to measures to overcome areas of concern which offer the lowest risk of failure.

The principle of "keep it simple" should be considered at all stages of development of a landfill (i.e., in its siting, design, operation, closure, and aftercare).

The desire to increase standards of landfilling is often in direct response to legally enforceable regulations on environmental standards. Many such standards are set at levels more appropriate to the aspirations of high-income countries, which are well above what might in the short term be affordable or even achievable elsewhere. There may be a case to give regulatory authorities the discretionary power to set a realistic program for staged achievement of compliance with the stringent environmental standards found in national regulations.

The Guide is targeted at senior waste management staff in local authorities in middle- and lower-income countries and, of necessity, is written in a generalized way, recognizing that there will be wide differences in climatic, cultural, and political regimes which will significantly affect the criteria for selection, design, and operation of landfills.

Waste managers will also require the committed support of their political leaders (Figure 1.1) if they are to achieve and maintain real improvements in the standard of the service they provide. Two key recommendations of the WHO in its document for elected members in local authorities (World Health Organization 1995) are the following:

1. Local authorities must make provision for future landfill needs by allocating suitable land in their long-term plans.

2. All landfill sites should be operated to a standard which protects human health and the environment.

It is intended that this Guide provides the essential information for waste management staff within middle- and lower-income countries to ensure that landfills are located, developed, and operated to the highest standards that are reasonably affordable and achievable. What is reasonably affordable and achievable will vary from place to place.

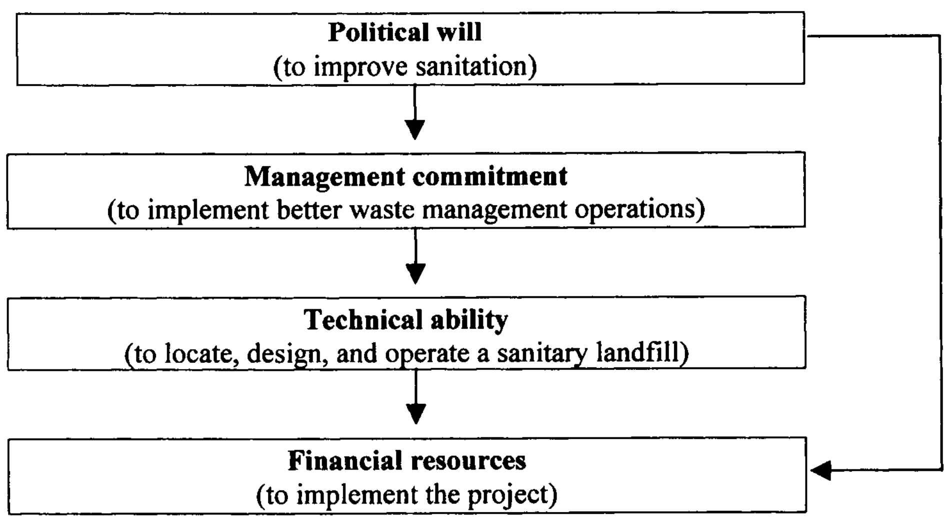


Figure 1.1 Route to successful project implementation

1.2 Problems with Inadequate Final Disposal

Inadequate final disposal (open dumping) of solid wastes thrives because of the mistaken belief that it is the cheapest disposal method (Figure 1.2). Deposition along roads and riverbanks or in abandoned quarries and "hoping" the waste will go away is both naive and dangerous. It is inevitable that the chemical and biological contaminants in wastes will find their way back to humans to affect health, quality of life, and working activities. Soluble and suspended contaminants in water leaking from the site (known as leachate) will enter surface watercourses and the groundwater. Contamination may then directly affect the drinking water supplies and/or the aquatic food chain. Grazing animals on dumps can pass on diseases via the terrestrial food chain, as well as by pests through infestation.

Figure 1.2 The disgrace of open dumping
(Source: IPT-CEMPRE 1995)

Those living on or near a dump are also at risk from direct hand-to-mouth transfer of contamination and from inhalation of volatile compounds and aerosols (Figure 1.3). Details on the common environmental health problems from poor waste management are presented in Cointreau-Levine et al. (1997), van Eerd (1996), van Eerd (1997), WHO (1995).

The general philosophy in the minds of some waste managers is that open dumping is acceptable because "we cannot do anything else." This philosophy is misplaced. The protection of the majority of citizens whose waste is collected and taken away should not be promoted at the expense of the health of a minority (i.e., those people who live near to the open dump).

A description of the sequence of the microbiological processes which occur in decomposing wastes is given in the Chapter 1 Appendix. The section also explains the cause of leachate and gas problems at open dumps.

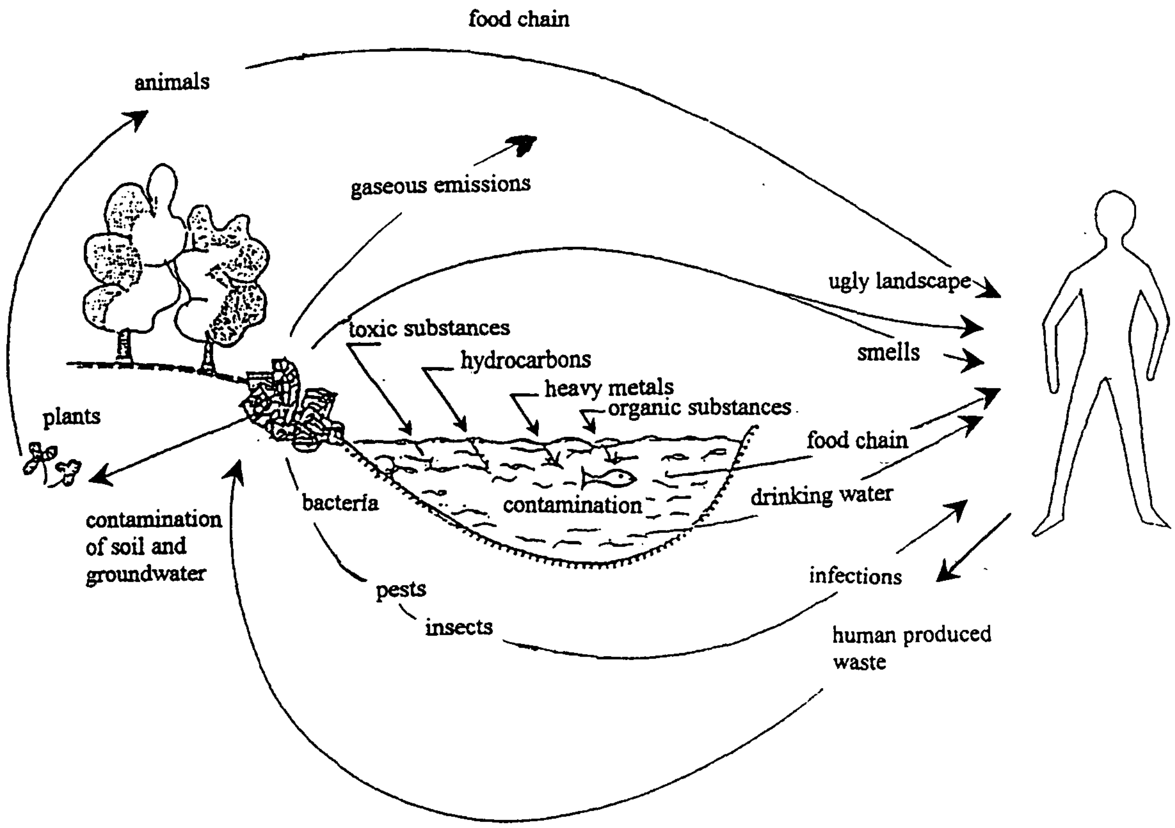


Figure 1.3 Routes of exposure to hazards caused by open dumping
(Source: Oeltzschner 1996)

The development of an upgraded landfill is neither too difficult nor too expensive, even for lower-income countries. An upgraded landfill has been estimated by one source as being three and eight times more expensive than open dumping, the variation attributed to the difference in costs between (1) making only modest improvements away from open dumping; and (2) making large changes and developing a sophisticated engineered landfill (Cointreau-Levine 1994, Cointreau-Levine et al. 1997).

The author above has calculated that an upgraded landfill in lower-income countries costs between US$3 and 10 per tonne (including both operating costs and debt servicing, at 1995 prices). It might therefore be inferred that the cost of operating an open dump in lower-income countries is about US$1 per tonne. However, the full cost of open dumping is probably much higher if the indirect costs of effects from environmental pollution, loss in land values, and treating people made sick by infections from waste are also taken into account. There are several ways to assess the economic cost of environmental problems, including poor waste management, as detailed in specialist publications such as McMaster (1991), Shin et al. (1997), and UNCHS (1993).

Often, significant improvements can be made by using, in a different way, the staff, equipment, and finance currently available. The improvement of landfill practice can be a step-by-step process. There is no one correct design towards a sanitary landfill. Designs vary widely depending on local conditions, but all should represent a progressive improvement over open dumping. No one should expect the immediate adoption and implementation of a sophisticated design and highly mechanized operation. What is important is to acknowledge those parts of the present landfilling operation that are unsanitary and look for ways to improve them. This Guide is intended to help landfill managers in this process.

1.3 Advantages of Better Landfilling

The commonly accepted, scientific or popular, definitions of "sanitary landfilling" require the isolation of the wastes from the environment until rendered innocuous through biological, chemical and physical degradation processes in the landfill. Primary differences between the landfill designs used are in the completeness of isolation and methods of construction. Isolation from the environment can range from

- no isolation (e.g., open dumping)
- partial isolation (some planned release to groundwater)
- containment (low permeability lining within the site and collection and removal of leachate)
- dry entombment (i.e., long-term storage in dry conditions, rather than disposal)

In high-income countries, the isolation prescribed in regulations is usually more complex than would be practical or affordable elsewhere, and in some cases the high degree of isolation may not even be technically proven as necessary to protect public health.

As a minimum, as outlined below, and as shown in the site layout in Figure 1.4, four basic conditions should be met by any site design and operation before it can be regarded as a better landfill:

1. *Full or partial hydrogeological isolation.* Preferably, a site should be located in or on low permeability geological strata to inhibit leachate migration off-site into an underlying aquifer. If this is not possible then additional materials should be brought to the site, to reduce the permeability at the base of the site. These will help control leachate movement from the waste into the groundwater and surrounding strata, and, if necessary, allow leachate to be collected for treatment.

2. *Formal engineering preparations.* A sanitary landfill should be constructed from prepared engineering designs developed from local site geological and hydrogeological investigations. Once constructed, a sanitary landfill has to be operated according to a "waste disposal plan" leading to a "final restoration plan."

3. *Permanent control.* Sufficient numbers of trained staff should be based at the landfill to supervise and direct all preparation, site construction, and waste emplacement activities, as well as the regular operation, maintenance, and monitoring of gas and leachate control systems.

4. *Planned waste emplacement and covering.* Waste should be spread in layers and, if necessary, compacted mechanically as part of the emplacement procedure, not dumped over a cliff-like working face. Where practicable the waste should be deposited in only a small working area and covered daily to render it less accessible to pests and vermin.

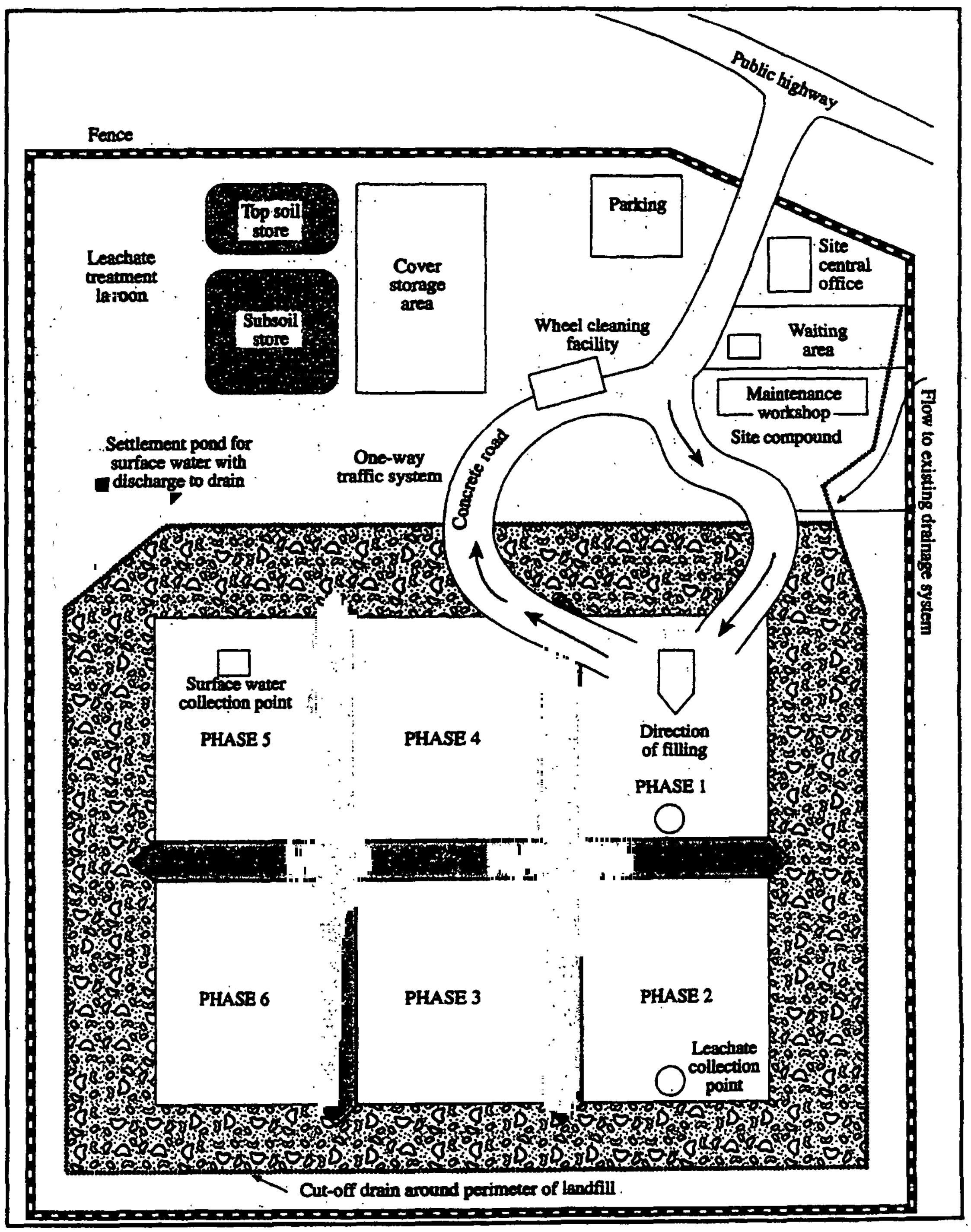


Figure 1.4 Typical operational layout for a sanitary landfill site
(Source: Department of the Environment 1986)

The techniques to develop away from open dumping towards sanitary landfills can be adapted to suit local conditions, materials, and technologies. The attainment of highly complex landfill designs and construction is probably not immediately possible in some middle- and lower- income countries. They may not even be necessary to achieve significant public health and environmental improvements. *The immediate goal should be to meet, to the best extent possible, the four stated basic conditions for better landfilling, with a longer-term goal to meet them eventually in full.* Small incremental improvements in landfill design and operation over several years are more likely to succeed than attempts to make a single, large leap in engineering expectations.

Clearly, large landfills will require more investment to improve their standard than will smaller sites. However, in the past, economies of scale have shown that the unit cost of these improvements (per tonne of waste landfilled or per head of population served) will decrease with increasing size of site.

Financial and other benefits will be gained by securing sites with long projected operating lifetimes (ten years or more), assuming that the high costs of acquisition and site preparation can be amortized over the lifetime of the site.

There is often a case for establishing large regional sites, where the cost of the longer travel distances is not too high. Such sites could serve two or more towns or cities, or even be shared by adjoining waste disposal authorities, to their mutual economic benefit.

One suggested pathway to upgrade, over time, the quality of municipal landfill sites (Rushbrook 1997) is outlined below and illustrated in Figure 1.5:

Stage 1: From open dumping to "controlled dumping." This involves reducing the working area of the site to a more manageable size (say, 2 ha for a modest sized city of 500,000 inhabitants); covering with soil, sand, or any other convenient material, any exposed wastes on unneeded areas of the site; stopping fires; and agreeing about rules of on-site work with scavengers if they cannot be removed completely.

None of these controlled dumping measures represent a major departure from the operational practices or resources used at an open dump. The advantage is that these operational improvements need little or no additional investment but begin the philosophy of introducing "control" and "isolation" into the waste disposal operation. Since this incremental step is relatively small, the risk of failure perceived by a landfill manager can, equally, be argued to be small.

Stage 2: From controlled dumping to "engineered landfill." This involves the gradual adoption of engineering techniques to control and avoid surface water entering the waste, extract and spread soils to cover wastes, remove leachate into lagoons, spread and compact waste in to smaller layers, prepare new parts of the landfill with excavation equipment, and improve the isolation of waste from the surrounding geology. A clear sign that a municipality is progressing through this stage successfully is the routine development of detailed designs prior to new landfills being developed, and the creation of disposal plans showing how a site will be filled with waste over its lifetime and how it will be finished off.

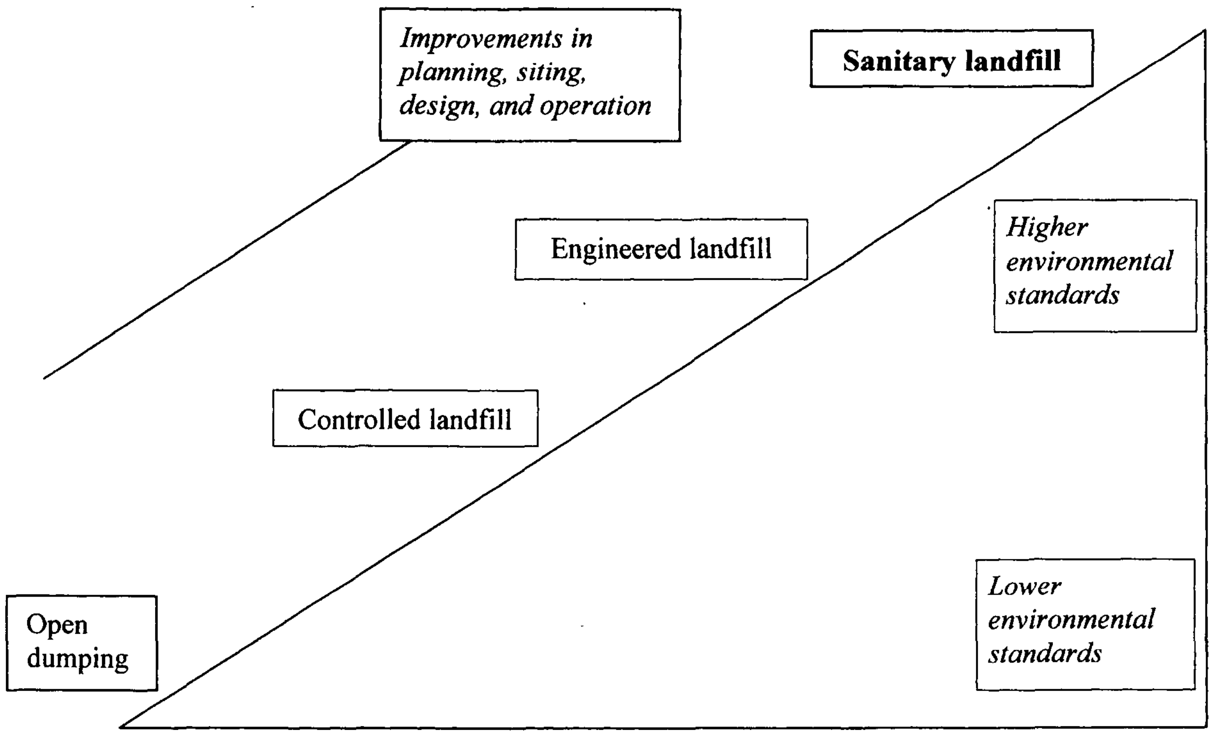


Figure 1.5 Evolutionary improvements in waste management

Stage 2 represents the longest period in the evolution towards sanitary landfill techniques. It encompasses the gradual accumulation of engineering expertise by those managers most local climate exists that encourages informed learning about waste engineering and gives waste managers an opportunity to try new things.

Stage 3: From engineered landfill to "sanitary landfill." It has to be recognized that some communities and countries will not achieve this stage of landfill development in the foreseeable future. The development to a truly sanitary landfill, as recognized in the higher-income countries, involves the continuing refinement and increasing complexity in the engineering design and construction techniques begun in the engineered landfill stage. In addition, sanitary landfills are more likely to have the pre-planned installation of landfill gas control or utilization measures, extensive environmental monitoring, a highly organized and trained work force, detailed record-keeping by the site office staff, and, where circumstances dictate, on-site leachate treatment to supplement a leachate collection system.

It is important to appreciate that the sustained adoption of sophisticated sanitary landfill can occur only where the local economy can afford the higher levels of operational expenditure necessary, where waste managers are given a professional status and authority commensurate with other engineering management roles, and where the advanced equipment and resources required to achieve and maintain high standards of operation are made available.

An overriding characteristic in communities operating sophisticated sanitary landfill is the ever-increasing social demand for higher environmental standards. Reflecting society's increasing intolerance with the *concept* of landfill, these standards have become increasingly divorced from the "pure" or simple protection of the public from credible health and environmental risks.

1.4 Format of the Guide

This Guide is presented in the format and style of a "user's" manual. A companion volume summarizing this Guide has been prepared for senior personnel. Recognizing that it is likely to be used by more than one individual or section within a municipality, the text is presented in discrete chapters, each dealing with a major topic related to landfilling. The format facilitates updating and copying for distribution.

The style of each chapter of the Guide has been standardized as far as possible to highlight the

- main points discussed
- key decisions to be taken
- general principles involved
- minimum standard of achievement which should be adopted
- desirable improvements to these minimum standards which will result in better management or greater environmental protection

For ease of reference, the expression "the municipality" is used throughout the Guide as meaning the department of the city, district, or regional authority responsible for waste disposal.

The Guide draws heavily from a wide range of published texts on sanitary landfilling, both in developed and developing countries. The prime sources used are listed in the Reference section and a separate Bibliography of further reading and information is also presented.

Most of the following, related aspects of sanitary landfilling are also mentioned, where relevant, in the chapters, but they are not topics specifically included in this Guide:

- waste management planning
- site permitting (licensing)
- waste treatment methods
- budgeting, cost control, and cost recovery

In addition, no specific reference is made to costs, since these will be nationally or locally determined by a country's economy. Rather, where appropriate, some guidance is given to the level of resources needed to develop and operate sanitary landfills. Further references, more specifically related to the financial aspects of cost control, budgeting, performance efficiencies, and charging and revenue collection are listed in the "Additional Reading" section at the rear of this Guide.

Appendix 1.A
Waste Degradation Sequence in Landfills

(Source: Rushbrook 1988)

As outlined below, and illustrated in Figure 1.6, all landfills have the potential, over time, to go through five distinct phases of waste degradation:

Phase I - Aerobic Decomposition

Organic wastes decompose in the presence of oxygen. Putrescible (vegetable and food wastes) materials degrade most readily, followed by paper, wood, natural textiles, and rubbers. This phase is characterized by rising carbon dioxide concentrations from aerobic respiration of microorganisms and rising waste temperatures, derived from accelerating exothermic microbial decomposition processes. Additionally, there are rising carboxylic acid (e.g., acetic acid, butyric acid) concentrations in leachates formed as products of incomplete metabolic degradation by bacteria. This phase lasts only a few days or weeks in well-run landfills. In poorly run landfills with a density of waste emplacement and no compaction this phase can predominate. In these circumstances the landfill will be characterized by high temperatures and high carboxylic acid concentrations in leachates. If released from the site these leachates could lead to surface and groundwater contamination. Landfills where only aerobic decomposition take place create a wholly unacceptable impact on the environment and are the most unacceptable type of landfill operation.

Phase II - Anaerobic, Acetogenic Decomposition

In most landfills, oxygen is rapidly depleted and the environmental conditions in the waste becomes more chemically reducing. Anaerobic bacterial systems take over. This second phase may last up to several months at well-run sites. During this period carbon dioxide concentrations rise to over 70% by volume and carboxylic acid concentrations also continue to increase. This phase is propagated by acid-forming and acetogenic bacteria whose metabolic conversion of cellulose produces carboxylic acids (predominantly acetic acid), carbon dioxide, and smaller quantities of hydrogen. Some landfills operate at this phase permanently. On the surface they may appear well run, but the waste degradation achieved can produce excessive quantities of high "strength"[1] leachate containing carboxylic acids. This is principally due to the establishment of insufficiently "reduced" chemical conditions in the landfill to enable strictly anaerobic methane-producing bacteria to thrive and utilize the carboxylic acids produced by the acetogenic bacteria.

The continued existence of acetogenic decomposition in a landfill generally indicates a need to improve the covering of wastes to seal them from the atmosphere.

[1] i.e., high "biological oxygen demand" leachates

Phase III - Anaerobic, Rising Methanogenic Decomposition

As oxygen depletion continues and the redox potential (Eh) of interstitial waters drops to below approximately -200mV, conditions become suitable for methanogenic activity to develop. Over the period of a few weeks methane concentrations begin to rise and carboxylic acids decline. This is due to the acetic acid in the leachates being utilized by the methanogens to produce methane, carbon dioxide, and water. Consequently, the environmental impact of any escaping leachate is substantially less than in Phases I and II, if the site is properly engineered.

In addition, landfill temperatures usually become stabilized in the mesophilic range (i.e., up to 40°C). The methane generated must be properly managed to avoid off-site migration, but good landfill design can achieve this.

Phase IV - Anaerobic, Stable Methanogenic Decomposition

This phase represents the most stable period in the decomposition of waste in controlled landfills. It is believed to persist for at least 15 to 20 years (although no one is quite sure) in temperate climatic areas and is characterized by methane and carbon dioxide concentrations of around 65 and 35% respectively. Lower carboxylic acid concentrations in leachates are observed, and there is a gradual depletion of the available cellulose substrate in the waste.

Phase V - Rising Aerobic Gaseous Composition

No one has yet studied waste decomposition in a landfill to completion. However, evidence from very old sites suggests that once the available cellulose is used up the methanogenic microbial activity reduces and methane and carbon dioxide concentrations gradually decline. It has been argued that, at some point in the future, oxygen levels will begin to rise. Eventually the remaining waste would be regarded as biologically "inert" and atmospheric gaseous conditions would become reestablished. This situation has not been demonstrated in the field.

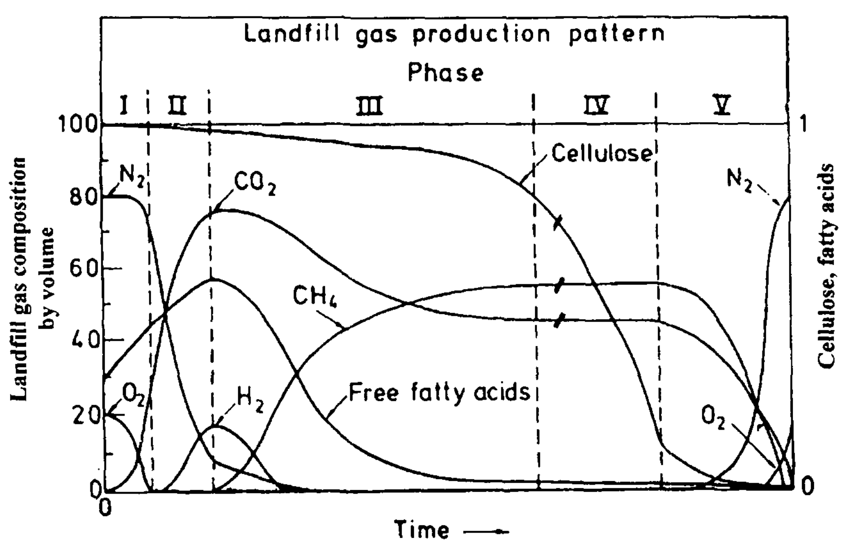


Figure 1.6 Landfill gas production pattern
(Source: Rovers et al. 1973)

Chapter 2 Waste Characteristics

2 WASTE CHARACTERISTICS

2.1 Main Points

In order to plan the development of waste management facilities, the waste manager needs information about the quantities and types of wastes that are generated within and around the municipality which may be included in the waste management system under the municipality's control.

Projected increases in quantities of each waste stream should also be estimated in order to plan for future provision of facilities. A knowledge of the composition of the waste stream is also necessary to judge whether landfilling is the best disposal option, or whether some form of the pre-treatment of a particular waste will be needed before it can be accepted in a municipal landfill.

Traditionally, municipal wastes have been classified into three general classes, residential, commercial, and industrial. Residential (also termed "domestic" or "household") solid waste consists of a wide variety of wastes produced by residents in houses and apartments. The fraction produced from the preparation and consumption of food is sometimes known as the putrescible (or food or compostable) component. The other major constituents of residential wastes, in addition to the putrescible component, are

- glass
- metal
- plastics
- waste paper and paper products
- rubber
- textiles
- cash, soil, and similar debris, including broken pottery and china
- bones
- leather and hide remnants

In all communities, people produce domestic wastes. At the most basic level this comprises putrescible food wastes, animal manure, ashes from fires, broken tools and utensils, and old clothing. In an agricultural community this waste is readily reabsorbed into the natural cycle. Domesticated animals consume the food remains and the other waste materials rapidly decompose. However, since the last century there has been an increase in the number of people living in towns. Urbanization and industrial development rapidly increased the range and diversity, as well as quantity, of wastes that require collection and disposal.

There are seven main sources of waste requiring management by a municipality. Inevitably, in those communities with only landfill disposal, all seven categories will need to be landfilled. An important step in understanding the characteristics of the waste produced in a town is to first identify the sources and to assess the range of compositions and quantities of each type produced.

The main factors which influence the composition and rate of production of solid waste include the following (WHO 1976):

- climate and seasonal variation
- finance available locally to municipalities and waste service operators
- economy of the region
- physical characteristics of the cities
- social and religious customs
- public health awareness
- quality of management and technical capacity
- environmental standards required to be achieved

Since each has a different potential effect on the type of wastes produced, the waste manager needs to understand the materials he or she will be handling and disposing.

Domestic (residential)

This category comprises wastes that are produced from household activities. These activities include food preparation, sweeping, cleaning, fuel burning, and garden wastes. They can also include old clothing, old furnishings, abandoned equipment, packaging, and newsprint. Where bucket latrines are used, these wastes will probably include faecal material. In lower-income countries this waste is dominated largely by food and ash wastes although plastic packaging is increasing, while in middle- and higher-income countries there is a larger proportion of paper, plastic, metal, glass, and discarded manufactured items.

Commercial waste

This category includes wastes from shops, offices, restaurants, hotels, and similar commercial establishments. The waste typically consists of packaging materials, office supplies, and food wastes and has a close similarity to some components of domestic waste. In lower-income countries food markets may contribute to a large proportion of this type of waste.

Institutional waste

This is waste produced in establishments such as government offices, schools, hospitals and other healthcare facilities, military bases, and religious buildings. The wastes generally include components similar to both domestic and commercial waste. However, generally there is a larger proportion of paper than food waste. Hospital wastes will inevitably include potentially hazardous, infectious, and pathological materials such as used bandages, sharp objects including syringes, needles, and items contaminated with body fluids including blood. It is important to separate the hazardous and non-hazardous fractions in healthcare waste to reduce the risk to health and pollution.

Street sweepings

This category of waste is almost always dominated by dust and soil together with varying amounts of paper, metal, and similar litter that is picked up off the streets. In some countries this may also include drain cleanings, varying amounts of household waste dumped at the side of the road, plant debris, and animal manure removed from the road.

Construction and demolition waste

The composition of this material depends largely on the type of building materials used in a particular town. However, it is inevitable that in some places construction waste cannot be recycled within the area of new construction and requires disposal. In the absence of any municipal land reclamation project which might benefit from receiving suitable construction and demolition waste, it is therefore common for this waste to be sent to the municipal landfill site since refusal to accept it may result in its indiscriminate dumping elsewhere. Construction and demolition waste can provide a valuable contribution to the requirements for cover material and temporary road construction on a landfill.

The main components of this type of waste are soil, stone, and brick, as well as varying quantities of wood, bricks, clay, reinforced concrete, and ceramic materials.

Sanitation waste (night soil)

In several lower-income countries no sewage networks exist within many towns to remove faeces and similar solid sanitation wastes. Specialized collectors of night soil often collect this waste separately from individual houses. This material can contaminate watercourses and become a source of infectious diseases if indiscriminately dumped. Consequently, in those cities where there are no sewage treatment facilities for night soil, it is common for this material to be used either for manure for agricultural crops or end up at the municipal landfill.

Industrial waste

The composition of industrial waste generated in a town is highly variable dependent upon the industrial practices undertaken. Much industrial waste is relatively similar to commercial and domestic wastes involving packaging, plastics, paper, and metallic items. However, a proportion of industrial waste arises from chemical operations and uses, and this is usually termed as "hazardous industrial waste" or "special waste." The disposal routes for hazardous and nonhazardous wastes are not necessarily the same, and careful attention has to be paid to learning more about the chemical composition of the waste produced by local industry. Where hazardous wastes are dumped either on land or into water in untreated form, they present a possible risk to waste workers, and to drinking water supplies. In many cases they can be disposed of to landfill, although for some wastes pre-treatment may be necessary to reduce their toxicity.

2.2 Key Decisions

Studies about the rates of generation and the composition of wastes around the world are contributing to a growing database of information that can be used by waste managers.

Table 2.1 shows the compositions of waste in a variety of cities representing high-, medium- and low-income countries. The percentages of each waste component may be taken as representative of the general differences in waste from cities in each of these three economic groups.

Type of Material	Higher Income			Middle Income						Lower Income				
	Brooklyn NY	London UK	Rome Italy	Singapore	Hong Kong	Medelin Colombia	Lagos Nigeria	Kano Nigeria	Manila Philippines	Jakarta Indonesia	Lahore Pakistan	Karachi Pakistan	Lucknow India	Calcutta India
Paper	35	37	18	43	32	22	14	17	17	2	4	1	2	3
Glass, ceramics	9	8	4	1	10	2	3	2	5	1	3	1	6	8
Metals	13	8	3	3	2	1	4	5	2	4	4	1	3	1
Plastics	10	2	4	6	6	5	-	4	4	3	2	-	4	1
Leather, rubber	-	-	-	-	-	-	-	-	2	-	7	1	-	-
Textiles	4	2	-	9	10	4	-	7	4	1	5	1	3	4
Wood, bones, straw	4	-	-	-	-	-	-	-	6	4	2	1	1	5
Non-food total	**74**	**57**	**29**	**63**	**60**	**34**	**21**	**35**	**40**	**15**	**27**	**4**	**18**	**22**
Food and putrescible	22	28	50	5	9	56	60	43	43	82	49	56	80	36
Miscellaneous inerts	4	15	21	32	31	10	19	22	17	3	24	40	2	42
Compostable total	**26**	**38**	**71**	**37**	**40**	**66**	**79**	**65**	**60**	**85**	**73**	**96**	**82**	**78**
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Note: The above values have been rounded to the nearest whole number, unless the amount was less than 1.0.

Table 2.1 Urban refuse composition data (in percentage by weight)
(Source: Cointreau 1982)

Table 2.2 provides an indication of the ranges of compositions and rates of generation for the three economic groups.

The key decision to be identified by a waste manager about local waste generation is therefore

Should a waste generation and composition survey be undertaken locally?

A locally conducted survey should address the following questions:

1. How much waste is being produced within the town and each district?
2. What is the general composition of the waste from residential areas?
3. What is the general composition of wastes, including hazardous wastes, from the other main sources of production?
4. How might the quantity or general composition of wastes change in the future?

Attention to the composition of wastes from residential areas and their future quantities and composition are essential only if treatment (e.g., composting or incineration) is being considered.

2.3 General Principles

2.3.1 Waste characteristics

A waste manager in a city must undertake a waste compositional study if any disposal option other than landfilling is to be considered, for example, recycling, composting, or incineration. Conducting a waste compositional study is not a technically difficult task, but does require organization. It involves the identification of one or more areas, statistically representative, within the city, and the sorting of a proportion of the waste collected in those areas into their individual components. Then, by a simple process of separating, weighing, and comparing against the total, the percentage ratio for each component can be calculated. It is this type of information that is expressed in Table 2.1.

As an integral part of a waste composition study, useful information can be gathered on the following parameters during the same sampling exercise. Knowledge of these waste characteristics is essential when considering the suitability of waste treatment processes, collection equipment changes, and recycling initiatives:

- *Moisture content* (i.e., the percentage of the weight of the wastes which is water). This can be determined by drying a known weight of waste and measuring the weight change. This weight loss is then expressed as a percentage.

- *Biodegradability.* The proportion of biodegradable material in the total waste is a good measure of the amount of bio-degradation possible and hence, the potential leachate or gas production that the waste is likely to produce once put into a landfill. The simplest way to estimate this is to dry the waste at a temperature high enough to burn off the organic component of the waste after having removed non-biodegradable organic materials such as plastic and rubber.

- *Calorific value.* This is the amount of heat energy that can be produced if all of the combustible components of the waste are burned. A waste sample is usually burned at a high enough temperature to combust both the biodegradable and non-biodegradable organic materials such as vegetable matter, plastic, wood, paper, and rubber. This information is essential when considering waste combustion technologies to determine whether or not the waste will "self-support" combustion, or require fuel such as oil or gas to make it burn.

- *Densities* (measured as the weight of waste per unit volume). The density of waste changes at different stages between generation and final disposal. The waste density figures of most interest to a waste manager are the density wastes in a storage container, the density in collection vehicles (since this determines how many vehicles are required to collect waste in a local area), and finally, the density of waste in a landfill (as indication of the amount of space that is used up and from which the lifetime of a landfill can be estimated).

- *Waste generation per person.* This is the measure of the amount of waste each person produces each day and is usually expressed as kilograms of waste per person per day. Examples for higher-, middle- and lower-income countries are given in Table 2.2. This table also indicates the general fact that the municipal waste generation per person in high-income countries is much greater than for lower-income countries. In the table this figure is approximately double for higher-income countries.

	Lower-Income Countries (a)	**Middle-Income Countries (b)**	**Higher-Income Countries**
Waste generation (kg/cap/day)	0.4 - 0.6	0.5 - 0.9	0.7 - 1.8
Waste densities (wet weight basis - kg/m)	250 - 500	170 - 330	100 - 170
Moisture content (% wet weight at point of generation)	40 - 80	40 - 60	20 - 30
Ranges of compositions (% by wet weight)			
Paper	1 - 10	15 - 40	15 - 40
Glass, ceramics	1 - 10	1 - 10	4 - 10
Metals	1 - 5	1 - 5	3 - 13
Plastics	1 - 5	2 - 6	2 - 10
Leather, rubber	1 - 5	-	-
Wood, bones, straw	1 - 5	-	-
Textiles	1 - 5	2 - 10	2 - 10
Vegetable/putrescible	40 - 85	20 - 65	20 - 50
Miscellaneous inerts	1 - 40	1 - 30	1 - 20
Particle size = 10 mm	5 - 35	-	10 - 85

(a) Includes countries having a per capita income of less than US$360 in 1978.
(b) Includes countries having a per capita income of more than US$360 and less than US$3,500 in 1978.

Table 2.2 Patterns of municipal refuse quantities and characteristics for lower-, middle-, and higher-income countries
(Source: Cointreau 1982)

Waste is much less dense at the point of collection in high-income countries compared with other countries. This is because the waste steam in high-income countries contains more packaging and lighter materials that are discarded, and less ash and food wastes. The wastes produced from poorer communities are denser than those wastes produced from more prosperous areas or countries which consume a larger number of manufactured products. Moisture content is often much higher in low-income countries due to the high proportion of water in food wastes. In high-income countries, since food waste is a lower proportion of the total quantity of waste generated, correspondingly, the moisture content is lower. Middle-income countries occupy the "transition zone" between the waste characteristics of lower-income countries and those of high-income countries.

2.3.2 Acceptable and unacceptable wastes to landfill

Almost all categories of waste discussed in this Guide may be disposed to better managed landfill directly. It is preferable for wet wastes, including night soil (human-faecal) wastes and sludges, to be dewatered before landfill or be deposited in the landfill in areas already filled with drier municipal or commercial waste. This will permit the excess water to be absorbed into the waste and enable microbiological degradation to proceed before any of the liquid passes to the bottom of the site. The ideal upper limit for moisture content as received is 70%. This is to avoid leachate passing too quickly through the landfill for it to undergo decomposition. Typically, the quantity of wet wastes deposited should be no more than one part in ten of dry waste and should be well spread.

Potentially, almost all wastes could go into a landfill if it is developed in the ways described in this Guide and is located on a low-permeability geology. Decisions based on social arguments about what is unacceptable to put into a landfill have to be made primarily by the municipality. If there are no other disposal outlets, then delivery of wastes such as industrial waste and hospital (healthcare) waste to landfill for disposal may be more acceptable to protect public health than not to dispose of them formally at all. Traditionally, healthcare waste, which contains infectious and pathological materials, is burned and the ashes are put in landfill where they can be buried immediately under fresh municipal waste. To achieve good biological decomposition, it is also possible to land dispose untreated healthcare waste in a well-managed site, provided it is immediately buried under municipal waste. In places where other solutions are not credible, this approach is better than uncontrolled dumping around the countryside.

It is important that the waste manager obtains more information on the chemical composition of the industrial wastes being produced in his or her area. The suitability of the waste for disposal to land should be considered carefully for each type of industrial waste. Those types of wastes which will destroy the microbiological degradation processes within the landfill (for example, some pesticide residues) are unwelcome in a landfill. Large quantities of process wastes, such as gypsum (calcium sulphate), which will degrade in acidic conditions to generate oxides of sulphur, can cause an environmental nuisance on a landfill. An estimation of the range and quantity of such wastes will enable a waste manager to plan for their proper disposal.

Those chemical wastes which are highly water-soluble and will pass through the landfill before microorganisms have had a chance to dispose of them (e.g., phenolic wastes) are undesirable. Furthermore, those types of wastes (such as strong acids and alkalis) which upset the chemical conditions within a landfill and therefore interrupt the decomposition processes are equally undesirable, unless they have been neutralized to a pH between 6.5 and 8. Highly flammable and volatile substances (e.g., waste solvents) and hot ashes should also not go to landfill since they may be the cause of initiation of fires on the site. More details on the landfill disposal of industrial wastes are given in Chapter 6 of this Guide.

2.3.3 *Difficult wastes*

Some waste types require additional consideration by the waste manager to determine how best to handle them at the landfill. These include

- abandoned vehicles
- tires and other low-density wastes
- animal remains (e.g., dead dogs and cats, rodents from pest control activities, veterinary wastes)
- bulky items (e.g., furniture) and construction debris (especially if in large quantities)
- asbestos

All of these wastes are commonly produced in towns.

Abandoned vehicles

These should be taken to scrap yards (wrecking yards) for recovery since most items in a vehicle can either be reused, or the metal and other components can be sold for recycling. Where they cannot be reused, it is preferable to not put them directly into a landfill, since they would lead to future settlement problems. If no other option exists then, after all fuel and oils have been removed, they can be cut up or crushed flat and the remains placed in the landfill at the base of the working face. They should then be covered with fresh domestic waste.

Tires and other low-density wastes

Old tires are frequently used in lower- and middle-income countries for the manufacturing of secondary products. In those countries where this is not possible, or where there is an excess of tires, the tires should be put to landfill with care. If possible, tires should be shredded before being deposited in the landfill.

The operator of the landfill should avoid putting too many whole tires in one part of the site since this will make that area liable to high and unpredictable settlement in the future. Tires should not be placed too near the top of the landfill when it nears completion. This is because other wastes degrade and settle more rapidly than rubber tires and, over time, tires can become exposed at the surface of the site.

Bulky wastes

There is a wide range of items which generally have a large bulk size but low density. They include old items of furniture, electrical appliances, animal cages, baskets, and similar materials. The principal problem with these is that, uncompacted, they occupy landfill space which may subsequently collapse when the waste decomposes. Bulky wastes can also retain pools of water which could develop as breeding sites for mosquitoes and other insects, some of which could be disease carrying. The usual approach is to break up the bulky items, either manually or by mechanical crushing with earthmoving equipment at the disposal site, before putting them into the landfill.

Asbestos wastes

This is a relatively newly appreciated problem following identification in the last twenty years that some forms of asbestos (especially dust containing asbestos fibers) can lead to severe medical problems. There are three forms of asbestos fibers, although in all instances it is common to treat asbestos waste as suspicious and to deposit it, preferably, in two sealed bags at the bottom of the working face of a landfill and then immediately cover it with fresh municipal waste.

2.4 Minimum Acceptable Standards

The minimum approach to acquiring information on local waste characteristics is to use existing data compiled or published by others. This data could come from records kept locally by other municipal departments and public institutes or from nationally estimated values. Alternatively, several international published texts (e.g., Flintoff 1974, Cointreau 1982) include general data on the likely characteristics of domestic wastes generated in areas of different income.

2.5 Desirable Improvements to the Minimum Standards

If a waste manager decides to collect information on waste characteristics through field survey and measurement, the information of most fundamental benefit is (1) composition of wastes; (2) sources of wastes in the seven categories discussed previously; (3) some indication on the production rate of wastes per person; (4) average and seasonal moisture content; and (5) waste density in storage containers. All of this information is relatively simple to obtain and will prove invaluable in selecting appropriate facilities and equipment for future waste management. Should the introduction of composting plants be under consideration, the ratio of carbon to nitrogen in the organic fraction should also be determined. If incineration of waste is to be considered, seasonal variations of the calorific value of the waste must be established.

Further guidance on waste survey techniques is given in Appendix 2.A.

Appendix 2.A
Waste Sampling Methods

(Based on Flintoff 1976)

Generation in Relation to Collection and Disposal

The generation of solid wastes varies in different types of dwellings as well as in different socioeconomic groups. The following are methods commonly used to estimate the total quantity of wastes to be collected and disposed:

- Average loads collected per day are multiplied by average volume per load ascertained by measuring a vehicle body, and converted to weight by using an average density obtained by sampling.
- Sample vehicles are weighed, using a weighbridge, the average is multiplied by the total loads per day.
- Every load is weighed on a weighbridge at the disposal site. This is the only accurate method.

Measuring the total weight of wastes delivered to a disposal site, however, is seldom an accurate indication of wastes generated, as distinct from collected, because of the losses at various stages. The following may be a typical pattern:

Stage	Handling Phase		Losses
	Total Generated		
1		minus	Salvage sold by householder
2			Salvage by servants or other domestic helpers
3			Salvage by scavengers (waste pickers)
4			Wastes disposed of by unauthorized means (e.g., on unused ground or in ditches)
	Total Collected		
5		minus	Salvage by collectors
	Delivered for Disposal		
6		minus	Salvage by disposal staff
			Salvage by scavengers
	Total Disposed of		

For certain purposes (e.g., to determine the volume required for storage of domestic wastes, or find the recycling potential of wastes), it is necessary to try to measure wastes actually generated. This can be done by sampling at source (i.e., at Stages 1 or 2).

Requirements for Estimating Domestic and Trade Wastes

Because the cycle of domestic activity varies throughout the week, it is necessary to obtain samples that precisely cover one week. For example, in India the following initial assumptions could be made:

- 350 g/person/day
- 6 persons/dwelling
- = 2.1 kg/dwelling/day, equivalent to 15 kg/dwelling/week. (including natural moisture content)

However, there is a very wide range of wastes generation as between different income groups and dwelling types, thus it is necessary to obtain samples from every identifiable group. The following is a typical classification:

Code	*Dwelling type*	*Income group*
A.1	Single unit	low
A.2	"	medium
A.3	"	high
B.1	Multiple, low rise	low
B.2	"	medium
B.3	"	high
C.1	Multiple, high rise	low
C.2	"	medium
C.3	"	high
D.	Shop and office wastes	

The classification must reflect the character of the city and, in some cases it would be necessary to include slums, squatter settlements, and semi-rural areas.

The minimum weight of a sample for a group of similar dwellings is about 200 kg; thus the minimum number of dwellings required per group for a daily collection would be about 100, based on the assumed rate of generation above. A sample weight above 200 kg would be preferable to reduce potentially unrepresentative results from being obtained.

The minimum number of 200 kg samples required for a city is about 12. Thus, if the number of classified groups is less than 12, more than one sample should be obtained from the largest group or groups.

On the above assumptions, a generation test in an Indian city would involve about 12 samples/day, each from about 100 dwellings, and would cover 1,200 dwellings and a population of 7,200.

Proposed Method of Collection of Samples

In cities where the storage of domestic wastes is in communal containers, it will be necessary to supply every dwelling with a container for the period of the tests; plastic bags offer the cheapest solution.

After selection of the sampling areas, each householder should be interviewed, to explain the purpose of the sampling project. It is desirable that this be done by social workers who are better trained in communication. An explanatory leaflet should be left at each dwelling.

The sampling program should extend over eight successive days. Wastes collected on the first day should be discarded, as the period they represent may be doubtful; wastes collected from the second to the eight day will represent one week's production.

The collector should carry a supply of plastic bags, one of which should be handed in at each dwelling in replacement of the full one collected. Each full bag should be labelled with its appropriate classification before being taken to the depot where the contents are weighed and the volume measured.

For calculation of total weight and volume generated in the city, a multiplier is used for each coded group based on the proportion of the population represented by that group. For example, if the A.1 sample is from 600 persons and the total population in that classification is 40,000, then the multiplier would be 66.7. In most cases, samples collected in this way would also be used for physical analysis, as described in the succeeding section, supplemented by samples representative of trade and commercial wastes. The labor requirement for a program of this kind is as follows:

Total calls/day for 1,200 dwellings	1,200
Calls/collector/day @ 20 calls/collector/hour for 6 hour/day	120
Number of collectors required per day	10
Period for which required (# days)	8

A basic weakness of this method of estimating generation is that, despite explanations given in advance, the householder may vary the normal pattern of wastes disposal for personal reasons if he or she knows that the wastes are going to be examined. Greater accuracy is assured when samples can be obtained without the knowledge of the householder; for example, the sampling collectors simply move in a little earlier than the normal house-to-house collectors. This is not practicable, however, in cities where the main storage methods are communal.

Collection of Samples from Communal Containers

For many purposes, such as deciding the design of refuse collection vehicles and the method of refuse disposal, collection of samples direct from source is unnecessary, and samples can be taken from communal containers or transfer stations. This is a much simpler procedure and requires merely the daily collection of at least 12 samples, each at least 200 kg or 500 litres, from areas which properly represent the selected socioeconomic groups and trade sources.

The density of samples collected in this way will be higher than for samples collected direct from source because the density of the wastes increases at each stage of handling, partly through the removal of light constituents such as paper, and also by compaction of material at low level by pressure from the weight of wastes above, and lastly by the gradual filling of interstices by dust. (Thus, for the calculation of domestic and trade wastes storage capacity at source, the density of communal wastes should be reduced by at least one third.)

Analysis and Protection

The physical analysis of wastes enables the following information to be obtained:

- density of wastes
- proportions of salvageable constituents
- proportions of other constituents
- proportion that could be incorporated in compost
- combustible proportion
- graded particle size
- moisture content

Three or four analyses are needed over a period of one year to cover the seasonal variations that occur as a result of the climatic cycle and the food production cycle.

Collection of Samples

At least 12 samples and not more than 20 are required, each of at least 500 litres and not more than 1,000 litres. The samples should be selected to represent commercial and market wastes as well as the domestic wastes sources referred to in the preceding section. When analyzing commercial and market wastes particular attention should be paid to identify any large accumulations of hazardous or difficult wastes.

The number of samples from each group should be proportionate to the population represented by that group, or else mathematical weighting could be used. If the purpose is to obtain information on collected wastes, samples can be taken from vehicles as they arrive at disposal sites, so long as the source is known with accuracy (for example, the collection route is well defined), or from communal storage points.

Method of Analysis

Samples should be analyzed within two hours of collection to minimize errors from moisture loss. The measuring box of 500 litres is filled by shovel; the contents should not be compressed but the box should be rocked back and forth three times during filling. The box is then weighed to find the density of the wastes. It is now necessary to sort the waste by hand into the required constituent piles. The piles are then transferred to a sorting table, constituent by constituent. The surface of this table is formed by a wire mesh grid of 50 mm, so that all material below this size will fall through it. The oversize vegetable-putrescible wastes are left on the table but all the other constituents are picked out and put in a marked container for subsequent weighing. Small hoes are used to turn over the wastes during the sorting process. When sorting of the oversize material is finished, the table is shaken to ensure that everything below 50 mm has fallen through. The matter remaining on the table is vegetable-putrescible over 50 mm.

The matter below 50 mm which has fallen to the ground is now shovelled up and passed over a hand screen of 10 mm mesh. The wastes remaining on the screen are now hand sorted until only vegetable-putrescible matter remains; this is the 10 to 50 mm average size.

By this time the wastes are completely sorted into the required constituents and sizes except that the fine matter below 10 mm will be a mixture of inert and organic matter, such as sand and food grains. The proportions can be established only in a laboratory by moisture and ignition tests, but with experience it is possible to make a fairly accurate estimate by visual examination.

Information from Analysis

The following example of a summary sheet shows the kind of information needed:

Constituent	Sample No. and % by Weight							
	1	2	3	4	Etc.	Max.	Min	Average
Vegetable/putrescible								
above 50 mm								
10 mm - 50 mm								
below 10 mm								
Total								
Paper								
Metals								
Glass								
Textiles								
Plastics & rubber								
Bones								
Misc. combustible								
Misc. incombustible								
Inert matter below 10 mm								
TOTAL								
DENSITY (kg/cu m)								
SOURCE OF SAMPLE	code letter							

Equipment Required

- One measuring box (1 metre high x 1 metre long x 500 mm wide) with a flat bottom. Weight should be minimized by using thin resin-bonded plywood for construction. A strong batten should be bolted along each side, projecting at the ends, to provide four lifting points for placing the box on a scale.
- One sorting table (about 1.5 metres wide x about 3 metres long) made from a stout softwood frame with corners halved and bolted, and entirely covered by wire mesh of 50 mm, wrapped around every side and securely fastened. The table can be supported on trestles or fitted with legs.
- One hand-screen of 10 mm mesh.
- Ten bins or boxes of about 60 litres to contain sorted materials.
- Three large, flat shovels.
- Six hand-hoes to turn over wastes during sorting.
- Six pairs plastic or rubber gloves for sorters.
- One platform weighing machine, preferably with capacity up to 500 kg.

Projections

Over time, if waste sampling continues, the annual and seasonal variations in waste quantities and compositions will become apparent, and reliable projections can be made for the following three to five years. It is also likely that changes may occur in the physical characteristics of wastes, from the following causes:

- A rising standard of living increases the production of solid wastes, particularly constituents other than vegetable-putrescible.
- Changes in packaging technology and retail distribution methods tend to increase packaging materials and volume per capita.
- Changes in domestic fuels, for example, a reduction in the use of solid fuel, could cause falling ash content and a reduction in weight per capita.

In cities where annual analyses have been carried out for fifteen years or more, changes of this kind appear on a graph as a curve from which it may be possible to extrapolate estimated analyses for up to ten years ahead. An example of a forty-year trend in weight, volume and density of waste is presented in Figure 2.1 to demonstrate the changes in waste characteristics that have been evident over time. Where such information does not exist, it is usually possible to make useful projections based upon national and local forecasts of economic growth and industrialization.

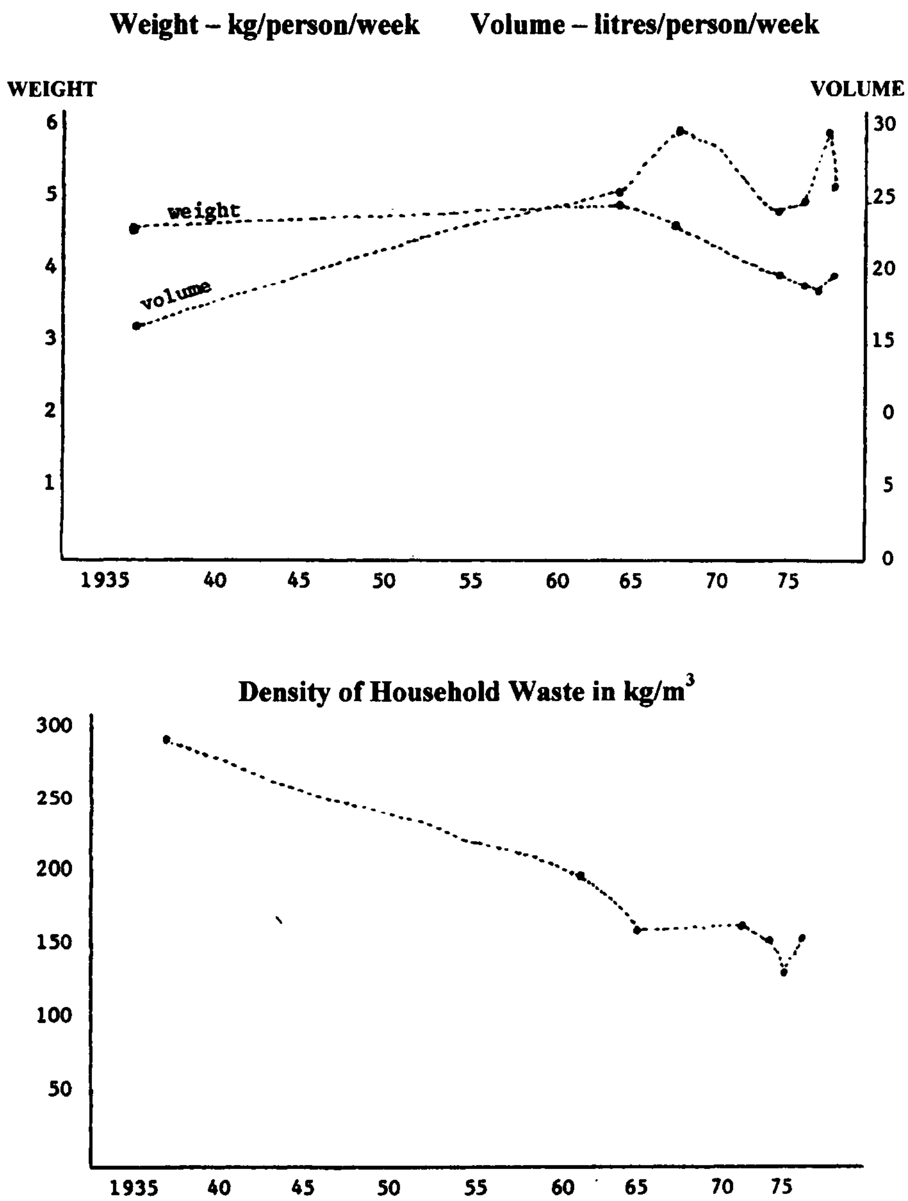


Figure 2.1 Changes in the weight, volume, and density of municipal waste between 1935 and 1976
(Source: INCPEN)

Chapter 3 Landfill Site Identification

3 LANDFILL SITE IDENTIFICATION

3.1 Main Points

The selection of a site for developing a landfill is one of the most important decisions to be made by the municipality in developing and implementing its waste management plan. A poorly chosen site is likely to require unnecessarily high expenditure on waste transport, site development, site operations, or environmental protection. It may also cause long-term political problems from public opposition. To ensure that an appropriate site is identified, a systematic process of selection needs to be followed. The selection criteria are themselves subject to prioritization according to local climatic, political, and cultural circumstances.

It is important to obtain sufficient information about possible sites. Desk and field studies can identify a short list of candidates. The majority of this information need only be qualitative. For the preferred site(s) only, it will be necessary to carry out investigations at the site(s) to confirm their geological and hydrogeological characteristics, develop conceptual design(s), and establish likely costs.

Measures to collect and treat leachate are often expensive. To reduce costs, priority should be given to areas where leachate would likely have little or no impact on the environment.

The impact in travel time and the implications for modes of transport on the waste collection service must also be considered, as this may have a dominant influence on the choice of site. This is most likely to be the case if a regional or remote site is considered.

3.2 Key Decisions

Two fundamental decisions must be taken before procedures to identify candidate sites should be started:

How large an area (catchment) should the site serve?

The geographical area(s) and types of waste to be accepted in the new landfill need to be decided. Together with a target lifetime, these factors will dictate

- restrictions, due to transport limitations, on general location of sites
- the type of environmental impacts likely
- the required volumetric capacity of candidate sites
- any inter-municipality cooperation that might be needed

What selection criteria are appropriate?

A wide range of criteria may be applied in the identification of suitable sites for landfill development. These may be grouped into the following aspects:

- transport related
- geotechnical, hydrological, and hydrogeological
- land use
- public acceptability
- safety

A chart indicating the steps to resolve these two key decisions is presented in Figure 3.1.

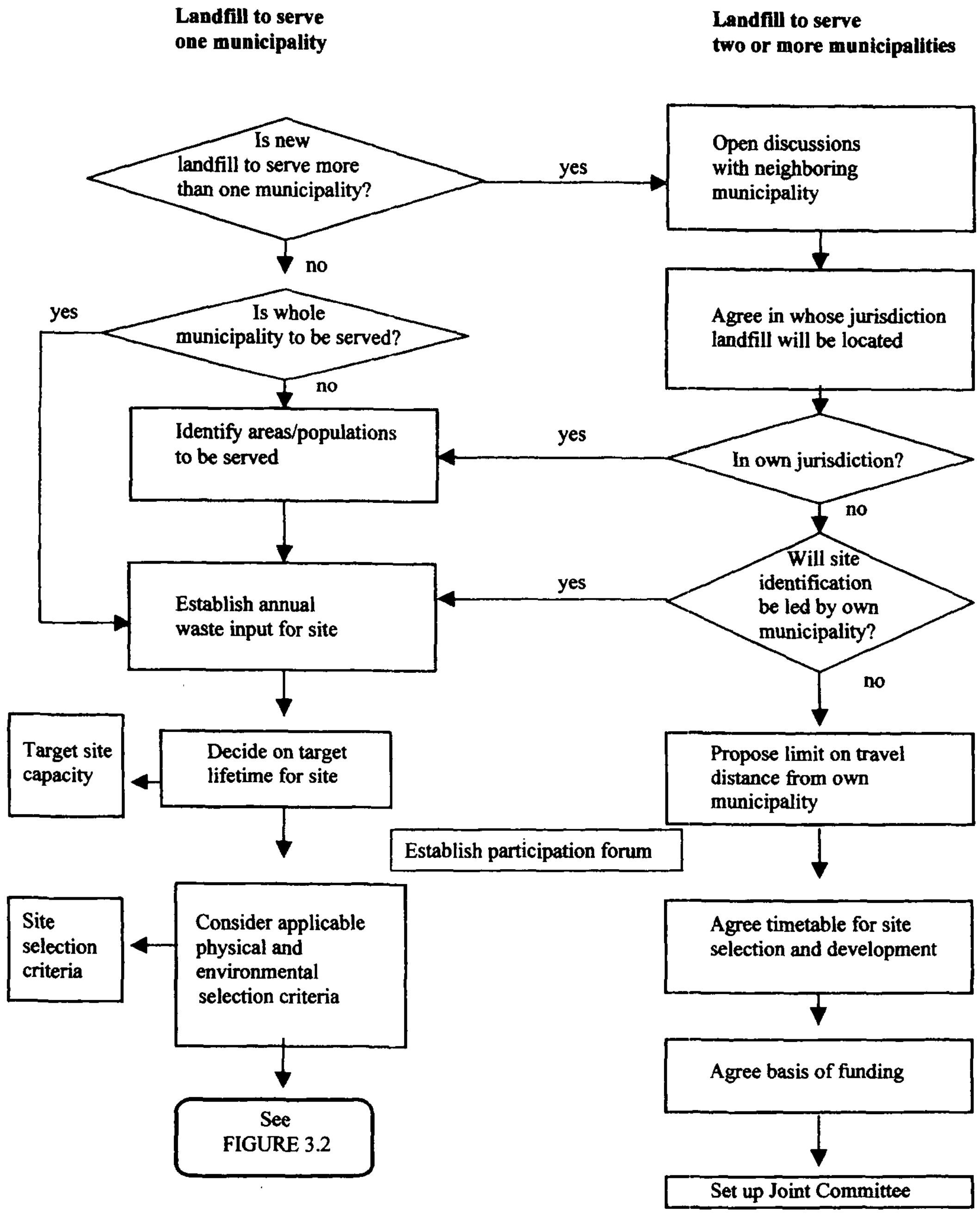


Figure 3.1 Resolution of key decisions

3.2.1 Participation arrangements

It is unlikely that these key decisions can be taken by one person or even one organization in isolation. Once the decision has been taken to seek a suitable site for developing a new landfill, the municipality should actively encourage participation in the site identification exercise from organizations which have a significant interest in the choice of site. Municipalities are urged to encourage actively the participation of the public in the procedure to identify a new landfill site. Community involvement may be encouraged by municipalities through a wider use of social scientists or anthropologists in the site selection procedure.

The ease or otherwise of establishing a new site for landfilling wastes will almost certainly be influenced by what is universally known as the NIMBY ("Not In My Back Yard") syndrome. The obstructive power of NIMBY should not be underestimated. Suggestions for implementing a public participation program are provided below and in Appendix 3A.

A similar affliction, NIMTO ("Not In My Term of Office"), can sometimes stall the decision-making process. Efforts should be made by all concerned to recognize the need for difficult decisions to be taken, not avoided. Politicians must be presented with well-researched and widely supported recommendations.

A suitable forum, perhaps a committee, should be established to consider matters which influence these key decisions. Representatives from affected organizations, which may include different departments within the municipality, communities, nongovernmental organizations and financial bodies should be identified to comment on issues affecting

- protection of water supplies
- land use and transportation planning
- waste collection system operation
- national or regional waste regulation
- neighboring municipalities, if appropriate

Public participation should be a consultation process. The objectives of a public participation program are to

- promote full public understanding of the need for a landfill and the principles of its operation
- keep the public well informed on the status of various planning, design, and operation activities
- solicit from concerned citizens their relevant opinions and perceptions involving landfill development
- promote consciousness of the public of their role as waste generators

The advantages of a public participation program include

- an increased likelihood of public approval for the final plans
- a method of providing useful information to decision-makers, especially where issues or factors that are not easily quantified are concerned
- assurance that all issues are fully and carefully considered
- identification of compensation requirements for affected communities

- a safety valve in providing a forum whereby criticism can be aired
- increased accountability by decisions makers
- an effective mechanism to show decision-makers the need to be responsive to issues beyond those of the immediate project
- an effective mechanism to encourage public reflection on their role as waste producers

However, it should be appreciated that public participation programs, if not properly conducted, can have a number of negative effects, including

- a potential for confusion of the issues if too many new subjects are introduced
- a possibility that erroneous information will be disseminated by unknowledgeable participants
- an added cost to the project due to public involvement
- possible delays in the project due to public involvement
- a possibility that the effort will not involve the appropriate people, or that the citizens will not develop an interest in the project until it is too late for changes to be initiated
- public resistance to landfilling may still be high despite the best efforts at public participation

An informative discussion on practical ways to establish realistic public participation is given in Petts 1994, and Petts and Eduljee 1994.

3.3 General Principles

The general process of site selection is likely to follow the step-by-step sequence illustrated in Figure 3.2, which indicates how the search for a new landfill can be progressively narrowed to a single preferred site.

3.3.1 Step 1: Constraint mapping

A large number of site selection criteria have the effect of excluding from further consideration whole areas of land. Several of these negative aspects may conveniently be recorded on a suitably scaled map of the municipality and its surroundings. Such mapping will reveal areas in which landfill sites might be located (subject to further criteria). Aerial photographs are also a useful aid to identify geological and hydrogeological features.

The list of area exclusion criteria which might apply in all parts of the world is summarized in Table 3.1. Subject to local climatic, cultural, or political conditions, a further list of exclusion criteria may be appropriate for consideration, as set out in Table 3.2. Discussion on the discretionary use of these criteria is provided in Section 3.4. The criteria in both tables can, in a number of instances, be relaxed, but generally at a cost.

The World Bank has also established a fuller set of descriptive landfill site selection criteria. These are reproduced in Appendix 3.B for reference.

Sources of information on which to base these exclusion areas include, but are not limited to, the following:

- planning and transport departments
- water supply authority
- military
- mining companies
- telecommunication authority
- geological institutes
- aviation authority
- hydrology and meteorology institutes
- government ministries

The ownership of land should also be recorded. This should include communal or tribal lands which are under multiple ownership, and lands which are sacred and should not be developed.

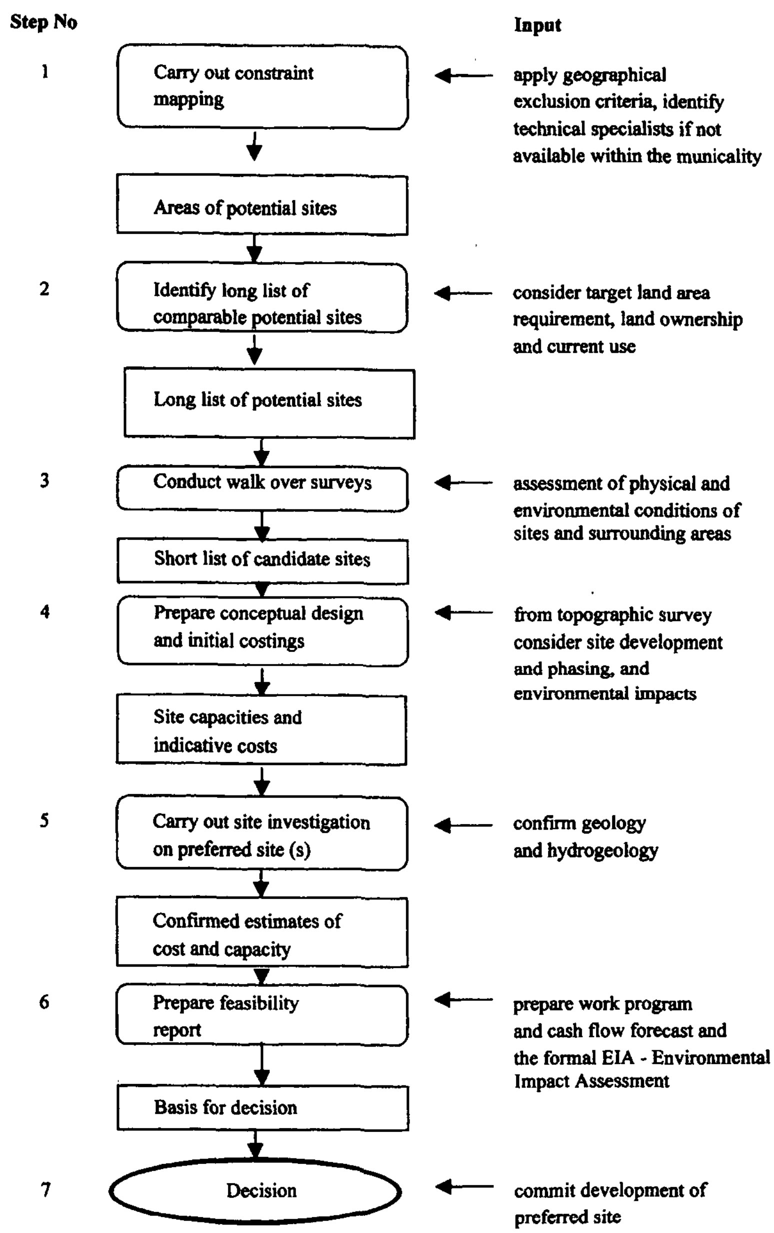


Figure 3.2 Identification of preferred site

Aspect	Criteria
Transport	T1. More than 2 km from a suitable main road T2. More than an economic travel distance from points of origin of waste collection vehicles
Natural conditions	N1. Flood plains or other areas liable to flooding N2. Extreme morphology (steep or over-steep slopes liable to landslips or avalanches
Land use	L1. Designated groundwater recharge, sole source aquifer or surface water catchment areas for water supply schemes L2. Incompatible future land use designations on or adjacent to the site, particularly hard (built) development or mineral extraction L3. Within a military exclusion zone
Public acceptability	P1. Within 200 m of existing residential development (this minimum distance may be larger in some places due political, geological or social requirements)
Safety	S1. Within 5 km of an airport runway in the direction of approach and take-off S2. Area of former military activity where buried ordnance may be present S3. Within a microwave transmitter exclusion zone S4. Within a safe buffer distance (say 100 m) from an existing or planned quarry, which will undertake blasting with explosives S5. Areas known to contain collapsing soils (such as loess)

Table 3.1 Area exclusion criteria applicable worldwide

Aspect	Criteria
Natural conditions	N3. High or seasonally high watertable N4. Karstic or geologically faulted areas, or areas containing mine workings, where leachate may migrate rapidly from the site to a potable aquifer N5. Wetlands (swamps or marshes) or other areas of ecological significance
Public acceptability	P2. Within an acceptable distance (desirable minimum distance 200 m) from historical, religious or other important cultural site or heritage

Table 3.2 Area exclusion criteria subject to local interpretation

3.3.2 Step 2: Preparing a long list of possible sites

The output from the constraint mapping exercise will suggest areas of search for possible sites. The target land area required, expected volume of waste over a site's life (obtained from the target site capacity, see below), may be used as a guide to identify areas, preferably in single ownership and preferably in a state of neglect or nonuse.

The task of finding possible sites will be considerably eased by considering a range of *positive* selection criteria. The principal environmental concern associated with waste disposal is the generation and fate of leachate. Leachate generation is not a problem in all parts of the world. It depends largely upon the local meteorological conditions. Where leachate may be expected to be produced, landfills should be sited in areas where its controlled or accidental release will have little or no impact on the local environment.

The first areas to seek out would be those having geology favorable to containing or at least inhibiting the release of leachate to the wider environment; for example, clays and silt deposits. Abandoned clay workings may be an example of a suitable location for effectively containing leachate, and refilling the void left by the former brick works can recreate a landform suitable for other purposes.

A second group of suitable areas to seek would include

- areas of saline intrusion or where other soluble salts and minerals render groundwater totally unsuitable for potable supply purposes, and where agricultural uses do not include food crops
- coastal or estuarine sites remote from habitation and away from inundation

The objective of protecting groundwater from contamination should be kept in perspective. In certain circumstances it may be acceptable to sacrifice a small area of unused groundwater (provided the area can be predetermined and future use of that water resource avoided), rather than invest large sums of money in landfill development in order to protect groundwater for its own sake. This approach may lead to the consideration of some sites which might otherwise be excluded.

Depending on the restrictions imposed by the constraint mapping exercise, the municipality should aim to draw up a list of up to, say, five possible sites. Identified for their positive features, these may include

- easy access to a road system
- proximity to the urban area
- ease of land acquisition
- lack of use for any other purpose
- beneficial after-use

This list of sites could include the municipal waste dump, which is to be replaced, provided it meets some of the criteria above and is likely to have a lifetime of several more years as a better managed landfill. Conversion of a waste dumpsite would have the apparent advantages of (1) being already available; (2) having an established use for waste disposal; and (3) being familiar to the collection agencies.

Determining the target site area

The required site area will depend upon

- the total quantity of waste to be disposed at the site over its lifetime

- the volume that this waste (and any cover material) will occupy in the site
- how this volume can be accommodated in the site (percentage of site covered, depth, and/or height of landfilled waste)

Chapter 2 of this Guide provides information on waste generation rates. Taking a typical rate of generation of household waste only, of 0.5 kg/person/day, the cumulative tonnage of wastes to be accommodated for a range of catchment populations and design site lifetimes are shown in Table 3.3.

Population	Site Lifetime		
	5 years	10 years	15 years
20,000	18,000	37,000	55,000
100,000	91,000	183,000	274,000
500,000	456,000	913,000	1,369,000

Table 3.3 Typical site capacities (tonnes of household waste)

These figures assume no growth in the serviced population or "per capita" change in waste generation. Both these factors need to be considered in a real situation. Conversion of these figures to volumes requires an assessment of likely long-term, in situ density. To these figures should be added a volumetric allowance for cover materials of, say, 10 to 20%.

Because landfill sites need areas to be set aside for various purposes, the net "useful" area will occupy perhaps 60% to 90% of the total site area, depending on the size and local requirements of the site.

The most variable parameter in determining the likely target area for a site will be the depth/height of wastes. Factors which will significantly influence this dimension include

- whether the site is essentially a void (e.g., quarry) to be restored to ground level
- whether there will be any aesthetic limit on the extent of land raising (e.g., in a flat plain)
- geotechnical constraints (e.g., low bearing capacity soils) which may limit height or slopes
- whether there is no constraint on height and the site capacity is to be maximized

Figure 3.3 provides a rough basis for estimating the land area which may be used as a target figure in the initial site identification exercise. The conceptual model landform is based on a rectangular land-raising fill (sometimes called a "tumulus"), as depicted in the inset. Steep-sided quarries or sites in mountainous terrain may be expected to have different area/capacity relationships.

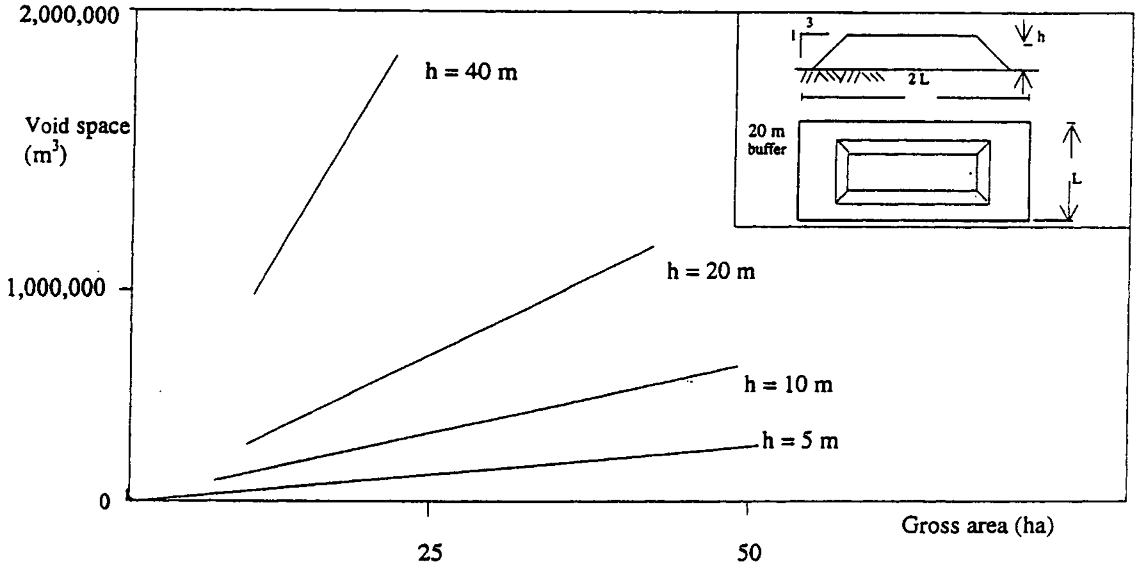


Figure 3.3 Target site areas

In view of the significant investments in land, labor, and resources which are likely to be required to develop and operate a better managed landfill, the target lifetime of a site, where possible, should be ten years or more. Any reductions in the period should be considered only if the municipality is unable to arrange finances for such a period, or suitable sites offering the void capacity required are simply not available within an economic distance of the sources of waste.

The absolute minimum lifetime of a landfill should be three years. In this situation a significant cost penalty will have to be paid by municipalities through a loss in the economy of scale of site construction works and shortness of the amortization period for capital investments.

3.3.3 Step 3: Walkover surveys

While the first two steps may not require first-hand knowledge of the possible sites, further elimination of sites will require a formal inspection of each site. A number of features, both favorable and unfavorable, may very quickly be identified by a walkover survey. The most consistent approach will be achieved by reference to a checklist of points, some of which will require confirmation by other authorities (e.g., presence or proximity of services). Table 3.4 sets out a suitable checklist.

The objectives of the walkover surveys should be to identify sufficient constraints to reduce the number of possible sites to a maximum of three. A suitability matrix such as is presented in Figure 3.4 may aid in this selection process.

A.	**Transport Aspects**
A.1	To what point is all weather access presently available?
A.2	How long does it take to travel from the urban area to the nearest accessible point to the site?
A.3	How far (by new or upgraded road) is the site from this point?
A.4	Will vehicles be able to gain access to all parts of the site (via site roads)?
A.5	Will access be unusually expensive to provide (large or long embankments, bridges, cuttings)?
B.	**Natural Features**
B.1	Is the site presently well drained?
B.2	Are there established watercourses within or adjacent to the site?
B.3	Is there evidence of ephemeral streams, springs, or sinkholes?
B.4	Can high watertable be inferred from the vegetation anywhere on the site?
B.5	Are surface water diversions likely to be extensive (considering extent of catchment)?
B.6	From a knowledge of the geology of the area, does the morphology of the site suggest significant or minimum depths of soft material (for daily cover and other purposes)?
B.7	Are there areas within a few kilometres of the site which may be suitable for borrow material?
B.8	Is there any evidence of geological features on or near the site?
B.9	Are there any features which will significantly limit the useful area of the site for landfilling?
C.	**Land Use**
C.1	What is the present land use of the site and the route of any access road to it?
C.2	What is the present land use in the immediate vicinity of the site and access route?
C.3	Are there likely to be any water abstractions (for drinking or livestock watering) downstream of the site (for example, within 1 km)?
C.4	Are there any overhead power lines crossing the site?
C.5	Is there evidence of buried electrical cables or water pipes in the site?
C.6	Is there any evidence to suggest where the nearest point of a water distribution or electricity distribution network might be to the site?
C.7	Are there any places of historic or cultural significance nearby?
C.8	Is there likely to be a need for resettlement?
D.	**Public Acceptability**
D.1	Are there any significant population centers on the principal route to the site which will be adversely affected by increased traffic volumes?
D.2	Is the site overlooked by, or overlooking, residential or commercial development, or sociopolitically sensitive sites?
D.3	Where are the nearest inhabited dwellings (e.g., farms)?

Table 3.4 Checklist for walkover survey

KEY

- ☐Significant impact
- ☐Low impact
- ☐Negligible impact
- ☐Unknown impact

Stage	ACTIVITIES / EFFECTS ON:	Human, Flora & Fauna								Land Use					Land			Water				Air					
		Rocks	Noise	Emissions	Visibility	Appearance & landscape	Population change	Flora	Fauna	Recreation	Archaeology	Footpaths	Minerals	Agriculture	Surrounding land	Geological	Physical effects	Chemical emissions	Pollutants	Drainage	Hydrographic	Climate	Offensive odors	Particulate matter	Chemical emissions	Associated development	Traffic
Development Stage	SITE FACILITIES																										
Development Stage	ACCESS CONSTRUCTION																										
Development Stage	SITE CLEARANCE																										
Development Stage	SOIL STRIPPING																										
Development Stage	DIVERSION OF SERVICES																										
Development Stage	DIVERSION OF WATERCOURSES																										
Development Stage	SCREENING																										
Development Stage	LINER INSTALLATION																										
Development Stage	EARTH MOVING																										
Operational Stage	TRAFFIC MOVEMENTS																										
Operational Stage	MINERAL EXCAVATION																										
Operational Stage	MINERAL PROCESSING																										
Operational Stage	WASTE UNLOADING																										
Operational Stage	WASTE COMPACTING																										
Operational Stage	DAILY COVER SPREADING																										
Operational Stage	LEACHATE																										
Operational Stage	GAS																										
Operational Stage	LITTER																										
Operational Stage	VERMIN																										
Operational Stage	CAPPING																										
Operational Stage	SOIL REPLACEMENT																										
Operational Stage	REVEGETATION																										
Operational Stage	TREE PLANTING																										
Final Stage	LEACHATE																										
Final Stage	GAS																										
Final Stage	AFTERCARE																										
Final Stage	MONITORING																										

Please note that the impact may have a positive effect, a negative effect, or a combined effect.

Figure 3.4 Suitability matrix for short-listing sites
(Source: UNEP 1994)

3.3.4 Step 4: Conceptual designs

To assist further in the identification of the preferred site, it is necessary to develop conceptual designs for each remaining candidate site. Designs need to be taken to the point that approximate estimates can be made, for comparative purposes, on the

- site capacity (in cubic metres of waste)
- volume of daily and final cover required
- resources needed to install an adequate leachate control system
- extent of surface water diversion works required
- extent of works required to provide all-weather access to the site
- cost of all the above, with the supplementary cost of importing cover material from elsewhere separately identified
- impact on the waste collection system of using this site and the cost of providing any extra resources (vehicles, transfer stations) for this service

Costs should also be estimated for the initial purchase of the land and the value of any eventual sale on completion for productive use. The estimated capacity of each site will indicate its approximate lifetime, over which the initial development costs could be amortized and the cost of supplying cover material would be spread. The estimate may then be used to develop indicative "costs per cubic metre of waste" for those elements considered above which are site specific.

A simple comparison matrix, such as the one shown in Table 3.5, may then be used to identify a preferred site. Clearly, in the example indicated, some weighting of the measures selected would be needed in order to identify a clear preference.

Measure	Site A	Site B	Site C
Incremental cost/m^3 (soil cover materials on site)	Low	Medium	High
Incremental cost/m^3 (soil cover 100% imported)	Medium	Medium	High
Impact on local residents	Medium	Low	Low
Environmental protection required (= risk to environment)	Low	High	Low

Table 3.5 Site comparisons

3.3.5 Step 5: Site investigations

Subsurface exploration and a topographic survey should be carried out at the preferred site and, if the indicated cost is sensitive to the cost of provision of environmental protection measures or the availability of cover material on site, also at the second choice site.

The investigations, generally conducted using a drilling rig and a mechanical shovel (backhoe), should be designed to confirm assumptions made in the conceptual designs on the

- quantity of soil material available within the site for cover purposes
- permeability of the base of the landfill and of the material to be used for final cover
- bearing capacity of the base of the landfill
- stability of any slopes to be cut
- groundwater regime
- baseline quality of ground and surface water

These site investigations will be critical to the success of the siting and design of the landfill. They should therefore be designed and supervised, and the results interpreted by an experienced geotechnical engineer, supported by a hydrogeologist.

From the results of the site investigation program, the estimates of cost and capacity of the preferred site(s) may be firmed up, and a clearly preferred site identified.

A checklist of sanitary landfill activities for assessment of various impacts on the environment is provided in matrix form in Table 3.6. The matrix can be used to prepare a feasibility report to identify, for the preferred site, which activities are likely to give rise to significant adverse impacts. The conceptual design for that site can be checked to see whether these impacts can, by attention to detail, be sufficiently mitigated.

A commitment to prepare a written Environmental Impact Assessment (EIA) on the preferred site will focus the minds of those responsible for site selection, since once a significant impact is acknowledged, either appropriate mitigation measures must be identified or it must be recorded that the impact is unavoidable.

1. The proposed action
a. Purpose and justification b. Project description c. Primary impact area
2. Existing conditions
a. Natural environment b. Human-made environment
3. Environmental impacts
a. Topographic, geological, and soils b. Water quality and drainage c. Ecological community d. Land use, zoning, and socioeconomic functions e. Aesthetic and landscape f. Health g. Air quality h. Noise i. Population displacement and resettlement
4. Unavoidable adverse impacts
a. Disruption of agricultural lands b. Increased traffic c. Modification of surface water drainage patterns
5. Alternatives to the proposed actions
a. No action b. Alternative to the project c. Alternative within the project

Table 3.6 Content of a typical environmental impact statement for a landfill
(After: Robinson 1986)

3.3.6 Step 6: Feasibility report, including environmental impact assessment

Having identified one preferred site, waste management staff of the municipality should then prepare a feasibility report on the viability of developing the preferred site as a better managed landfill site. The report needs to be able to demonstrate clearly that such a development is viable in five areas:

- physical and environmental
- technical
- economic
- social and cultural
- legal

The report should begin with a summary of the process of selection, justifying the basis on which the preferred site was identified.

The economic justification of the site needs to consider all financial implications to the waste management system, including

- the current costs of waste disposal at the existing site(s) which is to be closed
- the expected cost of the design, construction, operation, completion, and aftercare of the new sanitary landfill
- closing down the existing site(s)
- the current costs of collecting and transporting wastes to existing site(s)
- the expected costs of collecting and transporting wastes to the new sanitary landfill
- any proposed apportionment of costs between operating departments or benefiting municipalities
- any changes in cost recovery which may be expected during the lifetime of the new sanitary landfill

Such cost analyses should be expressed both as cash flow forecasts, so that the implications on future budgets can be clearly seen, and in terms of net present value (NPV).

Guidance on the format of an EIA for engineering projects is provided in Appendix 3C and in documents produced by several agencies. Some useful texts are indicated in the "Additional Reading" section of this Guide.

3.3.7 Step 7: Final decision

The final hurdle before any project can be implemented is to obtain approval, if not already secured, from the appropriate committee of the municipality, regulatory authorities, and the provider(s) of the funds for the landfill development.

The feasibility report should be the primary supporting document but the promoter of the scheme will need to present the case in a convincing manner, demonstrating clearly that

- there is an urgent need to improve current waste disposal practices

- the most appropriate way will be by developing and operating a long-term landfill
- the site chosen is the best available in the area
- the new landfill can and will be developed and operated to satisfactory environmental standards
- the impact of its introduction on the waste collection system has been fully accounted
- the cost of the changes to the waste management system is reasonable and affordable

3.4 Minimum Acceptable Standards

3.4.1 Setting selection criteria

Probably the single most dominant feature of a sanitary landfill which requires the greatest care in its design, construction, and operation is the leachate control system. It often attracts the highest element of development cost, and its failure has the greatest potential to affect human health. Every effort should therefore be made at the site identification stage to select possible sites where the need for a leachate control system is least or, if it is unavoidable, where the ease of its provision is greatest.

It should be remembered that in arid and semi-arid countries, there may be little or no potential for leachate to be generated by deposit of wastes. The conditions under which this favorable situation can be assumed are set out in Chapter 5 of this Guide. Elsewhere, it may be conventionally assumed that leachate will be generated to a greater or lesser extent and that site selection criteria should be adopted which take this into account.

Of the exclusion criteria set out in Tables 3.1 and 3.2, certain relaxations may be considered in order to bring sites which have positive attributes out of the excluded areas. These comprise the following:

T1: Remoteness may well be a positive attribute and the additional cost of longer road access may be more than compensated by reductions in other site-specific costs.

N3/N5: Saline or other mineral salt saturated, low-lying areas may permit lower leachate discharge standards to be considered, though the demand for significant quantities of cover material are unlikely to be met from within such sites.

N4: This restriction may be relaxed with care, if there are no existing or planned abstraction for potable water use for several kilometres from the site.

L2: Discussions should be held with the planning authority if this criterion excludes otherwise ideally qualified areas.

P1/P2: The distances may be reduced if visual intrusion is unlikely. In the case of P1 the criterion is also based on protection from landfill gas migration. Reduction of this distance will require the installation and long term maintenance of an appropriate gas control system.

S1: The local aviation authority may agree to reductions in the minimum required distance from flight paths.

3.4.2 Conducting the search for a landfill site

Figure 3.2 provides a full, systematic approach to the selection of a new landfill site. It provides a method of progressively narrowing the choices of sites down to a single preferred site based on technical, sociopolitical, environmental, and economic grounds. The procedure presumes that there could be a number of potential sites from which a choice can be made. Exceptionally, a municipality may discover that the first two steps leave no choice even after relaxing the constraints: Only one candidate site can be found, and any landfill developed on the site will have to be constructed and operated within the budgetary constraints of the municipality.

This should not be regarded as a failure of the procedure, but simply that the application of the procedure has revealed the acute problem that the municipality is facing in providing a single disposal outlet for its solid waste. If the problem is one of finding a suitable size of site, it may be appropriate to consider providing two smaller sites, perhaps on opposite sides of the conurbation so that transport of wastes across the conurbation is eliminated.

Walkover surveys of potential sites are essential to identify, on the ground, aspects which cannot be confirmed in a desk study. They are necessary to eliminate some sites from further consideration. Likewise, conceptual designs are essential to establish the potential capacity and cost of the short-listed sites and hence limit the need to carry out site investigations on no more than one or two preferred sites. Site investigations are critical in the search for a landfill site as they provide key evidence on which technical, environmental, and economic feasibility of the project must be based.

EIAs provide a formalized approach to considering the effects at all stages of a project's life (during construction, operation and closure) on people and the natural environment. EIAs are usually very detailed analyses of the activities carried out in the development of a landfill, and their likely impact (both positive and negative) on the environment. Emphasis is placed on adverse impacts, the means to reduce them (mitigation measures), and the acceptability of any unavoidable impacts. It is being advocated by more organizations to have the EIA process proceed closely with the work of the landfill design team.

3.5 Desirable Improvements to the Minimum Standards

3.5.1 Site lifetime

The time and level of effort involved in the proper identification, design, and development of a good landfill can be considerable. The capital cost associated with the exercise should be spread (amortized) over the operating lifetime of the landfill. It therefore makes sense to select a site which will have a reasonably long projected lifetime over which the capital costs may be financed. Some of the larger landfills in developed countries have projected lifetimes of thirty years or more and offer secure long-term disposal routes for solid wastes from the areas they serve.

It is suggested that the preferred lifetime for a new, better designed and operated landfill should be at least ten years, and ideally fifteen or twenty years, in order to justify the additional effort to identify a good site and engineer its development to a better standard (see also Section 3.4.1).

3.5.2 Selection criteria

Whenever possible, the exclusion criteria set out in Tables 3.1 and 3.2 should be respected. The results of the walkover surveys and, when undertaken, the subsurface site investigations should be carefully reviewed to confirm that the chosen site does not fall within the exclusion criteria. Only in arid and semi-arid environments, where water balance calculations clearly indicate that leachate is unlikely to be generated at any stage of the landfill's life, should any general relaxation of those criteria which relate to groundwater pollution be considered.

Appendix 3.A
Community Involvement in Site Selection

(Examples from various sources)

Important Factors

The following text is reproduced from Sloan (1993) and other work by the WHO:

The consideration of social and economic factors in a structured evaluation does three things. First, it forces the consideration of values frequently discarded as purely subjective. Putting community values into the siting equation also makes them legitimate items for negotiation. Second, it makes the developer and the approving authority accountable for community values, which are just as legitimate as, but expressed differently from, environmental standards based on the natural sciences. Finally, the consideration of social and economic factors protects the welfare of a community that is inarticulate or politically weak. The involvement of a social scientist or anthropologist in a site selection process may help to ensure community considerations are more fully recognized and addressed.

Community Involvement in Site Selection - Important Factors
Factors important to local people and communities 1. Welfare of the community and individuals (including local economy, social structure, culture, and amenities) 2. Use of local land (especially how its developed, land values, and aesthetic judgement) 3. Transport and traffic (especially road use and quality of road system) 4. Local taxes and municipal finances (including reserve and expenditure on community services, education, public facilities)

Need for compensation

Any siting process should include procedures or opportunities for negotiation and remedies or compensation that will leave individuals or the community as a whole as well off as before. Material remedies should be provided in facility siting for three reasons. It is fair to do so. It increases the economic efficiency of the siting process by paying social costs that are frequently neglected. Finally, remedies can reduce people's motivation to oppose a project and thereby contribute to a broader acceptance of the need for the facility.

Public Resistance

The following text is adapted from Armour (1985) and related work by the WHO.

Community Involvement in Site Selection - Public Resistance
Public resistance to site selection is derived from six attitudes: 1. Anxiety about environmental impacts. 2. Desire to oppose intrusions from outside. 3. Low confidence in science and technology. 4. Belief in human fallibility. 5. Lack of trust in regulatory agencies. 6. Community loss of control of events affecting their quality of life.

Attitudes behind public opposition

As outlined in the box, public resistance to siting proposals stems from at least six important attitudes.

The first is anxiety about environmental impact. The public is constantly exposed to scares about human-made environmental problems. Environmental contaminants are high on the list of concerns. People see these problems as pervasive and out of control. Anxiety reduces the ability and willingness of the public to assess a siting proposal on its own merits, as the public associates the proposed facility with all the worst cases.

Second, people feel that they must oppose intrusion by outside forces. A negative reaction to a proposal frequently stems from the perception that an outside force is threatening the family and community. The issues are usually framed in terms of perceived threats to safety, economic security, way of life, and the vitality and viability of the community.

Third, confidence in science and technology is low. Opponents waste management facilities are often highly skeptical about the abilities of science and technology. They tend to doubt the ability of scientists and engineers to control technology or to evaluate objectively its strengths and weaknesses.

The fourth important attitude is a belief in human frailty. Coupled with the low confidence in science and technology is the expectation that operators of facilities will make errors, take shortcuts, or break the rules to save time and money.

Fifth, people may lack trust in government regulators. The citizens who would be affected by a proposed facility are reluctant to defer to authority and to assume that their interests are being safeguarded.

Sixth, people confronted with a siting proposal often express strong feelings of loss of control over events affecting the quality of their environment and their lives. They become concerned about how decisions on siting proposals will be made, and particularly the extent to which they will be involved and whether the process will be fair.

Fair and effective relations with the public

These attitudes offer a number of clues to dealing more effectively with the public. Four strategies are suggested to help resolve conflict over facility proposals that are appropriate in technology and location. They are not intended to manipulate a substandard project into being. The strategies can help to ensure that the project is appropriate, as defined in part by the community's standards, and the project design meets, as far as possible, the community's goals and standards.

Giving equal importance to procedural and substantive issues

Substantive issues focus on outcomes and the net social value of a facility. Procedural issues have to do with rights and fair treatment in decision-making, particularly on proposals seen to have a major effect on the quality of life. Fairness is usually taken to mean that a process is conducted without bias, in accordance with established rules. Developers and the public, however, usually have quite different views about what constitutes bias and appropriate rules. Procedural controversies tend to include at least three issues. The first is the scope of studies undertaken; each side has different perspectives on the relevant factors. The second is the validity of the resulting information; underlying this is usually the role of each side in assessing the merits of proposed technology. The third question is what constitutes a full opportunity for participation; access to information and the resources available to the citizen opposition are usually the main points of this debate. There will be other issues, as well.

Accepting a wide-ranging agenda and then giving each issue its due

Resolving siting controversies requires accepting and dealing honestly with a range of issues. Controversies about siting hazardous waste facilities do not constitute the classic conflict between industry and environmentalists. Opposition tends to be broadly based, cutting across a full range of community interests. It can cover health, scientific, and technical issues; quality of life issues; political issues (such as equity, responsibility to future generations, access to information, and the accountability of public officials); and moral and ethical issues (in particular the right of individuals to protect themselves from harm versus the social obligation to act in the public interest). Inadequately addressed, any one of these can cause failure in the siting process.

Accommodating the broad underlying anxieties

Research suggests that resolving the siting issues depends upon a decision-making process that acknowledges the concerns that fuel the controversies. This means accepting the need of the people affected to question the social implications and appropriateness of the technology, the validity of scientific and technical studies, and the trust-worthiness of project developers and government regulators. The third point is particularly important. Resistance involves more than just perceptions of the technology proposed; it involves a dread of its risks, potential impact, and social implications. It also involves the public's perception of the reliability and credibility of developers, operators and regulators. Communities differ in response according to the information they have, their experience with facilities and government, their social and economic status, and their satisfaction with their life and environment.

Gaining a sound understanding of the attitudes and values that will influence the acceptance of a facility is essential to successful siting. Various social science techniques, from formal surveys of attitudes and interviews of key informants to informal meetings with individuals and groups, can be used to meet this objective.

Skillfully responding to attitudes, issues, and preferences

Resolving controversies depends to a large degree on an accurate diagnosis of attitudes, issues and procedural preferences, and the careful design of a process that is responsive to local concerns. General siting methodologies must be tailored to suit the social and political setting in which they will be used. Experience suggests that such tailoring is best done in consultation with groups that would be affected by the proposed facility.

Strategic Errors

Community Involvement in Site Selection - Strategic Errors By Developers

- Initial position: Developers want the site to be used, while the community is suspicious of a developer's intentions and want the development rejected.
- Strategic errors observed in public participation programs include
  1. The "hard sell."
  2. Redefining the public agenda.
  3. Late involvement of the public.
  4. Over-reliance on technical arguments.
  5. Information not understood by the public.

Facility developers often make various strategic errors when approaching the public. Five well-known strategic errors are listed above. Not every error applies to every situation. Sometimes, for instance, members of the public can understand the most technical of documents or assemble accurate and valid technical information on their own. Nevertheless, the following mistakes do not help to resolve conflict and can be fatal to otherwise deserving projects.

The hard sell

The community may believe that the facility developer is attempting to "sell" a decision that has already been made. This perception is likely, whether true or not, when there is no formal mechanism (such as an opinion survey or structured workshops) for incorporating public feedback into the decision process. Whether real or perceived, the hard sell eventually undermines the credibility of the consultation process and public trust in the developer.

The regulatory agency can become enmeshed in the hard sell perception if the public believes that the agency has approved the proposal in advance. This is likely when (as is common, for example, in the United States) the regulatory agency studies the proposal on its own and then issues a tentative approval based on technical regulatory standards.

Redefining the public agenda

The developer may redefine stated public concerns as issues that he or she feels to be more technically correct and hence easier to handle. This happens most often in health and environmental risk assessment, when the methodological emphasis is on quantitative analysis. In such a case, concerns such as the compatibility of a facility with the community's way of life, social character, and cohesion, or its implications for the quality of life and satisfaction with the environment are dealt with superficially or in a way not meaningful to those concerned.

Approaching the public too late

The developer may fail to put sufficient effort into consultation during the design phase and to gain a sound understanding of community concerns. Alternatively, prior public education may be insufficient and the public may be unprepared to deal with the technical points of the proposal. Technical information is often withheld until late in the process. The result is self-education and independent data collection by citizens, who have no access to the corresponding information from the developer. Eventually, each side trusts only its own version of the facts.

Alternatively, the developer may rely on the public hearing, with its emphasis on defined positions, as a means of resolving issues. This is not an effective strategy.

Leaning too heavily on the facts

Facility developers, including many technical people steeped in "rational decision-making," have a strong belief in the force of facts as a means of resolving controversial issues. They assume that objective, scientific analysis can and should play the arbiter's role. This view ignores the frequent disagreements among scientists about facts and evidence, as well as the research indicating that, once people make up their minds, new information tends to confirm rather than reshape their attitudes.

Failing to tailor the information to the audience

The developer may produce information geared to the needs of the regulatory agency, not to those of the public. Experts usually write such information for their peers, or to respond to the need to withstand scrutiny at a public hearing. This contributes to an intelligibility gap between experts and decision-makers on the one hand and the public on the other.

Appendix 3.B
List of Descriptive Landfill Site Selection Criteria

(Adapted from Cointreau-Levine 1996)

The following criteria for site selection are provided as guidance. A proposed landfill site can be selected even though it does not meet each of the screening criteria. Engineering design can mitigate inadequate site conditions–but at a cost. When selecting a site which does not meet all of the screening criteria, possible engineering solutions which would bring the site into conformance with the intent of the unmet criteria should be incorporated in the design. Criteria which should be addressed as part of a screening process include, but are not limited to, the following:

- Adequate land area and volume to provide sanitary landfill capacity to meet projected needs for at least 10 years, so that costly investments in access roads, drainage, fencing, and weighing stations are justifiable.

- Preferably, a site accessible within 30 minutes travel time (a function of road and traffic conditions) is to be sought, even if it means buying land, because of the need to avoid adversely affecting the productivity of collection vehicles. At distances greater than 30 minutes travel, for collection operations to be economic, investment in either large capacity collection vehicles (5 tonnes per load or greater) or transfer stations with large-capacity vehicles (20 tonnes or greater) would be necessary.
- If transfer stations are necessary, preferably the landfill site would be accessible within 2 hours of travel time by transfer truck one-way from the transfer station. For longer distances, transfer by rail or barge directly to the landfill site needs to be considered. However, siting of rail or barge transfer sites within the refuse collection area may be difficult. Double handling by truck transfer followed by rail or barge transfer should be avoided.

- The seasonally high table level (i.e., 10-year high) of the groundwater is below the proposed base of any excavation or site preparation to enable landfill cell development.

- Soils above the groundwater's seasonable high table level are relatively impermeable (preferably, less than 10^{-6} cm/s permeability when undisturbed).

- No environmentally significant wetlands of important biodiversity or reproductive value are present within the potential area of the landfill cell development, unless they have adequate capacity to absorb/assimilate the pollution loadings anticipated.

- None of the areas within the landfill boundaries is part of the 10-year groundwater recharge area for existing or pending water supply development.

- There should be no private or public drinking, irrigation or livestock water supply wells down-gradient of the landfill boundaries if at risk from contamination, unless alternative water supply sources are readily and economically available, and the owner(s) gives written consent to the potential risk of well abandonment.

- No known environmentally rare or endangered species breeding areas or protected living areas are present within the site boundaries.

- No significant protected forests are within 0.5 km of the landfill cell development area. No major lines of electrical transmission or other infrastructure (e.g., gas, sewer, water lines) are crossing the landfill cell development area, unless the landfill operation would clearly cause no concern or rerouting is economically feasible.
- There are no underlying limestone, carbonate, or other porous rock formations that would be ineffective as barriers to leachate and gas migration, where the formations are more than 1.5 m in thickness and present as the uppermost geological unit.
- There are no underground mines that could be adversely affected by surface activities of landfilling, or mining resources which could be rendered less accessible by landfilling, unless the owner(s) gives explicit consent.
- No residential development is adjacent to the perimeter of the site boundary.
- Landscaping and protective berms can be incorporated into the design to minimize visibility of operations from residential neighbourhoods.
- There is no significant seismic risk within the region of the landfill which could cause destruction of berms, drains, or other civil works, or require unnecessarily costly engineering measures.
- No fault lines or significantly fractured geological structure that would allow unpredictable movement of gas or leachate are within 0.5 km of the perimeter of the proposed landfill cell development.
- The site is not within 3 km of a turbojet airport and 1.6 km of an airport for piston engine aircraft. For sites located more than 3 km and less than 8 km from the nearest turbojet airport (or more than 1.6 km and less than 8 km from the nearest piston-aircraft airport), no consideration is to be given unless the aviation authority has provided written permission stating that it considers the location as not threatening to air safety.
- The site is not within a floodplain subject to 10-year floods. If it is within areas subject to a 100-year flood, it must be amenable to an economic design which would eliminate the potential for washout.
- The site is not within 1 km of sociopolitically sensitive sites where public acceptance might be unlikely (e.g., memorial sites, churches, schools).
- The area is accessible by a competent paved public road which can accommodate the additional truck traffic without significant effect on traffic flow rates. From the public road into the site, the access road to be constructed should be less than 10 km for large landfills serving metropolitan areas and less than 1 km for small landfills serving secondary cities.

Appendix 3.C
Further Details on Environmental Impact Assessments
Sample Reports, Guidelines, and Terms of Reference

(Based on extracts from Emberton et al. 1989, WHO 1996, World Bank 1991)

The purpose of Environmental Impact Assessments (EIAs) is to ensure that the development options under consideration are environmentally sound and sustainable, and that any environmental consequences are recognized early in the project cycle and taken into account in project design. EIAs identify ways of improving projects environmentally, and minimizing, mitigating, or compensating for adverse impacts. By alerting issues early, EIAs (1) enable environmental issues to be addressed in a timely and practical fashion; (2) enable appropriate steps to be taken in advance or incorporated into project design; and (3) help avoid costs and delays in implementation due to unanticipated environmental problems. EIAs also provide a formal mechanism for inter-agency coordination and for addressing the concerns of affected groups and local nongovernmental organizations (NGOs). In addition, they can play a major role in building environmental capability in the municipality and country.

The fundamental issue to be resolved by any municipality or country developing an EIA procedure is the definition of "environment." Generally, it is interpreted to include the flora and fauna, geology and climate, watercourses, human habitation, traffic, and cultural and social factors. The more components that are included, the bigger the EIA becomes and bigger the reports produced. Hollick (1986) has identified common features in EIA systems throughout the world. These are reproduced below in a modified form:

- Guidance on the type of developments that require an EIA.
- Specifications of who is responsible for preparing an EIA and who is responsible for reviewing it.
- Nationally recognized guidelines on the topics to be included in the EIA.
- Requirements to conduct the detailed assessment of each topic with data from direct measurements and third parties, and to identify possible adverse and positive effects and alternatives.
- Preparation of reports.
- Review of reports by official planning/control authorities and interested parties.
- Regulations to encourage or enforce developers to seek public consultation.
- Identification of a formal appeal procedure with the option of a public inquiry.
- Identification of the stages where a positive or negative decision on the development can be made by the planning/control authorities, and, if an appeal is made, which body has the final decision.
- Provisions, legal or otherwise, required to punish noncompliance with EIA preparation or an inadequate EIA.
- Periodic reassessment of the EIA during construction and operation of the development.

The World Bank has produced an "Operational Directive" (No. OD 4.00) on the general content of an EIA report. In addition, recent WHO activities in the Western Pacific included the preparation of a detailed set of guidelines for conducting EIAs for municipal waste landfill sites. Both of these texts are reproduced in this Appendix for reference.

THE WORLD BANK OPERATIONAL MANUAL	October 1989
Operational Directive	OD 4.00—Annex A1

Sample Outline of a Project-Specific Environmental Assessment (EA) Report

(This directive was prepared for the guidance of staff of the World Bank and is not necessarily a complete treatment of the subjects covered.)

1) EA reports should be concise and limited to significant environmental issues. The detail and sophistication of analysis should be commensurate with the potential impacts. The target audience should be project designers, implementing agencies, and borrower and Bank staff.

2) The EA report should include:

a) *Executive Summary.* Concise discussion of significant findings and recommended actions.

b) *Policy, legal, and administrative framework* within which the EA is prepared. The environmental requirements of any cofinanciers should be explained.

c) *Project description* in a geographic, ecological, social, and temporal context, including any off-site investments that may be required by the project (e.g. dedicated pipelines, access roads, power plants, water supply, housing, and raw material and product storage facilities).

d) *Baseline Data.* Dimensions of the study area and description of relevant physical, biological, and socioeconomic conditions, including any changes anticipated before the project commences. Current and proposed development activities within the project area (but not directly connected to the project) should also be taken into account.

e) *Environmental Impacts.* The positive and negative impacts likely to result from the proposed project should be identified and assessed. Mitigation measures and the residual impacts that cannot be mitigated should be identified/estimated. Opportunities for environmental enhancement should be explored. The extent and quality of available data, key data gaps, and uncertainties associated with predictions should be identified/estimated. Topics that do not require further attention should be specified.

f) *Analysis of Alternatives.* Proposed investment design, site, technology, and operational alternatives should be compared systematically in terms of their potential environmental impacts; capital and recurrent costs; suitability under local conditions; and institutional, training, and monitoring requirements. To the extent possible, for each of the alternatives, the environmental costs and benefits should be quantified, and economic values attached where feasible.

g) *Mitigation Plan.* Feasible and cost-effective measures which may reduce potentially significant adverse environmental impacts to acceptable levels should be proposed, and the potential environmental impacts, capital and recurrent costs, and institutional and training requirements of those measures estimated. The plan (sometimes known as an "action plan" or "environmental management plan") should provide details on proposed work programs and schedules, to ensure that the proposed environmental actions are in phase with engineering activities throughout preparation. The plan should consider compensatory measures if mitigation measures are not feasible or cost-effective.

h) *Environmental Management and Training.* The existence, role, and capability of environmental units at the on-site, agency, and ministry level should be assessed, and recommendations made concerning the establishment and/or expansion of such units, and the training of staff, to the point that EA recommendations can be implemented.

i) *Monitoring Plan* regarding environmental impacts and performance. The plan should specify the type of monitoring, who would do it, how much it would cost, and what other inputs (e.g. training) are necessary.

Appendices

(i) List of EA preparers – individuals and organizations

(ii) References – written materials used in study preparation. This is especially important given the large amount of unpublished documentation often used.

(iii) Record of Inter-Agency/Forum Meetings, including list of both invitees and attendees. Where the views of affected groups and local NGOs were obtained by other means, these should be specified.

WHO Western Pacific Region

GUIDELINES FOR SCOPING ENVIRONMENTAL IMPACT ASSESSMENT OF MUNICIPAL SOLID WASTE LANDFILL

1. Project Description

The project description should address activities and estimated periods of the following phases of the landfill project:

- site preparation and construction (construction phase)
- landfilling operation (operation phase)
- closure and post-closure care (post-closure phase)

1.1 Construction phase

It should specifically contain descriptions on the following activities or information:

- clearing, levelling, and/or excavating of the site
- construction/reinforcement of dikes/bunds
- construction/reinforcement of access and on-site roads
- construction/reinforcement of surface run-on and run-off drainage channels
- construction or laying down of liners
- construction of leachate collection and retention systems
- construction of leachate re-circulation or treatment facilities
- construction of landfill gas ventilation/collection system
- setting up of monitoring facilities for ground/surface water, air and noise pollution
- construction/provision of fences, gate, office, weighbridge, water and power supplies, sanitation facilities, garage and workshop for heavy equipment and vehicles, cover soil, stockyard, and other facilities
- estimate of traffic volume during the site preparation and construction phase

1.2 Operation phase

- projected volume of the site for the landfill operation period
- projected volume and composition/characteristics of solid waste to be landfilled
- projected volume and type of cover material
- operational plan or schedule for landfilling
- levelling, covering, and compacting of solid waste
- extension/construction of on-site roads
- on/near-site excavation/trenching of soil for cover material
- estimate of traffic volume during the landfilling operation phase

1.3 Post-closure phase

- projected volume and type of final cover material including top soil
- landfill closure process detailing final capping schedule, removal/abandonment of facilities, setting up monitoring facilities for post-closure care, etc.
- projected final topography of the site
- post-closure monitoring, inspection and maintenance plan
- post-closure land use plan

1.4 General items applicable to all phases

- projected cost of construction, operation and maintenance of the site and facilities mentioned above
- contingency plan for natural and human-caused emergencies
- project site plans (e.g., 1:2,500 or 1:5,000) and design drawings showing the site and facilities, and maps (e.g., 5 km x 5 km area) showing the location of nearby human settlements and other land uses

2. Description of Existing Environment

The items that must be included in this section are categorically discussed below. As much as possible, existing information should be collected and used. However, site-specific field surveys are usually required to supplement the existing information.

When conducting the field surveys, samples should be taken at all locations where the site preparation, construction, landfilling operation, closure and post-closure care can affect environmental quality. Sampling stations and selection criteria for these specific locations should be given. Analytical methods and dates of sampling should be stated. Analytical results should be presented with absolute levels of accuracy and precision. All data should be summarized textually and preferably be presented graphically

2.1 Terrain and land use

- general and topographic map(s) (e.g., 1:50,000) showing the project site, the surrounding municipalities, water bodies, forests, etc.
- present land use
- relevant color photographs of the project site

2.2 Geology

- surficial geology of the project site and the surrounding areas
- soil characteristics of the project site (e.g., permeability, porosity, density, vertical profile, organic content, etc.)
- geological hazards, slope stability, past occurrence of earthquakes and landslides, seismological survey

2.3 Meteorology

- general climatological description of the project region
- meteorological data (gathered at the project site or taken from the nearest meteorological station), including
  - temperature (monthly averages)
  - rainfall (monthly averages), intensity (24-hour duration), number of rainy days
  - wind (frequency distribution of strength and direction, presented in wind roses)
  - occurrence of natural hazards such as typhoons

2.4 Hydrology and water resources

- surface hydrology of the project site and surroundings: natural drainage patterns, delineation of watershed and subwatersheds, stream flow rates at gauging stations, and estimates of discharges or flow rates at the project site, and seasonal changes in the flow rates

- subsurface hydrology of the project site and surroundings: groundwatershed, groundwater table, and estimates of groundwater flow rates
- water resources and uses in the watershed: drinking-water wells, reservoirs, springs, commercial and sport fisheries, irrigation, etc.

2.5 *Terrestrial ecology*

- survey of wildlife and vegetation: apparent species of fauna and flora, relative abundance, etc.
- utility or values (e.g., commercial or aesthetic), and indication whether it is rare or endangered

2.6 *Water quality and aquatic ecology*

- apparent aquatic organisms in the main freshwater environment (e.g., phytoplankton, zooplankton, macrophytes, benthic organisms, fish, shellfish, and water fowl)
- apparent aquatic organisms in marine waters (e.g., phytoplankton, zooplankton, vegetation, corals, fish, shellfish, and water fowl) for coastal reclamation project
- mixing and wave patterns, tides and vertical horizontal temperature profiles of marine waters for coastal reclamation project
- ambient water quality measurements of fresh, marine and groundwater, for the following parameters
  - acidity (pH), color, salinity
  - temperature, turbidity and suspended solids
  - dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and Cl levels
  - silica, sulphate, phosphate, ammonium, nitrate, nitrite
  - levels of metals, including heavy and trace metals (e.g., Si, Al, Fe, Ca, Ti, Mg, Na, K, Zn, Hg, Pb, Cu, Cr, As, Cd, Mn, and Se)

2.7 *Air quality and noise*

- ambient noise levels at and near the project site
- ambient levels of sulphur and nitrogen oxides and of particulates
- levels of odor at or near the project site

2.8 *Socioeconomic environment*

The EIA should include a socioeconomic profile of the municipalities adjacent to the project site. The information should include the following:

- administrative boundaries
- population, its distribution, density, and characteristics (age, sex, ethnic groups, and education level)
- industries, employment and productivity statistics
- transportation and traffic conditions
- health status data including morbidity and mortality rates available (data from direct impact areas should gathered, otherwise data from the municipality can be used), and health care facilities
- description about the community lifestyle(s), the present community needs and problems, the local peace, and other situations
- number of households that will be directly affected by the project
- perception study of the proposed project, based on interviews with the people who will be affected by the project activities (negative survey results will not necessarily result in project denial). A copy of the interview questionnaire should be appended.

The following requirements apply to the above perception study:

- The number of people questioned should be in the range of 10% to 25% of affected families in the community. However, in case the project affects a large population (more than 5000 people), the covered percentage can be less, but at a level that is generally considered as representative in social sciences.
- The results of the conducted survey and interviews should be presented in numbers and percentage points.
- The location of the surveyed households must be indicated on a map, to make an assessment on the representability of the survey possible.

2.9 Future project site without project implementation

The EIA should include a discussion on the future and developments of the project site and surroundings without the implementation of the proposed project.

3. Assessment of Environmental Impacts

The environmental impacts of site preparation, construction (construction phase), landfilling operation (operation phase), and closure and post-closure care (post-closure phase) of a municipal solid waste landfill project must be discussed quantitatively and qualitatively. The items that should be particularly addressed are given below:

3.1 Geology and hydrology

(1) Construction and operation phases

- erosion and sedimentation problems during and following site clearing and levelling, soil covering, etc.
- changes in drainage patterns which may affect water resources and wildlife habitat
- likelihood of flooding and landslides due to changes in geomorphology and slope stability

(2) Post-closure phase

- land subsidence due to decomposition of organic waste

3.2 Water quality

(1) Construction phase

- increase in turbidity of surface water due to surface soil erosion and airborne dust deposition

(2) Operation phase

- increase in turbidity of surface water due to surface soil erosion and airborne dust deposition
- increase in suspended solids, BOD, and other pollutants due to solid waste entering surface water bodies
- surface water pollution due to leachates from the site
- groundwater pollution due to leachates from the site
- residual impacts on water quality when leachate collection and treatment facilities are provided

- impacts on water quality due to structural failure, surface drainage and leachate collection and treatment facilities

(3) Post-closure phase

- all the items as in construction and operation phases if final cover, surface drainage, and leachate collection and treatment facilities are not provided
- impacts on water quality due to structural failure of final cover, surface drainage, and leachate collection and treatment facilities

3.3 *Air quality and noise*

(1) Construction phase

- dust and particulates during site clearing, levelling, excavating, etc., and access road construction
- sulphur and nitrogen oxides, carbon monoxide, etc. from vehicle emission
- noise due to traffic and heavy equipment works

(2) Operation phase

- all the items as in construction phase
- airborne or windblown particulates of solid waste
- odor and biogas due to biodegradation of organic waste
- toxic gas from chemical waste
- particulates and toxic gas due to open burning

(3) Post-closure phase

- all the items as in operation phase if final cover and appropriate gas extraction and disposal systems are not provided

3.4 *Flora and fauna*

(1) Construction and operation phases

- removal of vegetation and wildlife habitat due to site clearing, levelling, etc.
- general disturbance of wildlife in the surrounding areas due to increased traffic and heavy equipment works

(2) Post-closure phase

- site rehabilitation works including revegetation
- disturbance due to water quality degradation and gas emission

3.5 *Visual impacts*

(1) Construction and operation phases

- loss of green due to removal of vegetation
- changes in landscape

(2) Post-closure phase

- revegetation works; and
- final topography not well matched with the surrounding landscape

3.6 Socioeconomic and cultural impacts

(1) Construction and operation phases

- resettlement of people living on or around the project site
- potential decreases in crop yields and fish catch, due to water pollution or decreased water availability
- impacts of enhanced traffic: dust, noise, and safety
- potentially increased risk of open and subsurface fire
- public health problems due to the breeding of flies and vermin
- health and sanitation problems due to inadequate housing and sanitation structures of the laborers
- compromised safety of workers due to inadequate provision of facilities and equipment
- peace and order problems due to strong increase in the number of nonlocal laborers

(2) Post-closure phase

- post-closure land use and increase/decrease in land value
- residual fire hazards and toxic gas emission

4. Mitigating Measures

The EIA should list and discuss all necessary mitigating measures to minimize the identified adverse impacts. As mentioned earlier, for a municipal solid waste landfill project, the structural and operational mitigation measures are normally incorporated in the design and operational management plan. Some commonly applied mitigation measures are given below:

4.1 Geology and hydrology

(1) Construction and operation phases

- construction of dikes/bunds, drainage channel, and culverts to control hydrology
- vegetation cover, sediment traps, and planting of stripped areas to prevent erosion and siltation
- design consideration for the slope of landfill, and contingency planning for landslides and flooding

(2) Post-closure phase

- post-closure land use plan to prevent construction of heavy structures

4.2 Water quality

(1) Construction and operation phases

- sediment traps and planting of stripped areas to prevent erosion and siltation
- construction of a drainage system to collect polluted surface run-off
- application of liners to intercept leachates
- construction of leachate collection systems
- construction of a wastewater/leachate treatment system to treat polluted surface run-off and/or leachates

(2) Post-closure phase

- application of final cover to reduce surface water pollution
- design of final slope to reduce leachate production
- contingency planning for structural failure

4.3 *Air quality and noise*

(1) Construction phase

- minimization of dust generation by sprinkling stockpiles of removed earth and dusty roads with water
- choose working hours and use larger vehicles to reduce noise and air pollution levels due to traffic

(2) Operation phase

- all the items as in construction phase
- application of daily cover soil to prevent odor emission and airborne waste
- application of mobile fence to reduce windblown waste
- construction of biogas collection and disposal systems
- limiting the entry of hazardous/toxic waste

(3) Post-closure phase

- application of final cover to prevent airborne waste; and
- contingency planning for possible structure failure

4.4 *Flora and fauna*

(1) Construction and operation phases

- construction of buffer zones by planting trees, etc.
- construction of artificial wildlife habitat such as artificial wetlands

(2) Post-closure phase

- revegetation of the site

4.5 *Visual impacts*

(1) Construction and operation phases

- construction of green buffer zones by planting trees, etc.

(2) Post-closure phase

- revegetation of the site
- design of final topography considering the surrounding landscape and future land use

4.6 *Socioeconomic and cultural impacts*

- compensation measures for affected or resettled people
- planning for information campaign and dialogue with the population affected by the proposed project
- improvement of working environment, including protection measures for employees such as the provision of training, and safety hats and glasses, respiratory and hearing protection devices, first aid kits, etc.
- contingency plan involving local communities and workers

5. Monitoring

The EIA should contain an extensive monitoring program for parameters included in the baseline studies. The following guides could be used in the formulation of the monitoring program:

- Monitoring should be carried out through the entire project period including post-closure care.
- Sampling should be done at the same locations as in the baseline data survey and at effluent release points to check whether permit requirements are met.
- Samples should be collected and analyzed, using the norms and standard procedures for the monitoring of environmental quality and emissions as far as available.
- Corrective measures should be specified when the monitoring indicates the levels of impacts are not permissible.

It is common for municipalities and other developers of landfill sites to contract specialist individuals and organizations to prepare EIAs. An example terms of reference, prepared by the World Bank (1991), is given below for future consideration by those responsible for organizing the preparation of an EIA.

Sample Terms of Reference (TOR) for Environmental Assessment
(Name of Project Category)

Note: Comments in **[brackets and boldface type]** in this TOR Outline indicate where content may have been included, excluded, or modified in the project-specific sample TORs. When combined, the TOR Outline and the project-specific sample TORs provide comprehensive guidance for TOR preparation. Paragraph numbers in each correspond for ease of reference.

1. Introduction. This section should state the purpose of the terms of reference, identify the development project to be assessed, and explain the executing arrangements for the environmental assessment.

2. Background information. Pertinent background for potential parties who may conduct the environmental assessment, whether they are consultants or government agencies, would include a brief description of the major components of the proposed project, a statement of the need for it and the objectives it is intended to meet, the implementing agency, a brief history of the project (including alternatives considered), its current status and timetable, and the identities of any associated projects. If there are other projects in progress or planned within the region which may compete for the same resources, they should also be identified here.

3. Objectives. This section will summarize the general scope of the environmental assessment and discuss its timing in relation to the processes of project preparation, design, and execution.

4. Environmental Assessment Requirements. This paragraph should identify any regulations and guidelines which will govern the conduct of the assessment or specify the content of its report. They may include any or all of the following:
   - World Bank Operational Directive 4.00, Annex A: "Environmental Assessment," and other pertinent ODs, OMSs, OPNs, and Guidelines
   - national laws and/or regulations on environmental reviews and impact assessments
   - regional, provincial or communal environmental assessment regulations
   - environmental assessment regulations of any other financing organizations involved in the project

5. Study Area. Specify the boundaries of the study area for the assessment (e.g., water catchment, airshed). If there are any adjacent or remote areas which should be considered with respect to the development these should be noted.

6. Scope of Work. In some cases, the tasks to be carried out by a consultant will be known with sufficient certainty to be specified completely in the terms of reference. In other cases, information deficiencies need to be alleviated or specialized field studies or modelling activities performed to assess impacts, and the consultant will be asked to define particular tasks in more detail for contracting agency review and approval. Task 4 in the Scope of Work is an example of the latter situation.

7. Task 1. Description of the Proposed Project. Provide a brief description of the relevant parts of the project, using maps (at appropriate scale) where necessary, and including the following information: location; general layout; size, capacity, etc.; pre-construction activities; construction activities; schedule; staffing and support; facilities and services; operation and maintenance activities; required off-site investments; and life span. **[Note: there may be particular types of information appropriate in the description of the project category you are concerned with. Please specify them here.]**

8. Task 2. Description of the Environment. Assemble, evaluate and present baseline data on the relevant environmental characteristics of the study area. Include information on any changes anticipated before the project commences. **[Annotate or modify the lists below to show the critical information for this project category, or that which is irrelevant to it. You should particularly avoid compiling irrelevant data.]**

   (a) Physical environment: geology; topography; soils; climate and meteorology; ambient air quality; surface and groundwater hydrology; coastal and oceanic parameters; existing sources of air emissions; existing water pollution discharges; and receiving water quality.

   (b) Biological environment: flora, fauna; rare or endangered species; sensitive habitats, including parks or preserves, significant natural sites, etc.; commercially important species; and species with potential to become nuisances, disease vectors, or dangerous.

   (c) Sociocultural environment (include both present and projected where appropriate): population; land use; planned development activities; community structure; employment; distribution of income, goods and services; recreation; public health; cultural properties; tribal peoples; and customs, aspirations, and attitudes.

9. Task 3. Legislative and Regulatory Considerations. Describe the pertinent regulations and standards governing environmental quality, health and safety, protection of sensitive areas, protection of endangered species, siting, land use control, etc., at international national, regional and local levels (The TOR should specify those that are known and require the consultant to investigate for other.)

10. Task 4. Determination of the Potential Impacts of the Proposed Project. In this analysis, distinguish between significant positive and negative impacts, direct and indirect impacts, and immediate- and long-term impacts. Identify impacts which are unavoidable or irreversible. Wherever possible, describe impacts quantitatively, in their environmental costs and benefits. Assign economic values when feasible. Characterize the extent and quality of available data, explaining significant information deficiencies and any uncertainties associated with predictions of impact. If possible, give the TOR for studies to obtain the missing information. **[Identify the types of special studies likely to be needed for this project category.]**

11. Task 5. Analysis of Alternatives of the Proposed Project. Describe alternatives that were examined in the course of developing the proposed project and identify other alternatives, which would achieve the same objectives. The concept of alternatives extends to siting, design, technology selection, construction techniques and phasing, and operating and maintenance procedures. Compare alternatives in terms of potential environmental impacts; capital and operating costs; suitability under local conditions; and institutional, training, and monitoring requirements. When describing the impacts, indicate which are irreversible or unavoidable and which can be mitigated. To the extent possible, quantify the costs and

benefits of each alternative, incorporating the estimated costs of any associated mitigating measures. Include the alternative of not constructing the project, in order to demonstrate environmental conditions without it.

12. Task 6. Development of Management Plan to Mitigate. Negative Impacts. Recommend feasible and cost-effective measures to prevent or reduce significant negative impacts to acceptable levels. Estimate the impacts and costs of those measures, and of the institutional and training requirements to implement them. Consider compensation to affected parties for impacts which cannot be mitigated. Prepare a management plan including proposed work programs, budget estimates, schedules, staffing and training requirements, and other necessary support services to implement the mitigating measures.

13. Task 7. Identification of Institutional Needs to Implement Environmental Assessment Recommendations. Review the authority and capability of institutions at local, provincial/regional, and national levels and recommend steps to strengthen or expand them so that the management and monitoring plans in the environmental assessment can be implemented. The recommendations may extend to new laws and regulations, new agencies or agency functions, intersectoral arrangements, management procedures and training, staffing, operation and maintenance training, budgeting, and financial support.

14. Task 8. Development of a Monitoring Plan. Prepare a detailed plan to monitor the implementation of mitigating measures and the impacts of the project during construction and operation. Include in the plan an estimate of capital and operating costs and a description of other inputs (such as training and institutional strengthening) needed to carry it out.

15. Task 9. Assist in Inter-Agency Coordination and Public/NGO Participation. Assist in coordinating the environmental assessment with other government agencies, in obtaining the views of local NGOs and affected groups, and in keeping records of meetings and other activities, communications, and comments and their disposition. (The TOR should specify the types of activities; e.g., interagency scoping sessions, environmental briefings for project staff and interagency committees, support to environmental advisory panels, public forums.)

16. Report. The environmental assessment report should be concise and limited to significant environmental issues. The main text should focus on findings, conclusions and recommended actions, supported by summaries of the data collected and citations for any references used in interpreting those data. Detailed or uninterpreted data are not appropriate in the main text and should be presented in appendices or a separate volume. Unpublished documents used in the assessment may not be readily available and should also be assembled in an appendix. Organize the environmental assessment report according to the outline below:

    - Executive Summary
    - Policy, Legal, and Administrative Framework
    - Description of the Proposed Project
    - Description of the Environment
    - Significant Environmental Impacts
    - Analysis of Alternatives
    - Mitigation Management Plan
    - Environmental Management, and Training
    - Monitoring Plan
    - Inter-Agency and Public/NGO Involvement

- List of References
- Appendices:
  - List of Environmental Assessment Preparers
  - Records of Inter-Agency and Public/NGO Communications
  - Data and Unpublished Reference Documents

(This is the format suggested on page 60, in World Bank OD 4.00, Annex A-1; the TOR may specify a different one to satisfy national agency requirements as long as the topics required in the Bank's directive are covered.)

17. Consulting Team.

    [Environmental assessment requires interdisciplinary analysis. Identify in this paragraph which specializations ought to be included on the team for the particular project category.]

18. Schedule. Specify dates for progress reviews, interim and final reports, and other significant events.

19. Other Information. Include here lists of data sources, project background reports and studies, relevant publications, and other items to which the consultant's attention should be directed.

Chapter 4 Site Design and Preparation

4 SITE DESIGN AND PREPARATION

4.1 Main Points

Landfilling can be thought of as a civil engineering construction project in which the main source of ground-forming material is solid waste. Many of the skills required to plan, design, and execute a solid waste landfill project are the same as those required for, say, a road construction project.

The purpose of a detailed design for developing a better landfill is to provide a way of communicating (by drawings and specifications) how the landfill designer intends the site to be developed. It should be sufficiently detailed to define how, where, and when

- the site is to be prepared for accepting wastes
- wastes are to be landfilled and water will be controlled
- the site is to be restored
- monitoring is to be carried out to ensure the site has been developed, operated, and closed down in accordance with design

Careful attention to detail in the design of a better landfill can avoid, or at least reduce significantly, future operational problems. The ability to appreciate the practical and logistical problems of delivery, discharge, compaction, and covering of waste, in the quantities anticipated, is essential to planning and designing the landfill.

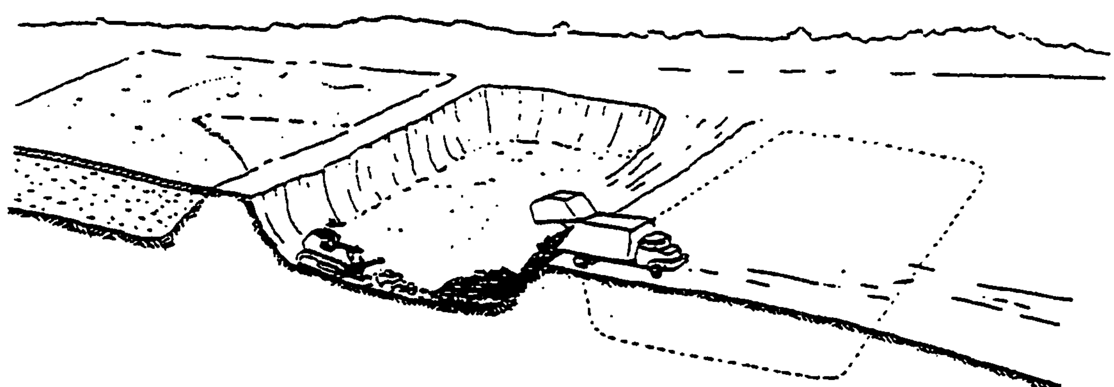
There are three general ways of landfilling depending upon local topography and landscape: the "trench," "ramp," or "area" methods (Figures 4.1a, b, and c). A trench landfill is usually located an area of flat land where the soil has been excavated and waste is deposited into the void. The stockpiled soil is then used to cover the waste. A ramp landfill is usually where a low bank is present or created and waste is deposited along one side. Soil excavated from the front of the face of the waste ramp is used to cover the waste. These two methods are usually confined to sites serving smaller population centers since the amount of soil excavation necessary to prepare the sites becomes very high where larger quantities (perhaps over 100 t/day) of waste have to be handled. In addition, it is difficult to control water movement through these sites or construct effective drainage control systems.

The most common method of landfilling is the area landfill. It can be constructed in a natural depression, excavated mineral workings, or built above ground into a hill. This type of landfill permits more waste to be placed on the same surface area than the other two techniques. Furthermore, waste is built up in layers vertically to form a rounded, domed site when complete, and not horizontally across the landscape as with the other two types of landfill (Figures 4.2a and b). Each layer is usually made up of a series of "cells" across the site, with each cell representing one to three months input of waste and separated from other cells by soil cover material (Figure 4.2c). Inside every cell it is suggested that the waste from each day is covered with a thin layer of soil to separate it from scavenging animals, improve the surface for vehicles traversing the site, and reduce the dispersal of waste by the wind (Figure 4.2d).

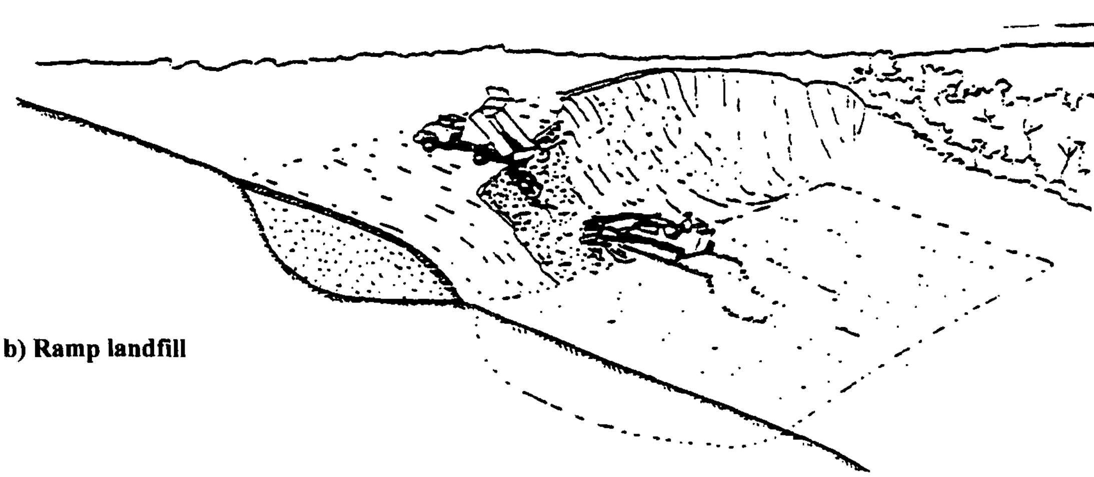
Controlling the movement of water into and out of a landfill is essential to designing a good site. This also means controlling leachate movement from a landfill site. The design of a landfill can follow one or two basic options for its control. It can either (1) provide complete hydrogeological isolation of the site from its environment and permit only controlled discharge of leachate after treatment to an appropriate quality standard; or (2) permit leachate to attenuate by gradually seeping through the soils immediately underlying the waste before entry into the groundwater.

Wherever possible, the design of a landfill should minimize the risk to public health and the environment in the event of failure of its construction and operation to meet planned design standards. Generally, this implies assuming only the minimum reliance on the

- continuous supply of power or fuel at the site
- the operation and maintenance of sophisticated or expensive mobile plant
- operation and maintenance of pumps, blowers, and other mechanical and electrical equipment associated with leachate or gas control
- long-term integrity of artificial liner systems

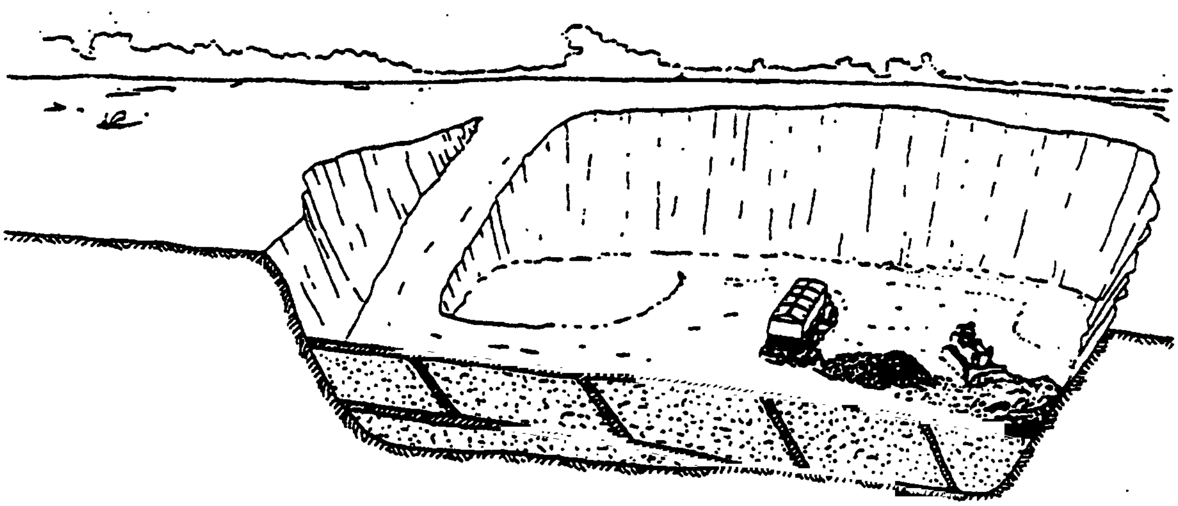


a) Trench landfill



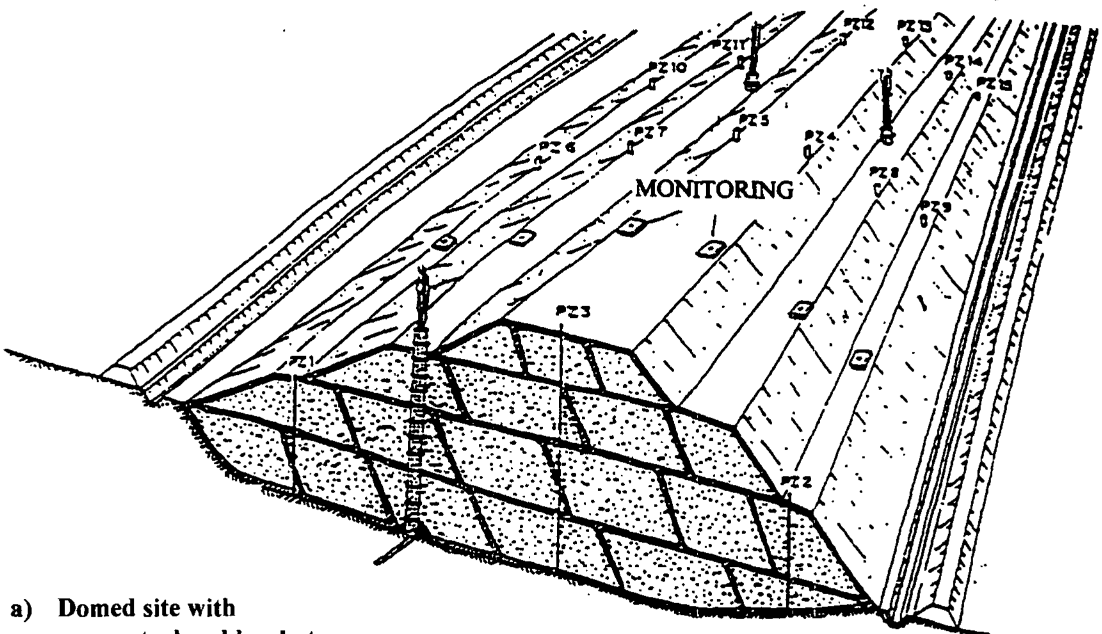
b) Ramp landfill

Figures 4.1a,b Types of landfill sites
(Source: IPT-CEMPRE 1995)

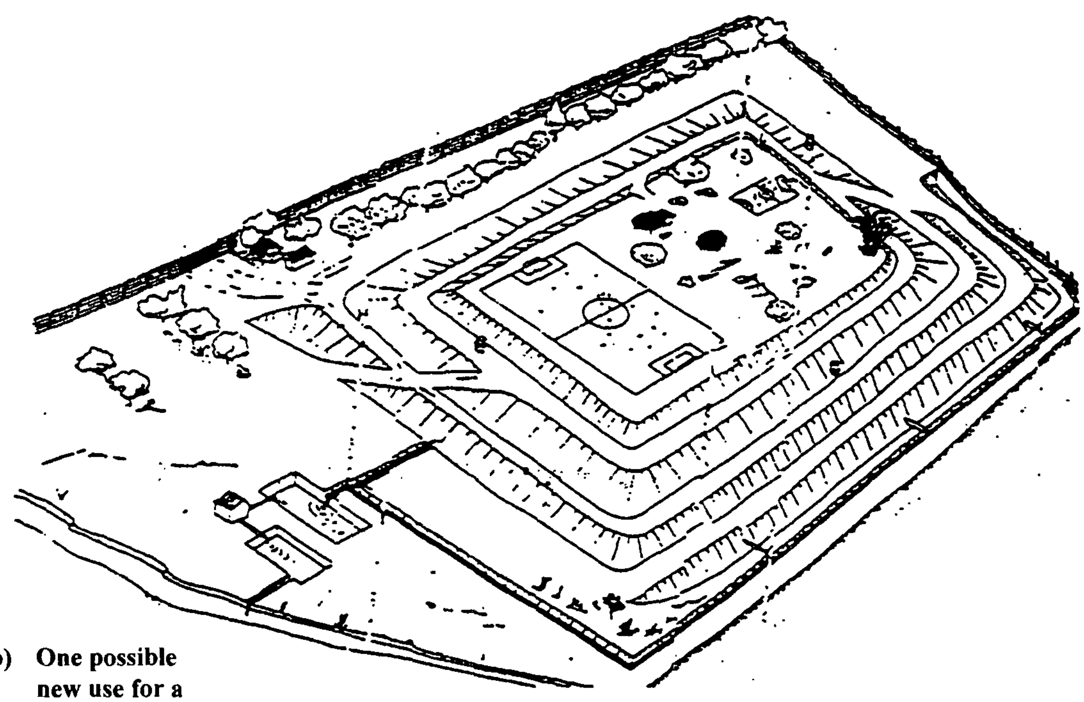


c) Area landfill

Figure 4.1c Types of landfill sites
(Source: IPT-CEMPRE 1995)

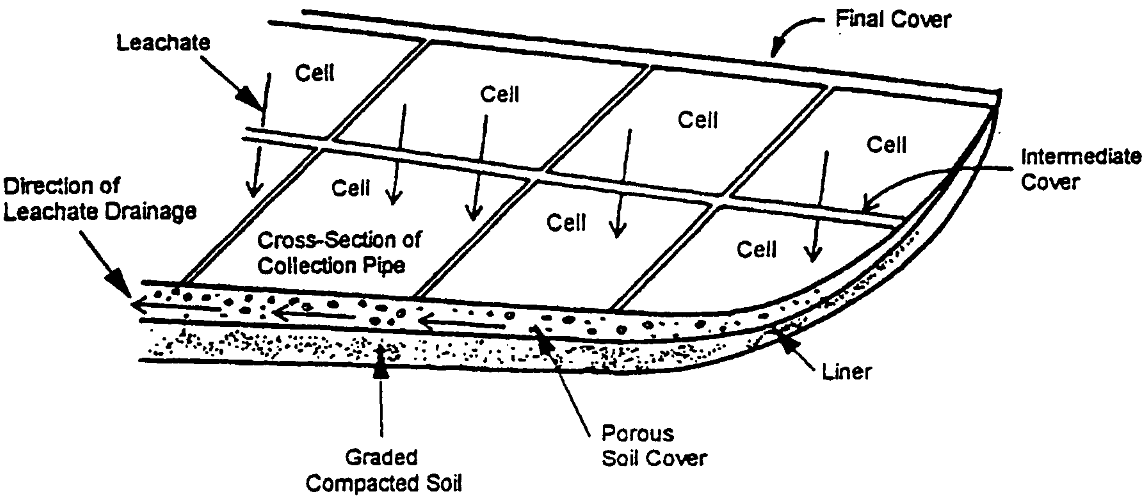


a) **Domed site with gas control and leachate monitoring points**

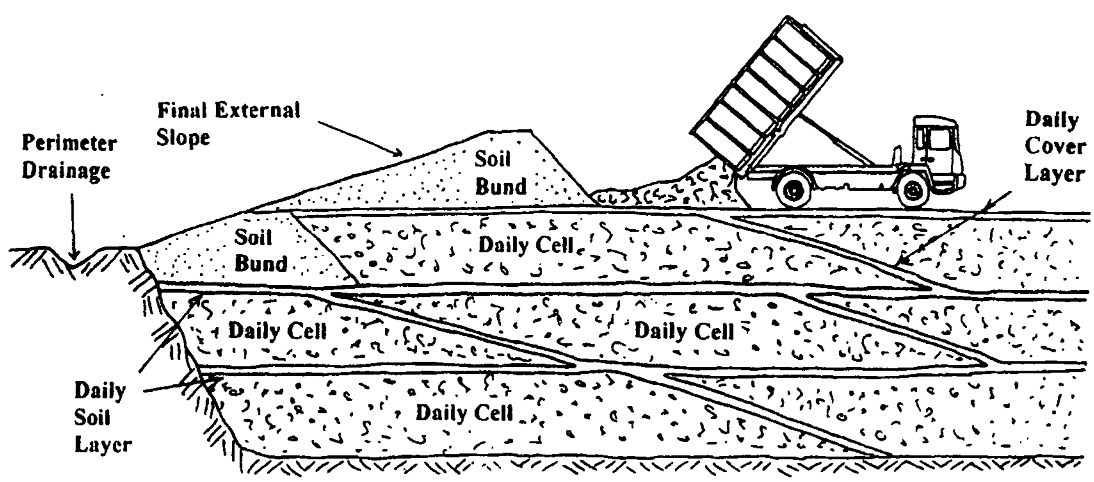


b) **One possible new use for a completed landfill**

Figures 4.2a,b Examples of completed landfill
(Source: IPT-CEMPRE 1995)



c) **The cellular structure of a landfill: Each cell could represent sufficient volume for one to six months of waste filling**



d) **Daily placement (one-day cell) of waste within one larger cell of a landfill**

Figures 4.2c,d Examples of completed landfills
(Source: Diaz et al. 1996)

The choice of options for leachate control largely affects how the site should be prepared for accepting wastes. The containment and treatment option is significantly more expensive to develop and operate. It requires a high level of quality control during site preparation, and a commitment to maintenance for a period well beyond the operational life of the landfill.

An emerging technology for leachate control and treatment is the construction and operation of a landfill as an anaerobic bioreactor. In such designs, collected leachate is recycled within the body of the waste, which has the effect of accelerating the anaerobic biodegradation processes and hastening the stabilization of the wastes. However, there remains insufficient operational experience on using this technology and it requires a significantly enhanced level of technical control (and risk of failure). Consequently, at the present time, it would not normally be considered appropriate to adopt the anaerobic bioreactor design concept in middle- or lower-income countries just beginning to develop upgraded landfills.

Consideration should be given to possible phasing of development (preparation) of the landfill so that the cost of some site preparation, not required for some time, may be deferred. This requires a disposal plan (sequence) to be identified as part of the design process. As part of this plan, areas of the site need to be identified for the temporary stockpiling of soil material removed from those parts of the site prepared for landfilling activities.

The design needs to cover the sequence of areas to be filled with waste, the provision of good quality access to and around the site, and reception facilities (Figure 4.3). The provision of semi-permanent and temporary vehicular access to the waste tipping face is needed. It will change periodically according to the disposal plan. In most climates, an area needs to be set aside to accept waste when bad weather prevents access to the normal working area.

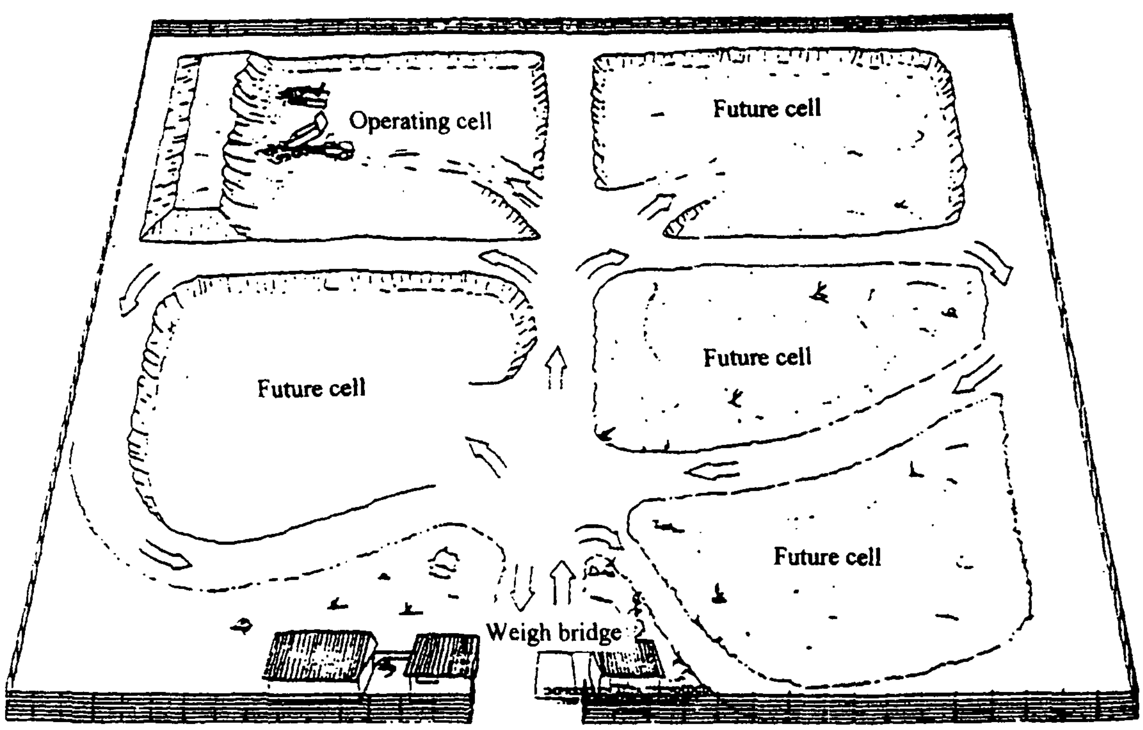


Figure 4.3 General example of the basic landfill site infrastructure
(Source: IPT-CEMPRE 1995)

4.2 Key Decisions

Having identified a preferred site for the development of an upgraded landfill, the municipality will be faced with two fundamental questions:

Does it have the technical resources to design and operate landfill?
(and if not, how can it acquire the necessary skills?)

What standards of design and operation are to be adopted?

Arising from these fundamental issues are two further questions of operational policy which will affect the basis of design of the upgraded landfill:

Will the landfill use mobile equipment for waste placement, or manual methods?

Should scavengers (waste pickers, informal recyclers) be permitted to operate at the site?

4.2.1 Availability of technical resources

The first question to be addressed by a municipality committed to developing an upgraded landfill is whether it has the technical resources to design, develop, and operate such a facility. A range of professional skills should be applied to the project, including the key disciplines of

- waste management
- civil engineering
- hydrogeology
- geotechnical engineering
- hydrology

A "project team approach," under the management of an experienced civil engineer, is regarded as the best way to develop a new landfill. The municipality must decide whether such a team can be assembled from within its own organization, whether members need to be brought in from other organizations, or whether part or whole of the project will have to be carried out by outside agencies (for example design institutes, consultants, or waste management contractors).

It would also be advisable to keep the organizations which were involved in the site identification exercise (Section 3.2) informed of key aspects of the landfill's design, development and operation.

4.2.2 Standard of design and operation

The second key issue to be decided by the municipality is the standard of landfilling to be adopted which will be reflected in the design and realized in the construction, operation and subsequent restoration and aftercare. How far down the shopping list of desirable improvements to the minimum standards should the municipality go, and how much can it afford? The landfill designer needs a written brief, setting out the basic performance criteria for the landfill which must be met and, where appropriate, a list of enhancements which may be added if the estimated cost of the basic design comes within the municipality's project budget.

This brief should cover criteria such as

- the intended end use of the site
- any site specific limitations on the use of the site for landfilling or associated activities
- the legal requirements, codes of practice and design standards which are to be met
- environmental emission standards, including emissions to ground and surface water, air, and noise
- site security, screening, infrastructure, and amenities (e.g., power, water, telephone)
- the program for design and development (including reporting of progress, approvals, etc.)
- clear capital and operating budgets for the project

4.2.3 Use of mechanical equipment

While it is easier to deposit waste carefully in a landfill using a bulldozer or similar mechanical equipment, for smaller sites (e.g., receiving less than 50 t/day) it is not necessarily essential. Manual operation (i.e., without the use of mechanical earthmoving equipment) can be effective if no machines are available and there is a plentiful supply of manual labor. Controlled landfilling using manual placement of waste is successfully operated in some smaller towns and cities in South America. A combination of the manual and mechanized approaches could be considered where the continuous service of a bulldozer cannot be guaranteed. The advantages and disadvantages of each approach are compared in Table 4.1 and discussion on manual landfilling procedures is given in Appendix 4.A.

4.2.4 Permitting waste scavenging

Scavenging is the unofficial picking through waste to recover useful items. By its nature, scavenging is disruptive to good landfill operation. Ideally, it should not be allowed to take place. However, in many places it is inevitable. If scavenging is to be allowed it should be controlled. The possibility may also exist to assimilate scavengers into the landfill workforce in the future.

The main concerns about scavenging activities are

- health and safety hazards to both scavengers and landfill employees
- interference with the efficient conduct of work at the site causing a reduction in the productivity of the equipment through delays in waste compaction and the application of soil cover
- the setting of fires

To tolerate the presence of scavengers requires decisions on how best to enable them to sort through the waste without interfering with the subsequent placement and covering of waste in the landfill. Additional practical information is presented in Section 4.4.2.

4.3 General Principles

The general philosophy of upgraded landfilling is to dispose of waste to land in a way that reduces to an acceptable level any adverse impact those wastes might have on the environment. The key objective of an upgraded landfill design should therefore be to identify what constitutes an acceptable level of adverse impact and to ensure, by the landfill design, construction, and method of operation, that this level is not exceeded.

Manual	Mechanized
Effective for small sites handling up to 50 t/day. Little experience for larger sites.	No limit on how large or small a site's daily tonnage.
Wastes in storage containers from higher-income countries have lower densities (e.g., 0.1 to 0.3 t/m3). Wastes from other countries can be around 0.4 to 0.5 t/m3. The manual placement of light, low-density waste is difficult and occupies a larger initial volume (e.g. 0.3 t/m3). The manual placement of denser wastes in middle- or lower-income countries is more manageable with a landfilled density of about 0.5 t/m3 (Flintoff 1976).	The weight of mechanized equipment can achieve higher initial densities (say 0.6 to 1 t/m3) and so requires less landfill volume. This improvement in density achieved on placement over manual approaches is much smaller for the more dense wastes from lower income countries. Therefore, emphasis on the better compaction capabilities of mechanized equipment is less important.
Manual waste emplacement is relatively lower in cost. This advantage is lost if wage costs become high and closer to the cost of operating mechanical equipment. Potential occupational hazards are increased from manual handling of some wastes.	Mechanical equipment requires expensive fuel, servicing and spare parts, and relies on technical competence to maintain in operation. More intensive training is required for operators of equipment.
Additional labor is required to excavate and spread soil cover material.	Some mechanical equipment can do this function in addition to waste placement.

Table 4.1 Comparison of manual and mechanical waste placement

The wide range of impacts that might be caused by a landfill was indicated in Figure 3.5. The most common areas of concern, on which guidance is appropriate, include

- contamination of groundwater by leachate
- pollution of surface water by leachate
- health and safety risks from gaseous emissions
- enhanced health risks from pests and animals transmitting infections

4.3.1 Groundwater protection

The concern which usually has the greatest influence on landfill design is that of minimizing contamination of groundwater by leachate. Leachates are formed by the passage of water through waste materials, picking up contaminating substances in solution or suspension. The quantity and strength of leachate depends on the local climate, the nature of the wastes, and the measures taken to control the entry of water into the wastes. However, it should be noted that in arid climates the potential for producing leachate is greatly reduced.

An approach used in South Africa to determine the level of groundwater protection needed is to classify groundwater aquifers beneath landfill sites according to three criteria (Department of Water Affairs and Forestry 1994a):

- the quantity of water that could be abstracted (known as the "potential sustained yield")
- the quality of the water
- whether or not that aquifer is needed (its "significance")

This system defines four classes of potential sustained yield from groundwater wells: low (below 1 l/s), medium (1 to 5 l/s), high (5 to 20 l/s), and very high (over 20 l/s). Most wells are in the low and medium classes. Once an aquifer has been identified and the potential yield estimated, the quality of the water is considered to see if it is suitable for one or more of the common uses for water, including agriculture, human consumption, industry, natural wetlands, or recreation and leisure. Finally, a rational view is taken on the significance of the aquifer below a site. In particular, judgment has to be made on whether or not the water is needed at present or in the foreseeable future. This last criterion has an important influence on the minimum standard of groundwater protection and leachate control that would be required at the site to develop an upgraded landfill.

Generally, two classical approaches to the problem of leachate control are commonly used. The choice depends on the importance, or not, of the groundwater as a potable drinking water resource or for other use, the depth below the base of the waste to the groundwater table, the type and hydrogeology of the soils under the site, speed of groundwater flow, and the size of the site (Figure 4.4).

If all these factors are favorable, then an "attenuate and disperse" design may be adopted (Figure 4.5). If the indications are that untreated leachate would have an unacceptable impact on the groundwater, then the alternative "containment" design would be indicated (Figure 4.6).

Protection Measure	**Required Level of Groundwater Protection**		
	Low	Intermediate	High
Hydrogeological isolation			Y
Leachate collection			Y
Leachate treatment			Y
Unsaturated zone beneath site		Y	
Exclude runoff water	Y	Y	Y
Progressive completion of site		Y	Y
Low permeability cap		Y	Y
Groundwater monitoring	Y	Y	Y
Leachate level monitoring		Y	Y

"Y" represents measure to be included in the protection of groundwater

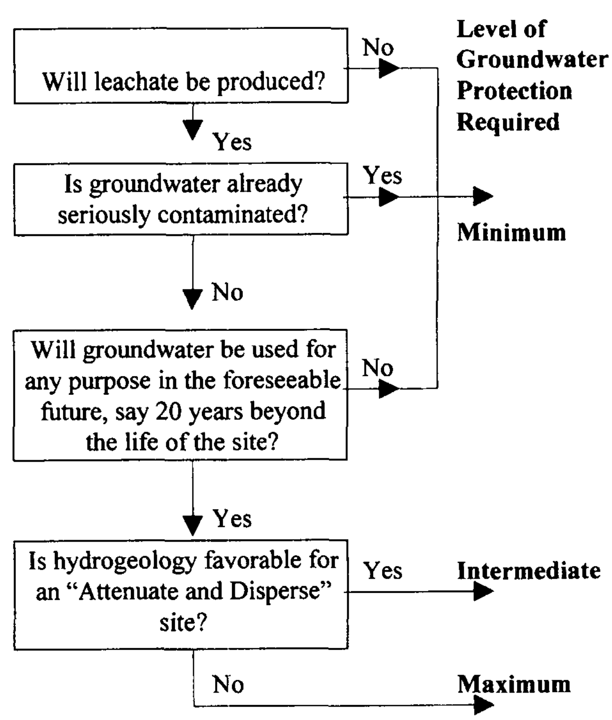


Figure 4.4 Flow chart to decide upon the level of groundwater protection to be provided

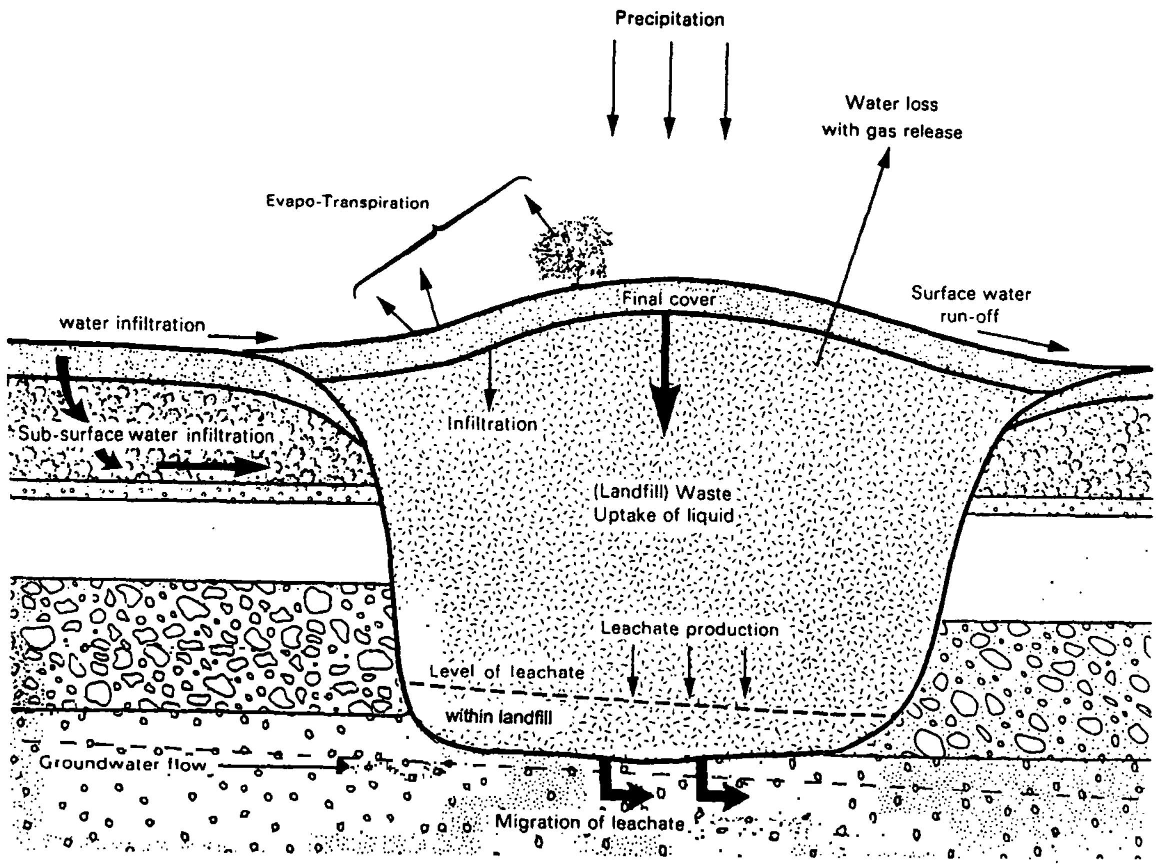


Figure 4.5 An "attenuate and disperse" design of landfill
(After: Department of the Environment 1986)

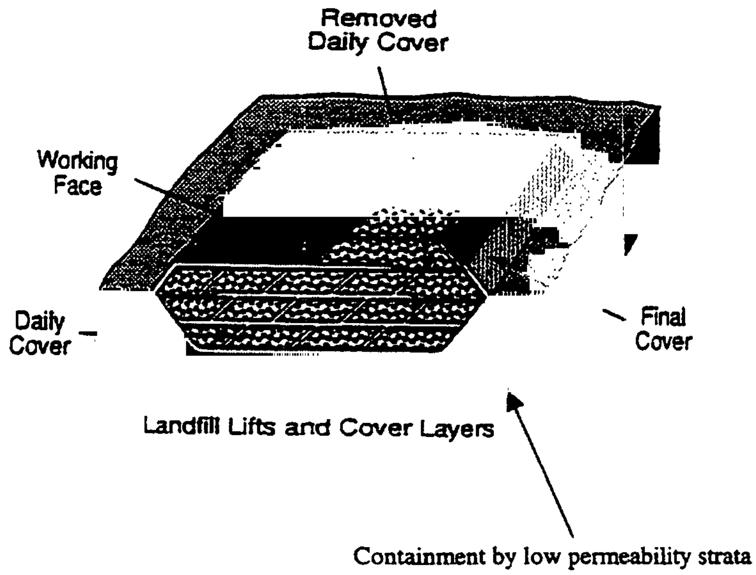


Figure 4.6 A containment design of landfill
(Source: Research Triangle Institute 1994)

4.3.2 Attenuate and disperse sites

Ideal ground conditions for an attenuate and disperse design would be

- low local groundwater recharge
- at least 3 m of unfractured, unsaturated low permeability (e.g., clay silt) material between the base of the landfilled waste and the seasonally high groundwater table
- high rate of ground water flow within a high permeability (sandy) aquifer immediately below. This implies either a confined aquifer or relatively steep topography.

The constraint mapping exercise should have established, by consultation with the water authorities, that the site is not within an area which is, or is planned to become, a protected water recharge area. Provided the walkover survey confirmed that there are no local water abstractions within a kilometre downstream of the site, and ground conditions (determined by site investigation) are satisfactory, the site may be designed as an attenuate and disperse landfill.

Where isolated water abstractions are found downstream of the site, it may be cost-effective to provide the abstractors with a piped supply from an area not influenced by the landfill.

4.3.3 Containment sites

The alternative design principle is that of a containment site which, by virtue of a natural geology (e.g., clay) or synthetic barrier system, inhibits the release of leachate into the surrounding soils. No synthetic barrier system can be considered 100% watertight, but, if properly installed, such sites can be regarded as effectively containing all leachate produced within the barrier system. Eventually, unless infiltration of ground and surface water is prevented, the leachate level will rise within the site until the barrier system is breached at some point. Complete water exclusion may not be achievable, so a system of leachate removal has to be provided. Before the leachate can be released into the environment (e.g., river, lake, estuary, or sea) it should be treated to an acceptable quality standard.

Containment sites should be considered whenever release of leachate to the groundwater may cause unacceptable degradation of the groundwater. Barrier systems can be designed to almost any level of containment, but their cost will usually be prohibitive to a lower-income country. Synthetic liners in particular are expensive to install and require a very high level of quality control of the site preparation, installation, and protection. Their use is not recommended in most situations.

Appropriate barrier systems can be developed using in situ soils, with or without modification, or locally excavated materials. Careful grading of the base of the site prior to installing the barrier system will be needed, and a leachate collection system should be installed within a layer of granular material placed on top of the barrier system (Figures 4.7a and b).

Unless the site is close to a municipal sewage treatment works, having spare capacity available, a leachate treatment plant will need to be established on the site. The form of treatment would be similar to that adopted for sewage treatment. In many climates, the simplest form of treatment could be achieved by either a series of lagoons designed to provide first anaerobic and then aerobic microbiological decomposition, or flow through wetlands. Lagoons or "stabilization ponds" permit the leachate to be retained for a long period of time (several months) and enable the microbiological decomposition of organic pollutants to take place before the water is discharged into a river or lake (Figure 4.7c). The time required for natural microbiological decomposition processes to proceed within stabilization ponds can be reduced by treating the leachate at the landfill. Various forms of on-site leachate treatment are possible. Those considered most commonly are active aeration (as sometimes known as "sparging"), flocculation, sedimentation, aeration, and leachate recirculation.

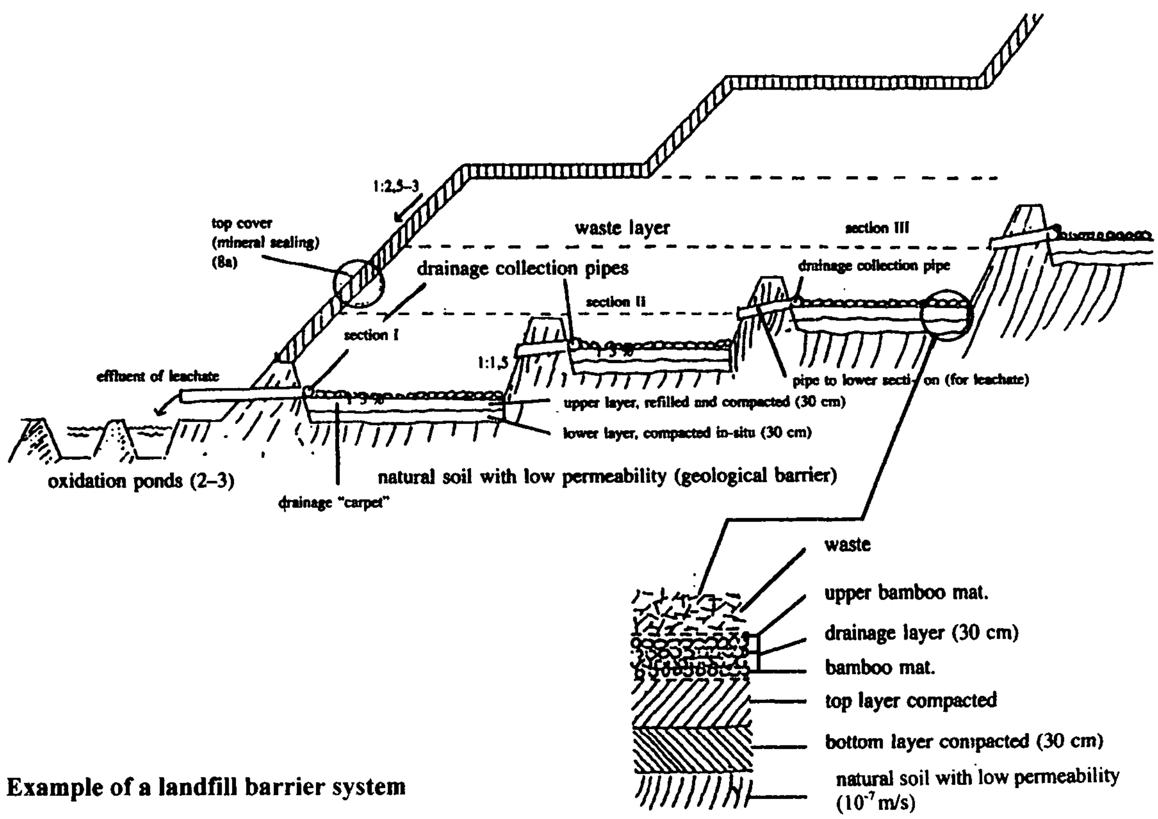
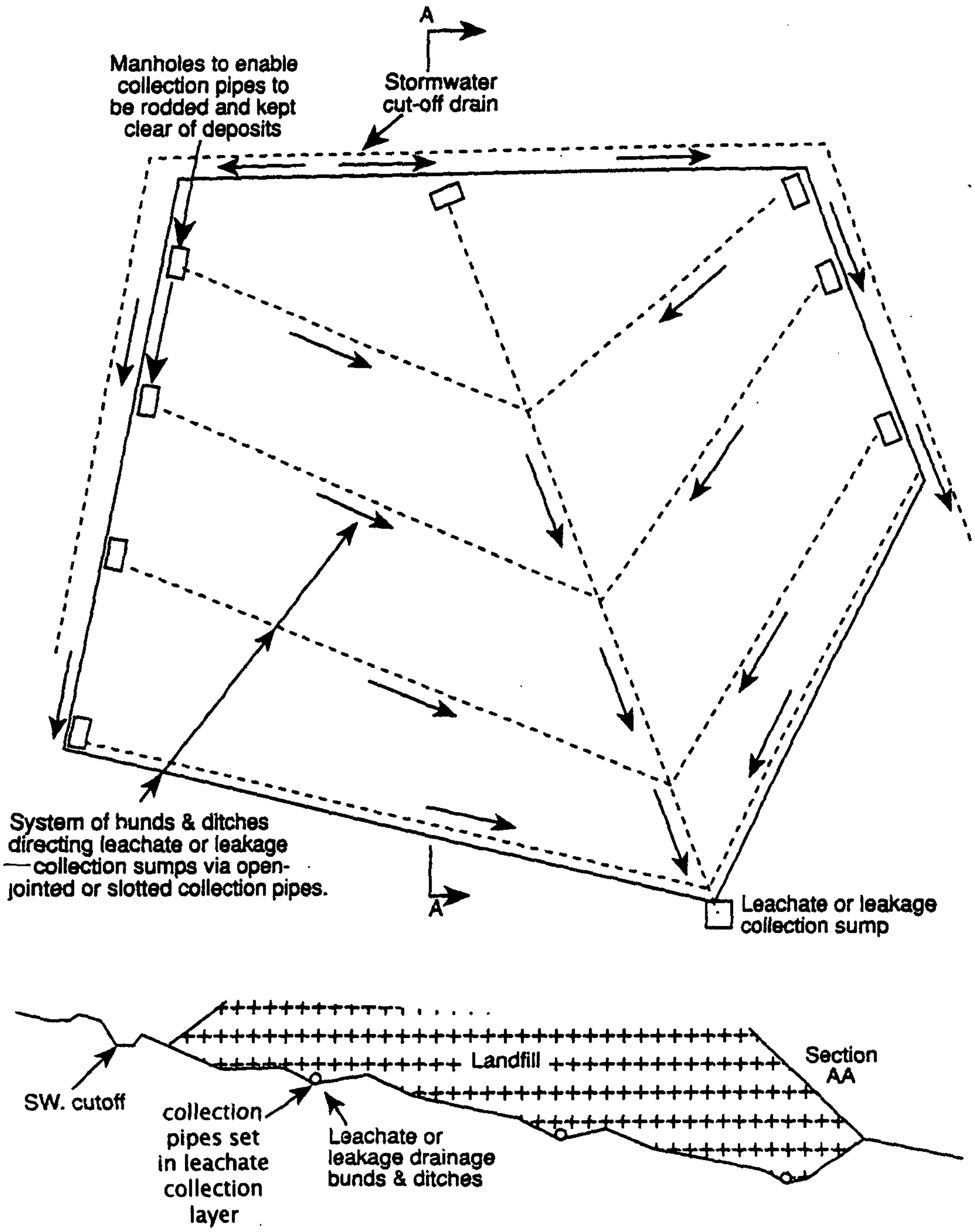
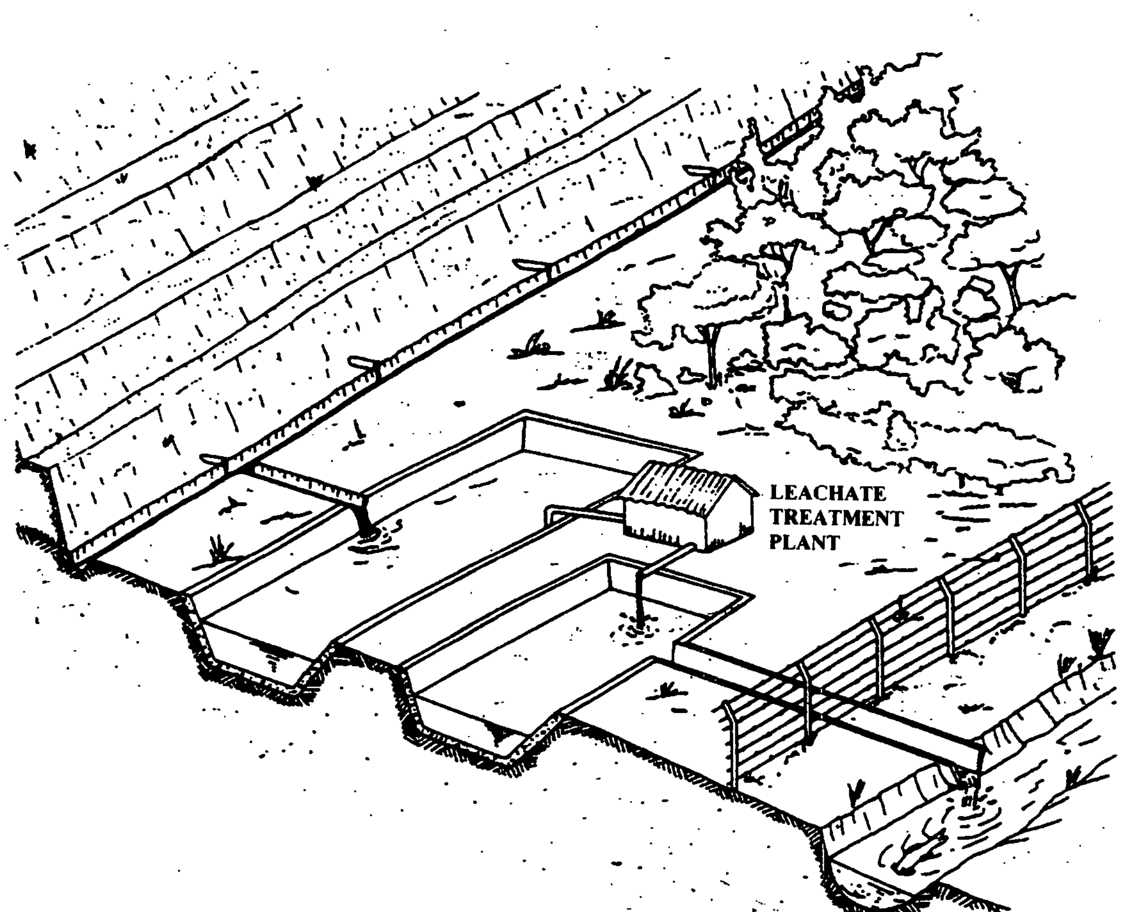


Figure 4.7a Elements of leachate containment systems
(Source: Oeltzschner et al. 1996)



Plan and section showing a leachate collection system

Figure 4.7b Elements of leachate containment systems
(Source: Department of Water Affairs and Forestry [RSA] 1994)



Leachate treatment lagoons

Figure 4.7c Elements of leachate containment systems
(After: IPT-CEMPRE 1995)

Active aeration

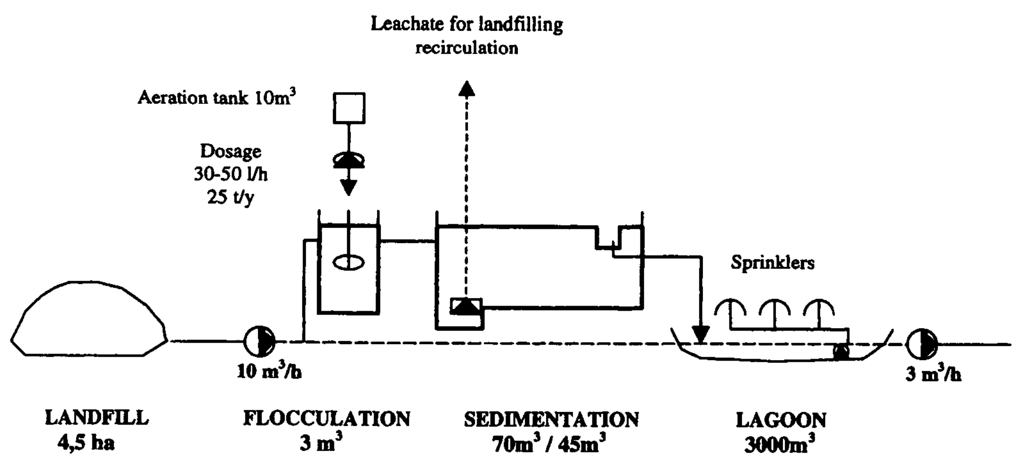
Active aeration is the simple process of introducing large volumes of air into a leachate lagoon, either using diffusers or mechanical aerators, to promote more rapid aerobic decomposition of the organic constituents of the leachate. The addition of air avoids the possibility of insufficient oxygen becoming a limit to the rate of aerobic microbial activity.

Flocculation, sedimentation, and aeration

This technique involves an initial, mechanical treatment of the leachate to remove some of the organic and suspended mineral particles present in the leachate before it enters an aeration lagoon. The leachate may first be screened to remove large objects, such as floating vegetation and litter from the leachate stream. Several individual treatment processes are then possible depending on the standard of leachate purification required and resources available locally. In its simplest form, leachate is passed through a sedimentation tank to remove heavier, suspended particles before entering an aeration lagoon. A further refinement is to add a flocculation stage before sedimentation to remove lighter organic and mineral suspended particles. This is achieved by adding a flocculation agent to the leachate to induce the fine particles to coalesce into larger ones and then either sink to the bottom or rise to the surface for subsequent removal (Figure 4.7d).

Leachate recirculation

This leachate treatment method involves the recirculation of collected leachate back through the landfill to encourage more decomposition of some of its soluble organic compounds by the bacteria present in the landfill. Other than through evaporation and use of the absorptive capacity of landfilled wastes, this method does not reduce the leachate volume for disposal. A proportion of the recycled leachate must be eventually bled off for final treatment (if necessary) and then discharged. The recirculation method can be either by an above ground spray over an area of the landfill where filling has finished or has reached an intermediate level, or by injection below the surface of the landfill into horizontal perforated pipes or a porous gravel layer.



Leachate flocculation, sedimentation, and aeration

Figure 4.7d Elements of leachate containment systems
(After: Nordic Ministerial Council 1984)

The spray approach enables some evaporation of leachate before entering the waste, but discolors large areas of the landfill surface red with iron oxide deposits, may create surface ponds if the rate of application is too high, and can interfere with landfill operations if the wind direction changes. Subsurface injection is operationally safer but requires more engineering forethought to install leachate dispersion pipes or gravel layer beneath the landfill surface. Leachate recirculation has gained in popularity with some landfill operators in recent years.

The level of treatment required would depend upon the assimilative capacity of the receiving water body. Table 4.2 indicates a range of typical water quality standards. The parameters listed represent only a sample of those covered by the standards mentioned in Table 4.2 and the data should not be used without reference to the original documents.

Parameter	Examples of Ranges of Leachate Compositions(1)	Guidelines for Unrestricted Irrigation Use(2)	Guidelines for Livestock Drinking Water Quality(2)	Potable (Drinking) Water Source(3)
Inorganics				
Arsenic	< 0.001 - 0.485	0.1	0.5	0.01
Cadmium	< 0.01 - 0.08	0.01	0.02	0.003
Chloride	1300 – 2100(6)			5
Chromium	< 0.03 - 0.56	0.1	1.0	0.05
Copper	< 0.02 - 0.62	0.2	0.5(4)	2
Lead	< 0.04 - 1.9	0.2	0.1	0.01
Manganese	< 0.04 - 3.59	0.2		0.5
Mercury	< 0.0001 - 0.0008		0.0003	0.001
Nickel	< 0.03 - 0.60	0.2	1.0	0.02
Nitrate	0.2 - 2.1		90	50
Nitrite	< 0.01 - 1.3		10	3
Ammoniacal-N	283 - 2040			
Organics				
BOD	97 - 1770			
COD	1160 – 23800(6)			
Carboxylic acids	5 – 5600(6)			
Microbiology				
Faecal coliforms (in 100 ml)		1000	20(5)	Nil
Intestinal nematodes (viable eggs per litre)		1		

1. Department of the Environment (1994b) (methanogenic leachates from 29 large, high-rate input UK landfills)
2. Canadian Water Quality Guidelines (all soils)
3. WHO Guidelines for Drinking Water Quality (World Health Organization 1993) based on health significance in drinking water.
4. Sheep 0.5, Cattle 1.0, Swine and poultry 5.0
5. Older cattle
6. Based on Batstone et al. 1989

Table 4.2 Typical water quality standards for different water uses (units: mg/l unless stated)

4.3.4 Leachate collection systems

Water balance

Fundamental to the design of a leachate removal and treatment system is an estimate of the volume flow of leachate expected to be produced in the landfill. The quantity of leachate which should be expected depends principally on the quantity of water that enters the site as rainwater through the landfill surface. Depending on the nature of the wastes and the method of their placement, leachate quantities can be greatest during the operational period of a landfill when waste is being deposited. Leachate flows may then be expected to decline slowly when landfilling ceases and after a thicker capping layer of low permeable soil has been put in place.

The most widely used approach for estimating the quantities of leachate is the classic "water balance calculation" expressed as

$$L = P - ET - R - \Delta S$$

Where

- L represents the leachate volume.
- P represents the volume of precipitation (i.e., rainfall, snowmelt water).
- ET represents the volume lost through evapotranspiration (i.e., evaporation from the ground surface and transpiration from vegetation).
- R represents the volume of surface runoff.
- ΔS represents the volume of moisture storage available in soils and waste.

The two factors relating to precipitation (P) and evapotranspiration (ET) tend to dominate water balance calculations. The two remaining factors, R and ΔS, have a smaller influence and are more difficult to estimate. Therefore, for the purpose of estimating an approximate size for a leachate management system a simplified calculation has been suggested, the "climatic water balance" (Department of Water Affairs and Forestry 1998):

$$B = R - E$$

Where

- B represents the leachate volume.
- R represents the volume of precipitation.
- E represents the volume of evaporation from the ground surface.

Both rainfall and evaporation data are usually collected routinely by meteorological stations. Therefore, an approximate but slightly over-estimated leachate volume can be readily estimated for a new landfill, provided meteorological data are available.

A discussion and series of examples illustrating the calculation of the climatic water balance for places in South Africa are given in Appendix 4.B. Consideration should be given to other, site-specific factors which can affect the potential to generate leachate. These include

- a site where groundwater is expected to infiltrate the site
- a site built over a culverted water course, where the culvert has to be assumed that it will eventually leak fresh water into the waste surrounding it (or leachate lost into the culvert, depending on the relative levels)
- a site on a river or coastal flood plain which is liable to periodic inundation be flood waters
- an existing site where surface water drainage has been inadequate to minimize entry of surface water in to the landfill
- a site expected to receive large volumes of high moisture content sludge or liquid waste

In these situations, a more thorough, classic water balance calculation is necessary to determine a more reliable estimate of the volumes of leachate that will have to be removed and disposed. To perform these calculations, it may be necessary to seek specialist assistance.

Leachate collection systems

Containment sites must be provided with an effective leachate collection system immediately above the liner in the base of the landfill (the "basal liner"). This is to limit the accumulation of a hydraulic head of leachate above the liner and thereby minimize the rate of leakage through the barrier system. The general form of leachate drainage systems is a layer of granular material (the "drainage blanket") placed on top of the basal liner within which is installed a network of perforated drains.

Leachate percolates down through saturated waste towards the bottom of a landfill. The base of a site must be graded before construction of the liner system to provide adequate gradients to direct leachate entering the drainage blanket towards the perforated drains. The perforated drains, which are generally made from high density polyethylene, then convey the collected leachate into one or more low points (known as "sumps" or "leachate collection points") from where it can be removed, by pumping if necessary, for treatment or disposal.

The granular drainage blanket should be large diameter aggregate, carbonate free, and with a 1×10^{-4} m/sec hydraulic conductivity or higher.

The perforated drainage pipes and the geotextile materials commonly used to prevent the movement of fine soils into the granular drainage blanket are both potentially susceptible to silting and clogging from biomass growth and mineral precipitation. Provision should be made in the design of the leachate collection system to facilitate clearing by rodding, scraping, water jetting or other means. Access manholes or rodding points should therefore be provided at the end of each line of drains. Small diameter drains (e.g., 100 mm diameter) are considerably more difficult to clear when blocked than larger ones.

Perforated drains can be installed in trenches excavated within the base of the site, and backfilled with granular material. Where this results in an unacceptable reduction in thickness of the bottom liner, or difficulty of construction, the drains may be laid within the drainage blanket layer, suitably protected from damage by heavy construction and compaction machines traversing the site by an additional thickness of blanket material. The required crushing strength of the drainage pipe must be determined with regard to its "bedding factor" and "projection condition." More details on these technical issues can be found in specialist engineering design reference books such as Bagchi (1994).

The construction of manholes at the ends of drain runs, including any downstream terminal drain covers or collection chamber, will need careful design if they are located over the liner system to ensure that their weight, and any negative friction induced by waste settling around them, does not damage the integrity of the liner. Flexible joints on pipes entering or leaving these structures need to be provided.

The means of removing leachate from the drainage system should be as sustainable as possible. Wherever possible, drainage by gravity to a treatment system should be sought. If this is not possible, adequately sized, reasonably shallow chamber(s) should be provided, with vehicular access for vacuum tankers. If the site conditions do not allow this, a fixed sump/pump arrangement has to be provided. This assumes that a permanent power supply can be made available and requires a commitment to long-term operation and maintenance of the installed equipment.

4.3.5 Leachate reduction

The problems associated with leachate may be minimized by limiting the amount of water getting in to the waste. This can be achieved in a number of simple design and operational measures:

- ensuring surface water does not enter the landfilled areas, or areas prepared for future landfilling by constructing interception ditches between the working areas and surrounding unused parts of the site
- ensuring water does not accumulate in the working area where waste is being landfilled
- keeping the open areas at the tipping face as small as practicable
- covering wastes at the end of each day with soil or tarpaulins
- ensuring that temporary (covered) waste areas are provided with a gradient away from the landfill
- progressively completing and grading areas of the site with a capping layer, as they reach their final design heights

All these techniques, except the first, are operational matters and are considered later in Chapter 5 Discussion here is limited to surface water control. Surface water diversion is an important matter, as not only will it significantly reduce leachate quantities, but it also removes flooding by surface water which can destabilize waste slopes, resulting in slip failures. Permanent catchwaters should be installed at appropriate elevations above the highest part of the site that is to receive wastes, and smaller, temporary ditches constructed above the rising level of landfilled wastes (Figure 4.8). Culverting of surface water drainage beneath a landfill should be avoided.

An approximate "rule of design" for the hydraulic design of permanent structures should be to a design storm frequency (return period) of twice the lifetime of landfill, or every ten years, whichever is the greater, up to a maximum of 25 years. A number of options for management of surface water below surrounding ground level within the landfill area may be available to the designer, depending on local circumstances. These include the following measures:

- Arranging for uncontaminated runoff to drain to point(s) in the base of the landfill which can be isolated from any leachate produced from previously deposited wastes. In a containment site, this could be in areas where installation of the liner and/or leachate collection systems may be deferred. If the base of the site at these point(s) is of low permeability, collected runoff will need to be removed periodically by pumping.

- For containment sites, where the phasing and sequence of filling allows, arranging for temporary interception and removal of leachate from parts of the leachate collection system covered by wastes, and using any remaining installed but exposed leachate collection system as a means of collecting and removal of uncontaminated runoff.

- As a variation on the above, making provision for the installation of temporary drainage (to be abandoned at an appropriate time) to convey separately any collected leachate in solid wall pipes, through areas of the site which are acting temporarily as a runoff collection system, to connect with installed permanent leachate removal facilities.

Such operational methods need to be given careful consideration and planning during the detailed design of the site's preparation.

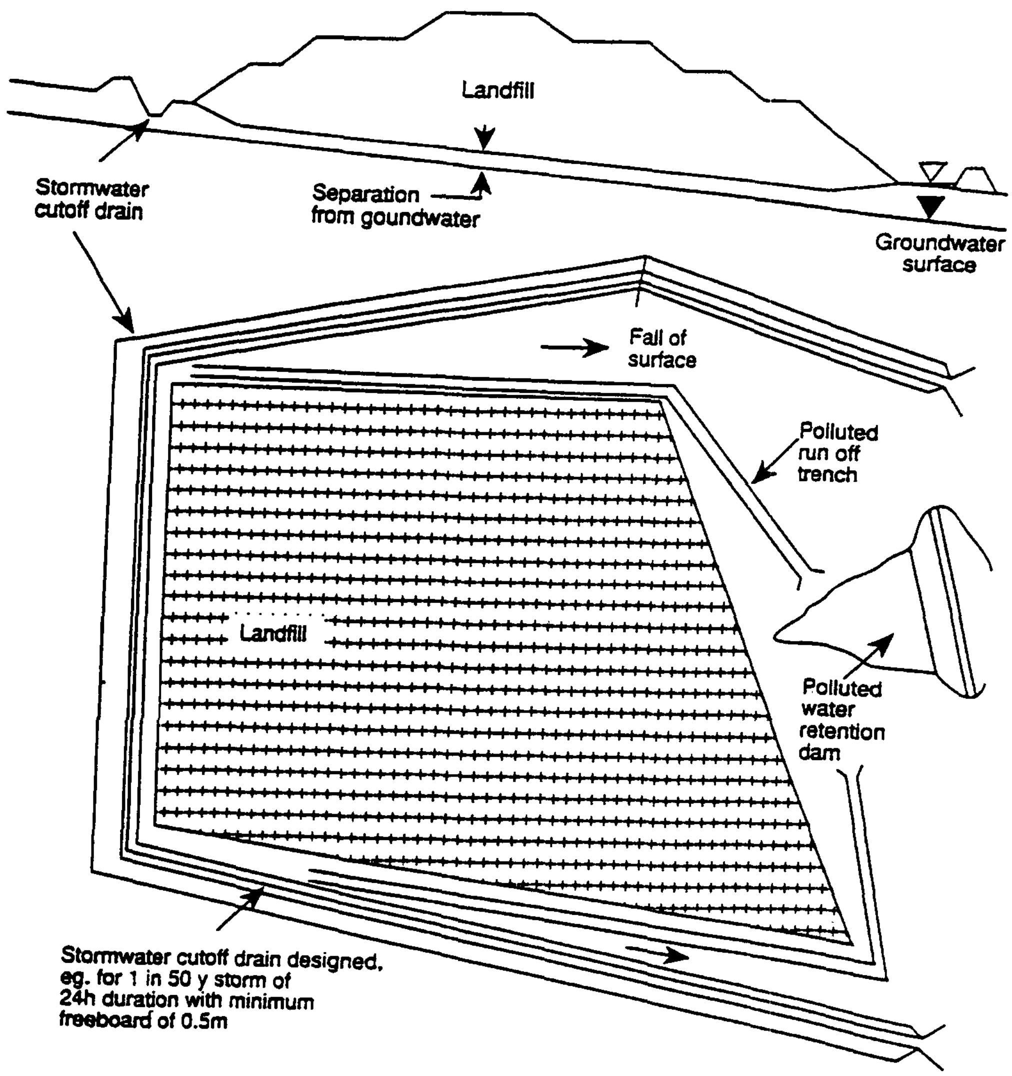
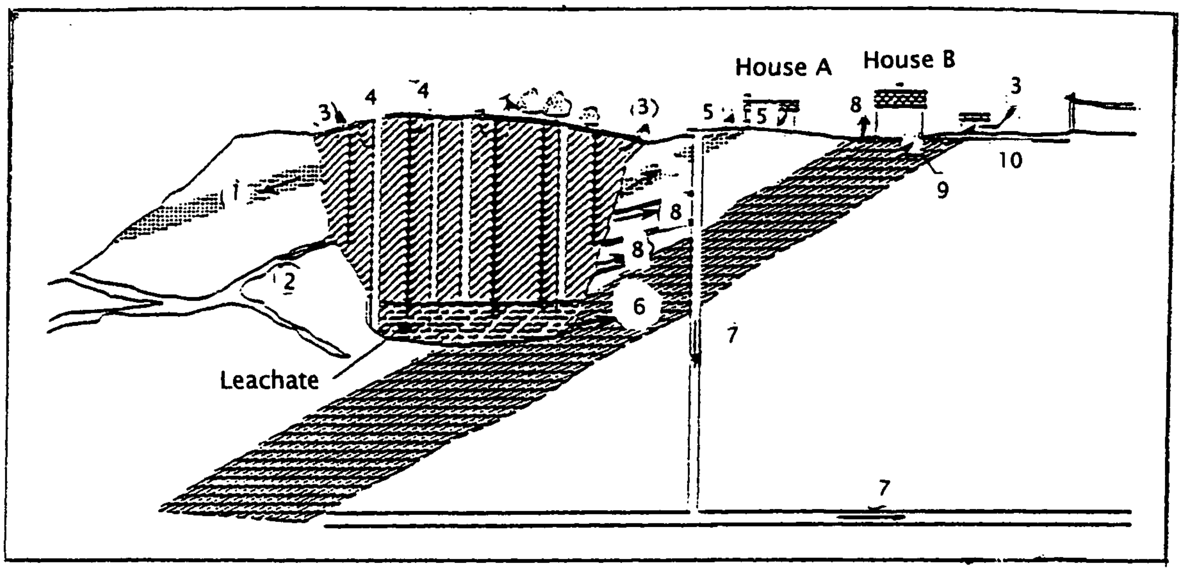


Figure 4.8 Separating external surface water from a landfill
(Source: NCS-GTZ 1995)

4.3.6 Gas control systems

Construction of a landfill will generate "landfill gas" (a mixture of gases consisting predominantly of methane and carbon monoxide) as the bioreactive wastes decompose. Depending on the ambient temperature, organic content, and moisture content of the wastes, gas production can start within a few weeks of wastes being landfilled and continue for many years after the landfill is closed. Ten to 15 years is a typical period for high rates of gas production. Decreasing rates may then continue for decades afterwards. In fractured or permeable geological strata landfill gas may migrate considerable distances from the landfill, as indicated in Figure 4.9.



Gas pathways to atmosphere

1. Through high permeability strata down the bedding plane
2. Through caves/cavities
3. Through desiccation cracks of the capping at the site perimeter, around tree root, etc.
4. Around site features which provide vertical pathways; gas or leachate wells
5. Through high permeability strata up the bedding plane, to atmosphere or House A
6. Through fissurės caused by explosives etc.
7. Along human made shafts etc.
8. Through highly fissured strata into the atmosphere or buildings such as House B or shed, etc.
9. Into underground rooms
10. Along underground services

Notes

i) Gas may vary depending on its source from within the landfill and the migration route, e.g., route (5) gas compared to route (8) gas.

ii) Leachate may degrade to give rise to gas generation at some distance from the site.

Figure 4.9 Possible gas migration paths
(Source: Her Majesty's Inspectorate of Pollution 1989)

The primary concern is methane, a potent greenhouse gas, which is commonly produced in concentrations up to 65% of the landfill gas. Methane is potentially explosive at concentrations between 5 and 15% methane in air in confined spaces. Therefore, if landfill gas is allowed to accumulate in enclosed spaces it can form an explosive mixture with air.

Carbon dioxide, the second predominant constituent of landfill gas, is asphyxiating and, being slightly heavier than air, can accumulate in buried structures. Landfills can be designed to collect and safely vent or burn the landfill gas, and systems can be installed to prevent off-site migration whenever there is a risk to life or properties. Details on the development of gas control systems are presented in Sections 5.4.11 and 5.5.3.

4.3.7 Cover requirements

Soil or similar inert material (such as ash from power stations, construction excavated materials, dewatered sewage sludge, dewatered river dredgings) should be used throughout the lifetime of the landfill:

- to cover the landfilled wastes daily
- to provide intermediate cover protection to interim levels of fill, and, if appropriate,
- as final cover on reaching design completion elevations

The commonly held view on the preferred choice of cover materials is that daily cover should be of high permeability, to discourage the later development of perched leachate tables, while intermediate and final cover should be of low permeability, to inhibit the percolation of rainwater into the wastes below (and thus minimize leachate generation). The counter-argument, against the exclusion of water into the wastes, is that, if all water is excluded, the rate of waste degradation may be expected to reduce significantly, thereby extending the period over which landfill gas will be generated, settlement will take place, and the site becomes environmentally benign.

In most situations, it may be several weeks before the next layer of waste is deposited on top of the location currently being filled. The use of daily cover is therefore important for several reasons:

- to reduce the attraction of wastes to birds and rodents, and render any food inaccessible
- to reduce the suitable habitats for flies and vermin
- to provide a better surface for vehicles travelling over the landfill
- to reduce exposure to atmospheric conditions by restricting air entering deposited wastes
- to reduce the scattering of light wastes (litter) by the wind
- to inhibit direct infiltration of rainwater into the waste

Ideally, cover materials should be dug from within the site, thereby increasing its void capacity. This will require a certain amount of stockpiling and double handling. Adequate space should be allocated within the site for this purpose.

Rarely can a landfill site provide the full amount of material required for daily, intermediate, and final cover and any necessary bund construction. In such circumstances, the deficit needs to be brought in from elsewhere.

Where a regular supply from waste producers (e.g., from construction and demolition) cannot be relied upon, it is usual to develop a "borrow area" site dedicated to supplying suitable excavated soft material. The search for potential borrow areas should be conducted at the same time as the possible landfill sites are shortlisted. A check that sufficient soil materials are available for the landfill site needs to be confirmed by subsurface site investigation.

A common investigative approach is to excavate trial pits to inspect the depth and type of material. It is only possible to excavate a trial pit to a depth of about 4 m with commonly available equipment. If the site investigation needs information on deeper soil strata, exploratory boreholes should be sunk. The excavation of boreholes is more expensive but it is a practical and proven technique to obtain geological information and is essential for groundwater monitoring.

The operation of a borrow area should be subject to the same level of operational control and official regulation as the landfill site in respect of

- provision of access
- development of an orderly excavation plan
- dealing with noise, dust and visual impact
- dealing with surface water runoff
- restoration of the site when finished

4.3.8 Environmental monitoring

Landfills should not only be designed and constructed to provide an acceptable level of protection to the environment, they need to incorporate systems which allow this protection to be demonstrated. At the site preparation stage, certain facilities should be provided (such as boreholes and sampling points to monitor the quality of the groundwater and the presence or absence of landfill gas). They allow the future impact of the landfill on the environment to be measured at any time.

Generally, the impacts of most concern are contamination of the groundwater by leachate and migration of landfill gas away from the site. However, dust can also be a nuisance to landfill workers, local inhabitants, and wildlife, and should therefore be controlled. Even if physical construction of monitoring facilities is not required for this purpose, it is usual for a baseline survey to be carried out during the design work on those aspects believed to be of potential future concern, to obtain quantitative data on conditions before any construction takes place. Whenever practicable this should include data on groundwater elevation and quality.

4.3.9 Final landform and end use

The conceptual design should have considered one or more possible end uses for the completed landfill. The designer must now develop the final landform in detail, taking into account any topographic or geological constraints identified during the site selection process.

The surface of landfills will undergo significant settlement for several years after filling, due to decomposition of the bioreactive wastes. It is necessary therefore to anticipate this settlement and plan to "over-fill" the landfill, so that the final, settled surface profile creates the desired landform. The amount of overfilling that can be made requires local experience to be built up while the landfill is in operation. It is a highly site-specific characteristic determined by the density achieved when the waste is first deposited and the composition of the wastes received at the site. A useful "first approximation" would be to assume a final waste density of 1.0 t/m^3. A settlement of the order of 50% might then be expected if the initial waste placement is only 0.5 t/m^3 (e.g., manual landfilling). If the initial waste placement density is 0.8 t/m^3 (e.g., well-operated, mechanized landfilling) then the overall settlement might be of the order of 20%. Such large settlements are not observed (at the surface) since a significant proportion of settlement occurs as the level of wastes is raised, due primarily to consolidation of lower layers under surcharge.

Slopes should be designed which are stable, sympathetic with surrounding land forms, and suitable for surface water drainage purposes. They should also be appropriate for the intended end use of the site. Care must be taken not to design areas of relatively flat surface, since differential settlement of wastes may create depressions in which surface water will collect and infiltration will be encouraged. A final plateau slope of between 1 in 20 and 1 in 50 (5% and 2% gradients respectively) would be satisfactory in most places.

End uses which are compatible with a waste landfill development are generally limited to agriculture and open space recreation. Hard development for housing, commercial, or industrial use should not normally be considered due to the problems of settlement and methane hazard. Engineering a site for these end-uses is expensive. However, intermediate use for vehicle parking, open markets, and open storage could be considered.

4.3.10 Disposal plan

A key element of the design procedure for a landfill is the identification of the most appropriate sequence of filling to achieve the final design landform. The purpose of a disposal plan is to minimize the environmental impact of the landfill while at the same time deferring, where possible, the amount of preparatory construction works. This is achieved by identifying a sequence of filling that

- minimizes the area being filled
- accelerates restoration of filled parts of the site
- minimizes double handling of material excavated from the base of the site
- allows progressive installation of surface water diversions, leachate, and gas controls
- permits an optimum development of access and haul roads

Factors which will affect or dictate the phasing sequence include

- existing surface water drainage patterns and the need to provide diversions
- the desirability to limit stockpiling of natural excavated soil from the first area of filling
- the overall leachate drainage pattern and the general need to install the deepest sections first
- the desire to make the least changes to the principal haul road(s) within the site
- the need to provide screening of operations from sensitive neighbors by early filling and restoration of areas closest to them

Unless the site allows leachate collection systems to be developed independently, phases should be considered that will accommodate wastes for a period between 12 and 18 months (Department of the Environment 1994b).

A key aspect of the design which should not be overlooked is the need to identify in the site layout, at each stage of development, areas of sufficient space to stockpile for later use:

- top soil material stripped from areas to be landfilled
- sub soil material excavated from areas to be landfilled
- inert, construction and demolition material suitable for daily cover, bund construction or haul road construction and maintenance
- imported cover materials, where its rate of supply may exceed the rate of use

The disposal plan for an upgraded landfill should be set out as a comprehensive "manual" for use by site operators. The range of topics which should be covered, to the extent that they are relevant in any particular circumstance, is set out in Appendix 4.C.

4.4 Minimum Acceptable Standards

4.4.1 Groundwater protection and leachate control

The majority of decisions on standards of design and construction of landfills depend upon the level of groundwater protection required. As was shown earlier (Figure 4.4), three basic levels of required protection may be considered:

- *Minimum:* were the groundwater is unsuitable for human or agricultural use, where its degradation will not unacceptably impact on the local ecology, or where the local climate will prevent the generation of leachate from any landfill.
- *Intermediate:* for which attenuate and dispose designs may be sufficient.
- *Maximum:* for which full containment designs are needed.

The ideal site, subject to any other constraints or considerations identified during the site selection process, will be one in which the minimum level of leachate control is required.

Each of these three design levels for leachate control are considered in turn, followed by consideration of other, common aspects of design and construction.

Sites with minimum groundwater protection needs

Despite the fact that such sites may pose little threat to its environment due to leachate contamination of the groundwater, measures to reduce leachate production (in climates where it can be expected) should be implemented as a matter of good practice.

Where necessary, surface water diversion works should be designed to prevent surface runoff from outside the site from entering the landfill.

Groundwater monitoring facilities for detecting and quantifying the extent of leachate migration from the site should be provided only if such information is of value. Small diameter drilled wells with permanent sampling access would be required for this purpose.

Excavation of soil material from within the site for use as daily and final cover should extend no further down than to the seasonal high watertable. Areas below this level, which will be liable to flooding, should be raised by filling with inert material to provide a firm foundation on which to start landfilling.

The quantity of inert material for bund construction, and daily and final cover, likely to be needed for a minimum groundwater protection site, can be expected at around 10% of the volume of the landfill void. This may be significantly reduced if alternative forms of daily covering of waste are proposed (e.g., use of tarpaulins).

Attenuate and disperse sites

Surface water diversion channels should be provided as indicated above. In large sites where significant quantities of surface water runoff from areas below permanent catchwaters (large drainage channels) may enter the landfilled waste, it may be necessary to plan for the construction of temporary catchwaters above the rising levels of waste and to arrange for conveyance off-site. If the base of the site is sufficiently permeable it may be possible to plan for uncontaminated surface water flows emanating from within the site to drain towards soakaway(s) within the base of the site until such time as that part of the site is to be filled with waste. Any local improvement of permeability for this purpose should be reinstated before wastes are deposited in these areas, to avoid the subsequent release of concentrated plumes of leachate. Due account will need to be taken of the "blinding" effect of silt material carried in runoff from exposed soil surfaces.

A minimum of two groundwater monitoring facilities (drilled wells) should be installed down-gradient of the landfill, and one up-gradient, to monitor the impact of leachate on the underlying groundwater. The location and design of these wells need to be decided carefully to sample adequately the expected contamination plume entering the groundwater.

Excavation of soil material from within the site for use as daily, intermediate and final cover should extend no further than 3 m above the seasonal high watertable. In sites where the groundwater is less than 3 m from the surface, the depth of unsaturated soil will need to be increased by filling with suitable material. Suitable materials would include clay silts, having a reasonably low permeability.

The quantities of inert material for daily, intermediate and final cover is likely to be around 15% of the airspace available at this type of site. Again, this may be significantly reduced where alternative forms of daily covering of waste are proposed.

Containment sites

To minimize the quantity of leachate requiring treatment, careful control of water coming into contact with the waste must be exercised.

Leachate control systems required for containment sites are extensive. The principal element of the system will be the leachate barrier. For the in-situ soils to act as an effective barrier, they must have a low permeability (less than 1×10^{-7} cm/s) and should extend at least 1 m below the deposited wastes. If there is insufficient thickness in situ, suitable material will need to be either found elsewhere on the site or imported from elsewhere. The common material having the required characteristics of low permeability and strength when exposed to landfill leachate is clay. A soil that is deficient in a particular characteristic may be rendered suitable by blending it with another soil or similar material.

Appendix 4.D provides guidance on the design and installation of a soil liner and leachate collection system. The leachate collection system needs to cover the entire base of the site (Figure 4.7b). Independent systems may be provided in different parts (phases or cells) of the site.

Leachate will need to be removed, by pumping if necessary, for treatment on- or off-site. Leachate removal and treatment facilities need to be sized to deal with the peak rate of leachate generation. If leachate treatment is needed to avoid excess pollution to local rivers and lakes, then a minimum approach is to construct leachate lagoons. Leachate from the landfill is conveyed to lagoons and, after a period for further microbiological decomposition, drained into a receiving watercourse. A discussion on leachate lagoons was given in Section 4.3.3.

Minimum standards for the provision of the leachate collection system should be

- 300 mm thick drainage blanket
- 2% minimum gradient on the drainage blanket and 1% on the leachate drains
- 150 mm diameter perforated drain with a maximum spacing at 50 m centers (25 m maximum cross flow on drainage blanket)

The quantities of inert material required for daily, intermediate, and final cover will be the highest of all landfilling methods, and may be as much as 20% by volume. The minimum acceptable standard of provision of groundwater monitoring facilities will be that as indicated for attenuate and disperse sites. Limited monitoring of leachate quality (and quantity), together with treated effluent quality, will also be needed.

4.4.2 Other matters

Access roads

An all-weather access road needs to be constructed from the nearest suitable public road and designed for two-way traffic. The standard of construction needs to be appropriate for the number and size (laden weight) of vehicles likely to use the site during its lifetime. Where necessary, the public road along which the waste collection vehicles will travel to and from the site should be upgraded.

Access roads within the site should be designed to a standard appropriate for the duration of their use. Roads should be at least 6 m wide and constructed of stone, crushed aggregate, or selected hardcore (e.g., broken bricks or concrete). The depth of construction will depend upon the subgrade strength needed and the type of vehicles using the roads (including mobile plant on-site). In areas where an access road has a steep, downhill side slope, the width of road should be sufficient to provide a safety zone. Attention should be paid to road drainage, as concentrated runoff can often scour road cuttings and damage the road surface.

Reception facilities

Limited office facilities should be provided for use by the site supervisor and other staff. Locating this office close to the entrance to the site will allow vehicle movements into the site to be monitored. The office should be provided with basic amenities including

- heating and/or ventilation as appropriate
- lighting
- drinking water
- toilet facilities

The site reception area should also have an area for vehicles to park without interfering with the traffic flow, and, on large sites (e.g., receiving over 500 t/day), an area where a weighbridge could be installed.

To restrict access to the site, the entire perimeter should have a suitable animal-proof barrier. This may take the form of a wire fence, or, at the minimum, a ditch constructed such that excavated material is placed to form a bund on the site side of the ditch, on which may be planted indigenous species to form a hedge barrier. A distinctive buffer zone can be established between the site and the surrounding area by planting trees and shrubs, where climatic conditions permit. The entrance to the site should incorporate a cattle grid to deter entry of animals and an after-hours disposal area just outside the gate.

Mobile plant maintenance facilities

A covered area should be provided, close to the landfill area where mobile plant (bulldozers, wheeled loaders, and trucks) can be maintained. A securely locked compound (perhaps an I.S.O. container) should be provided for secure storage of spare parts and lubricants and tools for routine maintenance and repair. A suitably located lockable diesel fuel tank should be installed in this area, sized to accommodate perhaps a week's supply of fuel.

Accommodation of scavengers

The presence of scavengers on a landfill is highly disruptive and can prevent modern landfill operational techniques. Where their presence is inevitable then they have to be accommodated so they cause minimal disruption. Some suggestions on how to achieve this are given in Appendix 4.E.

Environmental monitoring

In a minimum approach to landfill development, only groundwater quality monitoring facilities need to be provided during the site development phase. The landfill designer will have to consider when there will be the need in the future to install a gas monitoring system near to buildings close to the site which may become at risk from gas migration once waste landfilling has started.

4.5 Desirable Improvements to the Minimum Standard

4.5.1 Groundwater protection

Enhancements to the design and construction standards for groundwater protection are generally limited to increasing the level of security offered by engineered barrier systems for containment sites. Other than increasing the minimum thickness of a natural clay or modified soil lining to the base of the landfill, another approach is the installation of one or more synthetic flexible membrane liners (FMLs) or geosynthetic clay liners (GCLs) in a composite barrier construction (Appendix 4.D).

The effective use of composite barrier systems involving FMLs or GCLs requires an extremely high level of quality control and most likely the need to import an expensive proprietary liner product and technical support. For these reasons it is strongly recommended that, whenever locating new landfills, sites requiring such complex and expensive barrier systems to groundwater protection should be avoided if at all possible.

Improved standards for a leachate collection system should be

- up to 600 mm thick drainage blanket
- 4% minimum gradient on drainage blanket and 1% on the leachate drains
- 200 mm diameter perforated drain with a maximum spacing at 30 m centers (15 m maximum cross flow on drainage blanket)

Commensurate with other improvements of standards, additional facilities should be provided for monitoring groundwater quality around the site. This might be achieved by providing additional permanent monitoring wells around the lower part of the site and even outside the site boundary. For attenuate and disperse sites, the additional wells should be located to monitor the dispersion of the contaminant plume in the underlying groundwater.

4.5.2 Leachate treatment

An enhanced approach to the management of leachate is to collect it and then actively treat it. A wide range of treatment options are available which can be tailored to locally available materials and financial resources, as well as to meet required or practicable treatment standards. There are, principally, two types of enhanced leachate treatment both involving the implementation of some specialist equipment and engineering, and requiring the continuing involvement of technically competent personnel. The first type of leachate treatment are aerobic techniques ranging from simple aeration of a leachate lagoon to more specialized pretreatment by flocculation and sedimentation (settling) prior to discharge of the leachate into an aeration lagoon.

The second type of treatment involves the recirculation of leachate back into the landfill to enable the resident bacteria a second opportunity to degrade the organic constituents in the liquid. Recirculation can be achieved by above ground spraying over completed or dormant parts of the landfill, with subsequent infiltration through a permeable landfill cover material, or direct subsurface injection into previously laid horizontal distribution pipes or a free flowing gravel layer.

A discussion about leachate treatment methods was presented in Section 4.3.3.

4.5.3 Other matters

Reception facilities

To improve control of use of the landfill site, the site should be secured, outside of opening hours, by a locked gate, located beyond the after-hours tipping area, which ideally could be monitored by a night security officer.

Control of the use of the site would be improved by providing a manual counterbalanced barrier. In large sites, where numbers of vehicle movements may be expected to be significant, a traffic light system may be more appropriate.

Monitoring waste quantities entering the site will be of benefit for future waste management planning, particularly where further facilities (landfills, transfer stations, etc.) may be required. While using vehicle counts to estimate waste quantities has limited value, the installation and use of mechanical or electronic weighbridges near the entrance of a sanitary landfill will provide better weight records for later analysis. The expense and maintenance involved in providing a weighbridge facility is probably justified only for large landfills, serving towns with 200,000 or more inhabitants.

The standard of office and welfare provision may also be enhanced, in relation to the scale of activities. Separate office and canteen facilities may be provided as permanent, fully serviced buildings. In remote areas, power may need to be generated on site and potable water may need to be locally abstracted (upgradient of the landfill activities) or supplied by tanker. A telephone in the office would be desirable for communication with the municipality to report operational problems.

Site scavenging and fencing

The site security measures suggested in Section 4.4.2 may be enhanced by provision of a more robust form of fencing, the principal objective being to discourage people, and to prevent scavenging animals, from entering the site.

Depending on the proximity of housing or public roads, and the desirability to provide a visual screen to the site and its activities, earth banks, with or without planted trees or shrubs, may be formed around sensitive parts of the site boundary.

To raise the image of the site, particular attention should be given to landscaping the entrance to the facilities. A smart signboard should be provided, indicating the name of the facility, hours of opening and the name and telephone number of the person to whom any queries (e.g., complaints) should be directed. A color illustration of the proposed completed landfill could also be included on the signboard.

Mobile plant maintenance facilities

Improvements to the on-site maintenance facilities which would lead to a more efficient use of mobile plant would include

- provision of an enclosed maintenance bay where equipment can be stripped down under cover and away from extremes of temperature
- a power source to provide lighting and allow use of electrical tools and compressed air
- a high-pressure washing unit to prepare plant for maintenance or repair

Environmental monitoring

Further enhancement of environmental monitoring facilities is likely to be limited to installing gas monitoring wells around the perimeter of the landfilled wastes. Such measures are usually only justified if there are structures at risk from gas migration (i.e., typically within 200 m of the landfilled wastes in some countries). Some countries set a higher exclusion zone for buildings near to landfills. The precise minimum size for this type of zone has not be agreed scientifically, although it is reasonable to assume that lateral gas migration could be more extensive in rock strata of higher porosity.

Appendix 4.A
Procedure for Manual Landfill Operation

(Sources: Flintoff 1976, WHO 1996)

Manual landfill operation means execution of landfilling activities without the use of machinery. This procedure is suitable for small-scale landfill operation of up to 30 tonnes/day where machinery for landfill operation is not available. If carried out with proper care it can effectively meet the basic requirements of a controlled landfill. For this purpose, the following procedures should be followed:

1. Access Road and Cover Material

It is assumed that, like any normal, controlled landfill, an all-weather access road from the nearest road to the landfill has been provided and cover material would be stocked with about a week's supply at any one time near the working face. The cover material can be excavated on-site (if available) or transported from an off-site location.

2. Formation of the First Strip

The position of the first strip should be defined by pegging two rows of pegs into the ground. The height of the first layer should be guided by posts with cross pieces which can be used for sighting. The width of the strip should be approximately 6 m at the top with 45-degree flank and the depth should be about 2 m as shown in Figure 4.10. The formation of the first strip would then be used as a guide for the subsequent strips.

3. Formation of Strips

The vehicle delivering the solid waste should be reversed to as close to the working face (i.e., the location where solid waste is deposited for landfilling) as possible to reduce the distance over which solid waste has to be moved manually. To ensure accessibility especially during rainy season, access for the vehicle to the working face can be reinforced by timber, metal sheet or hard-core made of construction waste, or other suitable materials. A heavy bumper bar made of timber should be placed across the strip at the point where the rear wheels are intended to stop to prevent the vehicle from reversing too far.

The solid waste unloaded by the vehicle should be well placed to form a heap above filling level immediately adjacent to the working face. The heap can then be easily dragged down by a worker using a three-tine "drag" (or rake) with a 1.8 to 2 m handle made of light but strong timber, as shown in Figure 4.11. Any empty containers such as oil drums found in the waste should be filled with waste and placed at the toe of the working face to prevent uneven settlement due to voids created by them. As the worker has to stand on the waste to operate, proper protective clothing and shoes should be provided. A proper facility for cleansing should also be provided at the site.

The flank of the strip will be formed by dragging the waste to form a 45-degree slope and covered by 0.15 to 0.2 m thickness of cover material. At the end of the day, the working face is dragged to form as steep a slope as possible and covered with cover material of the same thickness. The steep slope is to avoid wasting cover material. The spreading of cover material can be done by shovel and wide garden rake with short tines.

4. Emergency

An area near the entrance to the landfill next to the landfill access road should be set aside for an emergency situation when the working face has temporarily become inaccessible (e.g., when a vehicle breaks down or gets stuck on the access track).

5. Protection

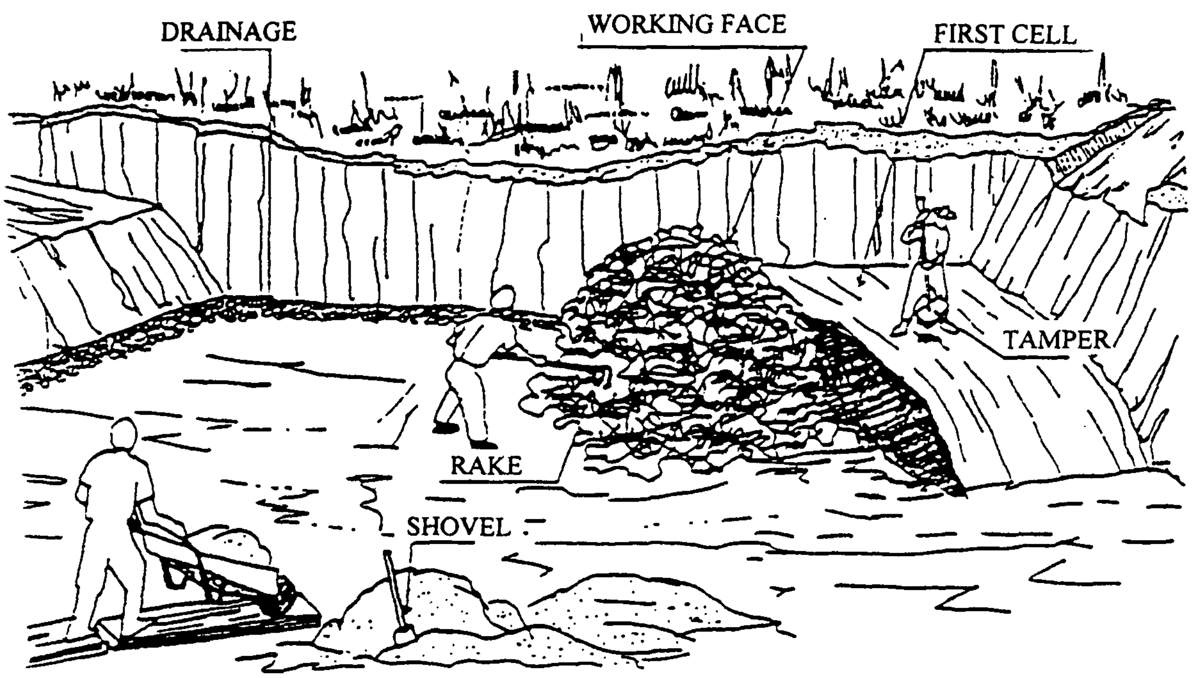
The completed final strip should be constructed with suitable grade and immediately planted with grass and other suitable plants to facilitate drainage by reducing seepage and the formation of leachate.

The working face must be covered with cover material at the end of the day for hygienic reasons. No solid waste should be accepted after the working hours. The working hours of the landfill should thus be publicized and made known to all users. Ideally, soil should be used for cover. However, as cover materials are scarce in some countries, coral sand, degraded wastes, and material from old landfills can be used. Compost is a good cover material. A composting process can be used to generate cover material in cases where cover material is very difficult to obtain.

6. Labor and Cover Material Requirements

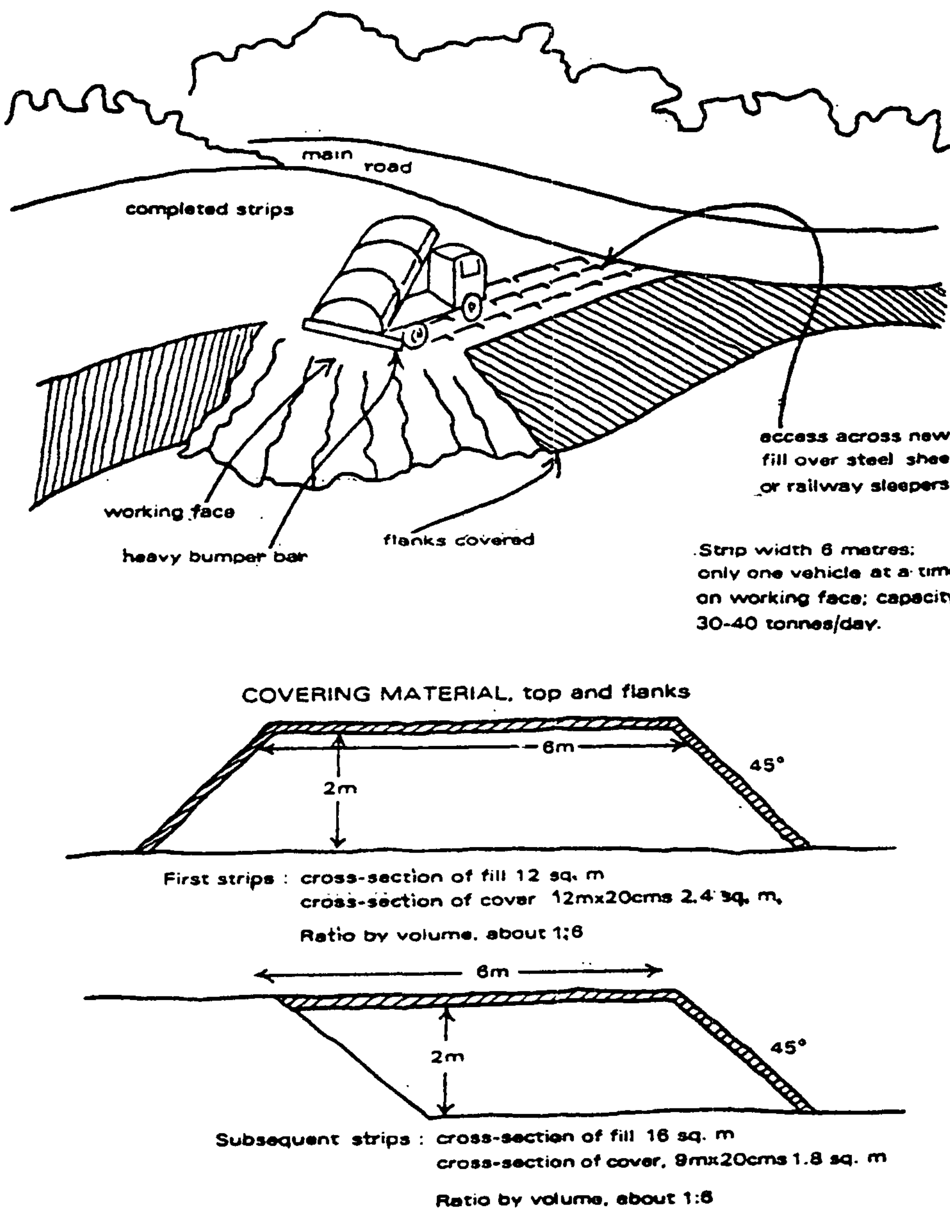
The following labor and cover material requirements have been suggested, based on experience in developing countries.

Population	**Waste Generation**		**In-Place Volume**	**Cover Material**	**No. of Laborers**
	Tonnes/day	m^3/day	m^3	m^3/day	
20,000	10	30	20	4	2
50,000	25	75	50	10	3
100,000	50	150	100	20	6



General view

Figure 4.10a Small, manually operated landfill
(Source: Jaramillo 1991)



Design details

Figure 4.10b Small, manually operated landfill
(Source: Flintoff 1976)

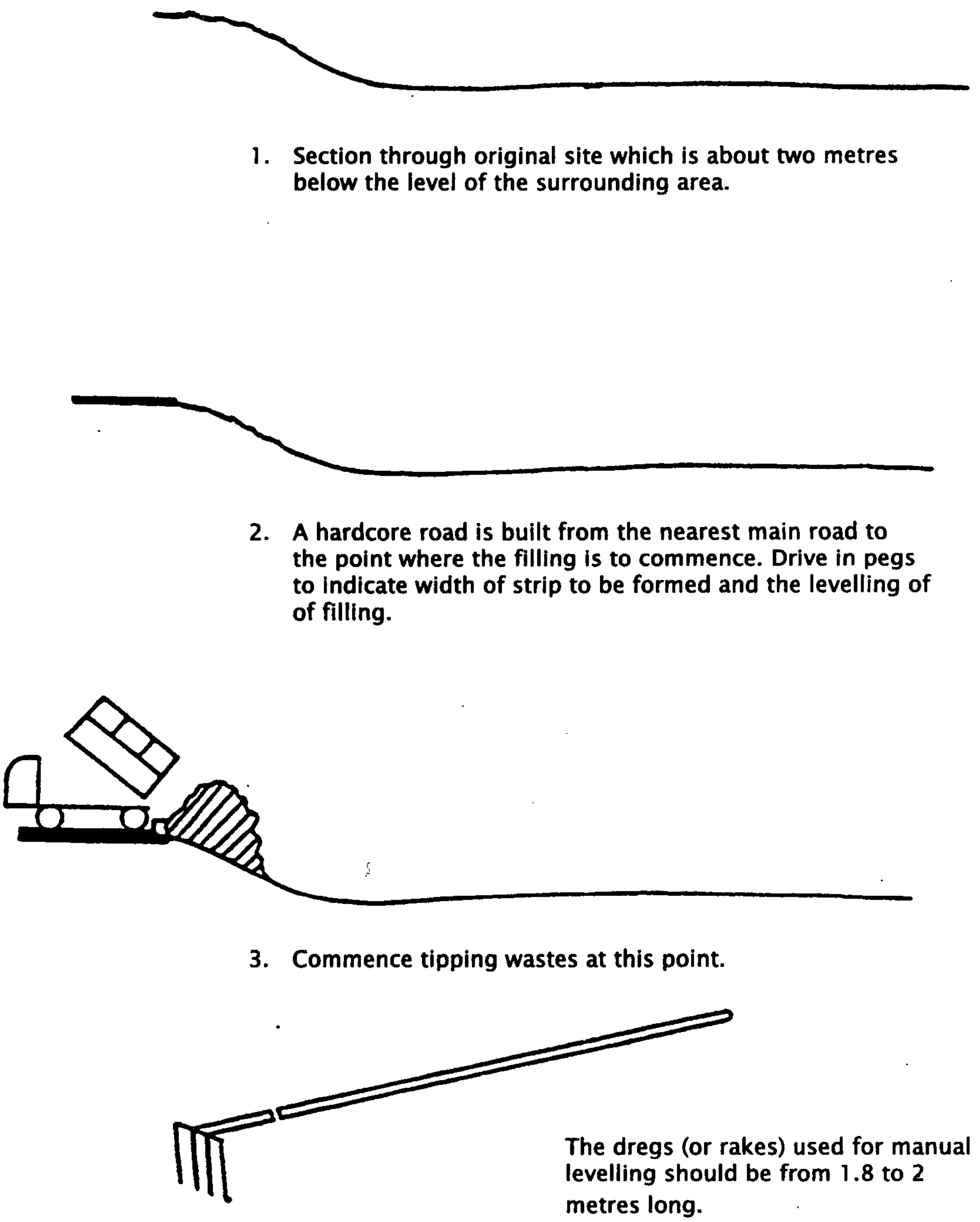
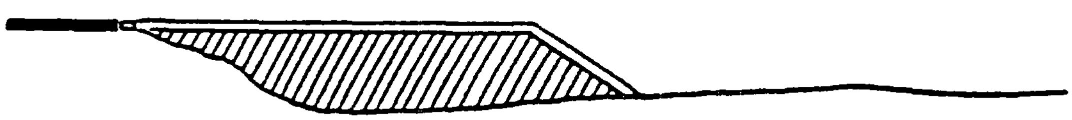
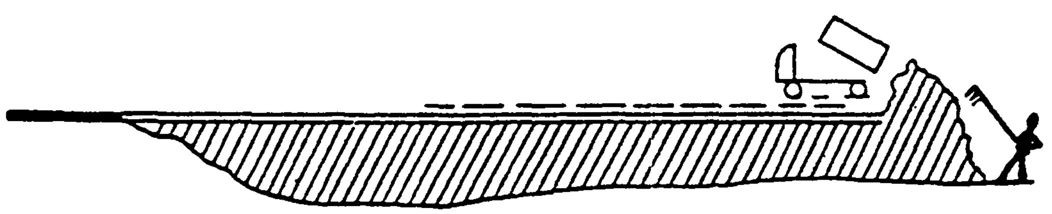


Figure 4.11 Manual landfill: Formation of first strip
(Source: Flintoff 1976)

4. The heaps of wastes are levelled by a three-tine drag (or rake) with a handle about 2 metres long and the flanks are formed to an angle of about 45°. Levels and strip width are guided by pegs driven earlier.



5. Every day the levelled wastes and the flanks are covered by between 15 cms and 25 cms of soil, sand, ash, or composted wastes, etc. Daily, or weekly, the working face is covered to form an enclosed cell of wastes.



6. Always take the vehicle right up to the working face to avoid dumping wastes on covered areas. If vehicles sink in, extend the hardcore road as far as possible, then use railway sleepers laid traversely, or steel sheets, to form a track over the newly deposited wastes. Always provide a heavy bumper bar at the point where vehicles unload.

Figure 4.11 (cont.) Manual landfill: Formation of first strip

Appendix 4.B
Climatic Water Balance: Example Calculations

(Source: Department of Water Affairs and Forestry, 1998)

THE POTENTIAL FOR SIGNIFICANT LEACHATE GENERATION, AND THE NEED FOR LEACHATE MANAGEMENT

To avoid water pollution, it is essential that significant leachate generation from landfills be managed by means of leachate collection and treatment systems.

All hazardous waste landfills are assumed to require leachate management systems.

General waste landfills are classified in terms of their potential to generate leachate. **This ensures that the risk of water pollution from leachate is identified at the earliest opportunity, even before a landfill site has been selected.**

Any landfill has the capacity to generate sporadic leachate in excessively wet weather conditions. However, it is only necessary to install leachate management systems (underliners, drains, and removal systems) when leachate generation could impact adversely on the environment.

A distinction should be drawn, therefore, between general waste landfills that generate **significant** leachate and those that only generate **sporadic** leachate. Though both types of leachate generation require management, significant leachate requires control by a proper leachate management system. Sporadic leachate can be handled with a less costly system

Significant leachate generation

This may be either seasonal or continuous throughout the year. It results mainly from climate and/or waste with a high moisture content.

In the case of existing landfills that do not meet the Minimum Requirements, other factors may also exist. These include fundamental problems with the landfill siting and/or drainage which result in significant ingress of ground or surface water into the waste body, and, hence, significant leachate generation.

Sporadic leachate generation

This is typical in arid climates and results from exceptional circumstances, such as a succession of excessively wet periods. This is often made worse by faulty site drainage. Sporadic leachate generation must always be minimized and controlled by drainage systems.

Determining Whether Significant Leachate Will Be Generated and if Leachate Management is Required

Even before a specific landfill site is considered, it is a Minimum Requirement to assess the potential for significant leachate generation and identify any need for leachate management identified.

The potential for leachate to be generated by a landfill depends on the water balance associated with the site; i.e., the **Site Water Balance.** This is affected by such factors as rainfall, evaporation, the moisture content of incoming waste, and water ingress into the waste body due to poor landfill site selection, design and operation. Of these, however, the relationship between rainfall and evaporation will, as a general rule, determine the Site Water Balance. Climate is the most common cause of leachate generation.

As ambient climate is the major uncontrollable cause of significant leachate generation at a landfill, a **Climatic Water Balance** is used as the first step in determining the potential for significant leachate generation (see below).

The **Climatic Water Balance** indicates whether the climate in which a landfill is located will cause it to generate significant leachate or not. It is thus a tool to alert the developer, as early as possible, about the need to address leachate management in the landfill design and costing. In many instances, this may be applied even before the site for the landfill is selected.

Thereafter, **Site Specific Factors,** such as waste moisture content, and ingress of runoff and ground water into the waste body, must be taken into account (see below).

The relationship between the Climatic Water Balance, Site Specific Factors and Site Water Balance is shown in Figure 4.12.

Calculating the Climatic Water Balance

The Climatic Water Balance is not a detailed classical water balance, such as one that would be used to determine ground water recharge. It is a simple calculation that assists in deciding whether leachate management is required or not. It therefore provides a conservative means of determining whether or not significant leachate generation will occur.

The Climatic Water Balance **(B)** is calculated using only the two climatic components of the full water balance, namely Rainfall **(R)** and Evaporation **(E)**.

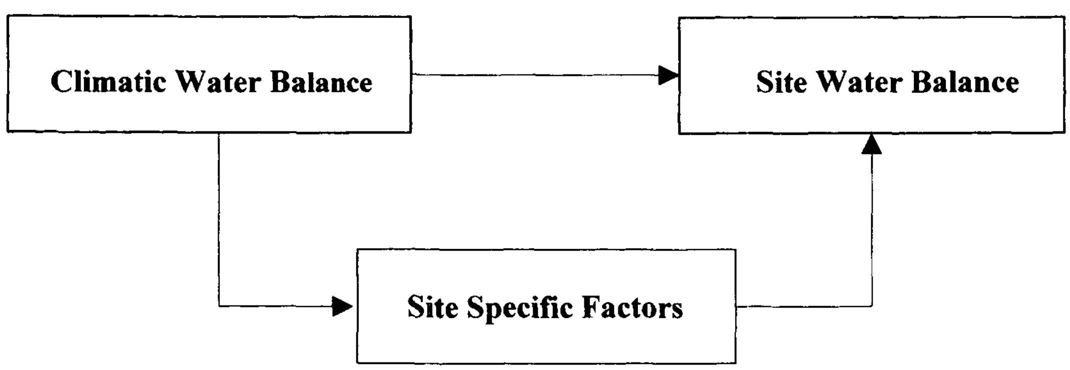


Figure 4.12 Relationship between Climatic Water Balance and Site Water Balance

The data used are the precipitation and A-pan evaporation or S-pan evaporation, easily obtainable from the latest edition of the Department's evaporation and precipitation records (Department of Water Affairs and Forestry: Hydrological Information Publication No.13: Evaporation and Precipitation Records.). The Responsible Person must identify the most representative weather station, or stations, on which to base the calculations.

The Climatic Water Balance is defined by

B = R - E

Where

B is the Climatic Water Balance in mm of water.
R is the rainfall in mm of water.
E is the evaporation from a soil surface in mm of water.

The value of B is calculated for the wet season of the wettest year on record, as shown by sample calculations in the Annex that begins on page 117. **B** is then recalculated for successively drier years, because the wettest year on record may only be so on account of unseasonal rainfall (i.e., the wettest wet season does not always occur in the wettest year). This calculation is repeated until it is established whether

B is positive for *less* than one year in five for the years for which data is available. *If so*

- There should be no significant leachate generation on account of the climate.
- The site is classified **B–**.
- If the Minimum Requirements for the siting, design, and operation are met, and only dry waste is disposed of, no leachate management system should be necessary.

or, **B is positive for *more* than one year in five for the years for which data is available.** *If so*

- There should be significant leachate generation.
- The site is classified **B+.**
- As such leachate requires management, leachate management systems are a Minimum Requirement.

Examples of the calculation of the Climatic Water Balance are provided in Annex 1. These demonstrate that using the iterative approach eliminates problems commonly encountered when working with averages.

Note that the Climatic Water Balance indicates where a specific landfill would plot on a hypothetical climatic index that ranges from arid to humid conditions. The cut-off point between **sporadic leachate generation (B-)** and **significant leachate generation (B+)** is where **B** is positive for more than one in five years, or for 20% of the time for which data is available. This calibration is based on long-term studies and observation of numerous landfills in Southern Africa, some of which are mentioned in the Annex. It is considered to be conservative, as a site which is classified as **B+** is, in fact, subject to **B-** climatic conditions for 80% of the time.

The calculation is conservative because it also ignores run-off and thus assumes that all precipitation falling on the landfill will infiltrate. Additionally, it ignores any moisture storage capacity of the waste body or the cover.

Site Specific Factors Affecting the Site Water Balance Classification

As noted earlier, it is possible that factors other than rainfall and evaporation could affect the water balance of a landfill site. These include the moisture content of the incoming waste and the ingress of either ground or surface water into the waste body, on account of poor siting, drainage design, or maintenance. These factors may affect the water balance to the extent that a site which is classified as $\mathbf{B}^-$, using the Climatic Water Balance, does, in fact, generate significant leachate.

In such instances, the Responsible Person must be aware of the situation, amend the classification to $\mathbf{B}^+$ and manage leachate in accordance with the Minimum Requirements applicable to $\mathbf{B}^+$ sites. It may also be necessary to implement remedial leachate management measures in the case of existing sites which do not meet the Minimum Requirements.

Typical examples of factors other than climate that affect the Site Water Balance include the following:

Co-disposal of high moisture content and liquid waste

Any landfill in which the co-disposal of liquids is permitted must be lined and equipped with leachate management systems that can contain, extract, and treat the resultant leachate flow. This is because the disposal of liquid and high moisture content waste adds extra moisture to the landfill and superimposes a hydraulic loading on the Climatic Water Balance. Depending on the amount of additional moisture added, this usually results in significant leachate generation.

In cases where the co-disposal of high moisture content and liquid waste is intended or practiced, more detailed water balance calculations are required. In such instances, the classification of the landfill is usually found to be $\mathbf{B}^+$, and leachate management is required.

Sub-optimal siting

The presence of a strategic aquifer would represent a "Fatal Flaw" and prohibit the siting of a landfill. In the exceptional event that a landfill has to be developed above or adjacent to a strategic aquifer, the Department of Water Affairs and Forestry would require that the landfill be classified as a $\mathbf{B}^+$ landfill. This would be an application of the Precautionary Principle and an example of the implementation of higher standards in order to protect a vulnerable receiving environment.

Badly selected sites

Significant leachate generation will occur in existing landfills sited either in excavations which penetrate the ground water or in areas of ground water seepage or springs. Although leachate will not be obvious in the first case, in the second case it is likely that leachate will be observed emanating from the toe and the sides of the landfill.

Significant leachate generation may also occur in existing landfill sites which are sited in a water course or across the drainage feature of a catchment. This is because run-off water will dam up behind the landfill and infiltrate the waste body, unless there is effective diversion drainage. Where run-off, damming, or water encroachment has occurred, leachate emission may continue long after the problem has been rectified by remedial design.

Badly designed and operated sites

Significant leachate generation may result if the landfill site does not adhere to Minimum Requirements. Examples could include cover excavations which penetrate the ground water, and infiltration from surface ponding on the landfill. The failure of drainage systems would also permit run-off to enter the landfill.

Conclusion

An existing landfill classified as $\mathbf{B^-}$ using the Climatic Water Balance may therefore have a $\mathbf{B^+}$ Site Water Balance and generate significant leachate. In this instance, the Responsible Person must amend the classification and either apply the appropriate Minimum Requirements for the amended classification, or undertake remedial work as necessary. In all such instances, the Department of Water Affairs and Forestry must be kept informed.

Alternative methods of determining significant leachate generation

In situations where the Climatic Water Balance method is inconclusive, or where Site Specific Factors are involved, a full, detailed Site Water Balance calculation may be required to establish whether or not a site will generate significant leachate. A program such as HELP could be useful in this regard (See Schroeder, P.R. [1989] *The Hydrologic Evaluation of Landfill Performance* [HELP] Model: Version 2, Source Code, Vicksburg, Mississippi.).

ANNEX: EXAMPLES OF CALCULATIONS OF THE CLIMATIC WATER BALANCE

As shown earlier, the Climatic Water Balance is calculated from the two climatic components of the full water balance, namely Rainfall (R) and Evaporation (E). The Climatic Water Balance (B) is defined by

$$\mathbf{B = R - E}$$

Where

- **B** is the climatic water balance in mm of water.
- **R** is the rainfall in mm.
- **E** is the evaporation from a soil surface, taken as 0.70 x A-pan evaporation in mm or 0.88 x S-pan evaporation in mm.

The factor of 0.70 used to convert A-pan evaporation to soil evaporation was arrived at by examining the predictions of all available soil evaporation formulae. From this evaluation, it became clear that a simple factor 0.70 x A-pan evaporation gives a result that is very close to predictions of most of the soil evaporation formulae. The factor 0.88 applied to S-pan evaporation gives values equivalent to those for A-pan figures. To allow for the effects of extreme weather conditions, the rainfall and evaporation figures for the calculation of **B** are selected as follows:

(i) **B** is first calculated for the wet season of the year having the maximum recorded rainfall.

This procedure may give problems, as evaporation records for very wet years are sometimes incomplete because the evaporation pans overflow. If there is an evaporation figure missing for a particular month, the figure is assumed to be the mean of those for the months before and after.

(ii) The value of **B** is calculated for the wettest six month period for the area under consideration, whether it falls within the period

May to October *or*
November to April

Where there is no well-defined wet or dry season, **B** is calculated for both of these periods.

If on the basis set above, **B is negative,** the site will, even in extreme conditions, have an annual water deficit, so that, provided only dry waste is disposed of and the landfill is correctly designed and operated, only sporadic leachate will be generated.

If **B is positive**, the site may at least have a seasonal water surplus under extreme conditions. There will be a possibility that significant leachate may be generated seasonally. Leachate management may be required.

B is then re-calculated for successively drier years to establish how **B** varies. This is because evaporation varies from year-to-year, and because a year may be wet because of unseasonal rain during the dry season. It is quite common for the maximum positive value of **B** to occur in a year other than the wettest year on record.

The calculations must be repeated until it becomes clear that

1. B is positive for less than one year in five for which data is available *or*
2. B is positive for more than one year in five for which data is available.

If case 1 applies, the site is classified as B^- and no leachate management system will be required. If case 2 applies, the site is classified as B and leachate management *will* be required.

In borderline situations, a full, detailed water balance calculation using a program such as HELP will be required.

The results of sample calculations that apply this principle follow:

1. JOHANNESBURG INTERNATIONAL AIRPORT (NOVEMBER TO APRIL)

1.	For the wettest year,	(1966/67)	B = 764 – 0.70 x 1170 =	–	14 mm
2.	For the 2nd wettest year,	(1974/75)	B = 855 – 0.70 x 1135 =	+	60 mm
3.	For the 3rd wettest year,	(1975/76)	B = 777 – 0.70 x 982 =	+	90 mm
4.	For the 4th wettest year,	(1979/80)	B = 734 – 0.70 x 1256 =	–	145 mm
5.	For the 5th wettest year,	(1971/72)	B = 760 – 0.70 x 1091 =	–	4 mm
6.	For the 6th wettest year,	(1977/78)	B = 716 – 0.70 x 1043 =	–	14 mm
7.	For the 7th wettest year,	(1963/64)	B = 715 – 0.70 x 1272 =	–	175 mm
8.	For the 8th wettest year,	(1957/58)	B = 584 – 0.70 x 1199 =	–	255 mm
9.	For the 9th wettest year,	(1970/71)	B = 589 – 0.70 x 1096 =	–	178 mm
10.	For the 10th wettest year,	(1960/61)	B = 569 – 0.70 x 1233 =	–	294 mm

Out of the 23 years on record, **B** has been positive on two occasions, close to zero on two and well into the negative on at least five occasions. Hence **B** is unlikely to be positive in more than one year in five, on average. Any site situated in the climate represented by the above statistics would be classified **B–**. Detailed observations on two landfills near Johannesburg International Airport have confirmed that they are unlikely to produce significant leachate except in quite exceptional weather circumstances.

2. CAPE TOWN INTERNATIONAL AIRPORT (MAY TO OCTOBER)

1.	For the wettest year,	(1976/77)	B = 553 – 0.70 x 556 =	+	164 mm
2.	For the 2nd wettest year,	(1973/74)	B = 635 – 0.70 x 588 =	+	223 mm
3.	For the 3rd wettest year,	(1961/62)	B = 447 – 0.70 x 558 =	+	56 mm
4.	For the 4th wettest year,	(1967/68)	B = 477 – 0.70 x 554 =	+	89 mm
5.	For the 5th wettest year,	(1958/59)	B = 358 – 0.70 x 642 =	–	91 mm
6.	For the 6th wettest year,	(1975/76)	B = 454 – 0.70 x 568 =	+	56 mm

For at least five years of the 23 years on record, **B** has been positive. On average, **B** will be positive in more than one in five years. This is a case where a site represented by the above statistics would be classified as **B+**, for which leachate management would be required.

Detailed observations on a landfill near Cape Town International Airport have confirmed that leachate is indeed produced every wet season, although the quantity produced is relatively small.

3. DURBAN INTERNATIONAL AIRPORT (NOVEMBER TO APRIL)

1.	For the wettest year,	(1957/58)	B = 1172 – 0.70 x 1011 =	+	464 mm
2.	For the 2nd wettest year,	(1960/61)	B = 920 – 0.70 x 1017 =	+	208 mm
3.	For the 3rd wettest year,	(1975/76)	B = 938 – 0.70 x 1201 =	+	142 mm
4.	For the 4th wettest year,	(1970/71)	B = 644 – 0.70 x 978 =	–	41 mm
	But to May and October of 1971		B = 578 – 0.70 x 652 =	+	122 mm
5.	For the 5th wettest year,	(1967/68)	B = 797 – 0.70 x 1084 =	+	38 mm
6.	For the 6th wettest year,	(1964/65)	B = 420 – 0.70 x 1024 =	–	297 mm
	But for May to October of 1965		B = 702 – 0.70 x 624 =	+	265 mm

For at least six years of the 23 on record, **B** was positive. Any landfill in this area would be classified as **B+** and leachate management would be required as, on average, **B** will be positive in more than one in five years.

4. BLOEMFONTEIN AIRPORT (NOVEMBER TO APRIL)

1.	For the wettest year,	(1975/76)	B = 845 - 0.88 (857) =	+	91 mm
2.	For the 2nd wettest year,	(1973/74)	B = 854 - 0.88 (978) =	–	7 mm
3.	For the 3rd wettest year,	(1971/72)	B = 634 - 0.88 (1066) =	–	295 mm
4.	For the 4th wettest year,	(1962/63)	B = 614 - 0.88 (1033) =	–	295 mm
5.	For the 5th wettest year,	(1974/75)	B = 537 - 0.88 (941) =	–	291 mm
6.	For the 6th wettest year,	(1966/67)	B = 503 - 0.88 (1230) =	–	579 mm

For the wettest year, **B** is positive. However, from the second to the sixth wettest years, **B** is negative, as is the case for the remaining twelve years on record. This is therefore a water deficit area. Any site situated in the climate represented by the above statistics would be classified as **B–** and would not generate significant leachate on account of the climate. This is borne out by observations in the field.

5. RUSTENBURG (NORTH WEST) (NOVEMBER TO APRIL)

1.	For the wettest year,	(1975/76) B = 1045 – 0.88 x 815 =	+	328 mm
2.	For the 2nd wettest year,	(1966/67) B = 1018 – 0.88 x 902 =	+	224 mm
3.	For the 3rd wettest year,	(1960/61) B = 777 – 0.88 x 857 =	+	22 mm
4.	For the 4th wettest year, (S–pan not on record)	(1977/78) B = 808 – 0.70 x 1304 =	–	105 mm
5.	For the 5th wettest year,	(1974/75) B = 777 – 0.88 x 894 =	–	10 mm
6.	For the 6th wettest year,	(1970/71) B = 692 – 0.88 x 949 =	–	143 mm
7.	For the 7th wettest year,	(1954/55) B = 783 – 0.88 x 847 =	+	37 mm
8.	For the 8th wettest year,	(1955/56) B = 639 – 0.88 x 923 =	–	173 mm

Here, **B** is positive on four occasions out of 26 years and close to zero (–10 mm) on one. No leachate management would be required according to the Minimum Requirements, but the Department might well insist on a detailed water balance calculation.

6. COMPARISON OF CALCULATIONS USING A– AND S–PAN DATA

1.	Repeat e.g. 1.10 above	B = 569 – 0.88 x 939	=	– 257 mm (–294 mm by A–pan)
2.	Repeat e.g. 2.1 above	B = 553 – 0.88 x 448	=	+ 159 mm (+164 mm by A–pan)
3.	Repeat e.g. 3.1 above	B = 1172 – 0.88 x 805	=	+ 464 mm (+464 mm by A–pan)
4.	Repeat e.g. 4.3 above	B = 1018 – 0.70 x 1061	=	+ 275 mm (+224 mm by S–pan)

Hence, calculations from A– and S–pan data give comparable results.

Appendix 4.C
Waste Disposal (Working) Plan

(After: Research Triangle Institute 1994)

A sequential disposal plan is developed to assist the operator in filling the site to provide constant drainage of surface waters off the landfill. It is also used to ensure that the site remains within the permitted areas, and when the site is full, the slopes on the top and sides are properly constructed to shed surface water but not too steep to allow final cover to be installed for recultivation of the area.

An efficient sequential filling plan has the following attributes:

1. The available landfill volume is efficiently and completely used.
2. The required amount of soil cover is applied without a need for extra soil to complete cells or layers.
3. Intermediate soil and (where appropriate) daily soil cover is sloped to encourage surface drainage of uncontaminated rainwater runoff.
4. The placement of the initial waste layer (between 2 and 3 m thick), also termed "a lift," on the landfill base is sequenced to limit the entry of uncontaminated rainwater.
5. As subsequent waste layers are placed, daily cover is removed from the base of lifts as needed to allow vertical leachate drainage and to prevent sidewall leachate seepage.
6. Lifts within the landfill are arranged so that surface water drainage does not interfere with vehicle traffic patterns and waste patterns.

The lifts are developed in a sequence that provides for efficient traffic routes on the landfill. The sequential filling plan should be prepared concurrent with the engineering design drawings. The landfill operations manager should be consulted during its preparation so that operational limits and efficiencies are incorporated into the plan.

The contents of a typical site working plan are given on the following pages.

Contents of a Typical Site Working Plan

(Source: UNEP 1993)

1. Introduction

- 1.1 The Site
- 1.2 Waste Inputs
- 1.3 Plant and Staff

2. Site Assessment

- 2.1 Geology
- 2.2 Hydrogeology
  - 2.2.1 Description and Permeability
  - 2.2.2 Piezometric Head
  - 2.2.3 Groundwater Quality and Monitoring
- 2.3 Hydrology

3. Infrastructure

- 3.1 Site Entrance
- 3.2 Site Security
- 3.3 Site Access
- 3.4 Site Amenities and Office
  - 3.4.1 Site Office
  - 3.4.2 Canteen
- 3.5 Parking
- 3.6 Workshop and Stores
- 3.7 Fuel Storage
- 3.8 Lighting
- 3.9 Signs and Direction
  - 3.9.1 Directions
  - 3.9.2 Safety and Warning
- 3.10 Wheel Cleaning
- 3.11 Fencing
- 3.13 Inventory of Plant and Equipment
- 3.14 Site Services
  - 3.14.1 Telephone
  - 3.14.2 Electricity
  - 3.14.3 Water
  - 3.14.4 Sewage
  - 3.14.5 Services Inspection
- 3.15 Communications
- 3.16 Staff Training Policy
  - 3.16.1 Introduction
  - 3.16.2 Technically Competent Persons

4. Operation methods

- 4.1 Introduction
- 4.2 Reception and Monitoring of Waste
  - 4.2.1 Input Monitoring
  - 4.2.2 Background Monitoring
  - 4.2.3 Monitoring and Non-Conforming Wastes
- 4.3 Access Roads
- 4.4 Traffic Movement
- 4.5 Cell Construction
- 4.6 Discharge of Waste from Vehicles
  - 4.6.1 Train Face
  - 4.6.2 Road-borne Waste Vehicles
- 4.7 Emplacement of Waste
- 4.8 Cover
- 4.9 Disposal of Asbestos Wastes
- 4.10 Difficult and Special Wastes
  - 4.10.1 Difficult Wastes
  - 4.10.2 Special Wastes
- 4.11 Secure Burial
- 4.12 Disposal of Liquid Waste
- 4.13 Final Refuse Level
- 4.14 Avoidance of Environmental Nuisance
  - 4.14.1 Smell
  - 4.14.2 Mud of Roads
  - 4.14.3 Traffic Queuing
  - 4.14.4 Noise
  - 4.14.5 Wind-borne Litter
  - 4.14.6 Rodents and Insects
  - 4.14.7 Birds
  - 4.14.8 Dust
  - 4.14.8 Visual Intrusion

10.7 Monitoring of Gas Compounds
10.8 Wildlife and Habitat Surveys
10.9 Aftercare Monitoring
10.10 Safety Inspections
10.11 Q.A (Quality Assurance) Compliance Audits

11. Operational Plan

11.1 Current Phase of Operations (Pit or Area 1)
- 11.1.1 Introduction
- 11.1.2 Filling Sequence
- 11.1.3 Access
- 11.1.4 Engineering Capping
- 11.1.5 Agricultural Capping
- 11.1.6 Control of Surface Water
- 11.1.7 Leachate Collection and Treatment
- 11.1.8 Gas Control
- 11.1.9 Current Engineering Works
- 11.1.10 Future Engineering Works

11.2 Phasing of Operations in Subsequent Pits or Areas
- 11.2.1 Introduction
- 11.2.2 Cell Sizes and Engineering
- 11.2.3 Description of Filling Sequence
- 11.2.4 Access
- 11.2.5 Capping
- 11.2.6 Surface Water Control
- 11.2.7 Leachate Control and Treatment
- 11.2.8 Gas Control and Utilization

Appendix 4.D
Barrier Systems

(Taken from previous internal World Bank reports)

Soil and Clay Liners

Soil liners are used in single liner systems and in composite liner systems. A soil liner may be either the only liner (single liner system) or the lower component of a composite liner system. Used as a single liner, a soil liner reduces or may even prevent leachate from migrating from the fill into the subsurface environment. As the lower component of a composite liner, a soil liner constitutes a protective bedding for the overlying flexible membrane liner (FML) and it serves as a backup for breaches in the FML. A useful function of all soil liners is to serve as a long-term structurally stable base for overlying works and materials.

Materials

To serve adequately as a liner, a soil must have a low permeability (less than 1 x 10-7 cm/s) when compacted under field conditions. After compaction, the liner should be able to support itself and the overlying materials. The liner material should yield to handling by construction equipment. Finally, a soil liner material should suffer no significant loss in permeability or strength when exposed to waste or leachate from the waste. A soil that is deficient in particular characteristic may be rendered suitable by blending it with another soil or with a soil additive. An example is the addition of bentonite cement to decrease permeability. Ideally, the compaction and permeability characteristics of the selected soil liner material should be determined by laboratory tests, so as to provide necessary information regarding the interrelationship between moisture content, density, compactive effort, and permeability.

Of the available materials, well-compacted clay soil is one of the most commonly used. A clay liner usually is constructed as a membrane up to 1 m thick. To function as a liner, the clay membrane must be kept moist. If sufficient clay is not available locally, natural clay additives (e.g., montmorillonite) may be disked into it to form an effective liner. The use of additives requires evaluation to determine optimum types and amounts.

If it meets the necessary specifications, the native soil at the site would best satisfy cost and convenience considerations. Otherwise, a suitable soil must be imported. Obviously, transport cost becomes an important consideration when off-site material is used. In most cases, a haul of any distance would be impractical. The liner material, whether excavated locally or imported, usually is stored as a borrow pile established at the site.

Design and installation

The soil liner underlies the entire landfill. The liner should have a sufficiently low permeability to impede leachate flow and be thick enough to provide a structurally stable base for overlying components (Figure 4.13). With allowances for leachate collection pipes and sump, the liner should be uniformly thick. However, the toes of sidewall slopes should be somewhat thicker to prevent seepage and to join adequately the bottom and sidewall liners.

In general, soil liners are constructed of compacted soils installed in a series of layers of specified thickness. The use of thinner increments (and, consequently, more layers) facilitates compaction, but adds to construction costs because the number of layers per unit of liner thickness is increased. Generally, thickness of liner layers prior to compaction is on the order of 150 to 250 mm.

Liner installation (construction)

The liner is installed (constructed) by placing the liner material (soil) with the use of scraper pans or trucks. The soil is spread evenly over the site and then broken up and homogenized by using disk harrows, rotary tillers, or manually manipulated implements to facilitate compaction. If soil additives are used, they are applied evenly over the site and then are thoroughly mixed into the soil.

The liner may be constructed in sections or in one piece. With a small site, the liner may be constructed in one piece over the entire area to be landfilled. Sectional (segmented) installation probably would be more suitable with large sites. In such operations, portions of the liner are built in stages. It is important that the sections (segments) be installed such that no break occurs between them. This can be done by bevelling or step-cutting the edge of a section as soon as it is installed so that the succeeding section can be tied in with the previously installed section.

Because the necessary degree of compaction is dependent upon a proper moisture content, any required addition of moisture should be made prior to placement of the liner material. Care should be taken to distribute the moisture uniformly throughout the soil. This is done by allowing adequate equilibration time after the moisture addition. The time may require days or even weeks if the soil is very dry or certain additives are used.

Practices followed and equipment used in earthwork construction are suitable for compacting a liner. The success of the compaction effort depends upon the individual liner layers being properly tied together. Tying together the layers can be accomplished by scarifying the surface of the last installed layer prior to adding the next one and ensuring that the moisture contents of adjacent layers are similar. If sidewall slopes are not very steep, they can be compacted in layers continuous with the bottom liner layers. Steeply sloped sidewalls may have to be compacted in horizontal layers because compaction equipment cannot operate on steep slopes. Tying together is especially important for steep sidewalls, because separation between layers can serve as pathways for the migration of leachate through the liner.

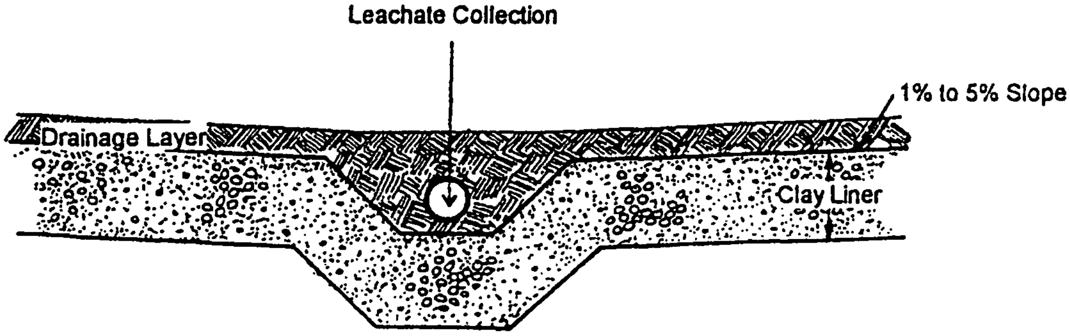


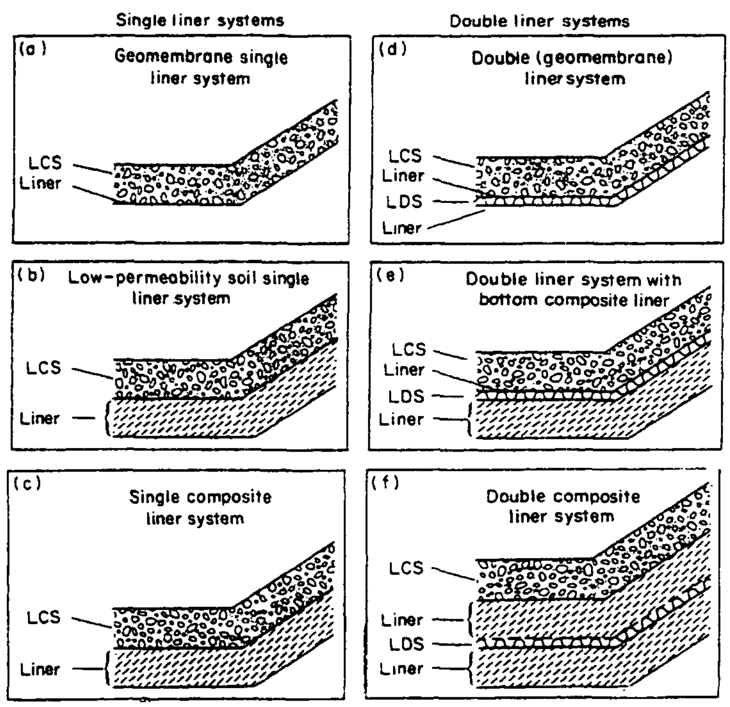
Figure 4.13 Soil liner with leachate collection system
(Source: Diaz et al 1996)

Binding segments of liner

There are a variety of techniques used to join together sections of liner. Because climatic conditions strongly influence activities related to soil liner construction, steps must be taken to minimize climate-related problems. For example, precipitation may interfere with construction operations by eroding or flooding the site or by over-moistening the liner material. A preventive step would be to seal-roll the compacted layer so that water will drain and not puddle or pond on the liner surface. Conversely, desiccation cracks can be remedied only by disking, adjusting the moisture content, and recompacting the affected portion of the liner. Liners must not be constructed of frozen soils and constructed liners must be protected from below-freezing temperatures.

Flexible membrane liners

The constituent material of a flexible membrane liner (FML) is prefabricated polymeric sheeting. A flexible liner may be used in many ways. For example, it may be used as a single liner installed directly over the foundation soil. On the other hand, it may be part of a composite liner placed upon a soil liner. Finally, it may be placed above or below a leak detection system in a double-lined landfill (Figure 4.14).



Note
LCS – leachate collection system
LDS – leachate detection system

Figure 4.14 Examples of flexible membrane liner systems
(Source: Fluet et al. 1992)

Major steps to be taken in the use of a flexible membrane liner are the selection of the FML material, designing of the subgrade, and planning the installation. The last step includes the design of subcomponents, such as sealing and anchoring systems and vents. A summary of the FML jointing methods is presented in Figure 4.15. Among the types of membranes commonly used for lining sanitary landfills are high-density polyethylene (HDPE) chlorinated polyethylene, chlorosulphonated polyethylene, and polyvinyl chloride. Important criteria to follow for selecting a FML include

- chemical compatibility with the leachate to be contained
- possession of appropriate physical properties such as thickness, flexibility, strength, and degree of elongation
- availability and cost

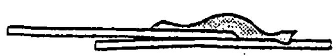
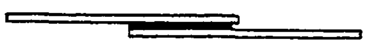
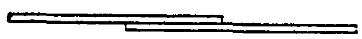
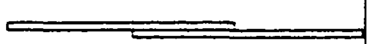
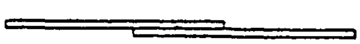
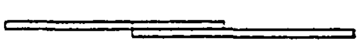
Method	Seam configuration	Typical rate	Comments
Extrusion fillet		200 ft/h	Upper and lower sheets must be ground Upper sheet must be beveled for 50 mil (1.25 mm) and greater Height and location are hand controlled Can be rod or pellet fed Extrudate must use same polymer compound Air heater can preheat sheet Routine used for difficult details
Extrusion flat		300 ft/h	Upper and lower sheets must be ground Good on long, flat surfaces Highly automated and patented machine Cannot be used for close details Estrudate must use same polymer compound Air heater can preheat sheet Controlled pressure and temperature
Hot air		50 ft/h	Good to tack sheets together Hand held and automated devices Air temperature fluctuates greatly No extrudate added
Hot wedge (a) Single track (b) Dual track	 	300 ft/h 300 ft/h	Single and double tracks available Double track may be patented Built-in nondestructive test Cannot be used for close details Highly automated machine No extrudate added Controlled pressure for squeeze-out
Dielectric		unknown	Only for factory seams Cannot be used for close details No extrudate added
Ultrasonic		unknown	New technique for FMLs Sparse experience in the field Capable of full automation No extrudate added
Electric resistance welding		unknown	New technique for FMLs Still in development stage No extrudate added Wire coating must use same polymer compound Wires provide possibility of doing spark test

Figure 4.15 Methods for joining flexible membrane lines
(Source: Carson et al. 1992)

In the absence of testing facilities, judgments as to compatibility will have to be made based on specifications listed by the manufacturer. Other mechanical properties to be considered are

- stiffness or flexibility at various temperatures, resistance to puncture
- thermal expansion
- seaming characteristics
- resistance to weathering
- resistance to biological attack
- instability of material on the service impoundment

Weathering may take the form of deterioration by ultraviolet light, ozone reactions, and plasticizer migration. Agents of biological attack include bacteria, fungi, and rodents. Here again, reliance is on data provided by the manufacturer. Although some published literature is available, such information may be difficult to obtain.

The subgrade upon which a FML rests is a key factor in the maintenance of its integrity. It does this by serving as a supporting structure and by preventing the accumulation of liquid beneath the liner. Liquid may accumulate as a consequence of infiltration of groundwater from surrounding soils. Consequences of the accumulation can be uplift stress and reduction of the strength of underlying soils. Leachate that escapes from the fill through breaks in the membrane can contaminate surrounding soils. In addition to those resulting from liquid accumulation, mechanical stresses may be caused by subsidence beneath the liner. Other mechanical stresses may take the form of tangential stresses due to differential movements of the subgrade, of concentrated stresses that lead to punctures and tears, and of repeated stresses that abrade the liner. All of these failure mechanisms can be prevented or minimized by

- taking general foundation design measures to prevent settlement, subsidence, slope failure, and other undesirable occurrences
- determining foundation configuration
- appropriately designing protective bedding layers
- specifying proper surface preparation measures

Among the foundation design measures are configuration of the subgrade to be free of abrupt changes in grade, and to be as plane and regular as is possible. Sidewall slopes should be such that tangential stresses do not exceed the tensile strength of the liner. Important design features of protective bedding layers are the provision of drainage to prevent the accumulation of gas or liquid and the protection of the liner from being punctured.

The drainage layer 'may consist of sand, gravel, or other comparable granular material. Alternatively, it may take the form of a geotextile (a fabric designed to provide tensile strength and serve as a filter protected by a layer of lower permeability soils).

Among the problems associated with drainage layers are the following:

- difficult to install on slopes
- not stable on steep slopes
- vulnerable to disturbance by workers during construction
- can be eroded by wind or water during construction
- possibility of the liner being punctured by damaged or displaced pipes

Surface preparation should include removal of rocks (larger than 25 mm), roots, and other debris from the surface. Organic material should be removed to minimize settlement and gas production under the liner. Finally, the substrate soil surface should be compacted to provide a firm and unyielding base for the liner.

The actual installation of a flexible membrane liner is a complex task. It should be done by a qualified and competent company under the supervision of the manufacturer or one designated by the manufacturer and should be independently quality assured.

Appendix 4.E
Provisions for Scavenging[1]

Introduction

The most desirable situation is not to have scavenging at a landfill site. Since sanitary landfilling is the subject of this Guide, this Appendix focuses on material recycling (scavenging) performed at the landfill site, and does not include scavenging at the point of waste generation, during collection, or during transport. Scavenging is the uncontrolled picking through waste to recover useful items, as contrasted to salvaging, which is the controlled separation of recoverable items. Presently, the sequence commonly followed with respect to scavenging at the disposal site is as follows:

1. Incoming refuse is dumped, as usual, at or near the working face (i.e., immediately behind or at the foot, or "toe," of the working face).
2. Scavengers sort through the dumped load.
3. Scavengers separate the retrieved materials into organized lots.
4. Machinery spreads and compacts the residues from the picking and sorting activities.
5. The remaining procedure is conventional landfilling.

Typical materials recycled in this manner include unbroken bottles, metals, plastics, cardboard, paper products, textiles, and glass.

Associated Issues

The case for scavenging must be strong enough to counterbalance the objections that can be raised against it at the site. These objections concern safety hazards to personnel of both scavenging groups and landfill employees, and interference caused by the scavenging activity that prevents the efficient conduct of work at the fill. Scavenging activities have severe negative impacts on the productivity of the equipment and the efficiency of overall operations. Hazards caused by the intermingling of manual scavenging activity and equipment-oriented sanitary landfilling activity increase when heavy equipment is involved, as is the case with landfills on a municipal scale. Furthermore, scavenging results in delays and often interferes with compaction and application of soil cover. Therefore, the problem is essentially one of developing a safe interface between scavenger and landfill equipment that allows for efficient operation of the landfill.

Designation of a Scavenging Site

The problem of developing an interface between scavenging and efficient landfill operation can be minimized or even eliminated by treating the scavenging activity as a first step in a sequence of steps that make up the landfill activity. Such an approach makes feasible a spatial separation of the two activities. Unfortunately, such a spatial separation adds a step to the overall operation. The

1. Also termed waste pickers or informal waste recyclers

step has two parts: (1) discharge of incoming wastes at the scavenging area of the disposal site; and (2) transfer of residue remaining after scavenging to the landfill site. Examples of this type of operation can be found around the world (e.g., Bahia, Salvador).

If the scavenging site is kept relatively close to the burial site, transfer of residue from one site to another may be done quickly by means of a bulldozer. Such an arrangement would demand that the scavenging site be movable. The two sites must not be so close as to promote mutual interference between people and machinery. The scavenging area could be located remote from the working face. In this case, the waste to be disposed would need to be transported by means of dump trucks.

A fixed scavenging site for the life span of the fill would be indicated when transfer by bulldozer is no longer feasible. A fixed scavenging area would be neither feasible nor advisable for a small disposal site. Dedication of a fixed portion of the disposal site to scavenging takes on many of the characteristics and advantages of a transfer station. For instance, scavenging done in a fixed area can be sheltered from the elements (wind, rain, etc.) and an undesirable impact upon the environment can be avoided or minimized. The operation itself can be kept orderly and controlled closely, and abuses can be discouraged. Furthermore, efficiency can be improved by including a certain amount of mechanization (e.g., conveyor belts and screens). Best of all, encounters between scavengers and landfill equipment could be more easily avoided. These advantages combine to enhance efficiency. This alternative would also allow for the provision of much needed sanitary facilities and a better working environment for the scavengers.

Perhaps the strongest objection to designating a fixed site is the fact that the added step of pickup and transfer mentioned earlier becomes a necessity. This objection is greatest when the distance between the scavenging and the landfill working face becomes great enough to make transfer by bulldozing no longer feasible. Of course, the capital expenditure associated with the erection of a building and introduction of added equipment would be another disadvantage. From the preceding discussion, it can be noted that the size of the disposal site is the decisive factor regarding advisability and necessity for dedicating a portion solely to scavenging. In general, a minimum life span of ten years would justify the incorporation of a fixed scavenging area.

Management of Scavenging Activity

Important factors when managing scavenging activities are the relative priorities of the scavenging and waste placement activities. Placement should have precedence over scavenging since the main purpose of the fill is the effective disposal of wastes. Therefore, scavenging must be managed in a way that does not unduly interfere with the main disposal activity of the landfill site burial, or disposal, of waste. Alternately, consideration must be given to the potential income from scavenging for the scavengers who are generally at the bottom of the economic ladder as well as to the loss of secondary materials to local industry.

Traffic

Unless carefully managed, traffic to and from the disposal site can be disruptive to the interface between scavenging and burial (disposal). Among the obvious causes of disruption are the increase in number of vehicles using the same road and the different moving speeds that result from the different types of vehicles involved. Scavengers' vehicles may be as small as pushcarts or as large as the vehicles used to transport the larger loads of recycled materials. Alternatively, waste collection and haul vehicles would surpass scavengers' vehicles in terms of size, weight, and speed. In some instances, long delays are brought about by the discharge of recyclable materials from the waste collection vehicles. Waste-hauling traffic would move at a much faster pace than scavenger traffic, and would be materially slowed by intermingling with scavenger traffic and by the increase in traffic density. Unfortunately, the best way to separate the traffic would be to provide separate access roads, but this would be the most expensive approach. Hence, the decision as to separation of access would rest upon economic feasibility.

The degree of access to the disposal site by scavengers depends upon the magnitude of separation between scavenging traffic and disposal traffic. If separation is complete, the access could range from unlimited to somewhat limited. Alternately, if the two traffic patterns are not separated, unlimited access is immediately ruled out because of the excessive interference with disposal traffic. If access is to be restricted, the problem arises as to which individuals are to be excluded. In arriving at such decisions, it should be remembered that political and social expediency would inevitably enter into any decision that would limit access, but social equity should be the goal.

Supervision

The scavenger activity should be under the direction of a supervisor whose principal function is to see that the activity proceeds efficiently and fairly, yet with a minimum of interference with the disposal operation. Accomplishing the latter implies working closely with the landfill manager. The latter should have the final say in decisions that affect the disposal operation. Hygiene and safety demand that good housekeeping be rigorously enforced.

Guidelines

A relatively fixed set of guidelines should be established that ranges from general to specific for the individual parties involved in scavenging activity. The following subjects could be regulated:

1. Census and registration of scavengers, and issuing of identity cards.

2. Assignment of spaces, refuse loads, etc., to individual scavengers or groups.

3. Removal of scavenged material from the site (i.e., the promptness, frequency and manner in which everything from separation of scavenged material to loading and hauling by cart or motorized vehicle is performed).

4. Responsibility for the sale of the recovered materials.

5. Welfare provisions for the scavengers are sometimes needed as a trade-off to obtain their compliance to avoid disrupting landfill operations. Provisions can include the supply of protective clothing and safety equipment, toilets, showers, eating facilities, and first-aid equipment.

The above guidelines should be enforced by the supervisor in a just manner. (This position may entail the taking of bribes, however small, from the different groups. To discourage such practices, the supervisor selected should be a scrupulous individual.)

Together with targeted programs to accommodate waste picking, authorities should initiate educational programs aimed at eventually shifting waste pickers and family members into other more productive and safer work.

Chapter 5 Landfill Site Operation

5 LANDFILL SITE OPERATION

There is no sensible reason to design and prepare for a better-engineered landfill if, subsequently, it is not operated in a better way than an open dump. There are two "classic" requirements of a sanitary landfill according to Flintoff (1976):

1. Wastes should be deposited and compacted in thin layers to no greater than about 2 m in depth.

2. Each day the surface of the newly deposited waste should be covered with approximately 15 cm of soil (or similar material).

The introduction of these requirements should be within the capabilities of most cities and towns.

5.1 Main Points

A good standard of waste placement is the foundation for a better managed landfill.

Safe and well-organized placement of waste distinguishes a controlled landfill operation from an open dump. Even the best designed and prepared landfill site will have many operational and environmental problems if it is operated badly. Conversely, well-managed site operations can compensate for weaknesses in site location and design (Flintoff 1976).

A competent landfill manager should be based on site full-time.

It is essential that strong emphasis is given to achieving a good standard of operation at a new landfill. This will inevitably mean, in many places, increasing the engineering and management skills of the staff working at the landfill. Good standards of operation are not possible if all qualified engineering and management personnel are located, for all or most of their time, in offices away from the landfill. A competent landfill manager, or at least a trained and motivated supervisor, should be based at the landfill site to direct day-to-day site activities. He or she should be supported by regular visits from other professional civil and municipal engineers to ensure landfilling is proceeding according to the "disposal plan" (described in Chapter 4 of the Guide).

A landfill manager should have enough delegated authority to get things done.

In parallel to placing a more experienced manager in charge of operating a new landfill, he or she should be given the power to decide how the daily site activities will proceed and given access to sufficient physical and financial resources. This means less intervention or questioning from office-based staff on day-to-day operations, and less double-checking with the head office before the manager can take operational decisions.

The disposal plan should be used to guide the operation of the site.

The landfill manager should use the disposal plan, prepared during the site design (see Chapter 4), as the basis of how he or she will organize and run the site. In brief, the plan should provide a detailed explanation of the following:

- Where waste is going to be placed during each phase of the site's lifetime.
- What site preparations and engineering are required during the site lifetime.
- How to deal with environmental nuisances (e.g., birds, litter, vermin, fires, gas, leachate).
- What equipment, materials, and staff are needed to run the site.
- What documentation and administration is need.
- What monitoring will be undertaken.
- When and how each part of the site will be completed and restored.

5.2 Key Decisions

The operational period of a landfill is the longest single stage in a site's lifetime. During this time senior management attention will be required on several occasions to resolve problems and issues beyond the capabilities of the landfill manager based at the landfill. Potential operational problems may be minimized by giving careful consideration to two key management decisions:

Who should operate the landfill?

There is no reason why a senior decision-maker should assume automatically that a new landfill has to be run by his or her present staff. The question must be asked: If they have the capability to run a better-managed landfill, why was this not done before? The reasons for past failings are often diverse and complex. It is more important to look to the future and decide who is in the best position to run the new landfill to an acceptable standard.

There may well be civil or highway engineering and managerial talent that can be identified within the municipality or public sector. A new tier of staff, the "middle manager," may need to be created or, if already present, be given greater recognition. This would typically be a trained professional likely to be based outside the head office and involved directly in running the day-to-day operations of one or more landfills. The best middle managers are those who are given the authority and access to resources to make operational decisions at the landfill, whose judgement is accepted by senior managers, and who can foresee realistic opportunities of future promotion to senior management. Such a person is needed to be the manager of operations at the new landfill. An example of a job description for a landfill operations manager is given in Appendix 5.A.

It should be recognized that, to run a landfill successfully, changes may be needed in the municipal department's organization, as well as in the delegation of powers. A better-managed landfill needs operational decisions to be made quickly by personnel working regularly at the site. Good landfill management cannot be achieved if a large burden of bureaucracy inhibits field operations.

A frank judgment should be made as to whether the public sector is the best organized to run a better- managed landfill. A careful consideration of the potential advantages and disadvantages of using the private sector should be made. It may be preferable to contract out the landfill operations and use municipal staff to ensure that the contractor is performing to the required standard of operation. The municipality would retain the responsibility for, and control of, waste management, but its senior managers would not have the distraction of dealing with the day-to-day operational problems. These problems would be the responsibility of the contractor. Details on the various forms of private sector contractual arrangements that can be considered, with examples, are described in Cointreau-Levine (1994) and Bartone et al. (1991).

Has enough money been made available to finance operations at the new landfill?

The operation of a better-managed landfill will in almost all situations cost more than open dumping. However, the operation should prevent additional money from having to be spent in the future to solve the problems caused by dumping. Additionally, if there is currently wastage of resources, over-staffing, and inefficiency in the municipal waste service, then cost savings in eliminating these could be achieved and made available to finance the new landfill operation. Elsewhere, if savings in current waste activities cannot be realized more funds will have to be made available from municipal budgets or through direct and indirect charges to residents and commercial waste producers (e.g., shops, hotels, industry). Getting sufficient finance to run a better managed landfill is crucial to the success of the scheme.

Acceptance by the financial controllers of the municipality's budget of the forecast expenditures must be sought and confirmed annually. This should ensure the continued satisfactory operation of the new landfill.

5.3 General Principles

A wide range of operational problems can occur at landfills (Table 5.1). To minimize or prevent these problems, the waste manager should be given resources to achieve the routine operational procedures listed below:

1. Waste should be compacted into thin layers, each up to 300 mm in depth, and, in turn, these layers should be built up into a total thickness of about 2 m. This improves the density of the waste and reduces the likelihood of voids and bridges within the waste that could cause instability and settlement problems in the future. The daily working area for waste placement should be kept as small as possible, say, no more than one hectare, at most sites.

2. Compacted waste should be covered with up to 15 cm of soil or similar material at the end of each working day. This measure reduces the infestation of waste by flies and other insects. It also provides a better surface on the site for waste collection vehicles to traverse, and it reduces the scattering of wind-blown litter.

3. No biodegradable waste should be deposited in water. This practice can create large quantities of water contaminated with leachate containing waste decomposition products. It could easily become a large source of water pollution.

4. Open burning of waste should not be permitted. If a fire is detected it should be extinguished quickly. A fire burning within a landfill benefits no one. The smoke is unhealthy and unsightly, and the fire creates "fire hollows" within the waste, causing potential instability. The fire may ignite (possibly catastrophically) pockets of landfill gas. If not extinguished quickly, the fire could become deep-seated and smolder pyrolitically for many years.

5. Inspections for vermin should be frequent and measures taken to prevent infestations. Vermin (i.e., rodents, other animals, flies, and birds) are a health risk. They should not be tolerated in excessive numbers anywhere.

Problem	Source/Causes
Leachate	*Pollutants that escape to contaminate surface or groundwater.*
Fires	*Due to self-ignition or mixing of incompatible substances; rupture of drums containing oxidizing substances.*
Dust	*From wastes, or from dry soil surfaces.*
Odors and gases (chiefly methane and carbon dioxide)	*From wastes and their decomposition.*
Handling hazards	*Due to hazardous wastes being accepted. Also a problem if scavengers have access to the site.*
Vermin	*Rats, birds, flies, and other vectors breeding, living, or feeding on any food wastes brought onto sites and spreading disease and nuisance to off-site areas.*
Litter and wind-blown rubbish (e.g., plastic and paper)	*Often a problem on access roads as well as the site itself.*
Visual intrusion	
Noise	
Runoff of sediment-laden or polluted water	
Uneven settling or consolidation	*Due to soluble or putrescible wastes, or containers rupturing under pressure.*

Table 5.1 Common landfill operational problems and their sources/causes
(After: UNEP 1994)

6. Litter should be collected regularly from around the site. The regular collection of wind-blown waste (at least once a week) is an important way to demonstrate the better management of a landfill. The continued presence of untidy, wind-blown paper, and plastic is a highly visible example of poor care and attention at a site.

7. Drainage ditches should be kept free of blockages. A blocked drainage ditch is useless and may lead to flooding during bad weather conditions. The basis of good site management is to undertake this type of routine maintenance to anticipate, and hence avoid, possible problems.

8. Site access roads should be regularly inspected and repaired. Filling holes on site roads will help reduce damage to vehicles, and allow the vehicles to deposit their loads quickly and efficiently. Broken fences should be maintained to prevent animals from entering the landfill. Animals on a site hinder waste operations and are a potential source of bacteriological infection to humans.

9. A record should be kept of all waste deliveries to the site. To check and keep clear site records about who is delivering waste, the quantity, where it is placed, what type and when, is part of a more controlled method of operation. It is also essential if disposal charges are (or are going to be) levied on waste disposers using the landfill.

10. Environmental monitoring should be performed routinely and records kept at the site as evidence of the impact that the site has (or does not have) on the environment. Even with better-managed landfills, the site operator should not be complacent and think that the

waste will be entirely benign. Unforeseen problems can occur, or at other times the site operator may wish (or be required by law) to demonstrate that there is no adverse impact. Both of these can be aided by routine monitoring of environmental features. Environmental monitoring can take many forms, ranging from relatively simple observations to very complex sampling and chemical analysis. The amount of environmental monitoring that is realistic to undertake has to be determined according to each landfill, the equipment available, and the existing environmental conditions in the locality.

There are two main reasons for taking water quality samples. The first is to safeguard the environment and public health (i.e., to demonstrate that water is safe to drink or use for animals and food crops, and is not dangerous for natural wildlife). If the landfill leachate entering off-site watercourses increases heavy metals or organic contaminants in the receiving waters, or increases the chemical oxygen demand, then it is possible the water may become unsafe. Many countries and organizations have set minimum concentrations for individual parameters (e.g., WHO Drinking Water Quality Guidelines 1993). If they are exceeded, then more controls on leachate discharges may be needed.

The second reason for water quality monitoring is to provide information to the landfill manager on the composition of the leachate within the landfill. This is useful to demonstrate or disprove, that landfill leachate caused an off-site pollution problem, and to indicate the state of waste decomposition conditions within the deposited waste.

11. The public should be excluded from the site for their own safety. Scavenging should be discouraged. Where, for social, economic, or other reasons, this is not a realistic possibility, areas away from the working area for waste placement should be provided to contain and minimize the disturbance from scavenging activities. This was described previously in Appendix 4.C.

The minimum level of staffing will vary depending on the quantity of waste received at a site and the method of landfilling in operation. For larger, well-managed landfill sites (say, over 250 tonnes per day), where waste is placed and compacted by machine(s), a reasonable staffing level includes

- a landfill operations manager (based at the landfill); at larger sites, the manager would be assisted by a landfill supervisor or deputy
- a gate keeper/office clerk
- security guards
- traffic marshals, one per working face (directing vehicles at large, busy sites)
- landfill and earthmoving equipment drivers
- a maintenance mechanic (if landfill equipment is maintained at the site); at large sites there may also be a mechanic's assistant and other workshop personnel
- manual laborers (to assist in continuing site preparations, drainage clearance, and similar general duties)

At a landfill where waste is spread and covered manually, the staffing should include, in place of the equipment drivers and maintenance staff, one group of six manual workers for each working face. Each group would comprise

- two top workers
- two bank workers
- two bottom workers

5.4 Minimum Acceptable Standards

The daily operations at a managed landfill fall into three general groups of activities:

(1) Waste reception
-checking vehicles and loads at site entrance
-segregating wastes and loads
-temporary storage (e.g., construction debris) for on-site roads
-record keeping and routine administration
-on-site traffic control and direction to the working face

(2) Waste deposition
-waste placement
-compaction
-excavating cover material
-spreading cover material
-construction of on-site temporary haul roads
-construction of bunds and earthworks

(3) General site maintenance and control
-litter (e.g., light plastic and paper) and dust control
-maintenance of mobile plant, buildings, fences, and similar items
-surface water management
-leachate control
-gas and odor control
-vermin and bird control
-environmental monitoring

These are addressed in the following sections. The specific approaches and methods to be employed at the landfill for each of these activities should be included in the site disposal plan written during the design phase of the site (Chapter 4). However, with each activity, operational and sometimes strategic decisions, need to be made during the operational life of the site.

5.4.1 Access control

The first step in controlling the way waste is brought to the landfill, and the types of waste disposal, is to control the access to the site.

A landfill should have a gatehouse and office in which a gate keeper, sometimes assisted by a clerk, records the details of each load: the type of waste, its source (location), and an approximation of the quantity of waste being carried. Quantities can be estimated by volume of the vehicle or the weight can be measured by a weighbridge if provided. However, the expense to buy and maintain a weighbridge is not justified for all landfills: Those serving a population greater than 200,000 should have one, as should sites where waste disposal charges are levied.

Access control can also better ensure that deliveries of waste are only accepted during operating hours of the landfill. Late deliveries of waste and uncontrolled after-hours access to a landfill can lead to a weakening in the management control of operations, fires, damage, and equipment theft. Therefore, the site entrance should be staffed for the whole day. During operating hours there would be a gatekeeper and at other times one or more security guards.

A second aspect of access control is to provide a means by which waste vehicles can be easily directed to the correct part of the site to dispose of their waste load. At large sites with many vehicles arriving, a traffic marshal is often used near to the working face of the landfill to avoid chaotic vehicle congestion and interference with the site equipment that is compacting deposited waste.

Access control has the additional advantage of being able to stop vehicles to check their loads. This is important if there is a suspicion that they are carrying wastes not allowed to be disposed at the landfill. A gate keeper may also be able to spot burning waste in vehicles when they first arrive at the landfill and direct them to a secure area to discharge their loads in safety.

5.4.2 Waste placement and compaction

The careful placement of waste is an essential aspect to a better standard of landfill operation. This is to ensure that all waste is well crushed and compacted to give the best possible filling density. This approach reduces the quantity of air remaining in the deposited wastes (which can lead to accelerated decomposition, strong odor, the propagation of surface fires, and water pollution). It prevents "bridges" and other voids that reduce stability of the waste and that could collapse.

Achieving good compaction of waste at its time of placement reduces the likelihood of future problems. Most landfills use mechanical placement of waste by a tracked bulldozer. Specialized "landfill compactors" with steel wheels are not essential to operate a well-managed landfill provided the more bulky wastes can be adequately reduced in size. The methods of placing waste vary. The technique recommended in Chapter 4 (the area method made from discrete "cells" of waste) is designed to compact waste effectively and maintain as small a working area as possible.

A waste collection vehicle reverses up to the base of the working face and discharges its load (Figure 5.1). The landfill machine then spreads the waste in a thin layer (no more than 300 mm deep) up the working face. The thin layers of waste are crushed by the weight of the machine. Typically, a machine will pass over the waste between three and six times to maximize compaction. The thin layers are built up until the waste layer is 2 m thick. The uncovered 2 m high platform is then covered at the end of the day with soil (often around 15 cm).

Larger landfills often have two working areas: one for collection vehicles to unload, and another for the landfill equipment to compact previously unloaded waste. The working areas are then alternated every 30 to 60 minutes. Sometimes it is beneficial to have separate working areas for mechanically and manually emptied wastecarrying vehicles.

The working face should be as narrow as possible without interfering with normal operations. To achieve this, the traffic marshal on duty at the face of the fill can use a whistle, horn, or flags to direct incoming vehicles to the appropriate area of the working face to unload. Barricades for traffic and width markers may be used to show the area that is to be used on a given day.

Further compacting of waste can be achieved by controlling the movement of the collection vehicles across the site. It is likely that collection vehicles will be directed to travel over previously filled (and covered) areas and so further compact the waste beneath. When possible, demolition debris and other dense rubble should be used to construct temporary haul roads across the site for collection vehicles to get to the working face more easily.

Site haul roads are typically around 6 m wide and constructed from whatever hard materials are available (e.g., sand, rock, broken bricks, stone, concrete, and demolition debris).

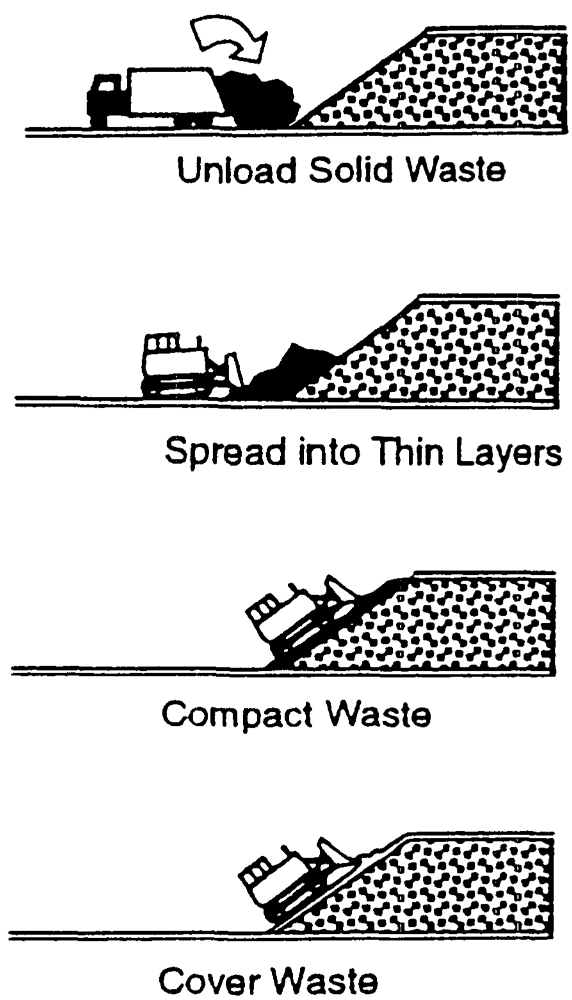


Figure 5.1 Waste placement
(After: Research Triangle Institute 1994)

Not all waste will be small items which are easily compacted. Most landfills will receive some "bulky" items. To avoid creating large voids within the landfill, it is important that larger items, such as old furniture, animal baskets and cages, and packaging boxes and containers, are crushed by the landfill equipment before compacting and spreading into thin layers. Tires are relatively resistant to being crushed and preferably should be cut up before placement. Noxious and potentially infectious items such as animal carcasses, animal and fish wastes, condemned food, permitted healthcare wastes, and waste oils and liquids, should be covered immediate after placement at the bottom of working face. Alternatively, such waste should be deposited and covered in excavated trenches in parts of the landfill previously filled with wastes. Both approaches also require scavenging to be controlled to avoid these waste materials from being dug up. Discussion about the disposal of these types of wastes is provided in Chapter 6 of this Guide.

5.4.3 Application of soil cover

As noted earlier, it is common to cover waste regularly (often daily) with soil, up to a depth of 15 cm. Where sites have a shortage of soil, they will inevitably use less cover material. Waste may be left waste uncovered for more than one day and a thinner layer of soil covering may be spread when cover is applied. The application of some soil cover is generally regarded as an important aspect of operating a better-managed landfill site. The spreading of soil cover can be carried out either by bulldozer or similar machine, or manually.

The daily soil cover can come from soil-like wastes that are stockpiled at the site, or excavated from on site or a nearby borrow area. Tractors with trailers, old tipper trucks or, if appropriate, animal carts are required to carry the cover material across the site to where it is needed.

Illustrations of the application of daily soil cover and the placement of waste are presented in Figures 5.2 and 5.3, respectively.

Alternatively, the unfinished (sloping) working face may be covered at night by tarpaulins or similar temporary fabric covers, which are rolled back at the start of the next day.

To avoid creating perched leachate watertables within the body of the waste, with consequent risks of slope instability or leachate breakout (springs) through the sides of the landfill, daily cover soils that are of low permeability should be scraped off or at least scarified immediately before being covered with further layers of waste. This will allow better vertical movement of leachate through the underlying waste.

5.4.4 Intermediate and final covers and cell construction

Several earthmoving operations have to be periodically undertaken at a landfill. On areas of the landfill that have been partially completed, but where further waste placement will not recommence for several weeks or months, "intermediate" soil cover should be spread. This is typically a thicker layer of daily cover, between 25 and 50 cm, which acts as a partial seal to restrict most surface and rain water movement down into the wastes, and prevents accidental exposure of the waste to sites workers and pests. Intermediate cover can be spread by mechanical equipment or manually, and should, preferably, have a gentle slope (at least a 1 in 50 gradient; i.e., 2% slope) away from landfill areas.

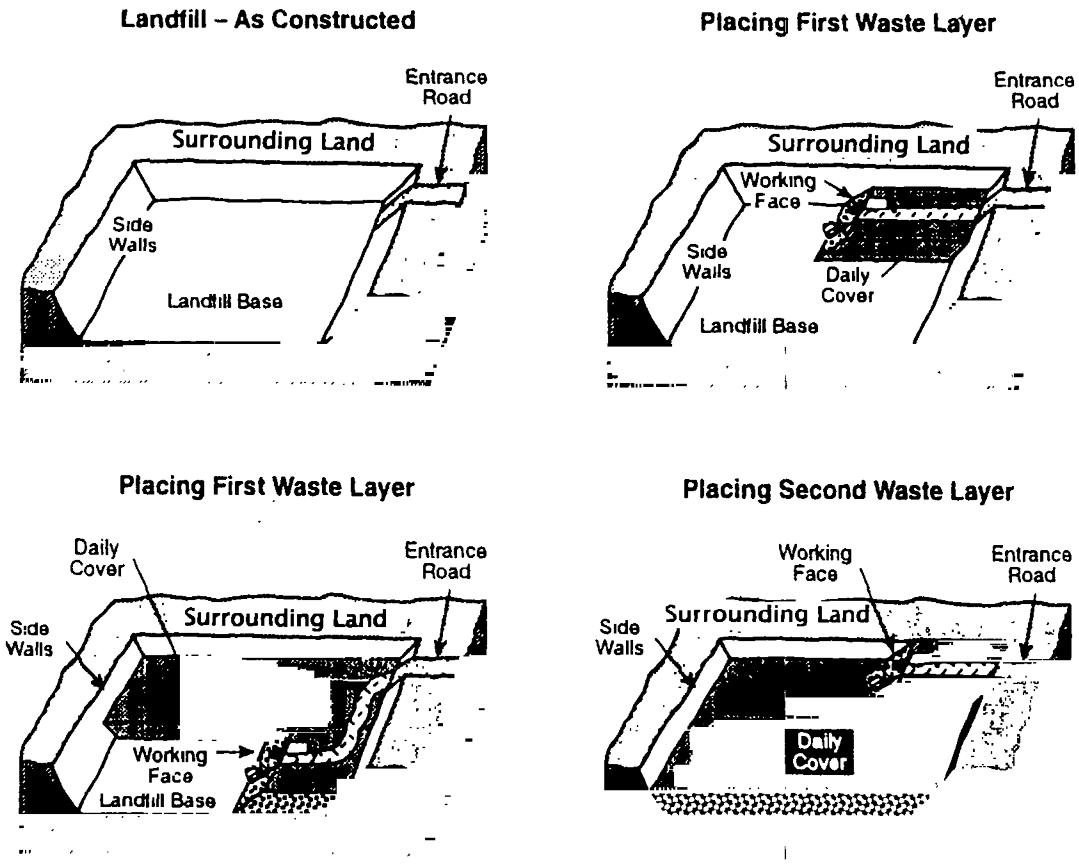


Figure 5.2 The placing of a daily covering of soil
(Source: Research Triangle Institute 1994)

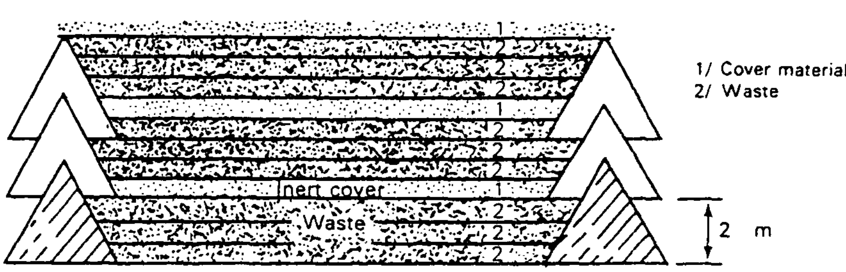


Figure 5.3 Alternating layers of waste and daily soil cover
(After: Department of the Environment 1986)

As parts of the landfill are filled to their final, preplanned elevation, a final cover (or cap) should be placed over the waste. This provides the long-term seal to isolate the waste from surface water entry and prevents release of odors and leachate. Discussion on the selection of a final cover design is presented in Chapter 7. It is important to note that parts of a well-managed landfill may be completed to final elevations before others. This is known as "progressive restoration." Therefore, routine site operations, after a few years, will inevitably include the placing of a thick layer of final cover over completed parts of the site.

Other earthmoving duties will include constructing the sidewalls of new landfill cells into which wastes are to be deposited. These sidewalls could be constructed from low-permeability soils if available, so that each cell is partially hydraulically separated from adjacent cells. If low-permeability soil is not available, then other soil materials available at the site may be used. For containment sites, where separated leachate collection systems are required, each cell wall should be built upon the cell beneath. Some restriction to water movement laterally within the waste is achieved by cell walls extending upwards through the whole void space of the landfill. This is illustrated in Figure 5.4. The presence of cell walls, one above another, should be recognized when completing sections of the site, since such areas will not undergo decomposition and may be expected to produce significantly lower settlement than elsewhere in the deposited wastes.

5.4.5 Mechanical landfill equipment

The waste manager has to make important investment decisions about the type of landfill equipment needed. Several factors influence the number and type of equipment the manager should obtain. The basic functions served by landfill mechanical equipment are

- functions related to soil (excavation, handling, compaction)
- functions related to wastes (handling, compaction)
- support functions

Depending on the type and size of the operation, the same piece of equipment may be used for more than one of the three functions. Versatility and ease of handling are essential considerations in the selection of equipment likely to be used for more than a single purpose.

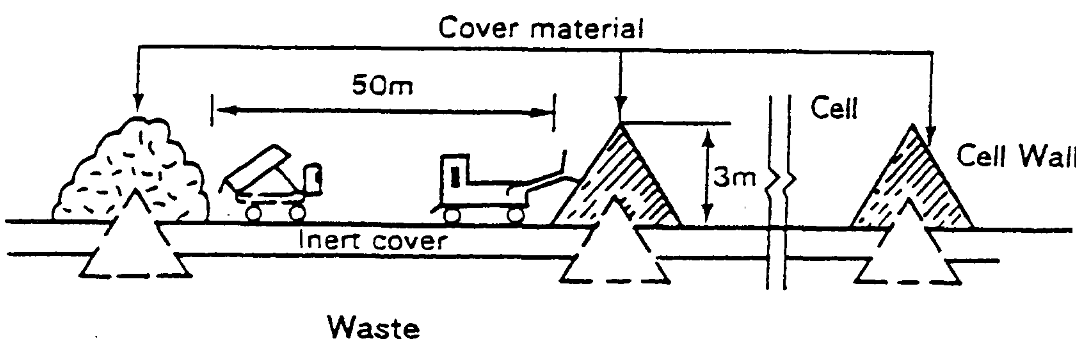


Figure 5.4 Cell wall construction at a landfill
(After: Department of the Environment 1986)

Soil-related functions

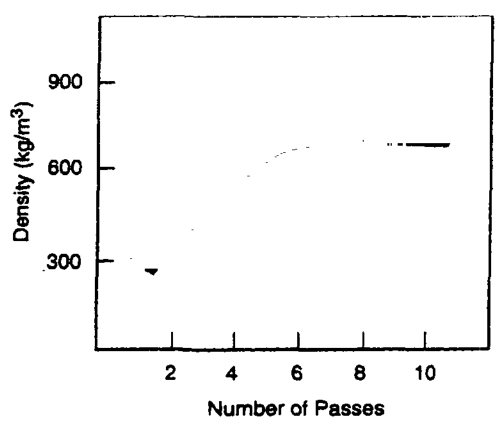
The need for excavation, handling, and compaction of soils used as liner and cover material should considered when choosing landfill equipment. Procedures and equipment to achieve these tasks differ only slightly from those used in other earth-moving operations. Consequently, the degree of mechanization and sophistication of equipment suitable for sanitary landfilling in a given situation would not differ from other earth-moving operations (e.g., road construction).

Wheeled equipment (such as a mechanical shovel) is satisfactory for excavating soils such as sand, gravel, clay loams, and silt loams. Alternatively, tracked equipment would be needed for soils such as clays. If soil is to be moved over distances shorter than about 100 m, mechanical shovels and bulldozers can be used. Old tipper trucks, tractors with trailers, or carts can be used for carrying soils for greater distances.

Waste-related functions

The waste-related functions served by equipment include spreading and compaction. Tracked machines are most commonly used for waste handling and compaction. However, for small-scale operations and those constrained by lack of funds, earth-moving equipment, such as mechanical shovels, are adequate for waste handling.

Achieving good waste compaction has many short- and long-term effects on the operation of the landfill and the rate and extent of waste settlement, and is an important factor in maximizing the overall capacity of the landfill. Heavy equipment specifically designed for compaction is more effective and efficient for this function than would be a piece of lightweight equipment designed primarily for earth moving. However, a weight difference can be compensated by an increase in the number of passes by lighter equipment over the waste mass (Figure 5.5). The number of passes required to achieve good compaction also depends upon the moisture content and amount of dense material in the waste.



The graph represents the number of landfill equipment passes to achieve higher densities in municipal waste landfills in higher-income countries. Denser municipal waste, such as that typically found in medium- and lower-income countries, requires fewer passes by landfill equipment.

Figure 5.5 Change in waste density at the working face, depending on number of vehicle passes

(Source: Reindl 1977, Research Triangle Institute 1994)

Landfill equipment must be rugged because operational conditions for equipment used on a landfill are tough. Radiators and air filters can become clogged, and the body and operating parts of the equipment can be damaged by protruding or dislodged wastes. Tires, even heavy-duty types, can be punctured or cut, which results in a short life span. This combination of unfavorable factors emphasizes the necessity for maintaining spare parts and an adequate repair and maintenance facility at or close to the landfill.

Support functions

Support functions during the operational phase of a managed landfill include extension and maintenance of on-site haul roads to the working face, drainage construction, fire protection, and removing stuck collection vehicles. The capabilities of some types of common mechanical equipment used at managed landfills are given in Table 5.2.

Type	**Solid Waste**		**Soil Cover**			**Site Preparing and Maintaining**
	Spreading	Compacting	Excavating	Covering	Hauling	
Tracked bulldozer	E	G	E	G	NA	G
Tracked loader *	G	G	E	E	F	G
Landfill compactor	G	E	P	F	NA	P
Rubber-tire bulldozer	G	G	F	G	NA	F
Rubber-tire loader *	F	G	F	G	G	F
Scraper	NA	NA	G	G	E	F
Dragline excavator	NA	NA	E	F	NA	F
Grader	NA	NA	G	NA	NA	G

* also known as a mechanical shovel

Key: E = Excellent; G = Good; F = Fair, P = Poor; NA = Not Applicable

Table 5.2 Landfill equipment capabilities
(Source: Flintoff 1976)

Preventive maintenance of landfill equipment.

The costs associated with the operation and maintenance of the mobile equipment used in landfills account for a major portion of total operational costs. A complete disregard of both frequent inspection and systematic maintenance can lead to severe problems. The problems can take the form of machinery breakdowns, resulting in inadequate compaction or insufficient cover material. Breakdowns can be costly. Poor compaction and lack of cover material can cause serious environmental impacts and deterioration in site operations equivalent to open dumping.

It is important to inspect regularly the equipment used on the landfill. Some parts of the equipment may require daily inspection while others may need only weekly inspection. In addition, continuous operation and low frequency of breakdowns can be achieved only through the implementation of a preventive maintenance program. This should be based on guidelines provided by the equipment manufacturers, and it should be the responsibility of the landfill manager to see that the program is implemented successfully. Proper maintenance and careful use of the equipment, accompanied by frequent checks and changes of engine oil, oil and fuel filters, and air filtration equipment, and daily visual checks of the exterior of the equipment, such as the state of hydraulic hoses, drive components, and protective shields, should be sufficient to implement a successful preventive maintenance program. In addition, it is good practice to keep a record of all routine maintenance procedures completed on each landfill machine. An example of a daily checklist for mobile equipment is presented in Figure 5.6.

Facilities are needed, either at the landfill or in the local town, to conduct routine maintenance procedures. As a minimum, basic hand tools and a stock of reconditioned or replacement parts are required. Equipment manufacturers should be required to provide a basic set of replacement parts for new machines and the name(s) and location(s) of sources for additional parts. Ideally, the source(s) should be located within the country and spares should be available for purchase with local currency. It is strongly recommended that the municipality purchase equipment which is locally available and supported by a local network of service engineers.

5.4.6 Surface water management

The prevention of water entering landfilled waste is a continuing requirement throughout the operation of a better-managed landfill.

Surface water, which might enter the landfill from outside the site, should be intercepted by perimeter drainage ditches (also known as storm water cut-off drains). Temporary drainage ditches in unused parts of the landfill, especially if located in a quarry or similar place, may be used to stop "clean" rainwater from moving laterally across the site and coming into contact with waste.

Routine operational requirements include inspecting, cleaning, and maintaining the existing surface drainage channels. This usually requires manual labor. It is essential after seasonal effects such as vegetation die-off, or strong winds blowing dust and debris. If such materials accumulate in the channels, they could cause blockages and overflowing when the next severe rain occurs. Drainage channels should cleared a minimum every six months and more frequently where seasonal heavy rainfalls occur more regularly.

5.4.7 Fire control

Open fires should not be allowed on a well-managed landfill. If a fire breaks out, it should be extinguished as quickly as possible to prevent it travelling deeper into the deposited waste. The most common technique, at sites where leachate minimization is to be practiced, is to excavate a trench around the burning area of waste to isolate it from the remainder of the site (Figure 5.7), and then the burning waste is smothered with sand or soil. Only in exceptional circumstances should water be used. Appropriate sources of water might be nearby rivers or lakes, on-site lagoons retaining collected rainwater, or even surface leachate ponds. In extreme circumstances, city fire tenders may be used.

An alternative technique to extinguish shallow fires is to dig a "firing hole" where the burning waste can be exposed to the air, to either burn out rapidly or be smothered with sand. This technique is described in Chapter 8.

Site: ____________________
Machine: ____________________
Date: ____________________
Completed By: ____________________
Hour Meter Reading: ____________________

REMARKS

BEFORE STARTING CHECK

WATER	☐	____________________
ENG. OIL	☐	____________________
TRANS.	☐	____________________
FUEL	☐	____________________

WATER ADDED FRONT	☐	__________	WATER ADDED REAR	☐	__________
ENG. OIL ADDED FRONT	☐	__________	ENG. OIL ADDED REAR	☐	__________
TRANS. OIL ADDED FRONT	☐	__________	TRANS. OIL ADDED REAR	☐	__________
HYDRAULIC OIL ADDED FRONT	☐	__________	FINAL DRIVE OIL	☐	__________

AFTER STARTING, LEVEL THE MACHINE AND CHECK

ENGINE OIL	☐	____________________
TRANS.	☐	____________________
HYDRAULIC OIL	☐	____________________
ANY LEAKS	☐	____________________
BRAKES	☐	____________________
STEERING	☐	____________________
TRANSMISSION	☐	____________________
PRESSURE	☐	____________________
GAUGES	☐	____________________
SHIFTING	☐	____________________
ENGINE	☐	____________________
TEMP.	☐	____________________
OIL PRESSURE	☐	____________________
WATER TEMP	☐	____________________
UNDERCARRIAGE	☐	____________________
TRACK ADJUST.	☐	____________________
ROLLER WEAR	☐	____________________
TIRES	☐	____________________
BLADE	☐	____________________
CUTTING EDGES	☐	____________________
HYDRAULICS	☐	____________________
PUMP	☐	____________________
JACKS	☐	____________________
OTHER	☐	____________________
AIR CLEANERS	☐	____________________
RAD. CLEAN	☐	____________________
TRACK CLEAN	☐	____________________
TIRES FREE OF MUD	☐	____________________

Figure 5.6 A daily inspection checklist for landfill equipment
(Source: Northeim 1987)

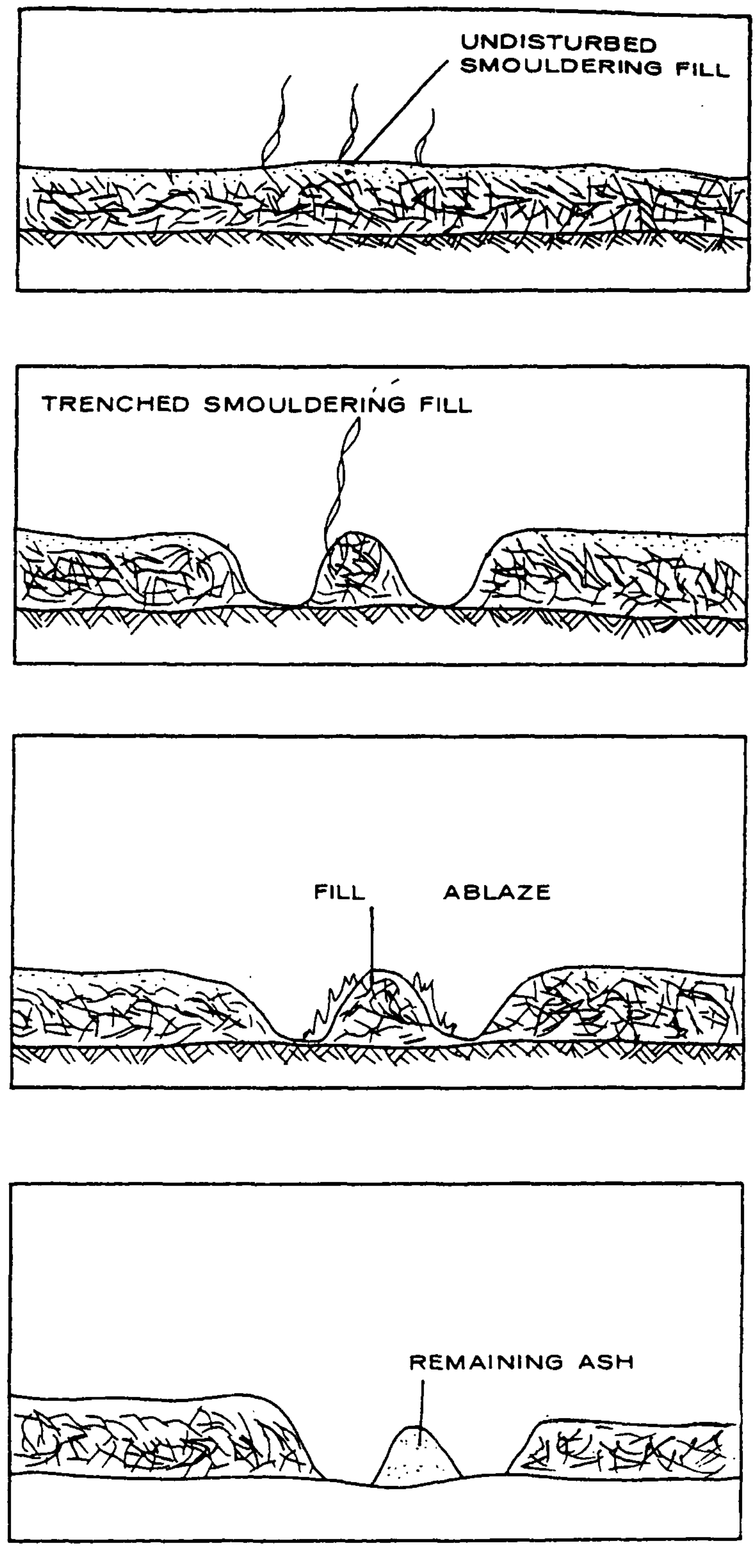


Figure 5.7 Operation sequence: Excavation of trenches to extinguish a fire
(After: Environment Canada 1977)

5.4.8 Pest control

Pests (e.g., birds, vermin, larger animals, and flies) are a large nuisance to workers and the surrounding inhabitants to a landfill. They are a potential public health risk that could be avoided. The abundance of pests around an open dump is a clear indication that poor waste management is being practiced.

Recently, the control of insects and rodents on landfills was considered in work undertaken in Hungary (Research Triangle Institute 1994). The advice from the study is reproduced below:

- Pests can be a great nuisance and public health problem at any improperly operated landfill. Flies and mosquitoes are two types of insects of primary concern because they both spread disease. Flies spread many food-borne diseases, such as salmonella, by physically carrying bacteria from the waste to food. Mosquitoes breed in water that collects in depressions on the landfill surface, and in uncompacted and uncovered wastes such as piles of tires and other bulky items. Mosquitoes carry diseases such as encephalitis, dengue fever, and malaria. Control involves compacting and covering wastes, and, where rainwater would tend to collect, filling depressions to eliminate breeding areas.

- Rats and other rodents spread diseases such as rabies, rat-bite fever, leptospirosis, typhus, and bubonic plague. Rodents are brought to the site in loads of waste or migrate from surrounding areas. They remain at the facility if there is food, shelter, and water. Covering the waste daily, properly compacting it, and filling the site to shed water will eliminate the three items rodents need for survival. If infestation is persistent, the use of poisons can be very effective in eliminating a rodent population. If poisoning or trapping of rodents is required, the operator should put up signs that inform all landfill workers, visitors to the landfill, and scavengers.

Details on rodent control are given in Appendix 5.B and WHO (1994b).

Birds, especially in coastal areas, are attracted to landfills for food. They may constitute a potential health hazard (for example, seagulls can carry salmonella), and be a nuisance because of noise and droppings, especially if residential areas are situated nearby. The most effective control practice is rapid and complete covering of all refuse. Noise production, distress calls, the use of captive birds of prey or similar measures can provide some temporary control. In places where there are persistent problems with birds, the erection of a net over the landfill working face has proven effective.

5.4.9 Litter control

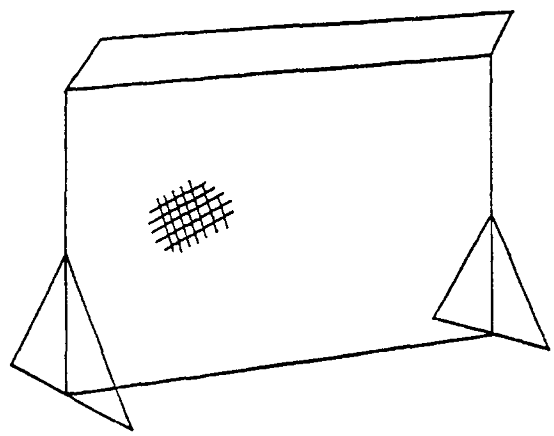
A landfill is not well managed if paper (litter) or other lightweight material is blowing around the site. Litter is a highly visible sign of poor control of the waste being deposited. It is also one of the simplest forms of pollution to contain.

Even the best run landfills have some litter, but various techniques can reduce the problem. Litter is a particularly difficult problem to control on windy days. The use of portable litter screens around the working face of the landfill is an effective way to control much of the wind-blown litter (Figure 5.8). Screens may be simple wooden or metal frames covered in wire mesh or netting. They should be cleaned manually at least once per day, at the end of each day, by landfill workers, and repositioned if the wind direction changes or the working area moves to a different part of the site.

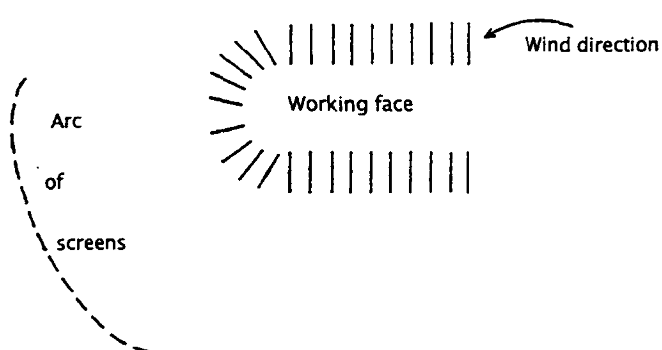
In addition, landfill site manual workers should also make a daily "litter patrol" around and outside the edge of the landfill to collect litter not captured by the litter screens. A perimeter fence can also act as a secondary litter screen to stop litter from travelling outside the landfill boundary.

Other measures, used when handling and depositing waste, can also help reduce the quantity of litter. These include

- discharging the waste at the bottom of the working face, not the top
- frequent covering of completed portions of the cell during the day
- application of water to dampen waste loads containing a high concentration of paper



Portable litter screen about 2.5 metres high, 2.5 to 3 metres long, covered with chicken wire, 20 mm to 40 mm mesh



A number of screens are used to form an arc, the position of which is changed in accordance with wind direction

Figure 5.8 Control of airborne litter
(Source: Flintoff 1976)

5.4.10 Leachate control and monitoring

The minimum that should be achieved at a managed landfill operation is to keep clean surface and groundwater separated from the waste. The construction of interception ditches, water collection ponds, and soil walls are all intended to achieve this. Leachate is created from water already present in the waste, or entering from outside, moving through the deposited waste. Rainwater, water from snowmelts, and poorly controlled groundwater are the three main sources of water entering deposited waste. Surface entry can be restricted by effective surface water diversion, having only a small working face open to the atmosphere, and through the use of daily soil cover.

Leachate contains extracted contaminants from the decomposing waste. The polluting potential from this leachate depend on several factors including the

- quantity of free liquid not absorbed into waste
- concentrations of pollutants in the leachate
- rate at which leachate can leave the site
- proximity of leachate beneath the site coming into contact with drinking water supplies
- ability of environmental, physical, chemical and biological processes to reduce the concentrations of pollutants before they come into contact with water supplies

Every landfill produces a unique combination of pollutant concentrations which also vary over time. The pollutants in the largest volumes in leachates are carboxylic ("fatty") acids which come from microbial decomposition of the waste. These are in one of the four classes of components that have been identified in leachates (Department of the Environment 1986):

- major elements and ions such as calcium, magnesium, iron, sodium, ammonia, carbonate, sulphate, and chloride
- trace metals such as manganese, chromium, nickel, lead, and cadmium
- a wide variety of organic compounds including carboxylic acids, which are usually measured as Total Organic Carbon (TOC) or Chemical Oxygen Demand (COD), together with some individual organic species, and phenol, which can be of particular concern
- microbiological components

Even at the minimum standard of landfill operation described in this Guide, some leachate monitoring will be necessary. There is no universal approach to managing leachate. If the site has been designed to allow some seepage of leachate into the underlying strata, no collection or treatment of leachate is needed. Groundwater should still be monitored to check that the leachate concentrations are continuing to be diluted and are acceptable. At least as frequently as every six months, monitoring should be conducted by analyzing samples taken from borehole(s) located down gradient of the site. The samples should be measured for the parameters commonly associated with leachate pollution (Table 5.3). Elevated levels of any of these against background will be indicative of a leachate plume impacting on the groundwater. The significance of this impact should be reviewed with the water authority.

At containment landfills, leachate will gradually accumulate at the bottom of the site. The depth of this leachate should be regularly measured via constructed monitoring wells. If the leachate drainage system is not entirely effective, the level of leachate may rise and there could be a situation where the waste becomes totally saturated. This would lead inevitably to leachate springs and ponds developing on the surface of the site. This eventuality should be considered at the design stage and, if it occurs unexpectedly, then leachate pumping will need to be undertaken. A drainage system is always required if the site is lined, to facilitate leachate removal for treatment/disposal, unless water balance calculations indicate no leachate generation at any time. It is just a matter of time that a natural containment site (e.g., clay pit) will eventually discharge leachate. The design of such a site should install drainage to control the discharges of leachate for future possible treatment and disposal. Monitoring of leachate levels beyond the life of the site would also be needed to anticipate this discharge.

As a minimum standard in routine landfill operations, the depth of leachate in the deposited waste should be regularly checked, at least twice a year. If the leachate level is found to be rising year-after-year, or the depth exceeds a level set by the regulatory agencies, the landfill manager should decide on additional leachate controls. This may include starting leachate extraction by pumping and treatment at the site. The techniques to be used will have been included in the disposal plan prepared during site design (Chapter 4), and will depend on the resources available locally. More details are given in Section 4.4.3.

Leachate quality monitoring may also be necessary. It is often a legal requirement in many countries to measure other parameters. An example of a minimum list of parameters to measure leachate quality is given in Table 5.3.

General Waste
pH
Electrical conductivity (EC)
Potassium (K)
Chloride (Cl)
Ammoniacal Nitrogen (NH4-N)
Chemical Oxygen Demand (COD)*
Hazardous Waste
pH, EC, COD
*Plus***:
Volatile Organic Carbon (VOC)
Total Organic Carbon (TOC)

* If high COD, perform relevant toxicity tests, such as bioassaying

** For hazardous wastes the parameters recommended are for first screening purposes only, Subsequent tests should include all load-specific constituents

Table 5.3 A minimum list of water quality parameters to be routinely measured
(After: Department of Water Affairs and Forestry 1994)

5.4.11 Gas control and monitoring

One feature of a better-managed landfill operation is that more of the waste will decompose anaerobically, i.e., in the absence of air (oxygen). In open dumps most waste is burnt or decomposes in the presence of air (aerobic decomposition). The presence of air leads to worsening odors and a more polluting leachate.

Anaerobic decomposition ultimately leads to the production of landfill gas (a mixture of carbon dioxide and methane gas, as well as traces of other gases). This gas has to be monitored and controlled whenever there is a potential risk of accumulations of flammable concentrations in the site or from landfill gas migrating off-site.

The generation of landfill gas should be considered as inevitable. The natural tendency of landfill gas is to migrate upwards, from those areas where waste is placed, eventually dispersing into the atmosphere. In sites where upward migration of the landfill gas is restricted, it will begin to travel laterally, and, depending on the local geology, perhaps even migrate off-site. Migration pathways were described in Chapter 4 of this Guide.

If deposited waste lies beyond an agreed distance from buildings (cited in some texts as a minimum of 200 m), gas monitoring and control may not be necessary. On the landfill itself, no site building should be built directly on to the ground. If no gas control measures are installed, then no subsequent development within 200 m should be permitted without a survey of conditions and establishing a monitoring system. If gas migration is subsequently found or suspected, gas control will be necessary.

To avoid off-site, migration a "path" of low resistance has to be provided for the gas to escape to the atmosphere. This can be achieved by constructing gravel- or rock-filled gas interception ditches around the perimeter of the site (Figures 5.9a and c), and inserting wells or pipes into the surface of the landfill to act as passive vents (Figure 5.9b). Gravel- or rock-filled windows can be excavated into the surface of the landfill into which are built gas vent pipes (Figure 5.10a). Alternatively gravel-filled gas vents may be constructed progressively in-situ as the waste filling continues at the site (Figure 5.10b) though these can exert excessive forces on any liner installed (through negative friction) and will act as a vertical leachate drain, short circuiting flows to the base.

Wherever possible, landfill gas vented through vertical pipes should be ignited to oxidize the methane to the less potent greenhouse gas (carbon dioxide).

Where off-site migration of gas is threatening to affect residences then, in addition to vents, it may be necessary to install a "barrier wall." This is a trench backfilled or lined with a material impermeable to landfill gas, such as clay (Figure 5.11).

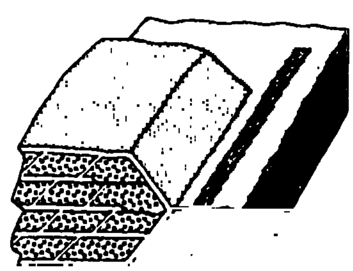
If the quantity of landfill gas being generated becomes excessive, then passive venting to avoid the accumulation of hazardous concentrations may need to be supplemented with mechanized ("active") gas collection and control methods. This is most likely to be needed at very large sites receiving high daily inputs of waste. More information on active gas collection is given in Section 5.5.3.

The minimum monitoring requirement for landfill gas should be to check for the presence or absence of landfill gas in wells, under buildings, and in underground ducts and chambers to ensure that flammable concentrations have not accumulated. Carbon dioxide on its own, being heavier than air, can also accumulate in underground places and may reach asphyxiating concentrations. The safe way to monitor for landfill gases is by using hand-held, spark-proof, battery-powered gas detectors, montoring for methane and carbon dioxide. However, this would require the purchase and maintenance of such monitoring equipment.

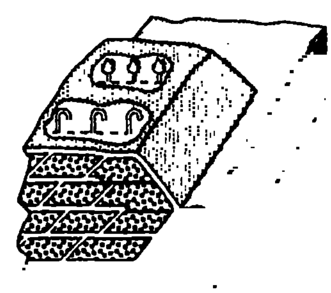
A very basic approach for buildings and chambers can be copied from the historic use by miners of birds in cages. If a bird shows distress in the place being monitored, then asphyxiating gas concentrations are probably indicated.

Monitoring for landfill gas should be both on- and off-site. Migrating landfill gas can travel several hundreds of metres if there is fissured or faulted underground rock strata or if a rising inclined strata of high permeability intersects directly with the waste.

a) Venting trench



b) Passive vent



c) Detailed cross-section of landfill gas perimeter venting trench

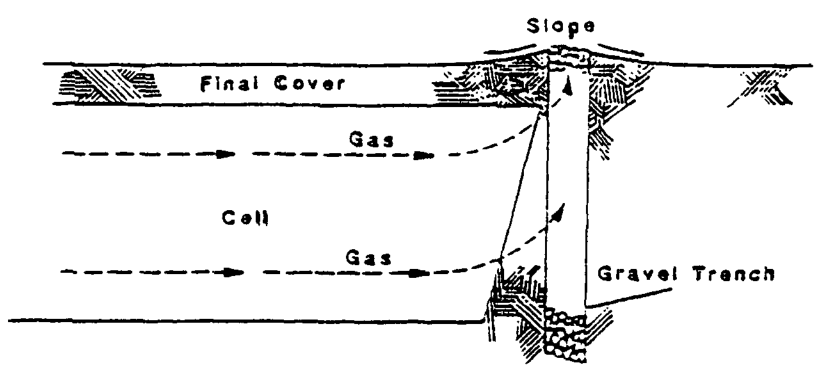
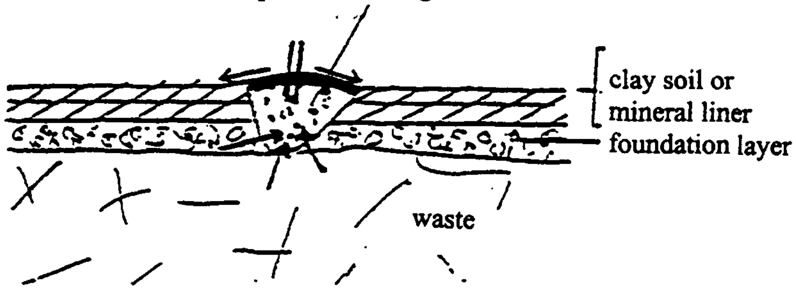
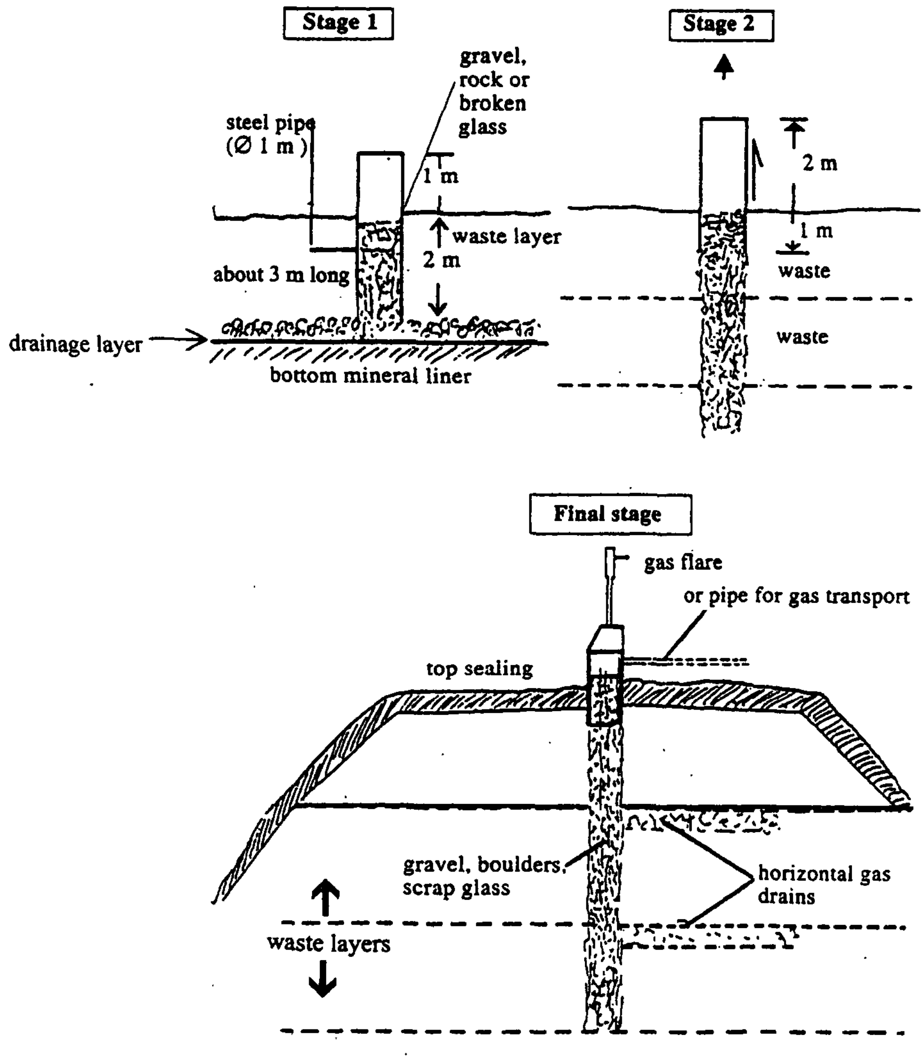


Figure 5.9 Landfill gas-venting trenches and pipes
(Source: Parts a,b: Research Triangle Institute 1994; Part c: Internal World Bank Document)

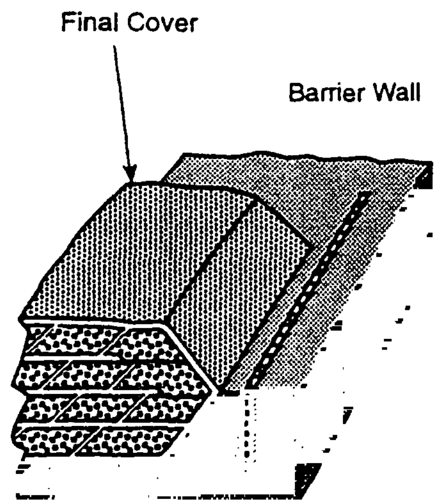


a) Landfill gas "window" with cap and vent pipe



b) Landfill gas vent constructed in-situ during waste filling

Figure 5.10 Low-cost landfill gas collection systems
(After: Oeltzschner 1996)



A barrier wall works only if it extends below the base of the waste or into the water table. These walls are not an effective method in soils with low permeability.

Figure 5.11 Landfill gas barrier wall
(Source: Research Triangle Institute 1994)

5.4.12 Record-keeping

An integral part of site operation and maintenance is the formal keeping of records for both quality control and management purposes. This is a discipline to place upon the landfill manager and site staff. It should not be a mechanism for office staff in a municipality to criticize the landfill operation. Instead, it should be a way to record the outcome of each day's activities and decide about future priorities.

There are, broadly, five classes of records that a landfill manager should establish. Even with a minimum standard of operation, an attempt should be made to keep records in each of the classes:

- equipment maintenance
- daily operation
- environmental monitoring
- personnel matters
- financial revenues and expenditures

Equipment maintenance records usually refer to establishing a separate file on each machine. Details of the routine daily and weekly checks should be kept (an example form is presented in Figure 5.6). In addition, records should cover each occasion when a machine receives maintenance and/or new parts. This results in a complete life history of each piece of landfill equipment.

Daily operational records chiefly consist of two types. The first is "daily waste input," which records the quantities (weight or volume) of waste received from each vehicle arriving at the site, and where the waste is placed in the landfill. This information is essential to determine how fast the landfill is being filled and to predict when construction of new areas of the site will be necessary. An example is given in Figure 5.12.

Date ___________

Vehicle Number	Time	Wastes		Weigh In	Weigh Out (tare weight)	Amount Delivered	
		Source*	Type**			Solid waste	Cover material
					TOTAL		

Signature ______________________________

Instructions:
To be completed for each vehicle each time it makes a delivery

* R = Residential
I = Industrial
Other codes as appropriate

C = Commercial
A = Agricultural

** H = Household
D = Demolition/construction
T = Tires

B = Bulky waste –
Furniture,
Refrigerators, etc.

Figure 5.12 A daily waste input record
(Source: Ministry of Housing and Urban Development 1994)

The second set of daily operational records relates to the activities on site. Each day an "activity summary" should be completed by the landfill manager or supervisor. This records the approximate quantities of soil cover material used and the number of hours worked by the landfill machines and manual staff. The data from the summaries can be compiled on one chart to produce a monthly record (Figure 5.13).

Environmental records comprise the recording of individual measurements at each monitoring point for landfill gas and water quality and depth. In addition, a wider "summary of the operational and environmental performance" achieved at the site each day should be kept. This record is the main source of information to decide on the operational priorities for the next day (Figure 5.14).

Personnel records refer to the employment details of each person working at the landfill and their attendance for work each day. They should also record any item of equipment, uniform, or personal protective clothing issued to the individual, for which he or she is personally responsible.

Financial records relate to the arrangements within the municipality to record expenditures and incomes. The landfill manager should have the delegated authority to make the expenditures necessary to ensure that the landfill runs smoothly. The landfill manager should also be directly involved in preparing the budgets for future operational and investment expenditures and, subsequently, to oversee that all approved expenditures are kept within the budget.

A set of forms covering a range of site records, including financial aspects of operating a landfill is presented in Appendix 5.C.

Month ___________

Year ___________

	Solid Waste		**Cover Material**					**Machine Hours**		
Date	Loads	Tonnes	Begin	Received	Used	Remain	Staff hours	Use	Down	Site hours
1st										
2nd										
3rd										
Etc.										
TOTAL										

Signature ________________________________

Instructions:

To be completed by the site supervisor at the end of each day. Record of cover material in either tonnes or cubic metres. Today's beginning material equals yesterday's remaining.

Figure 5.13 A daily activity summary
(Source: Ministry of Housing and Urban Development 1994)

		Satisfactory	Not Satisfactory	Remarks
1	General method of working in accordance with plan and specification			
2	Site security			
3	Condition of site roads			
4	Control of tipping area width of face			
5	Compaction and formation of layers to specified depth			
6	Depth of primary cover			
7	Primary cover completed each day			
8	Measures for handling difficult waste			
9	Litter control			
10	General site tidiness			
11	Arrangements for bad weather or emergency working			
12				
13	Employees' amenities			
14	Fire precautions			
15	Pest control measures			
	Leachate control: drainage, pumps			
	General Remarks			

Figure 5.14 A daily operational and environmental performance summary
(Source: Ministry of Housing and Urban Development 1994)

5.4.13 Settlement

Settlement of waste will occur throughout the operational phase of a landfill. It will not be uniform throughout any landfill. Undoubtedly, the larger the organic waste fraction, and deeper the site, the greater will be the extent of settling. The rate of settling depends largely upon the initial density of the waste achieved during placement, and compaction and the rate of decomposition of the wastes.

Settlement is inevitable and should be anticipated in the design of the site and the disposal plan. Care should be taken when filling the landfill with waste to avoid any differential settlement (anticipated or otherwise) creating depressions in the surface. These encourage ponding and infiltration of rainfall or runoff from elsewhere.

When excessive settlement is seen to be taking place, the placement of additional waste or soil in any depression may be sufficient to restore the shape of the surface of the landfill. If large areas of unexpected settlement are found, the landfill manager should review the procedure for waste placement to ensure it is being done properly.

5.4.14 Accommodating on-site scavenging (informal recycling)

As indicated in Chapter 4, scavenging on landfill sites should be actively discouraged, since it is disruptive to safe and well-managed landfill operations. However, where on-site scavenging cannot be completely prevented, operational decisions have to be made about its control. The key to managing the problem is gaining the agreement of the scavengers to restrict their activities to areas and times which suit the operators of the landfill. The minimum approach is to separate scavengers away from the landfill working face. Unfortunately, such a spatial separation requires subsequent transfer to the landfill working face the residue that remains after scavenging.

If the scavenging area is kept relatively close to the working face, transfer of residue to the working face may be done quickly by a bulldozer. Such an arrangement would demand that the scavenging area be movable. The two sites must not be so close as to promote mutual interference between scavengers and landfill machinery.

Alternatively, a permanent scavenging area could be located some distance from the working face. In this case, the remaining residue would need to be picked up and transported to the working face.

A fixed scavenging area would be neither feasible nor advisable for a small disposal site.

A permanent site for scavenging may take on many of the characteristics of a simple transfer station. Waste could be deposited onto a platform and after sorting, the rejects would be loaded into a site vehicle and carried to the working face. Scavenging may be done in a fixed area and may also be sheltered from the elements (wind, rain, etc.). The operation itself should be kept orderly and controlled closely, and abuses discouraged. A storage area for recovered materials should also be included in the layout of a permanent site. Efficiency of recovery may be improved by including a certain amount of mechanization (e.g., conveyor belts and screens). This alternative would also allow for the provision of sanitary facilities and a better working environment for the scavengers.

5.5 Desirable Improvements to the Minimum Standard

5.5.1 Adverse weather operations

Changes in the weather will influence the operations at a landfill. Long periods of excessive rainfall, freezing temperatures, or extreme heat can disrupt the working routine (Table 5.4).

Heavy rainfall can prevent waste collection vehicles from travelling across the site to discharge waste at the working face. To deal with such conditions, a useful improvement to a site operation is a wet weather disposal area. This is usually a cell constructed within the landfill close to the site entrance. Here, vehicles can deposit their loads without the need to travel far from the main site access road. The landfill disposal plan should describe how to minimize these weather-related problems from affecting the operations at the landfill.

PROBLEM ENCOUNTERED	POSSIBLE SOLUTION
Wet Weather	
Access roads (muddy)	• Add cinders, crushed stone, or demolition debris • Maintain a special working area that has permanent roads
Landfill working face (muddy)	• Stockpile well-drained soils and apply as necessary • Keep compaction equipment off area by unloading and moving refuse at top or bottom of the working face • Grade unloading area slightly to permit runoff
Cover soil is wet or unworkable	• Maintain compacted stockpiles and/or cover with tarpaulin
Soil permeability/density varies from design	• Do not compact soils in very wet weather • Cover stockpiled soil
Surface water collection system clogging	• Add barriers (silt traps) for fines • Periodically clean channels and pipe network
Dry Weather	
Dry soils (more difficult to excavate and fissuring of natural liner materials)	• Cover soil to prevent drying • Wet soil
Cold Weather	
Soil (freezes)	• Insulate stockpiles with leaves, snow or straw • Add salt to soil • Continually strip and cut soil • Maintain well drained soil/sand • Use mechanical equipment, such as hydraulic rippers to break up frozen soil

Table 5.4 Adverse weather practice
(After: Northeim et al. 1987)

Dry and hot weather can make some soils difficult to spread as cover material or to excavate. Prolonged freezing can have the same effect on some soils and excavation work. In extreme cases, very low temperatures may affect the operation of site equipment as well as freeze the leachate collection system. A better-managed landfill should foresee such operational problems. For example, in areas that experience prolonged freezing, landfill equipment should be winterized. To prevent impact damage to subsurface pipes, equipment should be moved slowly over the frozen soil. Block heaters, fuel trace heating and battery incubation for the equipment is strongly recommended.

5.5.2 Increased environmental monitoring

One further aspect of good management is awareness of the conditions prevailing within and outside the deposited waste, and being able to demonstrate they are not causing environmental concerns. To achieve greater confidence that environmental and health problems are being minimized, an increased amount of monitoring is required above the minimum suggested in Section 5.4.

When starting an increased level of monitoring, most attention should be paid to measuring those essential parameters that give the most information on (1) the degradation conditions prevailing in the waste; and (2) the cleanliness of water outside or leaving the site. These provide an "early warning" function to identify if a problem is, or is likely to, occur, giving enough advance time to consider various engineering solutions. For some parameters, measurements can be made on site using hand-held equipment, while others require that samples are taken and later analyzed in the laboratory.

Landfill gas

If a gas monitor and its annual maintenance can be afforded then the following parameters may be measured within the wastes:

- *Gas temperature:* Indicates the temperature in decomposing waste. Any sudden rise may indicate a deep fire.

- *Gas flow rate:* Used to estimate the quantity of gas being produced from a known volume of waste; for example, one landfill cell.

- *Carbon dioxide and methane concentrations*: Usually around 35 and 65% of the gas mixture respectively, although the ratio between the two can vary widely. Any large drop in methane concentration (percentage) may indicate a change in the predominant form of microbial degradation to one which produces more polluting leachate.

- *Oxygen concentration*: Ideally, measurements will confirm the absence of oxygen within the waste. Oxygen may adversely affect the waste degradation or allow potentially explosive landfill gas (methane) concentrations to become established (i.e., between 5 and 15 % methane in air).

- *Carbon monoxide concentration:* Indicates the presence of subsurface fires.

Technicians will be required to use equipment and properly interpret the readings.

Off-site, simple, perforated pipes with a pointed end can be pushed into the soil surface to detect if landfill gases are in the soil and check if a migration pathway from the landfill is present. If off-site migration is likely to create a risk to people or crops, then an engineering solution is indicated. Where development is within a short distance of deposited wastes, if a methane concentration of 1% or more is found in the ground around the site, then the situation should be investigated and a solution found to reduce the concentration to below 1%.

Water quality

Where funds permit, improvements in water quality monitoring can be made with regard to the number of monitoring stations, frequency of monitoring, and range of determinants monitored. One suggested monitoring regime for landfills is outlined in Table 5.5.

5.5.3 Additional gas control and utilization

Landfill gas management may be necessary in the minimum standard of site operation. In Section 5.4.11 passive venting through gravel trenches and vent pipes was described as a suitable technique. However, where the quantity of landfill gas is large, more active methods of pumped extraction and burning may be needed to control the migration of gas.

Pumped gas systems must be designed and operated by a competent engineer. The basic concept is to install one or more vacuum pumps (blowers) to extract landfill gas. These pumps create a pressure gradient in the landfill towards extraction wells to draw in landfill gas from the gas reservoir (i.e. the decomposing waste). Gas extraction wells are most often drilled into completed parts of landfill and each well is connected by a pipe system to the vacuum pump. The collected gas is drawn through pipes on the landfill surface towards a flare stack where it is ignited and burnt. Such a system is illustrated in Figure 5.15a.

In some circumstances, it may be economic to use the gas for heating buildings, as an industrial fuel, for steam generation, or even electricity production using a gas turbine or converted internal combustion engine. There are now many landfills using their landfill gas on-site to save operating costs, or to increase revenue through selling the gas, or selling steam or electricity produced from the gas, to off-site users. As described above, it is dewatered and pumped to its next use (Figure 5.15b). An example of a landfill gas extraction well is shown in Figure 5.16. Pumping tests are needed at the landfill to estimate the sustainable pumping rate for the site. This is the pumping rate which will not cause oxygen from the atmosphere to be sucked into the landfill, where its presence would create an explosion hazard and would inhibit the methane-producing bacteria in the waste. As a general principle, for the use of landfill gas to be economic, the following criteria usually need to be met (Department of the Environment 1986):

- A suitable nearby use for the gas must be identified.
- The landfill must have a minimum depth of at least 5 m, and preferably 10 m of unsaturated biodegradable waste.
- There must be a large quantity of waste already deposited. Experience suggests that at least 0.5 million tonnes is required.
- The waste should not be too old. Wastes deposited for between five and ten years usually give the highest gas yields. This period will be sooner where mainly vegetable and food wastes are deposited.
- The water (leachate) level should be at least 5 m below the landfill surface. Saturated conditions are not conducive to landfill gas collection.

Surface Water (where impacts are possible)	**Monthly** (will depend on water body and flow rate)	Temp, pH, EC, DO, NH_4-N, Cl, COD
Groundwater (where impacts are possible)	**Monthly**	Water level, Temp, pH, EC, DO, NH_4-N, Cl
	Quarterly (may be reduced to semi-annually if there is evidence of stable conditions)	As monthly plus: SO_4, Alk, TON, TOC, Na, K, Ca, Mg, Fe, Mn, Cd, Cr, Cu, Ni, Pb, Zn
Leachate at Discharge Points	**Weekly**	Discharge volume, pH, Temp, EC
	Monthly (reduce to quarterly if stable conditions prevail)	As weekly plus: NH_4-N, Cl, BOD, COD
	Quarterly	As monthly plus: SO_4, Alk, TON, TOC, Na, K, Ca, Mg
	Semi-annually (reduce to annually if stable conditions prevail)	As quarterly plus: Fe, Mn, Cd, Cr, Cu, Ni, Pb, Zn
Leachate at Monitoring Points (a)	**Monthly**	Leachate level, Temp, pH, EC
	Quarterly (may be reduced to annually if there is evidence of stable conditions).	As monthly plus: Cl, NH_4-N, SO_4, Alk, COD, BOD, TON, TOC, Na, K, Ca, Mg
	Annually	As quarterly plus: Fe, Mn, Cd, Cr, Cu, Ni, Pb, Zn

(a) sump from which leachate is removed from the cell/site.

Note: In cases where wastes are known to contain specific elements or compounds, particularly list I and substances, then those substances should be added to the appropriate list of determinants.

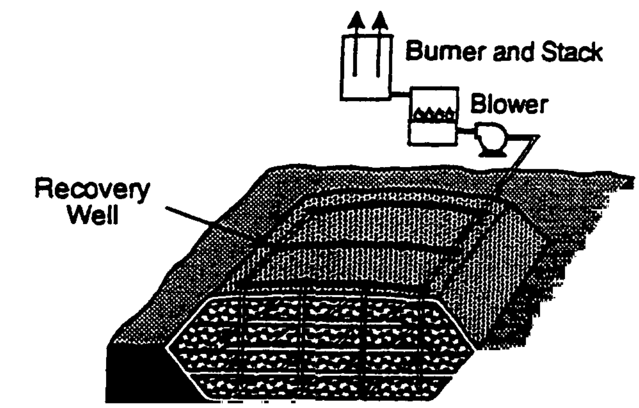
DO – dissolved oxygen
EC – electrical conductivity
Temp – temperature
COD – chemical oxygen demand
BOD – biochemical oxygen demand
Alk – total alkalinity as $CaCo_3$ at pH4.5
TON – Total oxidized nitrogen
TOC – Total organic carbon

Table 5.5 A wider list of water and leachate quality parameters
(After: Department of Environment 1994)

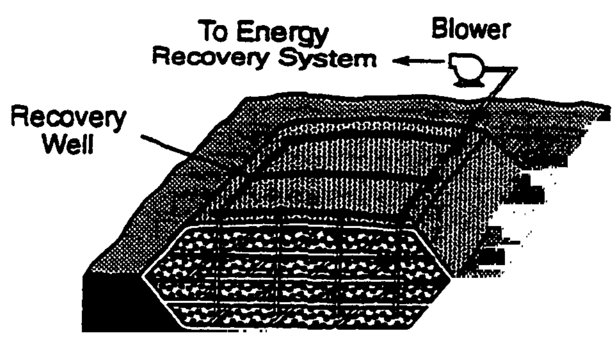
At some landfills, where all or part of the site has been completed and the final cap has been placed, the gas collection pipes from the wells to the pump can be constructed under the cap.

Landfill gas has too many trace impurities, and does not have a high enough methane gas concentration, to be suitable for injecting into the public gas supply system. The cost of cleaning it so it is of sufficient quality for public supply is widely regarded as being too expensive. However, such an effort is being undertaken in Rio de Janeiro, Brazil.

The more sophisticated forms of sanitary landfill design (which are beyond the scope of this Guide), such as "landfill bioreactors" tend to accelerate the formation of landfill gas and increase the economic feasibility for large-scale recovery and utilization.

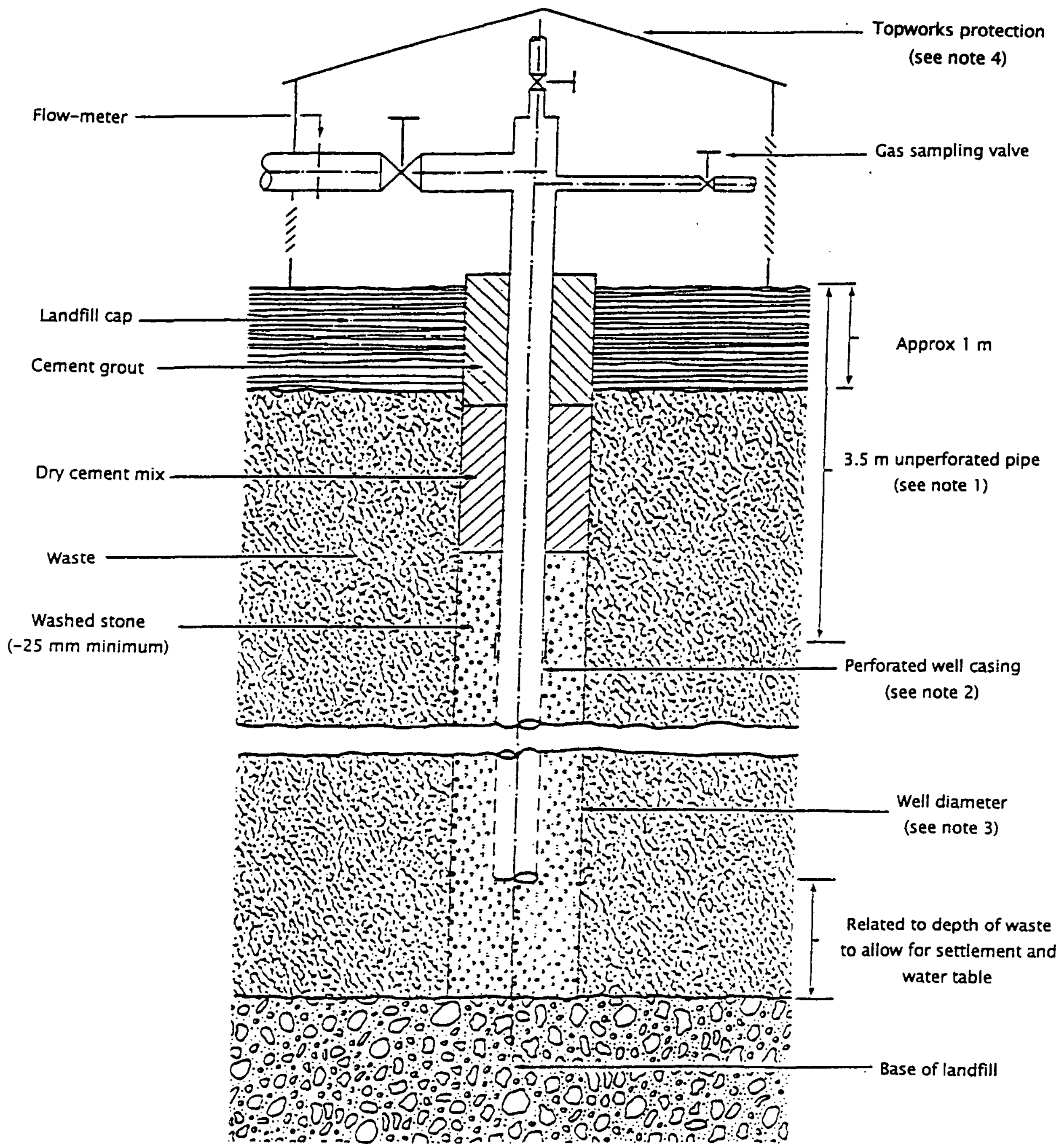


a) Gas extraction and flaring



b) Gas extraction and utilization

Figure 5.15 Active gas extraction systems
(Source: Research Triangle Institute 1994



Notes:

1. **Upper 3-5 m of pipe should be unperforated, the exact length depending on the depth of the waste and the height of the water/leachate table within the waste.**
2. **The remaining pipe should be perforated (approx. 20% perforated area) preferably made of uPVC, Hdpe, or polypropylene and of at least 110 mm in diameter.**
3. **Overall well diameter depends on the amount of landfill gas to be extracted from the well. This should be determined by static tests on trial wells and in most circumstances should preferably be a minimum of 300 mm in diameter.**
4. **Topworks may be suitably protected above ground, by a robust ventilated enclosure or below ground, in a manhole which does not compromise the integrity of the landfill cap.**

Figure 5.16 Construction of a landfill gas extraction well
(Source: Department of the Environment 1986)

5.5.4 *Protective clothing*

The health and safety of the work force may be enhanced by providing staff with personal protective clothing. Each worker at the landfill should be issued

- overalls
- working boots
- gloves
- dust mask
- goggles
- hard hat

Staff should be made personally, and possibly financially, responsible for the safekeeping of their personal equipment. They should be required to keep their safety equipment clean and serviceable.

Every member of staff should receive training on the work they are expected to undertake. It is poor management to expect new staff to know how to work safely and efficiently, or to hope they can achieve this by guesswork or copying others.

More information on occupational and environmental health measures that can be implemented at a better-operated landfill is given in Appendix 5.D.

Appendix 5.A
An Example Description of the Duties of a Landfill Operations Manager and Landfill Supervisor

Landfill Operations Manager

Responsible for all matters concerned with the development, operation, and completion of the landfill in accordance with the disposal plan. Primary duties include the following:

- Forward planning for human, technical, and financial resources for the proper operation and maintenance of the landfill.
- Preparation of such forecasts for consideration by the municipality's officer responsible for waste management.
- Recruitment of staff and procurement of equipment and materials within approved budgets to operate and maintain the landfill.
- Development of detailed health and safety plan, emergency plan, and environmental monitoring plan as extensions to the disposal plan.
- Assignment of tasks to site staff and ensuring that the landfill supervisor(s) authority is known to others. Training staff as necessary.
- Instruction of landfill supervisor(s) on a frequent basis as to the areas of the site to be prepared/filled/capped, and the extent of environmental monitoring to be carried out.
- Review of daily and weekly reports prepared by the landfill supervisor(s), and others, on site activities.
- Preparation of monthly/quarterly/annual management information reports, approval of salary payments, and authorization of equipment and materials purchases.

Landfill Supervisor

Responsible for the daily activities on the landfill site in accordance with instructions received from the landfill operations manager. Duties include

- Supervision of labor to control admission of wastes, movements of vehicles within the site, tipping in approved areas, compaction, and covering of tipped waste.
- Maintenance and supervision of plant and/or vehicles.
- Winning borrow material for use as daily/intermediate/final cover and stockpiling of cover material.
- Supervision of housekeeping activities on site carried out by nontechnical staff.
- Preparation of daily and weekly activity reports.
- Reporting to the landfill operations manager any developing problems in the areas of personnel, equipment, materials, waste inputs, public complaints.

Appendix 5.B
Rodent Control

(Adapted from: Environment Canada 1977, and U.S. Department of Health, Education and Welfare 1970)

When closing a site or converting an open dump to a sanitary landfill type of operation, it may be necessary to carry out a rodent-baiting program. The rodents must be exterminated so that they will not migrate to surrounding areas when their food supply is cut off at the landfill site. *It is essential to ensure that the use of bait does not become a health threat to children, scavengers, or landfill workers.*

Time Schedule

1. It will be necessary to close the site for a minimum of three days, even if it will continue in the future as a sanitary landfill.

    a) On the first day, the site must remain free of activity to allow the rodents to feed on previously deposited refuse and use up their existing food supply.

    b) On the second day, the bait is distributed in burrows and in sheltered areas.

    c) On the third day, the rodents are allowed to feed on the bait. (If an anticoagulant type rodent bait such as warfarin is used, this time will have to be extended to at least four or five days.)

2. The poison having done its work, dumping may be resumed and heavy equipment should be brought in immediately to initiate conversion to sanitary landfill and/or to spread, compact, cover, and seal the area if the site is being closed. There should be no delay in completing this work.

Bait

There is no such thing as an absolutely safe rodent poison. Freak accidents have occurred even with red squill and anticoagulants. It is imperative, therefore, to use the safest possible pesticides, apply them safely, and guard the disposal site during the poisoning period. A list of suggested bait formulae is presented below.

Distributing the Bait

1. Only trained personnel should be allowed to conduct the operation since the improper use of poisons is dangerous. The work is best done by a pest control expert or by a public health specialist.

2. Baiting should not be done on days when rain or snow is predicted during the next 24 hours.

Suggested Bait Formulae

Red squill

This product has probably been used for more than a thousand years. It still has merit. Its greatest advantage is its safety, because it contains a natural emetic. Rats do not vomit, but are poisoned by it. The greatest disadvantage is its bitter taste to rodents, which must be overcome by mixing with food that is more palatable. One suggested bait formula is:

Fortified red squill	0.5 kg
Corn oil or salad oil	1 kg
Chicken mash or corn meal	1 kg
Ground beef, horse meat or fish	2.5 kg
Total	*5.0 kg*

Depending upon availability, it may be necessary to substitute ground up returned bakery goods for some of the grain. Rats also consume bacon grease, which can be substituted for the corn oil. Inexpensive, canned mackerel and tuna fish also can be used to increase bait acceptance.

The finished baits may be rolled up in 150 mm squares of wax paper, about a tablespoon to the bait, or distributed with a tablespoon at the site on paper squares where there is a rat infestation. Larger "bait stations" of 100 gm to 200 gm may be covered with a board, so they will be accessible to rats but screened from the weather. The best way to know how much to use is by rebaiting on successive days, as the baits are taken until no more "takes" are seen. Then, remove all baits when the public or domestic animals again have access to the site. For initial baiting, estimate one bait for each rat hole or 250 gm for every 10 square metres of land area.

Zinc phosphide

This rodenticide is a black powder with a distinct phosphine odor. It may be advisable to add tartar emetic (animony potassium tartrate) to the bait formula to induce vomiting in case the rodenticide is accidentally eaten by domestic animals or humans. This will, however, make the bait less appealing to rats.

Zinc phosphide	100 gm
Ground meat, canned fish, bacon, or fresh tomatoes	10 kg
Tartar emetic	400 gm

Canned mackerel is a good material for at least some of the bait. A substitution of oats or corn meal for half or more of the bait achieves a drier and more economic mixture. Distribute as was suggested for red squill. If the dump has a face, about 1.5 kg of bait for each 10 metres of face on the first application is sufficient.

Anticoagulants

These rodenticides are comparatively safe to use where the public may have access to them. They reduce the clotting properties of the blood and cause internal bleeding, which results in death of rats after they have fed on the bait for four to ten days. Besides the safety factor, they are advantageous to use because the rats accept the bait well, and cheap, dry baits consisting mostly of grain can be used. The main disadvantage lies in the amount needed. About 100 gm of bait per rat is required. During the period of poisoning, birds may eat many of the grain balls. This will not affect the birds, but may cause the use of more bait.

In the anticoagulant group are warfarin, pival, fumarin, and diphacinone. It really does not matter which one is used.

Anticoagulant (0.5% concentrate)	11 kg
Corn oil or mineral oil	11 kg
Powdered sugar	11 kg
Rolled or ground oats	5 kg
Corn meal or corn chop	14 kg
Total	*52 kg*

The complete bait may be placed in small pans not over 15 mm high and inserted under boards or other locations at the dump site. The bait should be checked at two-day intervals and replenished until there is evidence that no more feeding has taken place.

Most of the anticoagulants mentioned above can also be purchased as wax-treated bait blocks or rodent cakes with meat or fish flavor to attract rats.

Water baits can be used also. The most popular ones are warfasol, fumasol, or piralym. They should be used according to instructions on their packaging.

For dump poisoning, it is sometimes preferable to use red squill or zinc phosphide to reduce the rat population, and follow up with bait stations of anticoagulant for final cleanup.

Calcium cyanide

This is a material commonly used for the gassing rats. In the presence of moisture in the air or soil, the chemical forms hydrocyanic acid gas (HCN). Both calcium cyanide and the gas are deadly poisons for animals and humans, and must be handled with extreme care.

Calcium cyanide is commercially available as a dust and should be applied with a pump made and sold for this specific purpose. The pump is so constructed that it may be held in place with the foot, leaving both hands free for the operation of the pump. A glass jar holds about 300 gm of dust, which is sufficient to treat approximately thirty-six burrows at one time without reloading. Air is forced through the glass jar containing the power, and the dust-laden air passes through a hose into the rat burrow. The end of the hose is placed 250 to 300 mm inside the burrow, the entrance is closed with earth, and several strokes are make with the pump. If the dust comes out of other holes, they should be covered with soil. The valve on the bottom of the pump is then switched to "air" position and the gas is forced through the entire burrow system.

Application should not be attempted during a strong wind. In opening cyanide cans or loading the pump, the operator should stand to windward to avoid exposure to dust or fumes. He or she should also be careful to apply the dust so that it will not drift towards other individuals in the area.

Further information on both rodent and insect control is available in WHO (1994b).

Appendix 5.C
Examples Set of Data Recording Sheets for Financial Control of Landfill Operations

(After: WHO 1996)

The recording of data generated in the fieldwork is the first step in the development of a financial control system for landfill operations. Examples of data recording sheets, which can be used for a solid waste landfill, are presented in the following order:

1. Operation summary table
2. Disposal work log
3. Complaint report
4. Weekly labor report
5. List of facilities
6. List of vehicles
7. Vehicle/equipment service road
8. Vehicle/equipment maintenance and repair record
9. Disposal cost summary table

OPERATION SUMMARY TABLE

Period: from ____________

through ____________

Items	Current Year	Variations	
		Actual to budget ratio	Ratio to same period of previous year
Weight (tonnes) of disposed waste			
Total operating cost			
Total operating cost per tonne			
Total disposing labor cost per tonne			
Vehicle operating cost per tonne			
Common expenses per tonne			
Equipment operating cost per tonne			

DISPOSAL WORK LOG

<table>
<tr><td colspan="6">Disposal site ____________________

Weather ____________________</td><td rowspan="9">Time
Vehicle No.
Driver No.
Net travel time (hrs)
Net distance (km)
Fuel (litres)

Check if trouble is encountered:

Engine temperature [ ]
Oil pressure [ ]
Amperage [ ]
Hydraulics [ ]
Brakes [ ]
Lights [ ]
Other points [ ]

Check, if any, and report to the supervisor:

Injury or death [ ]
Damage to vehicle [ ]
Damage to other items [ ]</td></tr>
<tr><td colspan="6">Driver____________________</td></tr>
<tr><td colspan="6">Notes:</td></tr>
<tr><td rowspan="2">Start Time</td><td rowspan="2">Finish Time</td><td rowspan="2">Weight of Waste</td><td rowspan="2">Operation Time</td><td colspan="2">Idle Time</td></tr>
<tr><td>Hours</td><td>Reason</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>TOTAL</td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

COMPLAINT REPORT

[ ] a.m.

Date of receipt: ____________ Time of receipt: ________ [ ] p.m.

Name: ___________________

Address: ____

____

Description of complaint:

Date of taking remedial action: _________________________

Description of the remedial action:

WEEKLY LABOR REPORT

Disposal site: ____________________ **Date:** ____________________ **Signature:** ____________________

Staff No.	Mon		Tue		Wed		Thu		Fri		Sat		Sun		Total per Person	Reason of Absence, Overtime Note, Etc
	Work	Hr	Work	Hr	Work	Hr	Work	Hr	Work	Hr	Work	Hr	Work	Hr		
Total	**X**		**X**		**X**		**X**		**X**		**X**		**X**		**X**	**X**

Notes: Supervisor is to fill in this form every working day for all the staff, including those hired hourly. Enter the starting time of work in "Hr." Enter work code* in "Work." At every weekend, send a copy to the Accounting Department and keep the original.

*Work codes

- D = driver
- SW = sweeper
- EM = equipment maintenance
- BM = building maintenance
- C = clerk
- F = foreman
- S = supervisor
- W + weigher

LIST OF FACILITIES

As of / /

To be used by Accounting Dept.

Facilities	Short Description	Start of Use	Market Value	Estimated Total Life	Other Depreciation	Annual Depreciation	Monthly Depreciation
Land							
Buildings							
Garage							
Weighing machines							
Drainageway							
Drainage equipment							
Roads							
Streetlights							
Protective walls							
Observation posts							
TOTAL							

Financial data → **Equipment and facilities**

Type of Bonds	Face Value	Market Value	Interest Rate	Interest per Annum	Interest per Month

Notes: Supervisor or, if data are available at Accounting Department, Accounting Department must complete.
"Estimated total life" must be based on the residual life determined by the supervisor.
Depreciation by fixed installment method or fixed percentage method.

LIST OF VEHICLES

As of

To be used by Accounting Dept.

Type	Registration Number	Capacity	Model/Year	Manufacturer	Purchase Date	Initial Value	Disposal Value	Estimated Life	Annual Depreciation	Monthly Depreciation	Activity Code*
TOTAL	X	X	X	X	X	X	X	X			X

Notes: Accounting Department or supervisor is to complete this form.
"Estimated life" must be based on the residual life estimated by the supervisor.
"Monthly depreciation" by fixed installment method or fixed rate method.
"Activity code: "A" for active vehicles, "I" for inactive vehicles.

VEHICLE/EQUIPMENT SERVICE RECORD

Disposal site ________________ **Period:** **From**__________**through**__________

Inventory Number	Total Working Time Scheduled	Downtime	% of Downtime to Total Scheduled Working Time	Maintenance Cost	Fuel Cost	Maintenance Cost/Hr	Fuel Cost/Hr	Total Cost/Hr	Total Cost
Total	X		X			X	X	X	
Average									
Budget									

VEHICLE/EQUIPMENT MAINTENANCE AND REPAIR RECORD

Equipment No: ____________________

Equipment type: ____________________ **Period: From**__________**through**___________

Date	Type of Service/ Repair	Down Tme	Work Time	Parts Used	Labor Cost	Parts Cost	Subcontract Cost	Fixed Cost @ X hrs	Total Cost
TOTAL	**X**			**X**					

DISPOSAL COST SUMMARY TABLE

Period: From ___________

Through ___________

Data	Actual in Current Period	Budget of Current Period	Cumulative Total in Year	Total Budget of Year
Weight of disposed waste (tonnes)				
Operating cost				
Investment cost				
Total cost				
Operating cost per tonne				
Investment cost per tonne				
Total cost per tonne				

Note: Accounting Department is to complete this table periodically from
Page 177: Operation Summary Table
Page 181: List of Facilities, and
Page 182: List of Vehicles

Send a copy to the Mayor or equivalent

Appendix 5.D
Occupational and Environmental Health Measures

(Based on extracts from World Bank 1989, WHO 1995b, WHO 1996, WHO 1997)

Solid wastes can come into direct or indirect contact with human beings at several stages in the waste cycle. The groups at risk are therefore broad and numerous and include the following: the population of unserved areas, especially preschool children; waste workers; workers in facilities that produce infectious and toxic material; people living close to waste disposal facilities, and populations whose water supplies have become polluted due to waste dumping or leakage from landfill sites. Additionally, industrial dumping of hazardous waste that has been mixed with household solid waste can expose populations to chemical and radioactive hazards.

Organic domestic wastes in particular pose serious health risks since they ferment, creating conditions favorable to the survival and growth of microbial pathogens. They are especially hazardous if they become intermixed with human excreta due to poor sanitation. Organic wastes also provide feeding stock and a natural environment for insects, rodents, and other animals which are potential carriers of enteric pathogens.

Even if solid waste is collected, it may create health risks for large numbers of people if disposed of improperly. For example, groundwater used for drinking purposes can become chemically or microbiologically polluted if wastes are disposed in or near water sources. Direct dumping of untreated solid wastes in rivers, lakes, or seas can also result in the accumulation of toxic substances in the food chain due to their uptake by plants and animals. Infectious diseases spread by poorly managed solid waste are listed in Table 5.6.

Handling solid waste obviously entails health risks, potentially leading to infectious and chronic disease and accidents. Table 5.7 outlines those relating to waste workers.

Type of Waste	Diseases by Cause		
	Bacteria	Virus	Parasite/fungus
Infected sharp waste	Staphyloccosis Streptococcosis Tetanus	Hepatitis B Hepatitis C AIDS	
Waste-generated infected dust	Anthrax Pneumonia (bacterial)	Trachoma* Conjunctivitis Pneumonia (viral)	Mycosis
Vectors living or breeding in waste-generated ponds		Dengue fever Yellow fever	Malaria filariasis Schistosomiasis
Stray animals and rodents feeding on waste	Plague Leptospirosis	Rabies	Leishmaniasis Hydatidosis

*by chlamydia

Table 5.6 Selected diseases associated with solid waste
(After: UNEP 1996a)

INFECTIONS
❖ Skin and blood infections resulting from direct contact with waste, and from infected wounds. ❖ Eye and respiratory infections resulting from exposure to infected dust, especially during landfill operations. ❖ Zoonoses resulting from bites by wild or stray animals feeding on wastes. ❖ Enteric infections transmitted by flies feeding on wastes.
CHRONIC DISEASES
❖ Incinerator operators are especially at risk of chronic respiratory diseases, including cancers resulting from exposure to dust and hazardous compounds.
ACCIDENTS
❖ Musculoskeletal disorders result from handling heavy containers. ❖ Wounds, most often infected, resulting from contact with sharp items. ❖ Poisoning and chemical burns resulting from contact with small amounts of hazardous chemical waste mixed with general waste. ❖ Burns and other injuries resulting from occupational accidents at waste disposal sites, or from methane gas explosions at landfill sites.

Table 5.7 Occupational hazards associated with waste handling
(Source: UNEP 1996b)

The WHO Western Pacific Region recently compiled a checklist for the inspection of landfills to identify if the operations could affect the environmental health of nearby residents and landfill workers (Table 5.8). They also prepared a list of actions the landfill operations manager could implement to reduce or prevent any adverse environmental health problems (Table 5.9).

Problem Areas	Severity		
	Not present	Minor	Severe
1. Fly breeding			
2. Rats and vermin			
3. Odor			
4. Smoke from open burning			
5. Drinking water contamination by leachates			
6. Waste pickers or scavengers			
7. Organic pollution of receiving water by leachates			
8. Chemical pollution of receiving water by leachates			
9. Fire hazard caused by open burning			
10. Visual impact			

Table 5.8 Checklist for the environmental health inspection of a landfill
(Source: WHO 1996)

Problem Areas	Most Appropriate	Other Options
1. Fly breeding	Apply cover soil	Spray insecticide
2. Rats and vermin	Apply cover soil	Spray vermicide
3. Odor	Apply cover soil	No other practical method
4. Smoke from open burning	Instruct site workers and others not to set a fire	Apply cover soil to extinguish it
5. Drinking water contamination by leachates	Stop the use of contaminated sources of water and switch to other sources	Repair the leak, if possible
6. Waste pickers or scavengers	Discourage waste picking by cutting off access (e.g., fence)	Instruct site workers to control
7. Organic pollution of receiving water by leachates	Stop the use of water source	Repair the leak, if possible
8. Chemical pollution of receiving water by leachates	Stop the use of water and consumption of fish and shellfish from the water	Repair the leak, if possible
9. Fire hazard caused by open burning	Instruct workers not to set a fire	Extinguish the fire
10. Visual impact	Provide buffer trees and apply cover soil	Provide enclosure walls around the site

Table 5.9 Checklist for corrective actions to reduce environmental health problems
(Source: WHO 1996)

The WHO European Region is currently preparing a comprehensive review of the diverse and incomplete literature on health effects from handling and disposing of wastes.[1] A WHO special study undertaken in Egypt by the Eastern Mediterranean Region (WHO 1995b) found that workers involved in domestic and industrial solid waste management, compared to a control sample, were more exposed to the following hazards:

- respiratory diseases, particularly chronic bronchitis
- eye diseases, particularly conjunctivitis and pterygium
- skin disease
- parasitic infestations particularly *Ascaris, Ancylostoma, Trichuris,* and *Schistosoma haematobium*
- accidents particularly wounds, backaches, dog bites, and sunstroke
- enterica and diminished vision
- high bacterial counts

[1] More details can be obtained from Dr. Philip Rushbrook, WHO Regional Office for Europe, 8 Scherfigsvej DK-2100, Copenhagen, Denmark.

The main cause for the high incidence of these hazards include the lack of personal protective measures, lack of water supply and washing facilities at working sites, and the presence of sensory defects among workers.

To reduce these impacts, safety measures have to be adopted. The most important single measure is to achieve sanitary solid waste management starting at the source of generation and ending at the disposal site. Solid waste workers could benefit from guidelines to alleviate the health hazards affecting them. These should include

- pre-employment examination to exclude persons with sensory defects
- health education and training of all personnel engaged in SWM
- supply of protective measures as uniforms, gloves, boots, and hats
- use of mechanical means to lift heavy loads to avoid the occurrence of low backaches and hernia
- provision of water facility at work site for drinking and washing
- provision of first aid kits in the trucks and at the disposal site
- an adequate system of salaries and compensation allowances, with incentives for achieving optimum performance and safer working practices

Example of Health and Safety Guidelines for a Landfill Site

The following items are considered to be essential for the safe and healthy operation of better landfill and should be the basis of achieving good working practices.

- <u>Standard Operating Procedures for Equipment and Work Activities</u>

  Each procedure should be formalized in writing and should contain a summary of (1) the potential hazards associated with the activity, (2) safety precautions such as clothing, (3) emergency procedures, and (4) a system to ensure safety during work activities. It is the responsibility of the landfill operations manager to ensure that landfill workers adhere to these procedures, and to update them regularly.

- <u>Trained Operators</u>

  Operators should be trained to perform their functions in a safe and responsible manner, adhering at all times to a specified system of work, and safe work practices.

- <u>Housekeeping and Maintenance</u>

  Good housekeeping is essential to prevent unnecessary hazards and accidents. They can include the prevention of fires, the diversion of stormwater, and the prompt repair of damaged equipment. Lack of maintenance can result in a fractured pipe or leaking pump seals, and possibly lead to a dangerous occurrence. A regular maintenance program should be initiated.

- <u>Emergency Procedures</u>

  Procedures for the evacuation of the site in the event of an incident should be written up and rehearsed. The site should have adequate fire-fighting equipment, showers, protective clothing and similar items.

- Operator Hygiene

  Operators should be trained to observe basic rules of personal hygiene, such as changing out of dirty clothes and using washing facilities before entering the canteen or leaving the site. Smoking and eating should be prohibited in all areas, except designated buildings.

- Information

  Personnel should be given detailed information regarding the different types of wastes handled, possible hazards, methods of hazard avoidance, and measures to be taken should exposure occur. Personnel should be made fully aware of the consequence if they do not follow the prescribed safety precautions. Any change in the composition of waste or working procedures should be brought to the attention of all workers before changes are implemented.

- Personal Protection Equipment

  Personnel should be provided with protective clothing and equipment to minimize the risk of physical injury and infection.

- Medical Assistance

  Personnel working with wastes should have access to a first-aid kit at the landfill and medical services, if necessary. A proper immunization program should be administered where appropriate and a program of medical monitoring should be carried out.

Chapter 6 Additional Provisions for Difficult Wastes

6 ADDITIONAL PROVISIONS FOR DIFFICULT WASTES

6.1 Main Points

Many kinds of *difficult* wastes can be landfilled satisfactorily, provided certain procedures are followed. There are advantages to the landfilling these types of waste in middle- and lower-income countries, since landfill represents a widely available, long-term disposal method.

Common types of difficult wastes that can be landfilled include

- pulverized fuel ash from power stations
- incineration and furnace ashes
- mining and minerals processing residues
- sealed asbestos wastes
- food processing wastes
- night soil and similar human wastes
- septic tank and wastewater treatment sludges
- healthcare wastes
- scrap metal items
- vehicle tires
- nonhazardous, solid industrial wastes and manufacturing off-cuts
- solid and semi-solid oily residues

Many of these wastes may presently be co-collected with municipal wastes and thus already be brought to the landfill for disposal. This practice has inherent health and safety risks to both waste transportation and disposal personnel. In order to effect safe disposal procedures, such wastes need to be separately collected and transported for supervised disposal at the landfill.

The disposal of *hazardous* industrial wastes (sometimes known as "special" wastes; Table 6.1) in landfill sites is a contentious issue. Few waste-related specialists and organizations recommend the direct disposal of hazardous wastes into municipal waste landfills, or similar disposal sites. This is because the important and essential special procedures and careful management necessary at a sanitary landfill cannot always be guaranteed. The WHO is preparing a technical report on this subject which should be ready for publication in late 1998. The best available advice, at present, is that

> *where sanitary landfilling principles are not yet applied, untreated hazardous industrial wastes should not be landfilled.*

Instead, factory-based or centrally located waste treatment plants should be promoted as the means to reduce the toxicity of hazardous waste. The residues after treatment may then be landfilled.

The purpose of treating hazardous wastes before they are deposited in a disposal site is to achieve one or more of the following (Department of the Environment 1986):

- reduction of bulk (e.g., dewatering of sludges)
- reduction of hazard potential when handling or transporting to a landfill
- conversion of the waste to a less reactive or easier to handle form for landfill disposal

More specifically, several treatment technologies are available, including (UNEP 1993)

- reduction in waste volumes produced at the places of generation by installing modifications to the industrial processes that produce the wastes
- recycling, recovery, and/or reuse of various components of the waste
- physical/chemical treatment for separation of solid and liquid mixtures and their detoxification
- biological treatment for removal of biodegradable organic components
- solidification/stabilization/fixation for converting liquid wastes to solid form and for encapsulating hazardous components
- thermal treatment for destruction of organic wastes

Hazardous Industrial Waste
Acids and alkalis
Antimony and antimony compounds
Arsenic compounds
Asbestos (all chemical forms)
Barium compounds
Beryllium and beryllium compounds
Biocides and phytopharmaceutical substances
Boron compounds
Cadmium and cadmium compounds
Copper compounds
Chromium compounds
Cyanide-containing compounds
Explosive and shock-sensitive compounds
Heterocyclic organic compounds containing oxygen, nitrogen, or sulphur
Hydrocarbons and their oxygen, nitrogen, and sulphur compounds
Inorganic cyanides
Inorganic halogen-containing compounds
Inorganic sulphur-containing compounds
Laboratory chemicals
Lead compounds
Mercury compounds
Nickel and nickel compounds
Organic halogen compounds, excluding inert polymeric material
Organic solvents
PCB (polychlorobiphenyl) compounds
Pharmaceutical and veterinary compounds
Phenolic compounds
Phosphorous and its compounds
Selenium and selenium compounds
Silver compounds
Tarry materials from refining and tar residues from drilling
Tellurium and tellurium compounds
Thallium and thallium compounds
Vanadium compounds
Zinc compounds

Table 6.1 Common types of hazardous waste
(After: Rushbrook 1989, UNEP 1993)

The treatment of hazardous wastes before disposal is preferred in order to protect the environment and public health to as great an extent as possible. Additional, extensive details on hazardous waste treatment and disposal options that could be implemented in middle- and lower-income countries are presented in a previous World Bank publication (Batstone et al. 1989).

There are two basic approaches to the disposal to land of difficult wastes: (1) deposition in a "mono-disposal" landfill; or (2) a direct deposition in a "co-disposal" landfill.

Mono-disposal

Mono-disposal is the disposal of difficult wastes which have the same overall physical and chemical characteristics. After landfilling, wastes in mono-disposal landfills remain unaltered and chemically active. Mono-disposed wastes should be monitored regularly to ensure that contaminants do not eventually leach into the environment in an uncontrolled way. Some wet wastes will gradually dewater (e.g., lagooned mine tailings). As this process proceeds, the waste becomes more physically stable, in some cases forming a solidified mass through pozzolanic or other cementation processes.

This method of disposal to land is most suited to those types of difficult wastes that will become more stable over time and are not likely to lead to long-term pollution. Pulverized fuel ash (PFA) is one type of waste that is amenable to mono-disposal. Mono-disposal is not well suited for those wastes that remain chemically reactive or contain contaminants that are mobile in solution, since they have the continuing potential for environmental pollution and danger to public health. An example of a layout for mono-disposal at a specially engineered site is depicted in Figure 6.1.

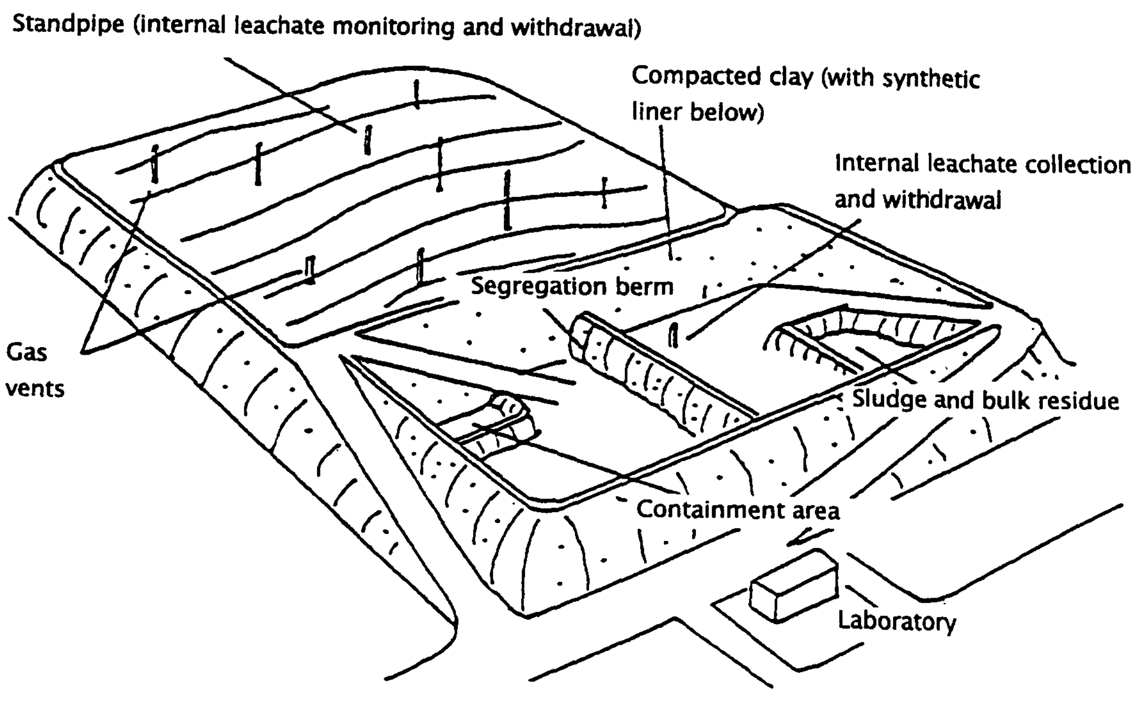


Figure 6.1 The layout of a specially engineered mono-disposal landfill site
(Source: Diaz et al. 1996)

Co-disposal

Co-disposal is the mixed disposal of difficult wastes with municipal wastes. The intention is to use the physical, chemical, and biological attenuation processes taking place within the landfilled municipal waste to make the other waste less mobile and less chemically reactive (Table 6.2). For these attenuation processes to be fully effective, a high standard of management of co-disposal landfill operations is essential. It has to be recognized that this is unlikely to be achieved at most landfill sites in middle- and lower-income countries.

Nevertheless, with a minimum level of effort and organization, it is possible to co-dispose of difficult wastes in municipal landfills to achieve an adequate level of environmental protection and, of more immediate benefit, improved health and safety of site operatives and any scavengers active on the landfill.

Physical Processes	Chemical Processes	Biological Processes
Adsorption, absorption	Acid-base reactions	Aerobic and anaerobic
Filtration	Oxidation, reduction	Microbial degradation
Dilution	Precipitation, co-precipitation	
Dispersion	Ion exchange	
	Complexation	

Table 6.2 The physical, chemical, and microbiological attenuation processes within a mature municipal waste landfill
(Source: Rushbrook 1988)

6.2 Key Decisions

When beginning to consider the options for disposal of difficult wastes, three fundamental decisions have to be taken:

Who should be responsible for disposal of difficult wastes?

Should it be the public or the private sector? If responsibility is given to the private sector:

How can the municipality assist producers of difficult wastes to provide acceptable treatment and disposal facilities?

If the municipality perceives that control of difficult wastes should be a public sector responsibility:

Does the municipality want to dispose of some types of difficult waste at its better-managed municipal landfill site?

In some middle- and lower-income cities and countries, the co-disposal of municipal and difficult wastes may be one of the compromises that is necessary in the short and medium terms to achieve an improvement beyond simply stockpiling or crude dumping of difficult wastes.

6.3 General Principles

The general principles for the disposal of generic types of difficult wastes are discussed below.

6.3.1 Semi-solid wastes

This subsection considers materials such as night soil collections, septic tank contents, and wastewater treatment sludges.

The delivery to landfill of large quantities of wastes with high moisture content should be discouraged. They contribute significantly to the generation of leachate and, when their disposal is concentrated into specific parts of a landfill, can cause operational difficulties due to their low ground bearing capacity. In extreme cases, they can contribute to slope failures due to excessive pore water pressures developing in the waste. This has occurred recently at the Dona Joana landfill in Bogota, Columbia and the Mobeni landfill in Durban, South Africa. Liquid wastes should be kept to an absolute minimum, if not banned altogether, and sludges should be dewatered as far as practicable before land disposal to reduce their bulk and improve their handling capabilities. The deposition of semi-solid wastes typically uses trenching techniques.

Trenches are excavated in an area of deep, mature, landfilled municipal waste. Mature municipal waste is waste that has been in the landfill for at least three months and which has already begun to decompose anaerobically. Either a row of single trenches, 5 m apart, or a pattern of connected trenches, are constructed (Figure 6.2). The trenches may be either left open or loosely backfilled with old bricks, rubble, or tires. The trenches should be fenced. The liquid waste is transferred to these trenches via fixed discharge pipes directly from the cart or road vehicle delivering the waste, or by the manual discharging from drums.

The purpose of trenching is to provide sufficient surface area for the liquid waste to seep into the underlying mass of municipal waste, where it will be absorbed into waste particles and its organic content reduced by physical, chemical, and microbial reactions. When the design volume of liquid waste has been reached, the trenches are backfilled with municipal refuse and covered with an intermediate soil cover. However, this technique has a disadvantage for sludges which tend to clog the trench rapidly and prevent further liquid from passing into the underlying waste.

An alternative technique is to dig trenches or pits immediately in front of the landfill working face in the previous lower layer of municipal wastes. After they are filled with sludge, the trenches are immediately buried under the advancing working face. This technique is especially suitable for thick or odoriferous sludges, oily sludges, and night soil, and minimizes the potential environmental impacts on workers at the landfill site.

6.3.2 Solid wastes

The types of solid industrial and other difficult wastes suitable for land disposal were described in Section 6.1. The disposal of these wastes may be conducted in a similar way to that described above for sludges. Dry solids can be deposited in single trenches which, once filled to about two-thirds of their depth, are backfilled with municipal waste and an intermediate soil cover. Dust dispersal can be a problem in some places if the waste is not dampened. Excavated pits can be used to dispose of one-load waste deliveries of potentially dangerous solids (e.g., sealed asbestos waste), which need to be immediately covered. Trenches and pits in front of the landfill working face, which are then buried by fresh municipal waste, are also commonly used.

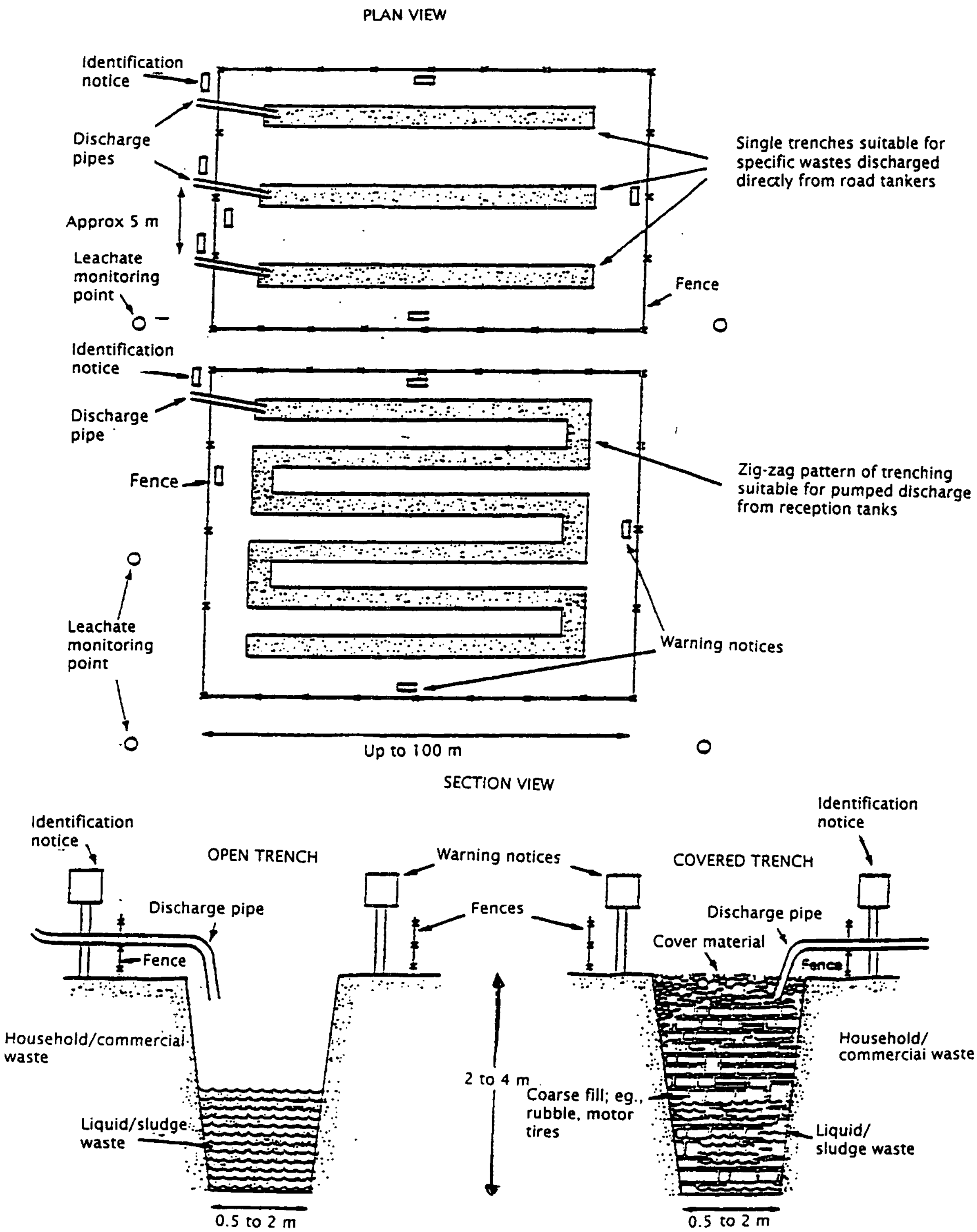


Figure 6.2 Co-disposal trench designs
(Source: Department of the Environment 1986)

6.3.3 Healthcare wastes

The land deposition of healthcare wastes is sometimes very emotive, in particular for those constituents that are potentially infectious; contain body tissues (e.g., foetuses, placentas, and limbs); contaminated with blood or body fluids and pathogens; sharps (needles, syringes etc.); or waste pharmaceutical compounds. Where a landfill is operated to the minimum standards described in this Guide, then it should be possible to deposit securely these materials into a site. Within the environment of decomposing wastes at a well-managed landfill, deposited organic healthcare waste is likely to decompose in exactly the same manner as food and animal remains in municipal waste. *Scavenging prior to disposal must be prevented.*

It is therefore recommended that healthcare waste is deposited in the same manner as solid industrial waste: that is, in a pit excavated in mature municipal waste at the base of the working face and immediately covered by a two-metre deep layer of fresh municipal waste. *It is essential that scavengers and animals are not permitted to re-excavate deposited healthcare waste.*

Alternatively, a specially constructed small landfill pit or bunded area could be prepared on part of the site to receive only healthcare waste. This would be covered immediately with soil after each load. The use of a pit would enable closer, or dedicated, supervision by landfill staff and, therefore, it should be easier to prevent scavenging. An example of dedicated pit design is given in Figure 6.3. The pit can be two or more metres deep and filled to one metre from the surface. For added health protection and odor suppression, it is suggested that lime be spread over the waste (World Health Organization 1994).

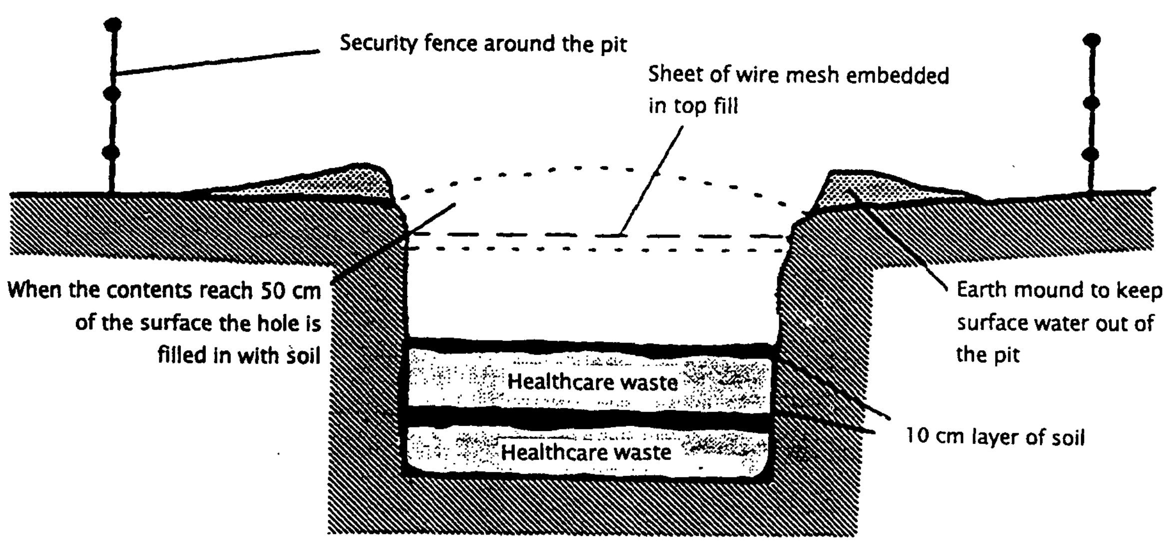


Figure 6.3 A small landfill pit for healthcare waste
(Source: World Health Organization 1994)

6.3.4 Drummed waste

Steel drums with a capacity of 220 litres (55 US gallons, 45 Imperial gallons) are widely used in many manufacturing industries to transport raw materials. Subsequently, they are often reused to carry wastes to a disposal site Often, some types of difficult waste arrive at landfills in drums. A landfill operation would be improved by the banning of difficult waste being delivered in drums.`

It is difficult for landfill staff to check the contents of every drum on a vehicle, especially if the load contains a different mixture of wastes in each drum. The process is time consuming, and the possibility of incompatible materials being mixed inadvertently is increased. Filled drums also occupy a large volume and cannot be crushed in a safe manner by landfill equipment. They will subsequently corrode in the landfill, leave hollows, and cause settlement. Alternatively, they have to be manually emptied and crushed, which is not recommended for safety reasons.

Chapter 7 Site Closure And Aftercare

7 SITE CLOSURE AND AFTERCARE

7.1 Main Points

In a better landfill, the cessation of landfilling with wastes is followed by a transitional period during which the highest levels of waste are covered with an increased thickness of soil (final cover), and sometimes other surface capping systems may be installed in preparation for the site's after-use.

On large sites, areas can be progressively completed and released for after-use. This not only accelerates the return of land to productive use, but also helps reduce the production of leachate by restricting rainfall infiltration in those areas of the site which have had final cover material applied.

The intention of a final cover system is to

- control infiltration of rainfall into the waste
- control erosion of its surface (by wind and water runoff)
- provide durable surface drainage systems over the landfill
- control the migration of gas and leachate generated within the landfilled wastes
- support the planned after-use of the site
- maintain all the above while the landfilled wastes continue to decompose and settle

Unfortunately, landfills cannot be relied upon to behave exactly as designed. Unpredicted settlements, weaknesses in construction quality, and nature itself will inevitably compromise, to a greater or lesser extent, the environmental protection systems built into the design. It will be necessary to institute an inspection/monitoring program and follow up with any necessary maintenance or repair of the systems in place.

If the landfill has been designed as a "containment" site, leachate will continue to be produced at the rate that groundwater and rainwater infiltration takes place. There will be a need to operate and maintain the leachate removal and treatment systems for as long as the leachate poses an unacceptable threat to the local ground and surface water environments.

7.2 Key Decisions

A site closure plan will have already been considered in detail as part of the original disposal plan, developed during the design stage of the landfill. As the landfill operation approaches the point where the first areas are reaching their final elevations, it will be appropriate for the waste disposal manager to consider the following:

After so many years, is the site closure plan still relevant?

In the intervening time, stricter environmental legislation may have been enacted, land use plans may have changed, and the intended after-use of the site may no longer be appropriate. The availability of capping material may also have changed due to over/under use of material for daily and intermediate cover.

It would be an appropriate exercise to review the site closure plan and consider carefully its resource and cost implications. By this time, procedures are likely to be well in hand for the preparation of the next, replacement sanitary landfill, which may compete with the current site for resources and finance. This naturally leads to a second important question:

For how long should, and at what cost, can an aftercare program be sustained?

Budgetary constraints may cause the waste disposal manager to consider limiting not only the duration of the aftercare program but also its scope. He or she may need to prioritize the various aspects of the program. Would it be better, for example, to maintain the integrity of the landfill cap, or spend the budget on groundwater monitoring and laboratory analyses? Should preference be given to filling low spots and cracks in the landfill cap or to repairing a storm drainage system on the slopes of the landfill? These and other areas of compromise are discussed later in this part of the Guide.

7.3 General Principles

Restoration plans need to consider the following matters:

- the type of final cover (cap) for the completed landfill
- the interception of leachate from the site to avoid polluting surface and groundwater
- the types of surface and groundwater monitoring which can be achieved
- the new works and maintenance required to continue to keep surface water away from the deposited waste.
- the methods to prevent soil erosion from the final cover.
- the options available to maintain, or install, landfill gas and leachate collection (and treatment) systems
- the requirements necessary to maintain the long-term integrity of the final cover, to control settlement and provide revegetation
- the means to restrict access to the site after closure and capping and the site's potential after-uses

7.3.1 Capping design

A primary aim of the cap (in most climatic zones) is to isolate the wastes from the environment, and restrict the infiltration of rainwater and other surface water into the wastes below the cap.

The best caps for this purpose are those constructed of natural soil materials (such as clay) which have a permeability of below 1×10^{-7} cm/s. The landfilled waste is usually domed or contoured to give a slope upon which the cap materials are placed. This further encourages the runoff of surface water. A well-laid clay cap, protected from soil erosion by planting grasses and from desiccation by an adequate thickness of cover soils, will prevent most of surface water entering the waste.

In some countries, complex and expensive multilayer final caps have been designed, primarily to prevent the cap being disrupted by erosion, the drying of the clay, plant roots, or burrowing animals. However, there is considerable debate over whether the extra benefit from complex designs is great enough to be worth this extra effort. The cap should be about 1 m thick, although as little as 0.3 m has been used successfully where materials are scarce. If the site's after-use is planned to be grassland, then a light topsoil dressing over the cap would be suitable to promote the rapid growth of grass. If arable crop uses are contemplated, a total soil depth of up to 1 m over any clay capping may be needed to prevent plowing from disturbing the integrity of the cap.

Whatever the final intended use of the site, the capping system should be protected from erosion by the early establishment of a grass or similar indigenous vegetation.

Where clay is not available, any soil material could be used. However, the more permeable its properties, the higher the percentage of rainwater that will infiltrate. Useful alternatives to clay include

- bentonite supplemented sands and silts
- pulverized fuel ash from power stations, sometimes blended with lime or cement
- colliery shale
- mine tailings
- river mud dredgings

Synthetic materials, such as those used for lining the base of a site, can be used as caps, but these are both expensive (especially if imported) and can be more easily damaged by settlement in the waste.

Final covers made from natural materials are often better at "self-sealing" if disrupted by waste settlement. Commonly, a bedding (or buffer) layer is placed between the top of the waste and the bottom of the cap. The purposes of this layer are to prevent items of waste from working through the cap and to give a uniform base onto which the cap can be compacted. A layer of gravel is often used. This helps landfill gas migrate to a gas collection system rather than accumulate beneath the cap.

For sites which are to be revegetated, a final (top) layer of a growing medium (topsoil) is required. The depth of topsoil required will depend upon the type of vegetation to be supported, and the vegetation's root depth. In areas where topsoil is in short supply, it may be possible to improve the quality of indigenous soils using additives such as digested sewage sludge, compost or suitable food processing wastes. Care should be taken if the after-use of the capped site is for food cropping. Additions to such a prospective site should not contain excessive levels of heavy metals or other toxic elements which might enter the food chain.

Where possible, sites should be restored to their final profile progressively, so that parts can be capped well in advance of the completion of the entire site. This helps to prevent more water from infiltrating than simply waiting for the whole site to be full before capping. Figure 7.1 shows one example of this "progressive" landfill completion technique.

An integral part of the capping system is the provision of surface water drainage channels and structures. These should be of flexible construction to accommodate future settlement of the cap. Where drainage slopes are gentle, the provision of grassed swales will be adequate. On steeper slopes, at risk from erosion, close-centered herringbone drainage may be needed. The use of concrete U-channels should be avoided since they may encourage scouring of the surrounding cap surface in the event of differential settlement. Energy dissipating drainage structures (e.g., cascades) on steep slopes of waste may be particularly prone to inducing scour unless generously sized and designed for future settlement.

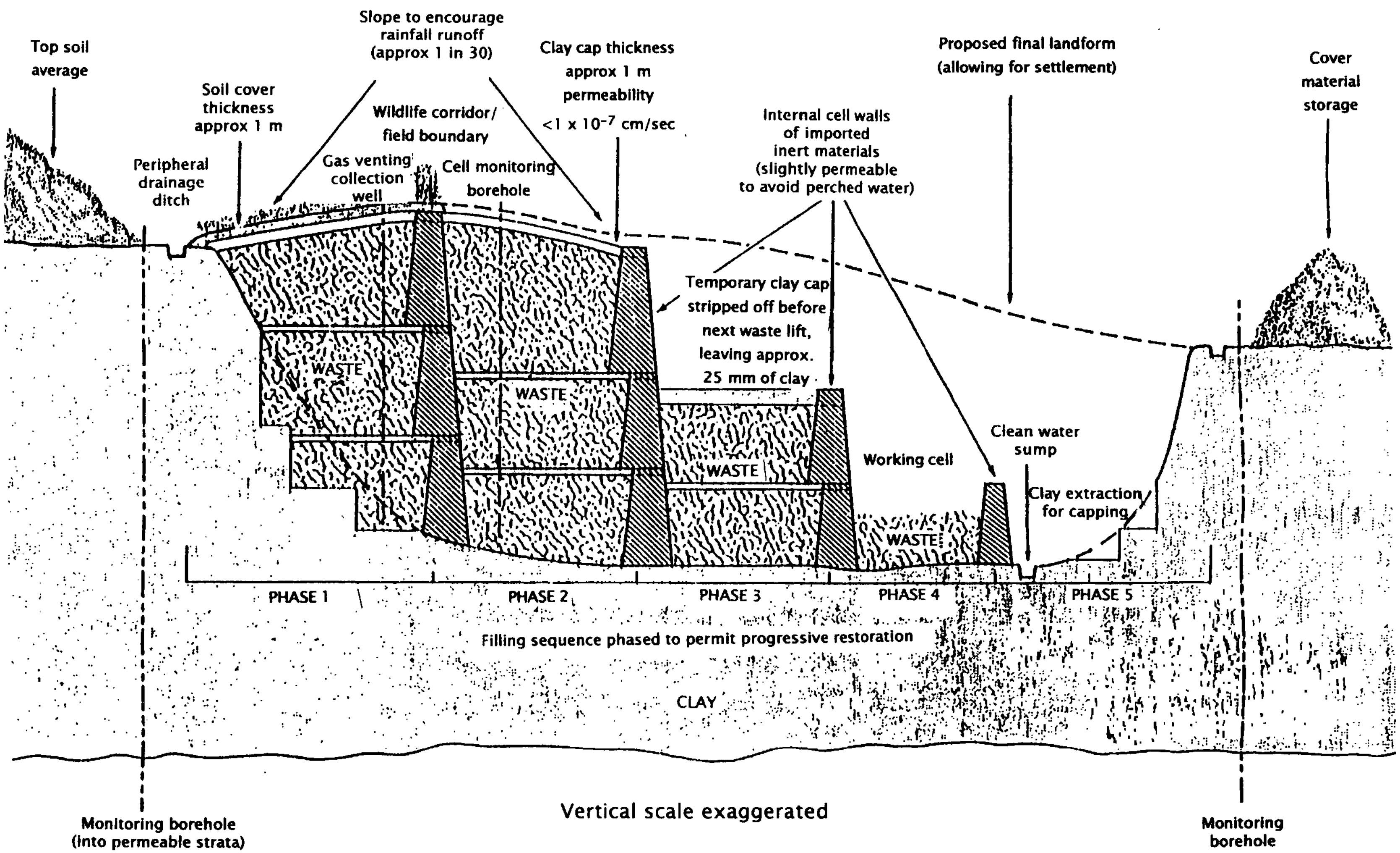


Figure 7.1 Section through landfill situated on clay strata
(Source: Department of the Environment 1986)

Failed surface drainage systems are the prime cause of increased leachate generation from completed landfills. Careful attention to the design of these systems, to provide low or easy maintenance drainage elements (e.g., channels, interceptors, and manholes), will be most cost-effective in the long term.

7.3.2 *After-uses*

Near urban areas, there may be strong competing pressures to return landfills to an apparently normal land profile. Potential after-uses include (UNEP 1994) the following:

- Agriculture — arable land, grazing, exercise pasture
- Forestation — woodland, tree screens, nature reserves
- Amenity — open space, buffer zones, airport runways
- Recreation — parks, playing fields, sports complexes, tracks, and golf courses
- Habitation — caravan sites, gardens, play areas, squatter (peri-urban) settlements
- Industry — open-storage areas, parking, fabrication areas

Among the important constraints affecting the use of a former landfill are those that arise from

- low load-bearing capacity
- extensive settling (especially uneven settling)
- the presence of combustible and potentially explosive gases
- the corrosive character of the decomposition products to concrete and steel, and the varied biochemical internal landfill environment in general

These constraints continue long after the fill has been completed. The duration of this aftercare period is a function of climate (rainfall, temperature), the nature of the buried wastes, and design and operational features of the landfill. For example, it may last 10, 20, or 30 years in a country located in a humid, tropical setting, and longer than 100 years in an arid environment.

The ultimate uses of completed landfills may be divided into the three general categories: open space/recreation, agricultural, and urban development.

Open space and recreation

Many reasons can be given for viewing recreation as the most beneficial of the potential uses of a completed urban landfill. In some cases, the completed fill probably provides the only site that will be available for recreation within the foreseeable future. The list of potential recreational uses is extensive. The types of uses can reflect local sports culture (e.g., cricket, baseball, and football), although open space parks would appeal to a wider range of people, and a green area, landscaped with grass, shrubs, and trees, can provide benefit to the community. Additionally, no large structures that may exceed load-bearing capacity need be built on open space. Small, light buildings, such as concession stands, sanitary facilities, and equipment storage sheds, all of which are commonly needed in recreational areas, should not cause problems. Such buildings, and utility services thereto, should nevertheless be designed to avoid possible ingress of landfill gas and to accommodate differential settlement.

Agriculture

Completed landfills can be used as pasture or cropland. Among the agricultural uses are grazing, crop production, tree farms, orchards, nurseries, etc. In all cases, the cover should be deep enough to ensure that roots do not come into contact with the buried wastes. Not only would such penetration be inhibitory to the growth of crop plant(s), whether it be grass or trees, it may also serve as an avenue for introducing harmful substances into the food chain and the environment. The precaution becomes especially important when food crops are concerned. Examples of rooting depth (Department of the Environment 1986, Dobson et al.1995) are

- grasses – 0.3 m or more for some species
- cereals – up to 1 m
- root vegetables – over 1 m
- trees with laterally branching root systems – 1 to 2 m
- trees with tap root systems – up to 4 m

Construction and urban development

The use of completed landfills as sites for construction, and particularly for urban development, generally should be strongly discouraged because of many and often severe constraints. These include possible gas movement, concrete corrosion, low load-bearing capacity, and uneven settlement associated with the construction and utilization of structures erected on a completed fill. Although construction and urban development should be low-priority uses, a growing land shortage in some cities is prompting a favorable reconsideration of the potential of such sites. This is especially true for lower- and medium- income countries where the situation is exacerbated by rural to urban migration which can be found in most metropolitan areas. These marginal parcels of land are usually rapidly settled, but with substandard structures. For example, in Cairo, apartment buildings for the poor are built on landfills. In these regions, vacant space for residential and commercial construction is becoming increasingly scarce. When constructing housing and other structures on a former landfill, the only recourse is to apply extensive precautionary measures designed to overcome associated hazards.

7.3.3 Aftercare

A decision has to be made about the continued monitoring and maintenance of gas and leachate control systems that will be possible after a landfill has been closed and its final cap has been installed. For a landfill to be maintained as sanitary, a regular program to check the site is needed.

The main aspects to be monitored include the following (UNEP 1994):

- erosion control (including maintenance of surface drainage systems)
- observation of settlement and possible deformations
- groundwater monitoring
    - both up-gradient wells and down-gradient wells
    - measurement of groundwater level and groundwater quality
- leachate and gas control
- meteorological data
- observation of the condition of vegetation and presence of vermin and odors

Environmental control and monitoring

Leachate will continue to be produced for many years, although the quantity should be minimized if the final cap is properly maintained to limit water infiltration into the waste. Leachate control systems that collect, store, and discharge leachate, and any of which include on-site treatment, will have to be maintained during the aftercare period. Where leachate is known to be migrating off-site into groundwater, or is contained within the landfill, then its chemical composition, presence, or absence in groundwater; and its depth in the landfill, all need to be monitored routinely. Any change in the "status quo" should be investigated.

Leachate should not be allowed to build up to affect the cap and top soil or come into contact with buried service ducts and concrete foundations. Where this occurs, the leachate level should be lowered by pumping, and the cause of the problem should be identified and eliminated (if possible). Unfortunately, if a large volume of water enters the landfill and becomes contaminated with leachate, there is no easy or cheap method of handling this quantity of pumped leachate to protect the environment.

Landfill gas will continue to be formed by decomposing wastes. This gas may migrate to engineered vents, such as gravel trenches, or through or around the cap to escape into the atmosphere. If this occurs randomly across the site, there could be risk of the formation of potentially explosive concentrations. Additionally, off-site lateral migrations may lead to potentially explosive accumulations of methane, or asphyxiating concentrations of carbon dioxide in nearby houses and subsurface structures. These gases could have disastrous consequences on nearby residents and squatter communities. Landfill gas can damage the growth of plants and, globally, it is a significant source of greenhouse gases, particularly methane.

Where such risks occur, or are likely to occur, it is common to install passive gas venting trenches and windows (less desirable) in and/or around the final cover to provide a preferential path for landfill gas migration into the atmosphere.

It is not likely that pumped gas recovery systems will be needed on most open dumps that are converted to better landfills. This is because much of the open-dumped waste may have been burned, leaving a smaller quantity of available organic carbon for microbial degradation. Passive gas venting will be sufficient at most sites. Where a landfill has a pumped gas flaring or gas utilization plant on-site, this will need to be maintained, and probably continuously staffed, during the aftercare period.

Routine post-closure monitoring would involve on-site checking of the compositions of the bulk gases (oxygen, methane, carbon dioxide, carbon monoxide, and nitrogen), as well as gas flow rates and off-site monitoring for trace fugitive emissions of methane gas.

Settlement and cap repair

On completion of waste filling, it may be decades before all waste decomposition is substantially complete. Therefore, even after a final cap has been installed, further settlement will occur. This longer-term settlement may be as much as 10% by volume, especially if waste has been placed loosely at low density. It may therefore be necessary to return to the closed site periodically to maintain a domed cap profile if settlement causes depressions in the top surface of the final cap, and clean and repair damaged surface water drainage systems. Re-profiling as necessary with cap material and topsoil should be sufficient.

It is likely that most of the longer-term settlement will be completed within 10 years after site closure. Settlement is intimately linked to the physical, chemical, and biological conditions in the waste. Sites run as sanitary landfills require the operators to compact the waste more tightly during its emplacement. This should assist in the future by reducing the amount of longer-term settlement (and hence after-closure site repairs), perhaps to below 10% of volume. Some settlement is inevitable, and causes problems only when it interferes with surface drainage and other engineered features. Differential settlement (i.e., changes that occur unevenly across a landfill) is the greatest cause for concern, and there is no substitute for regular site inspections and repair of the cap and installed systems for several years after closure.

7.4 Minimum Acceptable Standards

Even for a minimum standard of site closure aftercare, the philosophy should be that it is better to solve, by simple remediation, a developing problem in its earliest stage, than wait until the magnitude of the problem is such that a major effort is required. Regular inspections conducted systematically, against a checklist of points to observe, should provide the necessary early warning of problems ahead.

This philosophy forces a high minimum standard of monitoring and preventative aftercare for sites where there is a need to protect groundwater resources. The significant investment in a leachate reduction system (i.e., the final capping) must not be wasted. Consequently, annual maintenance of the capping system should be given high priority.

The minimum period of aftercare should be five years from closure of the landfill, at which time the capping surface should be fully restored and revegetated as necessary, and outstanding repairs to all surface water diversion structures effected. However, treatment of leachate from containment sites is likely to be needed for at least a further five years or more, until it can be demonstrated that the leachate may safely be returned to the environment without treatment.

7.4.1 Site closure

The most important part of a landfill closure and restoration plan, where groundwater protection measures are in place, is to construct a low permeability cover, or cap, over the waste when the final elevations are reached. A cap constructed from a material such as clay is the most beneficial, but other materials can be used, and their permeability modified, if nothing else is available.
The following procedures are typically proposed to close and restore a landfill:

1. Cover all waste. All waste should be sufficiently covered, and any unstable areas of the landfill should be well marked with barriers.

2. Permit sufficient time for settling of any recently deposited wastes. Although the rate of settling varies, most settlement will occur within the first few years of landfilling. Accordingly, sufficient time should be allowed for the area to settle. As necessary, the area should be re-graded, taking into account further expected settlement. After maximum settlement has occurred, the area should be re-graded to provide proper drainage. Depressions and cracks should be filled using on-site or imported material. Bulldozers and/or graders are normally used for spreading and grading.

3. Apply final cover. This cover may include a surface layer of topsoil, which was stripped and stockpiled prior to commencing the landfill operation.

4. Grade final slopes to around 5% (1 in 20). Factors that influence the final grade are climate, vegetation, and soil characteristics. In a relatively dry climate, with suitable vegetative cover, slopes may safely exceed 5%. In areas with high rainfall, it is necessary to use extensive erosion and drainage control for slopes above 5%.

5. Install a permanent system of surface drainage channels (and cascade structures, where necessary) on the landfill. Since settlement will continue for several years thereafter, these drainage structures must be designed to be flexible so as to accommodate differential settlement within the waste)

6. Check sediment and erosion control and modify according to any change in slopes.

7. Disassemble temporary structures (e.g., site buildings) and waste receiving areas not required for the after-use of the site.

8. Seed the final cover with the appropriate mixture of grasses. Climate and final site use are major factors in determining the type of grass and vegetation to be used.

9. Outline a timetable to ensure that the following features are inspected at appropriate regular intervals:

   - settlement, cover soil integrity, and need for grading
   - sedimentation and erosion control facilities
   - leachate and gas control
   - vandalism and squatting prevention measures
   - vegetation
   - fencing
   - monitoring systems

Capping design

For sites where leachate generation is not expected (arid climates), it will be sufficient to ensure that wastes are covered with a sufficient depth of soil such that

- flies, vermin, and borrowing animals cannot gain access to the waste
- the site will support any vegetation that may be reintroduced
- settlement of wastes (which can be very slow in arid climates) will not expose or facilitate access to the waste

It is suggested that the minimum depth to achieve this objective would be 0.5 m.

For sites where the local groundwater is unlikely to be further degraded by leachate, the above requirements would suffice, though preference should be given to low-permeability soils, compacted to produce a self-draining surface (i.e., a minimum gradient, after settlement, of 3% to avoid ponding of water on the ground surface).

Attention should also be given to avoid possible scouring of the surface by making slopes too steep (thereby exposing wastes). Any surface not protected by a surface water drainage system should be limited to a maximum gradient after settlement of 5%. All capped surfaces should be revegetated.

For "attenuate and disperse," and containment sites, it is essential to install a capping system which will adequately inhibit infiltration of rainfall and surface water into the wastes. The minimum total thickness of capping materials should be 1.0 m, made up as follows:

- 100 to 400 mm topsoil
- 300 to 600 mm low permeability (10^{-7} cm/sec) material
- 100 to 400 mm buffer layer

Again, where soil desiccation or freezing may be a problem, the thicknesses of the upper two layers should be at the higher end of the range given above.

The depth of topsoil should be sufficient to avoid disturbance of the underlying low permeability material by cultivation techniques.

Ponding or scouring of surfaces should also be avoided in both attenuate and disperse and containment sites by respecting the (after settlement) gradient limits of 3% to 5% on surfaces not protected by a surface water drainage system. All capped surfaces should be revegetated as soon as practicable.

7.4.2 Refurbishment of leachate monitoring and gas control systems

Leachate

For those sites where protection of ground and surface water from contamination is required, at least one monitoring well should be installed in the waste (terminating at the base of the waste) to monitor leachate level and to enable samples of leachate to be taken for analysis. While monitoring wells could be constructed "lift-by-lift" with the landfilling of wastes, it may be more convenient to form the well by drilling through the full depth of the completed landfill. A typical drilled leachate well is illustrated in Figure 7.2.

Groundwater monitoring wells, installed during site development and used throughout the operational phase, will continue to be used during aftercare. They should therefore be maintained and the surface structure refurbished, if necessary, to a standard appropriate for further long-term use. Construction of a typical groundwater monitoring well is shown in Figure 7.3.

Landfill gas

Landfill gas is an insidious emission from a landfill. It will be produced by the decomposing waste for several years after a landfill has closed. Its natural tendency is to move vertically upwards, following paths of least resistance. Where a lateral path of lesser resistance is present, landfill gas will move sideways from the site and come to the surface outside the site boundary. To minimize the impact of gas migration, the concept of a "development control zone" around the site can be applied or continued from one which may have been created when the site was receiving waste. A control zone is intended to restrict the construction of new buildings near to the site, and to introduce gas protection measures for those already present. A control zone is often *at least* 200 m from the edge of the landfilled waste. Where this concept is applied, gas control measures should be omitted only where the landfill is more than 200 m from any development or structure. "Development" in this regard includes any temporary or permanent structures above, at, or below ground, where landfill gas may accumulate. "Structures" also include manholes and cable ducts.

Any such development or structure on the landfill site itself would be particularly at risk from landfill gas and, unless designed to prevent gas accumulation, should be removed or sealed on closure of the landfill. Any enclosed drainage structures which are to be retained after closure (e.g., leachate or surface water manholes) should be provided with an airtight cover and their location made clearly visible. If the landfill has a low permeability cap (for leachate minimization), gas vents should be installed to prevent an excessive pressure build up below the cap. The minimum vent spacing should be two per hectare.

If there is development within 200 m of the site, a passive venting trench should be installed along the perimeter of the landfilled wastes nearest the development. Perimeter gas monitoring wells should also be installed within a short distance of the venting trench to confirm its effectiveness. Such wells should be spaced 50 to 100 m apart in the vicinity of development. Groundwater monitoring wells may also be used to monitor for gas migration.

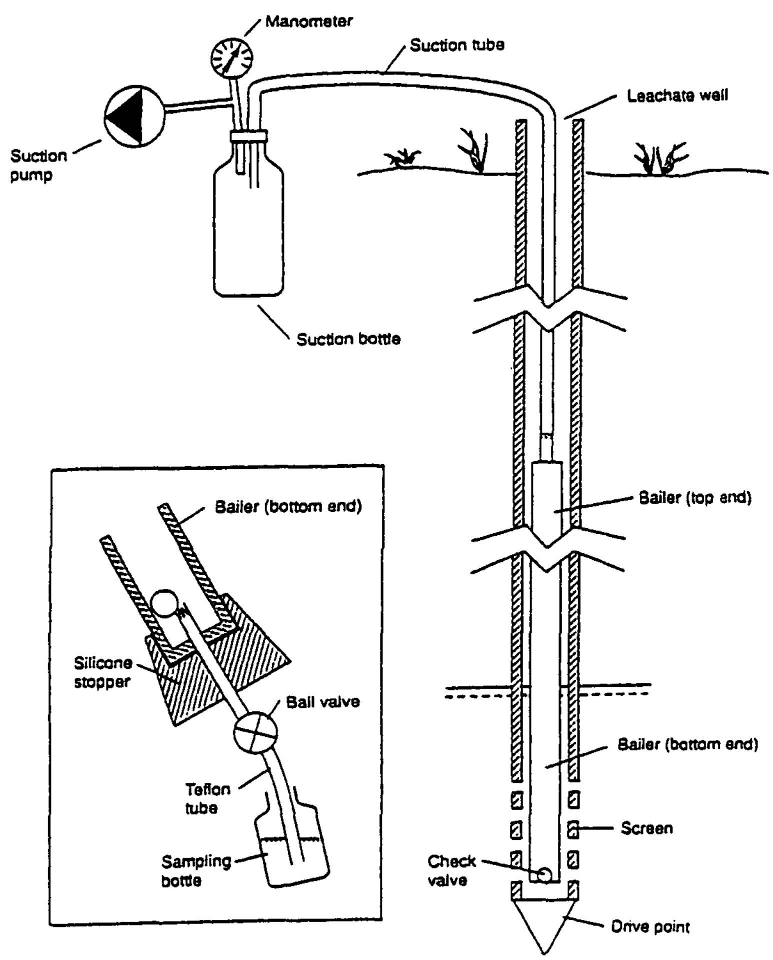


Figure 7.2 The construction of a leachate sampling well
(Source: Kjeldsen 1997)

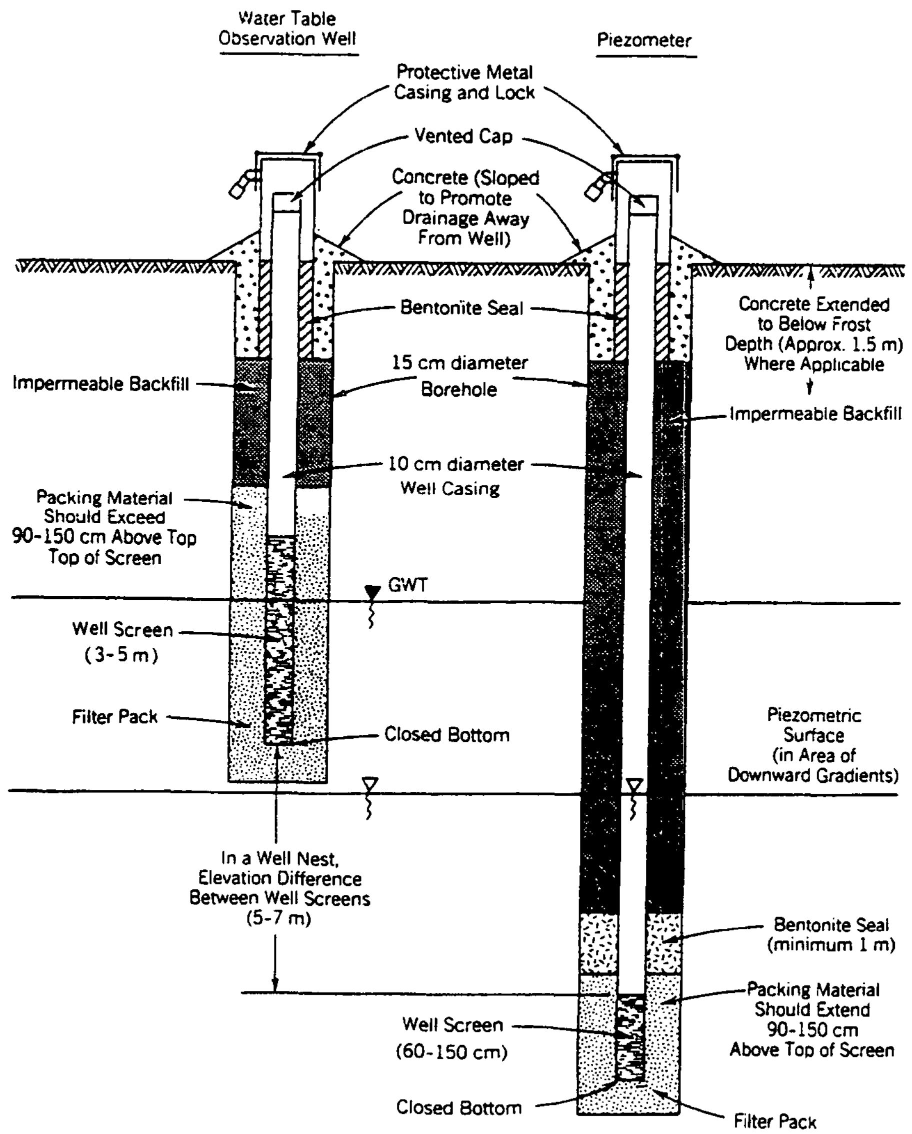


Figure 7.3 Typical groundwater monitoring wells
(Source: Bagchi 1994)

7.4.3 *Environmental monitoring*

Leachate

For any site where pollution of watercourses, streams, or rivers would be unacceptable, water quality should be monitored upstream and downstream of the site every three or six months for two years after closure, and annually thereafter. Evidence of pollution from landfill leachate should be traced to determine the source of the problem and appropriate remedial measures should be taken.

Analysis of samples of groundwater and surface water may be restricted to a few "indicator" parameters such as

- ammoniacal nitrogen
- COD
- conductivity

The need for an extended suite of analyses is considered necessary only when these indicate, by elevated values, the possibility of leachate contamination (see Table 5.5).

Leachate and groundwater level and quality measurements should be taken every three months for the first year after closure of the site, quarterly for the next two years, thereafter semi-annually. Inspection and repair of the capping system should be semi-annually for the first three years after closure, and annually thereafter.

Leachate and groundwater monitoring wells should be dipped (i.e., water levels taken) and sampled for analysis on each visit and the results added to those taken during the site-operation phase to determine any trends. If groundwater quality is shown to be deteriorating, and is not apparently linked to any recent observed problems with the capping layer, then steps should be taken to protect the health of those using the groundwater as a water source. This could include stopping the use of some wells and providing alternative supplies of drinking water.

The frequency of analysis, for the full suite of parameters, of treated effluent from a leachate treatment plant should follow that for groundwater quality monitoring described previously in this section. Daily measurement of key parameters should be taken, as an operational activity, in order to ensure that the treatment process is operating satisfactorily.

Landfill gas

Where development is within 200 m of landfilled wastes (i.e., gas migration is a potential hazard), all installed gas monitoring wells should be visited every three months. Should significant levels of methane (more than 1%) be detected in any of these wells, the frequency of these checks should be increased, and further measures should be considered for gas control. At these concentrations, a flammability risk is being approached (the lower explosive concentration in air for methane is 5%). Options for reducing gas concentrations should be discussed with engineering specialists.

7.4.4 Aftercare of control systems

Leachate

For sites where leachate generation is not expected or where groundwater contamination is not an issue, aftercare need only comprise an annual inspection to identify any cracks in, or scouring of, the capping materials. Remedial work (filling of cracks, replacing lost material) should be scheduled for completion before the onset of the wet season (if this is appropriate).

For attenuate and disperse sites, inspections should be semi-annual for the first two years after closure of the site, thereafter annually. Any remedial work should be carried out promptly. In the case of scouring, the likely cause should be identified, in the event that any additional surface water diversion work is necessary.

Any observed leachate springs or weeps at "dilute and attenuate" sites need to be dealt with by removal of an area of (saturated) cover material and replacing it with a gravel drain. The gravel drain should be provided with a low-permeability cover to minimize surface water infiltration and the drain should be connected to an appropriate outfall or soakaway.

Remedial work at containment sites should be carried out as for attenuate and disperse sites except that any leachate from springs and seeps must be intercepted and conducted via closed (i.e., unperforated) drains to the leachate treatment plant or disposal point, or pumped back into the landfill via one of the monitoring wells.

Where on-site leachate treatment is carried out, the treatment systems (e.g., ponds, pumps, etc.) should be operated until such time as the leachate quality/quantity generated by the site becomes acceptable for direct return to the environment, without treatment.

Landfill gas

All completed sites should be visited at least annually to establish whether any development, either legal or illegal, has taken place on or near the site which might be at risk from methane gas. If development has occurred, the level of landfill gas control and monitoring installed at the site should be carefully reviewed to determine whether it is sufficient and appropriate for the location and nature of the new development.

Settlement

Ideally, the period of aftercare should extend to the point that the site has stabilized physically, chemically, and biologically to a degree that the wastes deposited in the site are unlikely to cause pollution or harm human health. In practice, this point is likely to be several decades after closure and, although the cost of aftercare would be minimal at this time, such attention to aftercare has rarely been exercised. Aftercare programs are invariably reduced once it is observed that settlement has declined to insignificant levels, and gas, surface water, and leachate controls have become self-sustaining. This may be up to ten years from closure, depending on the rate of biodegradation of the waste.

7.5 Desirable Improvements to the Minimum Standards

7.5.1 Capping design

For sites where leachate generation is not expected (e.g., arid sites) it is unlikely that the climate will permit intensive agricultural after-use of the site. In the absence of any infiltration water, biodegradation will be very slow and the settlement of the wastes delayed. Any development of the site which requires the surface to have stabilized would not be appropriate for such sites for a considerable period. A cap of around 0.5 m is all that would be needed to enable the site to return to open space uses.

For sites where leachate is expected to be generated but where the local groundwater is not expected to be used, improvement of the capping may be directed to reducing leachate springs and weeps. This may be achieved by introducing a 100 to 400 mm thick "buffer" layer of high-permeability material beneath a 500 mm thick, low- permeability cap. Both layers should be compacted to improve the integrity of the cap.

At attenuate and disperse sites, the total depth of the capping system should be increased to at least 1.2 m, made as follows:

- 100 to 400 mm topsoil
- 500 to 800 mm low permeability material
- 100 to 400 mm buffer layer

At containment sites, the total depth of the capping system should be increased to at least 1.5 m, made as follows:

- 300 to 600 mm topsoil
- 850 to 1000 mm low permeability material
- 100 to 400 mm buffer layer

7.5.2 Additional environmental control and monitoring

Leachate

To allow the leachate levels and quality in each part of landfill to be separately monitored, a leachate well should be installed in each part of the site having a separate, isolated leachate collection system, or in areas of the base of the site separated by low permeability bunds.

For sites where groundwater and/or surface water quality must be safeguarded to protect the public health of nearby communities, an enhanced level of monitoring would be appropriate. Table 7.1 lists the parameters and monitoring frequency for surface waters, groundwaters, and leachates for such sites. These analyses include those recommended as desirable improvements in monitoring the operation of landfills (see Chapter 5).

Leachate from containment sites will be a legacy, treatment of which should be discontinued with care, as this may be needed for several years after the site otherwise appears to have become benign.

Landfill gas

For sites which have a low-permeability capping system and have development within 200 m of the landfill, it may be necessary to install a cut-off wall to prevent lateral gas movement, or an "active" gas control system. Active systems comprise a "field" of gas wells drilled into the completed wastes and connected, via surface/or buried pipelines, to a central extraction pump. The pump would deliver gas either to a flare stack for burning off, or to a gas-powered electricity generator, if there were a local demand for power. Alternatively, the gas could be pumped via a pressurized plastic pipeline and used as a fuel source for an appropriate industry in the vicinity (within approximately 3 km) of the site (e.g., a brick works, cement works, or pottery factory).

Utilization of landfill gas as an energy source requires careful study and design. The quantities of landfill gas which might be drawn off, and the duration over which a supply might be assured (for economic assessment), depend on a wide range of factors. These include the quantity and types of waste landfilled, the age and depths of the waste, the method of placement, and the control of moisture in the wastes. This work should be undertaken by specialists.

If an active gas control system is introduced on a landfill, it is generally not necessary to provide a gas venting trench, unless the gas monitoring wells, located on the side of the landfill, indicate that migration is taking place despite the active gas control measures.

Surface water if present	**Quarterly** (will depend on water body and flow rate)	pH, temp, EC, DO, NH_4-N, Cl, COD
Groundwater	**Quarterly** for first year and then semi-annually (may be reduced to annually if stable conditions are evident).	water level, pH, temp, EC, DO, NH_4-N, Cl, SO_4, Alk, TOC, TON, Na, K, Ca, Mg, Fe, Mn, Cd, Cr, Cu, Ni, Pb, Zn
Leachates if present	**Monthly**	Leachate level, pH, temp, EC
	Quarterly	as monthly plus: NH_4-N, Cl, SO_4, Alk, BOD, COD, TON, TOC, Na, K, Ca, Mg
	Annually	as quarterly plus: Fe, Mn, Cd, Cr, Cu, Ni, Pb, Zn

Note: In cases where wastes are known to contain specific elements or compounds, particularly list I and II substances, then those substances should be added to the appropriate list of determinants.

DO	– dissolved oxygen	Alk	– total alkalinity as $CaCo_3$ at pH4.5
EC	– electrical conductivity	TON	– total oxidized nitrogen
temp	– temperature	TOC	– total organic carbon
COD	– chemical oxygen demand	NH_4-N	– ammoniacal nitrogen
BOD	– biochemical oxygen demand	Cl	– chloride
SO_4	– sulphate		

Table 7.1 Parameters and monitoring frequencies for surface waters, groundwaters, and leachates during aftercare
(After: Department of the Environment 1994a)

Chapter 8 Closure and Conversion of Open Dumps

8 CLOSURE AND CONVERSION OF OPEN DUMPS

8.1 Main Points

In abandoning the practice of open dumping the municipality may either close its open dump(s), once a replacement landfill is ready to accept wastes, or convert the open dump(s) to operate as better landfill(s). This latter option will only be possible if

- the dump is in an area where groundwater pollution is not critical
- there is sufficient void space available to justify the effort and cost of the conversion

One option for remediation of a closed site is to remove all dumped material to a better designed replacement landfill. This is likely to be an expensive approach unless only a small volume of waste is involved. It will also use space in the replacement landfill that would otherwise be available for new waste.

Closing an open dump does not mean abandoning it. The standards to be adopted in remediating a closed site should be comparable to those which should be applied to the closure of a better-operated landfill in similar hydrogeological conditions.

Adequate arrangements must be made to prevent illegal dumping at a closed dumpsite. The provision of some form of waste reception facilities (for transfer by the municipalities) at the former dump site, for use by the public, may be necessary. A public awareness program should be initiated to encourage the use of new landfill facilities.

Remediation of an open dump requires preparation and planning. Initially, a field investigation is necessary to understand what options are available and plan an orderly closure or conversion of the site. The waste operator should clearly understand the concerns of people living near the dump.

Conversion of an open dump to a better landfilling operation, should be conducted to the same standards as for a new landfill. However, it must be recognized that the ability to protect the groundwater beneath the site will be limited.

8.2 Key Decisions

It has been assumed in this Guide that, with its intention to develop a better landfill, the municipality has decided to move away from the practice of open dumping. A new landfill will presumably replace one or more of the existing open dumps, which may or may not be reaching capacity for accommodating wastes. Three key decisions are involved in upgrading open dumps:

Should the dump(s) be closed or converted to a better standard of landfill?

If an open dump has available capacity for accepting wastes for at least three years, it might be feasible to convert it to a better landfill operation. For this to be considered it should first be established that the site does not fall within the exclusion areas determined by a constraint mapping exercise (Section 3.3.1).

Is the closed site to be remediated in any way?

The decision to close an open dump and move to a better designed and operated landfill elsewhere will have been taken in recognition that open dumping was having an unacceptable impact on the environment and on human health and safety. Simply abandoning the dump will not change its status as a local health hazard. Something will have to be done to improve its condition.

Conversion of an existing open dump may have a financial advantage over developing a new site, since the expected cost of closing the open dump should otherwise be an addition to the estimated cost of developing any new site.

Where an open dump is known to, or is likely to, contaminate a groundwater resource, it is not recommended to attempt to convert it to a landfill. Cleaning up a site or ensuring that such a site will not cause future contamination is technically extremely difficult. It would be better to limit the impact on the groundwater by applying a low-permeability cap and better off-site drainage, rather than delay the work necessary to exclude water infiltration by continued operation of the site.

Having decided to either close the dump or convert it to a better landfill, the question of standards of design and operation must be addressed. That is,

What standards are to be applied (or are achievable) at the dump site?

The answer is simple: The standards are the same as the municipality would want to be applied to a new, better-engineered landfill site (Section 4.2.2). However, the fact that no "site preparation" would have been carried out at the open dump may significantly limit the extent to which groundwater protection may be provided. This means that higher standards of capping design may need to be applied in order to minimize the infiltration of water, and, hence, the amount of further leachate that is produced.

8.3 General Principles

The first step to rehabilitating an open dump is to prepare an assessment of the condition of the site and its geographical setting. This should comprise

- a desk study of all available information on the site
- a walkover survey
- a site investigation survey
- a topographic survey

The desk study should endeavor to gather together a wide range of information about the site, including (Oeltzschner 1996):

- maps of the dump site area and its surroundings (scale 1 : 25000 and 1 : 5000, if possible)
- geological and/or hydrogeological and hydrological maps (if available) of the area concerned
- information about geology and groundwater beneath the dump site (Figure 8.1) and downstream
- photo documentation of the present situation and, if available, of former operation of the site or of the local situation before the dump site was established

- known pollution/contamination of soil, water, and air (e.g., methane and carbon dioxide from landfill gas) at, or in the vicinity of, the site
- the history of the site (i.e., uses before the operating period)
- the type and amount of waste dumped at the site; if known from where, by whom (e.g., industrial estates, small-scale industries)
- documentation of depths and morphology (surface relief) of the dump site
- information about responsibilities (e.g., management and operations, inspection and compliance, monitoring, issuance of licenses/permits)
- information about the operation of the dump site
- existing equipment at the site
- existing monitoring possibilities at or near the site

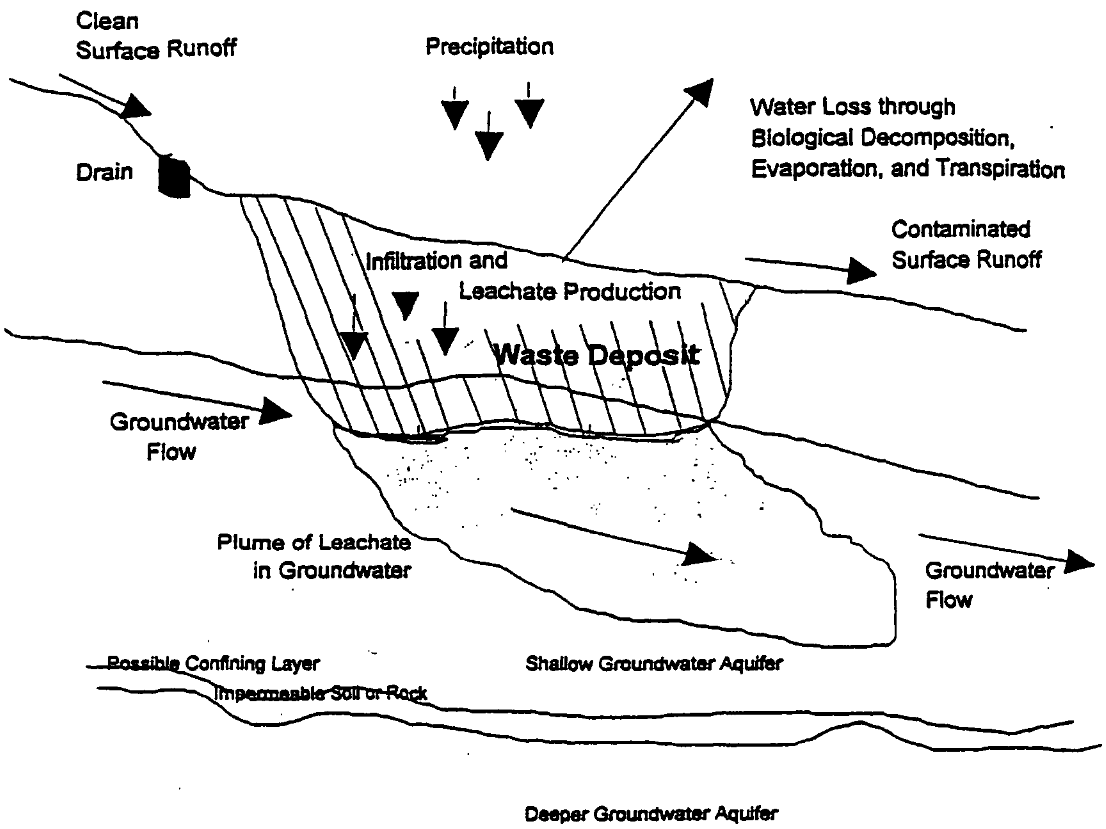


Figure 8.1 Contamination of groundwater and surface water by leachate from dumpsites
(Source: Cointreau-Levine 1996)

The walkover survey should cover all the relevant aspects of the checklist suggested for a potential landfill site (see Table 3.4), plus a supplementary list relating to the operational characteristics of the open dump (Table 8.1).

A	**Access to ravine (deep valley) sites**
A.1	Can earthmoving equipment get access to the base of the waste?
A.2	If not, what land clearance/construction will be needed?
A.3	If the site is to be converted to a landfill, what access road construction will be necessary?
B	**Impact of dumping activities**
B.1	What area is covered with dumped wastes?
B.2	What types of waste are evident?
B.3	Is leachate evident around the wastes? In the soils below the site? In watercourses?
B.4	Are there areas in the waste having unusual smells?
B.5	Are there signs of vegetation die-back on land and fish kills or algal growth in the water?
B.6	Is there evidence of wildlife being attracted to the site?
B.7	What physical hazards were noted during the survey?

Table 8.1 Supplemental checklist for walkover survey at open dumps

Extreme care should be taken in carrying out these surveys, since open dumps can present a range of health and safety hazards to people, including

- unstable slopes of loosely packed wastes
- hidden large voids
- sharp objects (metal, glass, syringes)
- hazardous chemicals (solids, liquids and gases)
- vector attack (rodents, mosquitoes)
- hidden water bodies
- risk of injury from falling waste (ravine sites)

The site investigation should be designed to obtain the same range of information as for short-listed new landfill sites (Section 3.3.5). In addition, where physically and safely possible, the depths of dumped wastes should be confirmed by drilling or trial pits (with a backhoe). Boreholes in and near the waste should extend down to the local groundwater table and samples should be taken of the groundwater and the soils above to detect any pollution by leachate. Such boreholes should be backfilled with bentonite on completion to prevent subsequent short-circuiting of leachate to the groundwater table.

A topographic survey should be conducted to provide a 1 : 500 scale base map of the site that can be used to prepare remediation plans.

The above assessments should be carried out once the decision has been taken to move away from open dumping, but before any decision has been taken as to whether the open dump(s) are to be closed or converted to better operated landfills; since the assessments will indicate the practicalities of the latter course of action.

The prime objective of remediation of an open dump is to minimize the environmental health and safety problems it creates. This may be achieved principally by

- extinguishing fires on the open dump
- eliminating vectors by covering the waste, poison baiting, and spraying with insecticides
- reducing groundwater and surface water pollution capping the wastes and installing any necessary surface water drainage structures

A typical sequence of operations would include the following measures (Environment Canada 1977):

1. Fence or otherwise restrict unauthorized access.
2. Place necessary information signs and assign a dump manager to the site during normal operating hours until the site closure is completed.
3. Extinguish fires.
4. Provided the alternate disposal site is operational, close dump to incoming refuse; if the new site is not yet operational, establish specific area(s) within the dump site and fill them as a landfill operation until it is possible to close the site.
5. Eliminate vectors.
6. Provide necessary drainage to divert surface water away from the site.
7. Clean up miscellaneous debris.
8. Grade and compact surface of waste.
9. Provide surface and groundwater protection systems and gas movement control when necessary.
10. Seed the area or otherwise prepare it for after use.
11. Maintain the cleanliness of the site and monitor it for settlement and cover material integrity.

Extinguishing fires can be difficult and expensive, particularly if they are deep-seated. Various techniques can be applied, depending on the availability of earth-moving equipment and materials to smother the fire. Deep-seated fires should first be isolated (by trenching) and then smothered with sand or soil. On sites where leachate generation is to be controlled, the fire should be doused with water only in exceptional circumstances. If attempts to extinguish the fire are unlikely to be effective, then excavating a trench should isolate the area of the site that is burning, and complete combustion encouraged with the ashes produced subsequently being smothered. Further details are given in Section 5.4.7.

Rodents should be exterminated so they do not simply migrate to surrounding areas when covering the exposed waste cuts off their food supply. A suitable rodent-baiting program was provided in Appendix 5.B, along with examples of bait formulae.

In some instances, even if the open dump is to be closed and the replacement landfill is already in operation, it may be beneficial to direct a limited quantity of solid wastes to the open dump for use in forming acceptable grades, prior to placing the capping system. At those open dumps which have developed by tipping wastes over a steep cliff into a valley below (e.g., ravine sites) the main problem may well be to stabilize the loose and dangerously steep slopes of wastes. Figures 8.2a and b indicate how this might be achieved by first constructing a retaining bund at the foot (toe) of the waste and using engineered landfilling techniques to raise progressively the landform to cover the dumped wastes.

Where there is no possibility of using more waste to complete a site with improved final contours, several methods can be used to isolate the dumped waste. These usually involve excavating and stockpiling soil material from a trench near the open dump and then pushing the waste into the trench. The waste is consolidated and compacted and then covered with the excavated soil. Once covered, the soil cap is compacted and revegetated (Figure 8.3).

An alternative approach is to consolidate the solid waste into a mound, especially when located on a gentle slope. A bund or berm is constructed first on the downslope side. The waste mound is then covered by spreading the capping layer of soil from the back of the mound towards the bund (Figure 8.4).

An inevitable problem that must be fully addressed when closing an open dump is the control of illegal dumping at the remediated site. The dump may well have been chosen for its convenient location. Quite probably the replacement landfill will be further away from the urban area(s). Private haulers and individuals may be reluctant to travel the extra distance. The municipality can address this problem by

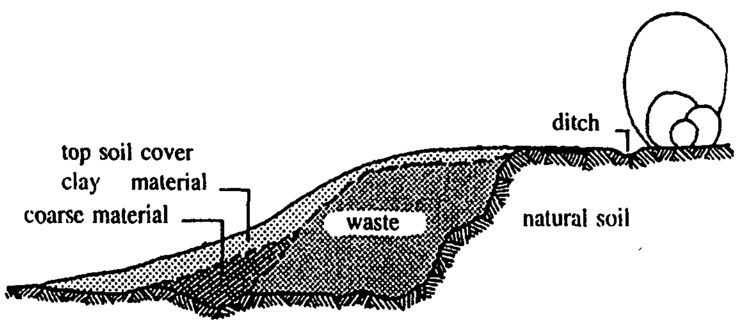
1. Conducting a public awareness program to encourage private haulers and the general public to use the new facility, while taking steps to prevent illegal dumping.

2. Providing a reception facility at the closed site, at least for a period of time, to accept wastes from private haulers and the general public. The wastes are then transferred by the municipality to the new landfill.

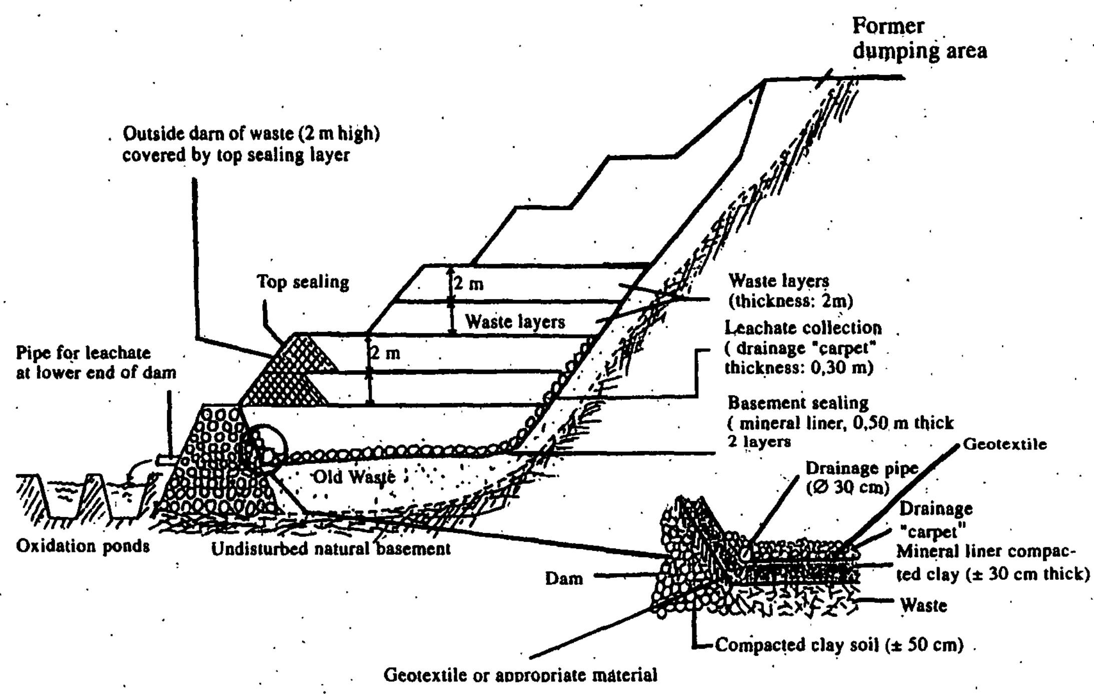
Both actions rely, for their success, on the cooperation of the public. Measures to prevent illegal dumping would include enforcement of local legislation and 24-hour supervision. Fencing the site will help limit the area over which wastes can be illegally dumped.

The second action requires some form of transfer station to be provided. In increasing order of cost and complexity, this might comprise

- a dedicated area of ground from which wastes are manually or mechanically loaded into a tipper vehicle
- a confined raised area from which accumulated wastes are subsequently pushed into the top of a waiting tipper vehicle
- open-topped roll on/roll off container(s) beneath raised platforms for public access



a) General approach to rehabilitating waste dumped down a hillside



b) Construction details

Figure 8.2 Rehabilitation and reclamation of a dump site (example)
(Source: Oeltzschner 1996)

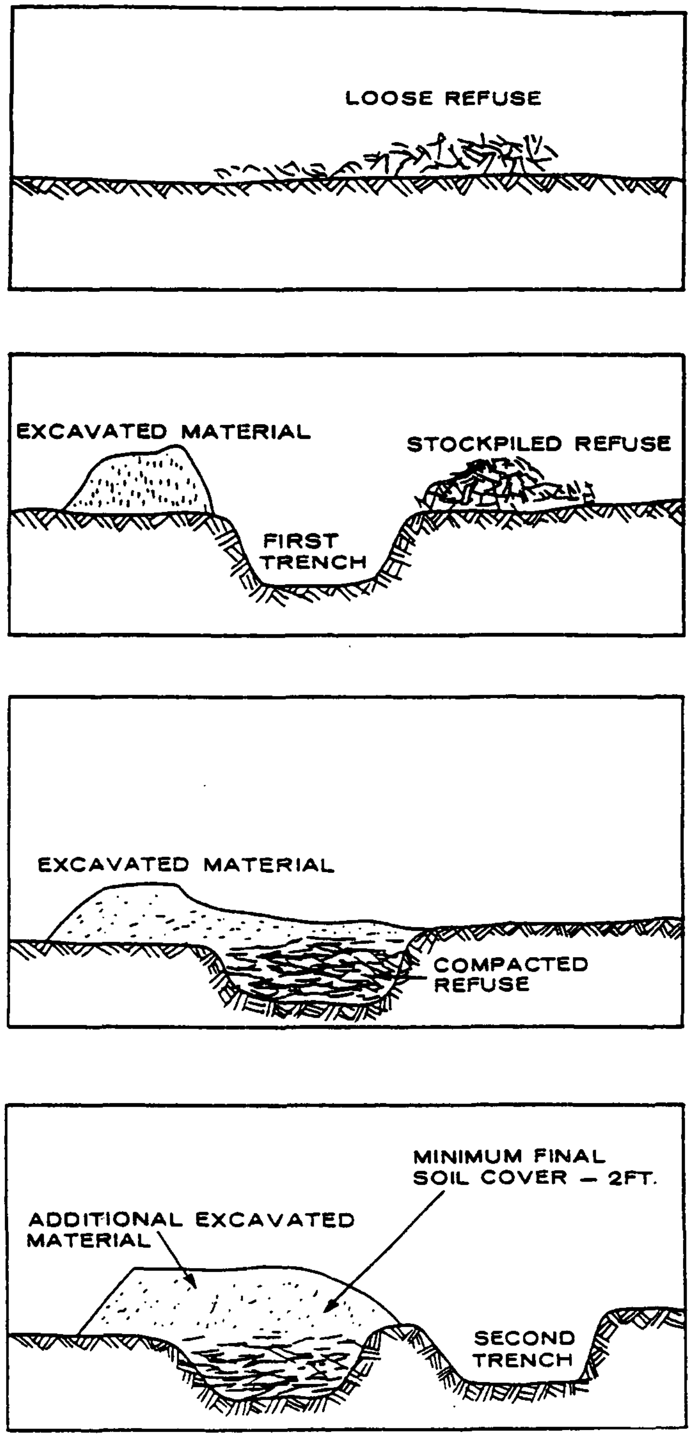


Figure 8.3 Trench method of dump conversion
(Source: Environment Canada 1977)

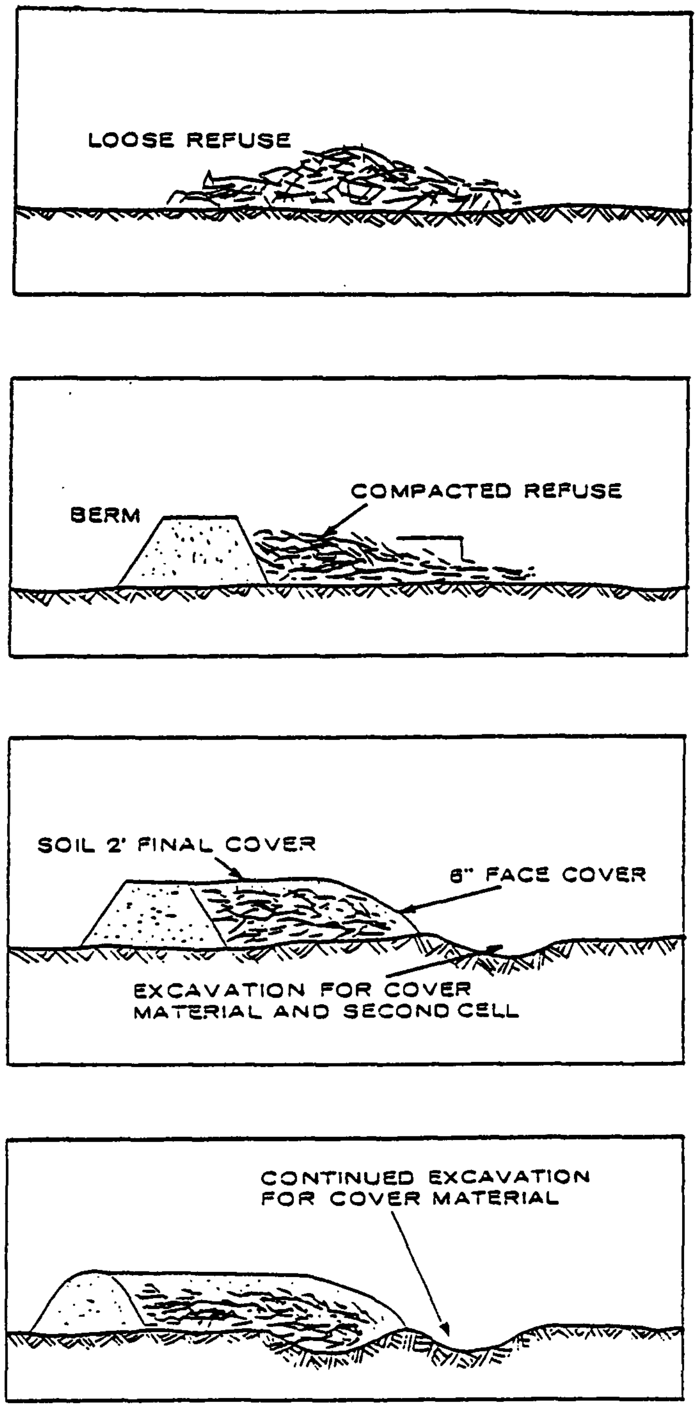


Figure 8.4 Area method of dump conversion
(Source: Environment Canada 1977)

The physical size and capacity of such facilities would need to be assessed, following a survey of current usage by the public and private organizations transporting waste directly to the open dump. Since other disposal facilities are often remote, in some countries such facilities are commonly provided as a free local service to the general public. However, the service is seldom offered to commercial/industrial users who should be obliged to transport their own wastes to the new landfill.

The aim should be to provide these facilities and, for a limited period after closure, perhaps six months, to conduct a public awareness campaign to encourage direct use of the new landfill. A key element of this should be to require operatives at the dump site to approach users of the new facilities to advise them of the new landfill and prevent commercial/industrial waste haulers from using the waste transfer facilities.

8.4 Minimum Acceptable Standards

The minimum standard for closure of an open dump should be broadly similar to that for completion of an engineered landfill. All fires must be fully extinguished before wastes are covered. However, rodent control measures need not be implemented if the site is to be closed immediately and is a remote location.

Dangerous (unstable) slopes of waste should be carefully levelled to provide a safe working environment for subsequent operation. If the site is to be closed, wastes should be graded to provide the necessary drainage to completed (capped) surfaces. Any compaction which can be provided to these graded wastes will reduce the quantity of capping soils required and improve the integrity of capping system.

The desk study and site investigation will have identified the level of groundwater protection which should be provided at the dumpsite. It will show whether the groundwater is

- unlikely to be impacted by leachate (arid sites)
- already contaminated (either naturally, such as by saline intrusion, or as a result of the wastes) beyond the point that it cannot be used for any purpose
- suitable for use for irrigation or livestock watering
- in an area reserved for extraction for potable uses

Capping systems, surface water diversion and drainage, leachate treatment, and groundwater monitoring should be provided which are comparable to the standards suggested for sanitary landfills in similar hydrogeological regimes.

Likewise, the level of landfill gas control, monitoring, and site aftercare should be similar to that which would have been provided had a well-operated landfill been established on the site.

Where an open dump is to be converted to a landfill operation, even for a limited period while a replacement site is established, the minimum standard of operation suggested in Chapter 5 should be adopted.

Where an open dump is located in an area where groundwater contamination needs to be avoided or limited, some means of interception and treatment of leachate should be included. This may not be possible to achieve if the underlying soils are of high permeability, or the groundwater table is high.

If the underlying soils are of high permeability, but not saturated, only areas of perched leachate may be removed (by vertical drilling and pumping). If the underlying soils are saturated, pumping wells drilled into the waste would need to extend into the underlying soils in order to intercept the leachate. Effective operation of the installed well field would result in significantly larger volumes of diluted leachate being generated as the local groundwater is lowered.

If it is decided to remove all previously deposited wastes to the new landfill, the site should be left in a clean and tidy state.

If a site investigation has confirmed in the borehole logs and analytical sampling that leachate has contaminated or is likely to contaminate a groundwater resource, the soils beneath the waste should also be removed and taken to the new landfill. The depressions so formed should be backfilled with clean compacted material of lower permeability than that which was removed, until the ground can be re-contoured to avoid any ponding of surface water in the excavated areas. The entire area previously covered by wastes should then be revegetated with indigenous grasses or other suitable ground cover.

The minimum provision for discouraging illegal dumping at a closed site should include

- a secure, high fence along any boundary which is easily accessible to the public
- prominent signs at the vehicular entrance to the former dump site advising of
    - its closure
    - the location of the new landfill
    - directions on the use of any facilities provided nearby for the public
- a dedicated area in which the public should leave their wastes for later removal by the municipality

8.5 Desirable Improvements to Minimum Standards

Desirable improvements to the minimum standards for conversion or closure of an open dump will be similar to those corresponding minimum standards applicable to operation or completion of an engineered landfill (Sections 5.5 and 7.5, as appropriate).

Efforts to discourage illegal dumping could be improved by early reuse of the site for other purposes, with an appropriate and vigorous public awareness campaign. The appearance of the closed site might be improved if, behind a boundary fence, some landscaping was provided, with fast-establishing species of trees or shrubs.

Facilities for dealing with residual wastes would be visually improved if a transfer system using open-topped containers was provided and regularly serviced. Attendance by staff for a period of time would increase public awareness.

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