CHAPTER 17
LANDFILLS

17.1 INTRODUCTION

17.1.1 Definition

The term 'landfill' is used herein to describe a unit operation for final disposal of 'Municipal Solid Waste' on land, designed and constructed with the objective of minimum impact to the environment by incorporating eight essential components described in Section 17.3. This term encompasses other terms such as 'secured landfill' and 'engineered landfills' which are also sometimes applied to municipal solid waste (MSW) disposal units.

The term 'landfill' can be treated as synonymous to 'sanitary landfill' of Municipal Solid Waste, only if the latter is designed on the principle of waste containment and is characterised by the presence of a liner and leachate collection system to prevent ground water contamination. The term 'sanitary' landfill has been extensively used in the past to describe MSW disposal units constructed on the basis of 'dump and cover' but with no protection against ground water pollution. Such landfills do not fall under the term 'municipal solid waste landfills' as used in this chapter.

17.1.2 Landfilling of Municipal Solid Waste

(a) Landfilling will be done for the following types of waste:

- (i) Comingled waste (mixed waste) not found suitable for waste processing;
- (ii) Pre-processing and post-processing rejects from waste processing sites;
- (iii) Non-hazardous waste not being processed or recycled.

(b) Landfilling will usually not be done for the following waste streams in the municipal solid waste:

- (i) Biowaste/garden waste;
- (ii) Dry recyclables.

(c) Landfilling of hazardous waste stream in the municipal waste will be done at a hazardous waste landfill site; such a site will be identified by the State Government and is likely to be operated by industries of a district/state. If such a landfill is not available, municipal authorities will dispose the hazardous waste in a special hazardous waste cell in the MSW landfill as shown in Fig. 17.1. Such a cell will be designed as per Ministry of Environment and Forests (MoEF) guidelines for hazardous waste disposal.

(d) Landfilling of construction and demolition waste will be done in a separate landfill where the waste can be stored and mined for future use in earthwork or road projects. If such a landfill site is not available, the waste will be stored in a special cell at a MSW landfill from where it can be mined for future use. Construction and demolition waste can be used as a daily cover at MSW landfills; however only minimum thickness of cover should be provided as indicated in section 17.8.4.5. All excess construction waste should be stored in the separate landfill cell.

(e) All existing and old landfills will be inspected and boreholes will be drilled for (i) recovery of leachate samples from the base of the landfill, (ii) recovery of subsoil samples beneath the base of the landfill for evaluation of permeability and soil properties and (iii) recovery of waste samples for waste characterisation. A minimum of 3 boreholes will be drilled with atleast one borehole for each acre of landfill area. The quality of leachate samples will be compared with (a) the ground water quality in existing borewells 2 km away from the landfill and (b) the Central Pollution Control Board (CPCB) norms for limits of contaminants in leachate. If the leachate quality and the permeability of the subsoil strata is observed to be satisfactory, the existing landfill can continue to operate with bi-annual monitoring of leachate quality in the drilled boreholes.

(f) If the leachate quality is observed to be of poor quality with respect to the local ground water quality or with respect to the CPCB norms, steps will be taken to close the existing landfill site and remedial measures adopted. All future landfilling will be undertaken in properly designed and constructed new landfills.

(g) New landfills will be established as per the norms given in this chapter for siting (section 17.4), site investigations (section 17.5), design (sections 17.6 and 17.7), construction and operation (section 17.8) and closure (section 17.9).

(h) The estimated annual cost for setting up and operating new landfills as per norms given in this chapter is estimated to lie between Rs. 200 to 300 per tonne of waste generated (at 1998 prices, excluding land acquisition cost). Provisions may be made by the municipal authorities for allocating adequate financial resources for establishing new landfills.

17.2 ENVIRONMENTAL IMPACT AND ITS MINIMISATION

The impact of dumping municipal solid waste on land without any containment is shown in Fig. 17.2. One notes from this figure that such dumps cause the following problems:

(a) Groundwater contamination through leachate

(b) Surface water contamination through runoff

(c) Air contamination due to gases, litter, dust, bad odour

(d) Other problems due to rodents, pests, fire, bird menace, slope failure, erosion etc.

Landfills minimise the harmful impact of solid waste on the environment by the following mechanisms (Fig. 17.3): (a) isolation of waste through containment; (b) elimination of polluting pathways; (c) controlled collection and treatment of products of physical, chemical and biological changes within a waste dump – both liquids and gases; and (d) environmental monitoring till the waste becomes stable.

Landfill design philosophy in the early 1990's tended towards total containment or isolation of waste. It is now recognised that this is unattainable and that it is more appropriate to design for controlled release rather than attempt indefinite isolation because all containment systems will eventually allow passage of water beyond the design period. The basic philosophy of all modern landfills revolves around the concept that waste which will not become stable or inert with time will be treated as 'stored' and not 'disposed'.

17.3 ESSENTIAL COMPONENTS

The seven essential components of a MSW landfill (Figs. 17.4) are:

(a) A liner system at the base and sides of the landfill which prevents migration of leachate or gas to the surrounding soil.

(b) A leachate collection and control facility which collects and extracts leachate from within and from the base of the landfill and then treats the leachate.

(c) A gas collection and control facility (optional for small landfills) which collects and extracts gas from within and from the top of the landfill and then treats it or uses it for energy recovery.

(d) A final cover system at the top of the landfill which enhances surface drainage, prevents infiltrating water and supports surface vegetation.

(e) A surface water drainage system which collects and removes all surface runoff from the landfill site.

(f) An environmental monitoring system which periodically collects and analyses air, surface water, soil-gas and ground water samples around the landfill site.

(g) A closure and post-closure plan which lists the steps that must be taken to close and secure a landfill site once the filling operation has been completed and the activities for long-term monitoring, operation and maintenance of the completed landfill.

17.4 SITE SELECTION

Selection of a landfill site usually comprises of the following steps, when a large number (eg. 4 to 8) landfill sites are available: (i) setting up of a locational criteria; (ii) identification of search area; (iii) drawing up a list of potential sites; (iv) data collection; (v) selection of few best-ranked sites; (vi) environmental impact assessment and (vii) final site selection and land acquisition.

However, in municipalities where availability of land is limited, the selection process may be confined to only one or two sites and may involve the following steps: (i) Setting up of locational criteria; (ii) Data collection; (iii) Environmental impact assessment and (vi) Final site selection.

17.4.1 Locational Criteria

A locational criteria may be specified by a regulatory agency (e.g. Pollution Control Board). In the absence of regulatory requirements, the following criteria are suggested. If it is absolutely essential to site a landfill within a restricted zone(s) then appropriate design measures are to be adopted and permission from the regulatory agency should be sought:

(a) **Lake or Pond**: No landfill should be constructed within 200 m of any lake or pond. Because of concerns regarding runoff of waste water contact, a surface water monitoring program should be established if a landfill is sited less than 200m from a lake or pond.

(b) **River**: No landfill should be constructed within 100 m of a navigable river or stream. The distance may be reduced in some instances for non-meandering rivers but a minimum of 30 m should be maintained in all cases.

(c) **Flood Plain**: No landfill should be constructed within a 100 year flood plain. A landfill may be built within the flood plains of secondary streams if an embankment is built along the stream side to avoid flooding of the area. However, landfills must not be built within the flood plains of major rivers unless properly designed protection embankments are constructed around the landfills.

(d) **Highway**: No landfill should be constructed within 200 m of the right of way of any state or national highway. This restriction is mainly for aesthetic reasons. A landfill may be built within the restricted distance, but no closer than 50 m, if trees and berms are used to screen the landfill site.

(e) **Habitation**: A landfill site should be at least 500 m from a notified habitated area. A zone of 500 m around a landfill boundary should be declared a No-Development Buffer Zone after the landfill location is finalised.

(f) **Public parks**: No landfill should be constructed within 300 m of a public park. A landfill may be constructed within the restricted distance if some kind of screening is used with a high fence around the landfill and a secured gate.

(g) **Critical Habitat Area**: No landfill should be constructed within critical habitat areas. A critical habitat area is defined as the area in which one or more endangered species live. It is sometimes difficult to define a critical habitat area. If there is any doubt then the regulatory agency should be contacted.

(h) **Wetlands**: No landfill should be constructed within wetlands. It is often difficult to define a wetland area. Maps may be available for some wetlands, but in many cases such maps are absent or are incorrect. If there is any doubt, then the regulatory agency should be contacted.

(i) **Ground Water Table** : A landfill should not be constructed in areas where water table is less than 2m below ground surface. Special design measures be adopted, if this cannot be adhered to.

(j) **Airports**: No landfill should be constructed within the limits prescribed by regulatory agencies (MOEF/ CPCB/ Aviation Authorities) from time to time.

(k) **Water Supply Well:** No landfill should be constructed within 500 m of any water supply well. It is strongly suggested that this locational restriction be abided by at least for down gradient wells. Permission from the regulatory agency may be needed if a landfill is to be sited within the restricted area.

(l) **Coastal Regulation Zone**: A landfill should not be sited in a coastal regulation zone.

(m) **Unstable Zone** : A landfill should not be located in potentially unstable zones such as landslide prone areas, fault zone etc.

(n) **Buffer Zone** : A landfill should have a buffer zone around it, up to a distance prescribed by regulatory agencies.

(o) Other criteria may be decided by the planners.

17.4.2 Search Area

To identify the potential sites for a landfill a 'search area' has to be delineated. The search area is usually governed by the economics of waste transportation. It is usually limited by the boundaries of the municipality. Typically search areas are delineated on a map using a 'search radius' of 5 to 10 km, keeping the waste generating unit as the centre. Alternatively, the search area may be identified by adopting a range of 5 km all around the built-up city boundary. One should start with a small search area and enlarge it, if needed.

17.4.3 Development of a List of Potential Sites

After demarcating the search area, as well as after studying the various restrictions listed in the locational critieria, areas having potential for site development should be identified. A road map may be used to show the potential sites that satisfy the locational criteria. Preliminary data collection should be undertaken with an aim of narrowing the list of sites to a few best-ranked sites.

In areas where land availability is scarce, degraded sites such as abandoned quarry sites or old waste dump sites can be considered. Special design measures are required for such sites.

To estimate the area required for a landfill, the landfill capacity may be computed as indicated in Section 17.6.2 and Annexure 17.1 and the area required for the operative life of the landfill should be evaluated.

17.4.4 Data Collection

Several maps and other information need to be studied to collect data within the search radius. Some are discussed below.

(a) Topographic Maps: The topography of the area indicates low and high areas, natural surface water drainage pattern, streams, and rivers. A topographic map will help find sites that are not on natural surface water drains or flood plains. Topographical maps may be procured from Survey of India.

(b) Soil Maps: These maps, primarily meant for agricultural use, will show the types of soil near the surface. They are of limited use as they do not show types of soil a few metre below the surface. They can be procured from Indian Agricultural Research Institute (IARI).

(c) Land Use Plans: These plans are useful in delineating areas with definite zoning restrictions. There may be restrictions on the use of agricultural land or on the use of forest land for landfill purposes. These maps are used to delineate possible sites that are sufficiently away from localities and to satisfy zoning criteria within the search area. Such maps are available with the Town Planning authority or the Municipality.

(d) Transportation Maps: These maps, which indicate roads and railways and locations of airports, are used to determine the transportation needs in developing a site.

(e) Water Use Plans: Such maps are usually not readily available. However, once potential areas are delineated, the water use in those areas must be investigated. A plan indicating the following items should be developed: private and public tubewells indicating the capacity of each well, major and minor drinking water supply line(s), water intake wells located on surface water bodies, and open wells.

(f) Flood Plain Maps: These maps are used to delineate areas that are within a 100 year flood plain. Landfill siting must be avoided within the flood plains of major rivers.

(g) Geologic Maps: These maps will indicate geologic features and bedrock levels. A general idea about soil type can be developed from a geologic map. Such maps can be procured from Geological Survey of India. They may be used to identify predominantly sandy or clayey areas.

(h) Aerial Photographs/Satellite Imagery: Aerial photographs or satellite imageries may not exist for the entire search area. However such information may prove to be extremely helpful. Surface features such as small lakes, intermittent stream beds, and current land use, which may not have been identified in earlier map searches, can be easily identified using aerial photographs.

(i) **Ground Water Maps**: Ground water contour maps are available in various regions, which indicate the depth to ground water below the land surface as well as regional ground water flow patterns. Such maps should be collected from Ground Water Boards or Minor Irrigation Tubewell Corporations.

(j) **Rainfall Data**: The monthly rainfall data for the region should be collected from the Indian Meteorological Department.

(k) **Wind Map**: The predominant wind direction and velocities should be collected from the Indian Meteorological Department.

(l) **Seismic Data**: The seismic activity of a region is an important input in the design of landfills Seismic coefficients are earmarked for various seismic zones and these can be obtained from the relevant BIS code or from the Indian Meteorological Department.

17.4.5 Site Walk-Over and Establishment of Ground Truths

A site reconnaissance will be conducted by a site walk-over as a part of the preliminary data collection. All features observed in various maps will be confirmed. Additional information pertaining to the following will be ascertained from nearby inhabitants: (a) flooding during monsoons; (b) soil Type; (c) depth to G.W. Table (as observed in open wells or tube wells); (d) quality of groundwater and (e) Depth to bedrock.

17.4.6 Preliminary Boreholes and Geophysical Investigation

At each site, as a part of preliminary data collection, one to two boreholes will be drilled and samples collected at every 1.5m interval to a depth of 20m below the ground surface. The following information will be obtained: (i) soil type and stratification; (ii) permeability of each strata; (iii) strength and compressibility parameters (optional); (iv) ground water level and quality and (v) depth to bedrock.

In addition to preliminary boreholes, geophysical investigations (electrical resistivity/ seismic refraction/others) may be undertaken to assess the quality of bedrock at different sites.

17.4.7 Assessment of Public Reaction

The public/nearby residents should be informed of the possibility of siting of a landfill in a nearby even as soon as a list of potential sites is developed. A preliminary assessment of public opinion regarding all the sites in the list is essential.

A site may be technically and economically feasible yet may be opposed heavily by the public. The "not in my back yard" (NIMBY) sentiment is high initially. However, with proper discussion it can be overcome in some cases. Early assessment regarding how strong the NIMBY sentiment is, can significantly reduce the time and money spent on planning for a landfill site which may not materialise. In many instances residents around a proposed site cooperate if the landfill site owner's representative listens to concerns of the area residents and considers those concerns in designing and monitoring a site. Noise, dust, odour, increases in traffic volume, and reduction in property value concern the area residents more than the fear of groundwater contamination.

Public reaction is less hostile if landfilling is done in an area already degraded by earlier municipal waste dumps or other activities such as quarrying, ash disposal etc.

17.4.8 Selection of Few Best-Ranked Sites

From amongst a large number of sites, the selection of a final site will emerge from a two-stage approach.

(a) Selection of a few best-ranked sites (usually 2 sites, sometimes 3) on the basis of pathway and receptor related attributes.

(b) Selection of final site on the basins of environmental impact assessment, social acceptance and cost of disposal.

For the selection of a few best ranked sites, the Ranking System based on Site Sensitivity Index developed by Ministry of Environment and Forests (MOEF) in 1991is recommended. Only the following attributes should be considered in such a study as indicated: (a) population within 1 km; (b) distance to drinking water well/tubewell; (c) use of sites by residents; (d) distance to nearest offsite building; (e) presence of airport; (f) presence of roads; (g) current land use; (h) distance to critical habitat nearby; (i) distance to nearest surface water; (j) depth to ground water; (k) soil permeability; (l) depth to bedrock; (m) susceptibility to flooding; (n) susceptibility to water erosion; (o) slope Stability of final landform; (p) air pollution potential and (q) susceptibility to seismic activity.

On the basis of the ranking, scores received by various sites, one or two sites (sometimes up to 3) may be chosen for environmental impact assessment and final selection.

17.4.9 Environmental Impact Assessment (EIA)

Wherever feasible, environmental impact assessment will be conducted for two alternate sites (in exceptional circumstances up to 3 sites) The impact of the landfill on the following will be quantified: (a) Ground water quality; (b) Surface water quality; (c) Air quality – gases, dust, litter; (d) Aesthetics – visual, vermin, flies; (e) Noise; (f) Land use alteration; (g) Traffic alteration; (h) Drainage alteration; (i) Soil erosion; (j) Ecological impacts and (k) Others.

A comparison of both alternatives amongst themselves as well as with the null alternative (that is what would happen if the project was not carried out) should be made and suitability of the sites summarised.

EIA aspects are covered in Chapter 22.

17.4.10 Final Site Selection

The final selection of the site from amongst the best-ranked alternatives should be done by comparing:

(a) the environmental impact;

(b) social acceptance; and

(c) transportation and landfilling costs.

Transportation costs may be compared on the basis of average hauling distance from the centre of the waste generating unit (city or part thereof). Landfilling costs are difficult to compute at the preliminary stage but may be compared on the basis of the shape of the completed landfill and material costs for liner system, leachate collection system, daily covers and final cover system.

A landfill site with low environmental impact, high social acceptance and low costs is the most desirable. If conflicting results appear for (a), (b) and (c), environmental impact minimisation should normally be given top priority.

17.5 SITE INVESTIGATION AND SITE CHARACTERISATION

The data collected during site selection is not sufficient for landfill design. To be able to undertake detailed design of a landfill at a selected site, it is essential to characterise the landfill site and evaluate the parameters required for design. It is necessary that all data listed under section 17.4.4 on 'Data Collection' is collected for site characterisation. If some data has not been collected, the same should be obtained before site investigations are undertaken for site characterisation.

A proper site investigation programme comprises of subsoil investigation, ground water/hydrogeological investigation, hydrological investigation, topographical investigation, geological investigation, environmental investigation, traffic investigation and leachate investigation.

Table 17.1 indicates the types of investigations to be carried out for site characterisation including suggested minimum requirements of such investigations. The output expected from each investigation is listed below.

TABLE 17.1 : SUGGESTED INVESTIGATIONS FOR SITE CHARACTERISATION

Type of Investigation	Suggested Scope of Work
Subsoil/Geotechnical Investigation	(a) For Landifill design (i) Two boreholes per hectare of land; minimum 3 boreholes; upto 10m below base of landfill; recording soil strata, ground water level, bedrock level (ii) One to two in situ permeability tests per hectare of land (iii) Performance of SPT tests and collection of undisturbed samples from boreholes (iv) Laboratory tests on undisturbed samples - permeability, strength, compressibility, and classification tests. (b) For borrow area of liner material and cover material (i) Two test pits or shallow boreholes per hectare of borrow area; minimum five pits (ii) Laboratory tests - classification, Proctor compaction, permeability and strength tests (c) For approach road to landfill. (i) As per IRC codes

Type of Investigation	Suggested Scope of Work
Ground water/ Hydrogeological Investigations	(a) One ground water well (per acquifer) for every hectare of land; minimum four wells - one upgradient, three down-gradient (b) Observations of g.w. level fluctuations and ground water flow (c) Collection of groundwater samples (monthly/bi-monthly) for g.w. quality testing for 1 year prior to landfill construction.
Topographical Investigation	Surveying of landfill area and preparation of a topographical map with 0.3m contour interval.
Hydrological Investigation	(a) Collection of detailed topographical maps of surrounding area from Survey of India. (b) Collection of hydrometeorological data from India Meteorogical Department (c) Performance of flood routing analysis for one in 100 year flood (d) Collection of surface water samples (monthly/bimonthly) for water quality testing one year prior to landfill construction
Geological & Seismic Investigations	(a) Geophysical survey - seismic refraction or microgravity for bedrock profiling (b) Joint mapping of exposed rock outcrop/quarry face. (c) Collection of seismic data
Environmental Investigation basis	(a) Collection of samples on monthly/bimonthly surface water samples ground water samples, and air samples (b) Transportation to certified testing laboratory and testing for regulatory parameters (c) Vegetation/ecology mapping survey
Traffic Investigation	(a) Collection of data on existing traffic - daily traffic volume and peak hour traffic volume - for six months (b) Road condition survey for existing road with suggestions for strengthening/widening.

Type of Investigation	Suggested Scope of Work
Waste & Leachate Investigation	(a) Waste characterisation of fresh waste collected from bins (b) Waste characterization of old waste collected from different depths in existing waste dumps or sanitary landfills. (c) Collection and laboratory testing of at least 6 samples of leachate from just beneath existing waste dumps or sanitary landfills. (d) Estimate of leachate quality from laboratory testing.

17.5.1 Subsoil Investigation

The suggested minimum recommended investigations is listed in Table 17.1. A detailed investigation plan may be drawn up in consultation with a geotechnical engineer.

The output from such an investigation should yield the following:

(a) Stratification of subsoil – type of soil and depth

(b) Depth to ground water table and bedrock (if located within 10m of base of landfill)

(c) Permeability of various strata beneath the landfill

(d) Strength and compressibility properties of subsoil

(e) Extent of availability of liner material, drainage material, top soil, and protective soil in adjacent borrow areas

(f) Subsoil properties along approach road.

17.5.2 Ground Water/Hydrogeological Investigation

The suggested minimum investigation is listed in Table 17.1. A detailed investigation plan may be drawn up in consultation with a ground water specialist/water resources engineer or a hydrogeologist. The output from such an investigation should yield the following:

(a) Depth to groundwater table and its seasonal variations

(b) Ground water flow direction

(c) Baseline ground water quality parameters – all drinking water quality parameters

17.5.3 Topographical Investigation

Construction of a landfill involves a large quantity of earthwork. It is essential to have an accurate topographical map of the landfill site to compute earthwork quantities precisely. A map of 0.3m contour interval is considered desirable.

17.5.4 Hydrological Investigation

The objective of a hydrological investigation is to estimate the quantity of surface runoff that may be generated within the landfill to enable appropriate design of drainage facilities. If additional run off from areas external to the landfill is likely to enter the landfill, this quantity should also be estimated to design interception ditches and diversion channels. Such an investigation should yield estimates of peak flows. If seasonal rivers or streams run close to the site, hydrological investigation should indicate the possibility of flooding of the site under one in 100 year flood flows.

Surface water samples for water quality analysis may be collected from during hydrological studies.

17.5.5 Geological Investigation and Seismic Investigation

Geological investigations should delineate the bedrock profile beneath the landfill base, if not confirmed by subsoil investigations. Geophysical surveys may be designed in consultation with a geologist.

In hilly areas or in quarried rocks, geological investigations should indicate the quality of surficial rock, depth to sound rock and the possibility of interconnected aquifers beneath the landfill base in the rock mass.

Detailed seismic data may be obtained as a part of geological investigations (if required).

17.5.6 Environmental Investigation

The following baseline parameters must be established for a one year period prior to construction of a landfill:

(a) **Ground Water Quality**: Minimum of 3 samples from each aquifer analysed in monthly basis for drinking water quality parameters.

(b) **Surface Water Quality**: Minimum of 3 samples from a stream/storm water drain analysed on a monthly basis and for parameters relevant for waste-water drains.

(c) **Landfill Gas**: Sampling and analysis for methane, hydrogen sulphide and other gases on a monthly basis.

(d) **Dust**: PM 10 (Particle size less than 10 Microns) monitoring on a monthly basis, specifically at noon, during hot, dry, windy days.

(e) **Odour**: Monthly analysis at the site and at 200m intervals from the landfill boundary to the nearest inhabited zone.

(f) **Noise**: Peak noise analysis at the site and nearby inhabited zone on a monthly basis.

(g) **Vegetative Cover**: Vegetative mapping on a seasonal basis.

17.5.7 Traffic Investigation

Traffic investigations must be conducted to identify peak traffic volume as well as the quality of existing roads near the landfill. The influence of increased heavy vehicle traffic due to landfilling should be analysed with a view to widening the existing road.

17.5.8 Waste Characterisation

Waste characterisation is normally conducted as a part of waste management studies or environmental impact assessment studies. Waste from all sources must be tested for the following properties: (a) composition; (b) physical properties; (c) chemical properties; (d) biological properties; (e) thermal properties; (f) toxic properties and (g) geotechincal properties.

17.5.9 Leachate Investigation

Leachate quality can be assessed from both laboratory studies and field studies. Laboratory leachate tests may be performed. In addition, (if feasible), leachate samples should be analysed from existing waste dumps or landfills near the new site. This will help in a leachate treatment strategy.

17.6 LANDFILL PLANNING AND DESIGN

17.6.1 Design Life

A landfill design life will comprise of an 'active' period and an 'closure and post-closure' period. The 'active' period may typically range from 10 to25 years depending on the availability of land area. The 'closure and post-closure' period for which a landfill will be monitored and maintained will be 25 years after the 'active period' is completed.

17.6.2 Waste Volume and Landfill Capacity

The volume of waste to be placed in a landfill will be computed for the 'active' period of the landfill taking into account (a) the current generation of water per annum and (b) the anticipated increase in rate of waste generation on the basis of past records or population growth rate.

The required landfill capacity is significantly greater than the waste volume it accommodates. The actual capacity of the landfill will depend upon the volume occupied by the liner system and the cover material (daily, intermediate and final cover) as well as the compacted density of the waste. In addition, the amount of settlement a waste will undergo due to overburden stress and due to bio-degradation should also be taken into account.

The density of waste varies on account of large variations in waste composition, degree of compaction and state of decomposition. Densities may range as low as 0.40 t/cu.m. to 1.25 t/cu.m. For planning purposes, a density of 0.85 t/cu.m. may be adopted for biodegradable wastes with higher values (typically 1.1 t/cu.m.) for inert waste.

Settlement of the completed waste mass beneath the final cover will inevitably occur as a result of the consolidation of waste within a landfill site. Initial settlement occurs predominantly because of the physical rearrangements of the waste material after it is first placed in the landfill. Later settlement mainly results from biodegradation of the waste, which in turn leads to further physical settlement. Accurate prediction of settlement is difficult because time-related settlement data are not readily rarely available. Initial settlement values of between 12 and 17% have been reported for household waste sites in the UK with long term (30 year) values of approximately 20%. A typical allowance of 10% can be made when usable landfill capacity is computed (less than 5% for incinerated/inert waste).

Annexure 17.1 gives the methodology for computing the landfill capacity, landfill area and landfill height.

The total landfill area should be approximately 15% more than the area required for landfilling to accommodate all infrastructure and support facilities as well as to allow the formation of a green belt around the landfill.

There is no standard method for classifying landfills by their capacity. However the following nomenclature is often observed in literature:

Small size landfill	:	less than 5 hectare area
Medium size landfill	:	5 to 20 hectare area
Large size landfill	:	greater than 20 hectare area.

Landfill heights are reported to vary from less than 5 m to well above 30 m.

17.6.3 Landfill Layout

A landfill site will comprise of the area in which the waste will be filled as well as additional area for support facilities. Within the area to be filled, work may proceed in phases with only a part of the area under active operation. A typical site layout is shown in Fig. 17.5. The following facilities must be located in the layout: (a) access roads; (b) equipment shelters; (c) weighing scales; (d) office space; (e) location of waste inspection and transfer station (if used); (f) temporary waste storage and/or disposal sites for special wastes; (g) areas to be used for waste processing (e.g. shredding); (h) demarcation of the landfill areas and areas for stockpiling cover material and liner material; (i) drainage facilities; (j) location of landfill gas management facilities; (k) location of leachate treatment facilities; and (l) location of monitoring wells.

It is recommended that for each landfill site, a layout be designed incorporating all the above mentioned facilities (see Section 17.6.17 on Site Infrastructure for details). The layout will be governed by the shape of the landfill area in plan.

17.6.4 Landfill Section

Landfills may have different types of sections depending on the topography of the area. The landfills may take the following forms: (a) above ground landfills (area landfills); (b) below ground landfill (trench landfills); (c) slope landfills; (d) valley landfills (canyon landfills); and (e) a combination of the above. Fig. 17.6 shows typical landfill sections.

Above Ground Landfill (Area Landfill): The area landfill [Figs. 17.6(a)] is used when the terrain is unsuitable for the excavation of trenches in which to place the solid waste. High-groundwater conditions necessitate the use of area-type landfills. Site preparation includes the installation of a liner and leachate control system. Cover material must be hauled in by truck or earthmoving equipment from adjacent land or from borrow-pit areas.

Below Ground Landfill (Trench Landfill): The trench method of landfilling [Fig. 17.6(b)] is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is not near the surface. Typically, solid wastes are placed in trenches excavated in the soil. The soil excavated from the site is used for daily and final cover. The excavated trenches are lined with low-permeability liners to limit the movement of both landfill gases and leachate. Trenches vary from 100 to 300 m in length, 1 to 3 m in depth, and 5 to 15 m in width with side slopes of 2:1.

Slope Landfill: In hilly regions it is usually not possible to find flat ground for landfilling. Slope landfills and valley landfills have to be adopted. In a slope landfill [Fig. 17.6(c)], waste is placed along the sides of existing hill slope. Control of inflowing water from hillside slopes is a critical factor in design of such landfills.

Valley Landfill: Depressions, low-lying areas, valleys, canyons, ravines, dry borrow pits etc. have been used for landfills. The techniques to place and compact solid wastes in such landfills [Fig. 17.6(d)] vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of leachate and gas control facilities to be used, and the access to the site. Control of surface drainage is often a critical factor in the development of canyon/depression sites.

It is recommended that the landfill section be arrived at keeping in view the topography, depth to water table and availability of daily cover material.

17.6.5 Phased Operation

Before the main design of a landfill can be undertaken it is important to develop the operating methodology. A landfill is operated in phases because it allows the progressive use of the landfill area, such that at any given time a part of the site may have a final cover, a part being actively filled, a part being prepared to receive waste, and a part undisturbed;

The term ‘phase’ describes a sub-area of the landfill. A ‘phase’ consists of cells, lifts, daily cover, intermediate cover, liner and leachate collection facility, gas control facility and final cover over the sub-area.

Each phase is typically designed for a period of 12 months. Phases are generally filled from the base to the final/intermediate cover and capped within this period leaving a temporary unrestored sloping face. Fig. 17.7 shows a simplified sequence of phased operation.

It is recommended that a ‘phase plan’ may be drawn as soon as the landfill layout and section are finalised. It must be ensured that each phase reaches the final cover level at the end of its construction period and that is capped before the onset of monsoons. For very deep or high landfills, successive phases should move from base to the top (rather than horizontally) to ensure early capping and less exposed plan area of ‘active’ landfills (Fig. 17.8).

The term cell is used to describe the volume of material placed in a landfill during one operating period, usually one day (see Fig. 17.9). A cell includes the solid waste deposited and the daily cover material surrounding it. Daily cover usually consists of 15 to 30 cm of native soil that is applied to the working faces of the landfill at the end of each operating period. The purposes of daily cover are to control the blowing of waste materials; to prevent rate, flies and other disease vectors from entering or exiting the landfill; and to control the entry of water into the landfill during operation.

A lift is a complete layer of cells over the active area of the landfill (Fig. 17.9). Typically, each landfill phase is comprised of a series of lifts. Intermediate covers are placed at the end of each phase; these are thicker than daily covers, typically 45 cm or more and remain exposed till the next phase is placed over it. A bench (or terrace) is commonly used where the height of the landfill will exceed 5 m. The final lift includes the cover layer. The final cover layer is applied to the entire landfill surface of the phase after all landfilling operations are complete. The final cover usually consists of multiple layers designed to enhance surface drainage, intercept percolating water and support surface vegetation.

17.6.6 Estimation of Leachate Quality and Quantity

Leachate is generated on account of the infiltration of water into landfills and its percolation through waste as well as by the squeezing of the waste due to self weight. Thus, leachate can be defined as a liquid that is produced when water or another liquid comes in contact with solid waste. Leachate is a contaminated liquid that contains a number of dissolved and suspended materials.

17.6.6.1 Leachate Quality

The important factors which influence leachate quality include waste composition, elapsed time, temperature, moisture and available oxygen. In general, leachate quality of the same waste type may be different in landfills located in different climatic regions. Landfill operational practices also influence leachate quality.

Table 17.2 indicates the typical data on characteristics of leachate reported by Bagchi (1994), Tchobanoglous et al. (1993) and Oweis and Khera (1990). Data on leachate quality has not been published in India. However, studies conducted by Indian Institute of Technology, Delhi, NEERI, Nagpur, and some State Pollution Control Boards have shown ground water contamination potential beneath sanitary landfills.

TABLE 17.2 : TYPICAL CONSTITUENTS OF LEACHATE FROM MSW LANDFILLS

Constituent		Range (mg/l)	
Type	**Parameter**	**Minimum**	**Maximum**
Physical	pH	3.7	8.9
	Turbidity	30JTU	500JTU
	Conductivity	480 mho/cm	72500 mho/cm
Inorganic	Total Suspended Solids	2	170900
	Total Dissolved Solids	725	55000
	Chloride	2	11375
	Sulphate	0	1850
	Hardness	300	225000
	Alkalinity	0	20350
	Total Kjeldahl Nitrogen	2	3320
	Sodium	2	6010
	Potassium	0	3200
	Calcium	3	3000
	Magnesium	4	1500
	Lead	0	17.2
	Copper	0	9.0
	Arsenic	0	70.2
	Mercury	0	3.0
	Cyanide	0	6.0
Organic	COD	50	99000
	TOC	0	45000
	Acetone	170	11000
	Benzene	2	410

	Toluene	2	1600
	Chloroform	2	1300
	Delta	0	5
	1,2 dichloroethane	0	11000
	Methyl ethyl ketone	110	28000
	Naphthalene	4	19
	Phenol	10	28800
	Vinyl Chloride	0	100
Biological	BOD	0	195000
	Total Coliform bacteria	0	100
	Fecal Coliform bacteria	0	10

(Source : Table compiled from data reported by Bagchi (1994), Tchobanoglous et. al. (1993) and Oweis and Khera (1990). Range of constituents observed from different landfills)

Assessment of leachate quality at an early stage may be undertaken to: (a) to identify whether the waste is hazardous, (b) to choose a landfill design, (c) to design or gain access to a leachate treatment plant, and (d) to develop a list of chemicals for the groundwater monitoring program. To assess the leachate quality of a waste, the normal practice is to perform laboratory leachate tests [Toxicity Characteristics Leaching Procedure (TCLP tests)] as well as to determine the quality of actual landfill leachate, if available. Difficulty arises when field data are not available for a particular waste type. Laboratory leachate tests on MSW do not yield very accurate results because of heterogeneity of the waste as well as difficulty in simulating of time-dependent field conditions. Leachate samples from old landfill sites near the design site may give some indication regarding leachate quality; however this too will depend on the age of the landfill.

For the design of MSW landfills having significant biodegradable material as well as mixed waste, leachate quality has been universally observed to be harmful to ground water quality. Hence all landfills will be designed with a liner system at the base as discussed in the Section 17.7 on Liner System.

A landfill may not be provided a liner if and only if the following conditions can be satisfied:

(a) if the waste is predominantly construction material type inert waste without any undesirable mixed components (such as paints, varnish, polish etc.) and if laboratory tests (such as TCLP tests) conclusively prove that the leachate from such waste is within permissible limits; and

(b) if the waste has some biodegradable material, it must be proven through both laboratory studies on fresh waste and field studies (in old dumps) that the leachate from such waste will not impact the ground water in all the phases of the landfill and has not impacted the ground water or the subsoil so far in old dumps. Such a case may occur at sites where the base soil may be clay of permeability less than 10^{-7} cm/sec for at least 5 m depth below the base and where water table is at least 20 m below the base. A leachate collection facility would have to be provided in all such cases.

17.6.6.2 Leachate Quantity

The quantity of leachate generated in a landfill is strongly dependent on the quantity of infiltrating water. This, in turn, is dependent on weather and operational practices. The amount of rain falling on a landfill to a large extent controls the leachate quality generated. Precipitation depends on geographical location.

Significant quantity of leachate is produced from the 'active' phases of a landfill under operation during the monsoon season. The leachate quantity from those portions of a landfill which have received a final cover is minimal. Fig. 17.10 shows the components of a water-balance approach for estimating leachate quantity for (a) actual condition and (b) simplified condition.

Generation Rate in 'Active Area': The leachate generation during the operational phase from an active area of a landfill may be estimated in a simplified manner as follows:

Leachate volume = (volume of precipitation) + (volume of pore squeeze liquid) – (volume lost through evaporation) – (volume of water absorbed by the waste).

Generation Rate After Closure: After the construction of the final cover, only that water which can infiltrate through the final cover percolates through the waste and generates leachate. The major quantity of precipitation will be converted to surface runoff and the quantity of leachate generation can be estimated as follows:

Leachate volume = (volume of precipitation) – (volume of surface runoff) – (volume lost through evapotranspiration) – (volume of water absorbed by waste and intermediate soil covers).

For landfills which do not receive run-on from outside areas, a very approximate estimate of leachate generation can be obtained by assuming it to be 25 to 50 per cent of the precipitation from the active landfill area and as 10 to 15 percent of the precipitation from covered areas. This is a thumb rule and can only be used for preliminary design.

For detailed design, computer simulated models [eg. Hydraulic Evaluation of Landfill Performance (HELP)] have to be used for estimation of leachate quantity generation. It is recommended that for design of all major landfills, such studies be conducted to estimate the quantity of leachate.

17.6.7 Liner System

Leachate control within a landfill involves the following steps: (a) prevention of migration of leachate from landfill sides and landfill base to the subsoil by a suitable liner system; and (b) drainage of leachate collected at the base of a landfill to the sides of the landfill and removal of the leachate from within the landfill.

Liner systems comprise of a combination of leachate drainage and collection layer(s) and barrier layer(s) (Fig. 17.11). A competent liner system should have low permeability, should be robust and durable and should be resistant to chemical attack, puncture and rupture. A liner system may comprise of a combination of barrier materials such as natural clays, amended soils and flexible geomembranes. Three types of liner systems (Fig. 17.12) are usually adopted and these are described hereafter:

(a) **Single Liner System**: Such a system comprises of a single primary barrier overlain by a leachate collection system with an appropriate separation/protection layer. A system of this type is used for a low vulnerability landfill.

(b) **Single Composite Liner System**: A composite liner comprises of two barriers, made of different materials, placed in intimate contact with each other to provide a beneficial combined effect of both the barriers. Usually a flexible geomembrane is placed over a clay or amended soil barrier. A leachate collection system is placed over the composite barrier. Single composite liner system are often the minimum specified liner system for non-hazardous wastes such as MSW.

(c) **Double Liner System**: In a double liner system a single liner system is placed twice, one beneath the other. The top barrier (called the primary barrier) is overlaid by a leachate collection system. Beneath the primary barrier, another leachate collection system (often called the leak detection layer) is placed followed by a second barrier (the secondary barrier). This type of system offers double safety and is often used beneath industrial waste landfills. It allows the monitoring of any seepage which may escape the primary barrier layer.

The advantages of a composite liner system are immense and often not widely recognised. The way that a composite liner works is sketched in Fig. 17.13 and is contrasted with individual geomembranes and soil liners. To achieve good composite action, the geomembrane must be placed against the clay with good hydraulic contact. To achieve intimate contact, the surface of a compacted soil liner on which the geomembrane is placed should be smooth-rolled with a steel-drum roller. All oversize stones in the soils should be removed prior to rolling. Also, the geomembrane should be placed and backfilled in a way that minimizes wrinkles.

On a basis of review of liner systems adopted in different countries (Fig. 17.14), it is recommended that for all MSW landfills the following single composite liner system be adopted (waste downwards) as the minimum requirement (Fig. 17.15):

(a) A leachate drainage layer 30 cm thick made of granular soil having permeability (K) greater than 10^{-2} cm/sec.

(b) A protection layer (of silty soil) 20 cm to 30 cm thick.

(c) A geomembrane of thickness 1.5 mm or more.

(d) A compacted clay barrier or amended soil barrier of 1 m thickness having permeability (K) of less than 10^{-7} cm/sec.

The liner system adopted at any landfill must satisfy the minimum requirements published by regulatory agencies (MOEF/ CPCB).

The liner system may have to be more stringent in free draining alluvial soils at locations where water table level is close to the base of the landfill.

The recommendations for the liner system are not expected to be reduced. However in circumstances where it can be proven by subsoil investigations as well as by hydrological investigations that the leachate will not cause harmful impact to the soil as well as ground water, the norms can be reduced after approval by the regulatory authority.

Detailed design and construction aspects of liners are covered in Section 17.7.

New materials can be considered for liner systems if:

(a) these are approved by regulatory agencies; and

(b) the use of such materials has been demonstrated over a 10 year period.

Cut-Off Walls: When a landfill is underlain, at shallow depths, by an impervious layer, vertical cutoff walls may be constructed around a landfill to intercept off-site migration. Cut-off walls are physical barriers (typical made of bentonite or bentonite-soil mix) and such barriers are aided by active pumping used to remove leachates from within the perimeter of the cutoff wall.

Liners for Steep Slopes and Vertical Quarry Faces: Liners along very steep slopes and vertical faces require site specific solutions which are usually complex.

17.6.8 Leachate Drainage, Collection and Removal

A leachate collection system comprises of a drainage layer, a perforated pipe collector system, sump collection area, and a removal system.

The leachate drainage layer is usually 30 cm thick, has a slope of 2% or higher and a permeability of greater than 0.01 cm/sec. A system of perforated pipes and sumps are provided within the drainage layer (Figs. 17.16). The pipe spacing is governed by the requirement that the leachate head should not be greater than the drainage layer thickness. Fig. 17.17 shows a typical layout of pipes and sumps. Pipe material selection is based on design requirements. HDPE pipes are most commonly used; other materials can also be examined for feasibility.

Leachate is removed from the landfill (Fig. 17.18) by (a) pumping in vertical wells or chimneys, (b) pumping in side slope risers, or (c) by gravity drains rough the base of a landfill in above-ground and sloped landfills. Side slope risers are preferred to vertical wells to avoid any down drag problems. Submersible pumps have been used for pumping for several years; educator pumps are also being increasingly used. In some landfills, the leachate is stored in a holding tank (for a few days) before being sent for treatment.

The possibility of fall in efficiency of the drainage system due to clogging associated with solid deposits and microbial growth is now well recognised. A number of options, including backflushing or breakthrough water after leachate head build-up need to be investigated at the design stage.

The design steps for the leachate collection system are:

(a) finalisation of layout pipe network and sumps in conjunction with drainage layer slopes of 2%;

(b) estimation of pipe diameter and spacing on the basis of estimated leachate quantity and maximum permissible leachate head;

(c) estimating the size of sumps and pump;

(d) design of wells/side slopes risers for leachate removal; and

(e) design of a holding tank.

It is recommended that the detailed methodology given in Sharma and Lewis (1994) be adopted.

17.6.9 Leachate Management

The alternatives to be considered for leachate management are:

(a) **Discharge to Lined Drains**: This option is usually not feasible. It can only be adopted if the leachate quality is shown to satisfy all waste water discharge standards for lined drains, consistently for a period of several years.

(b) **Discharge To Waste Water Treatment System**: For landfills close to a waste water treatment plant, leachate may be sent to such a plant after some pretreatment. Reduction is organic content is usually required as a pretreatment.

(c) **Recirculation**: One of the methods for treatment of leachate is to recirculate it through the landfill. This has two beneficial effects: (i) the process of landfill stabilisation is accelerated and (ii) the constituents of the leachate are attenuated by the biological, chemical and physical changes occurring with the landfill. Recirculation of a leachate requires the design of a distribution system to ensure that the leachate passes uniformly throughout the entire waste. Since gas generation is faster in such a process, the landfill should be equipped with a well designed gas recovery system.

(d) **Evaporation of Leachate**: one of the techniques used to manage leachate is to spray it in lined leachate ponds and allow the leachate to evaporate. Such ponds have to be covered with geomembranes during the high rainfall periods. The leachate is exposed during the summer months to allow evaporation. Odour control has to be exercised at such ponds.

(e) **Treatment of Leachate**: The type of treatment facilities to be used depend upon the leachate characteristics. Typically, treatment may be required to reduce the concentration of the following prior to discharge: degradable and non-degradable organic materials, specific hazardous constituents, ammonia and nitrate ions, sulphides, odorous compounds, and suspended solids. Treatment processes may be biological processes (such as activated sludge, aeration, nitrification (dentrification), chemical processes (such as oxidation, neutralisation) and physical processes (such as air stripping, activated adsorption, ultra filtration etc.). The treated leachate may be discharged to surface water bodies.

A leachate recirculation facility should be designed by a water supply specialist in conjunction with a geotechnical engineer. Procedures for design of recirculation facility are yet to be standardised and one may refer to Koerner and Daniel (1997) for further details. A leachate treatment facility should be designed by a waste water treatment specialist. The treatment facility will depend on the quality of the leachate and some treatment systems are discussed by Hogland (1997).

17.6.10 Estimation of Landfill Gas Quality and Quantity

Landfill gas is generated as a product of waste biodegradation. Biological degradation of the waste may occur in the presence of oxygen (aerobic bacteria), in an environment devoid of oxygen (anaerobic bacteria), or with very little oxygen (facultative anaerobic bacteria).

In all cases, organic waste is broken down by enzymes produced by bacteria in a manner comparable to food digestion. Considerable heat is generated by these reactions with methane, carbon dioxide, and other gases as the by-products. The typical percentage distribution of gases found in a MSW landfill is reported in Table 17.3 by Bagchi (1994). Tchobanoglous et. al. (1993) and Owies and Khera (1990). Methane and carbon dioxide are the principal gases produced from the anaerobic decomposition of the biodegradable organic waste components in MSW. When methane is present in the air in concentrations between 5 and 15 percent, it is explosive. Because only limited amounts of oxygen are present in a landfill when methane concentrations reach this critical level, there is little danger that the landfill will explode. However, methane mixtures in the explosive range can form if landfill gas migrates off-site and mixes with air. Published data on landfill gas quality in India is not available in literature.

The rate and quantity of gas generation with time, is difficult to predict. Typical generation rates reported in literature vary from 1.0 to 8.0 litres/kg/year. Bhide (1993) has reported landfill gas production rates of 6-0 cu.m. per hour from landfill sites in India having an area of 8 hectares and a depth of 5 to 8 m.

The experience of Sweden [Hogland (1997)] in the area of landfill gas generation is summarised hereafter and may be noted.

The potential volume of landfill gas generation can be estimated to be 200 to 300 cu.m. per tonne of municipal waste. 50 to 75 percent of this gas can be recovered in mixed waste landfills using well functioning recovery systems. The recovery time is difficult to predict and may vary from 10 to 20 years or even more.

TABLE 17.3 : TYPICAL CONSTITUENTS OF MUNICIPAL LANDFILL GAS

Constituent	Range (Percentage or Concentration)
Major Constituents	
Methane	30 to 60 %
Carbon Dioxide	34 to 60 %
Nitrogen	1 to 21 %
Oxygen	0.1 to 2 %
Hydrogen Sulphide	0 to 1 %
Carbon Monoxide	0 to 0.2 %
Hydrogen	0 to 0.2 %
Ammonia	0.1 to 1 %
Trace Constituents	
Acetone	0 to 240 ppm
Benzene	0 to 39 ppm
Vinyl Chloride	0 to 44 ppm
Toluene	8 to 280 ppm
Chloroform	0 to 12 ppm
Dichloromethane	1 to 620 ppm
Diethylene Chloride	0 to 20 ppm
Vinyl Acetate	0 to 240 ppm
Trichloroethane	0 to 13 ppm
Perchloroethane	0 to 19 ppm
Others	Variable

Gas outputs of 10 to 20 cu.m. per hour (corresponding to 50 to 100 KW of energy) have been recorded in wells of 15 to 20 cm diameter drilled 10 m into waste at a spacing of 30 to 70 m. For 1 MW output from a landfill site, 15 to 20 such wells are required.

Recovery of landfill gas from shallow depth landfills is more difficult than from landfill of depths greater than 5 m.

Landfill gases can move upward or downward in a landfill depending on their density. Although most of the methane escapes to the atmosphere, both methane and carbon dioxide have been found at concentrations up to 40 per cent at lateral distances of 100m or more from the edges of unlined landfills. For unvented landfills, the extent of this lateral movement varies with the characteristics of the cover material and the surrounding soil. If methane is vented in an uncontrolled manner, it can accumulate (because its density is less than that of air) below buildings or in other enclosed spaces close to a sanitary landfill. With proper venting, methane should not pose a problem (except that it is a greenhouse gas). Carbon dioxide, on the other hand, is troublesome because of its high density. The concentration of carbon dioxide in the lower portions of a landfill may be high for years.

Gas control within a landfill site (Fig. 17.19) involves the following features: (a) a containment system which encloses the gas within the site and prevents migration outside the landfill, (b) a system (passive or active) for collecting and removing landfill gas from within the landfill and in particular from the perimeter of the landfill; (c) a system for flaring or utilising the collected gas with adequate back-up facilities.

Landfill gas containment, extraction and use is discussed in Chapter 15.

17.6.12 Landfill Gas Management

The gas management strategies should follow one of the following three plans:

(a) Controlled passive venting

(b) Uncontrolled release

(c) Controlled collection and treatment/reuse

For all MSW landfills, controlled passive venting is recommended. Only for small (less than 100 tons per day), shallow (less than 5 m deep) and remotely located landfills, should uncontrolled release be allowed. Landfill gas monitoring will be adopted at all sites and remedial measure (such as flaring) undertaken if the gas concentrations are above acceptable limits.

Controlled collection and treatment/use will be adopted only after the feasibility of such a system is established and proven by an agency having experience in this area.

17.6.13 Final Cover System

A landfill cover is usually composed of several layers, each with a specific function. The final cover system must enhance surface drainage, minimise

infiltration, vegetation and control the release the landfill gases. The landfill cover system to be adopted will depend on the gas management plan i.e. (a) controlled passive venting; (b) uncontrolled release; or (c) controlled collection and treatment/reuse.

For all landfill sites where controlled gas venting is planned, the cover system shown in Fig. 17.20 is recommended. Gas vents will be placed at a spacing of 30 m to 75 m on the landfill cover and the level of methane will be monitored regularly. If methane concentration exceeds permissible limit a gas collection and treatment system will be installed with flaring facility.

For sites where landfill gas recovery is to be undertaken, the placement of passive and/or active gas venting systems will be governed by the energy recovery system. The cover system for such a site is shown in Fig. 17.21. Such a cover system minimises loss of gas to the environment.

For uncontrolled release of gas (in small, shallow and remote sites) the cover system shown in Fig. 17.22 is recommended.

The cover system adopted at any landfill must satisfy the minimum requirements published by regulatory agencies (MOEF/ CPCB).

17.6.14 Surface Water Drainage System

Surface water management is required to ensure that rainwater run-off does not drain into the waste from surrounding areas and that there is no water-logging/ponding on covers of landfills.

These objectives should be achieved by the following:

(a) Rainwater running off slopes above and outside the landfill area should be intercepted and channelled to water courses without entering the operational area of the site. This diversion channel may require a low permeability lining to prevent leakage into the landfill.

(b) Rain falling on active tipping areas should be collected separately and managed as leachate, via the leachate collection drain and leachate collection sumps to the leachate treatment and disposal system.

(c) Rainfall on areas within the landfill site but on final covers of phases which have been completed are not actively being used for waste disposal should be diverted away in drainage channels from active tipping areas, and directed through a settling pond to remove suspended silt, prior to discharge.

(d) Any drainage channels or drains constructed on the restored landfill surface should be able to accommodate settlement, resist erosion and cope with localised storm conditions.

(e) The final cover should be provided a slope of 3 to 5% for proper surface water drainage.

(f) All interceptor channels, drainage channels and settling ponds (storm water basins) should be designed by a hydrologist using hydrometerological data.

Fig. 17.23 shows a typical location of surface drainage facilities on completed landfill. Design of channels, ditches, culverts and basins is detailed by Bagchi (1994).

17.6.15 Slope Stability Aspects and Seismic Aspects

The stability of a landfill should be checked for the following cases (Fig. 17.24):

(a) stability of excavated slopes

(b) stability of liner system along excavated slopes

(c) stability of temporary waste slopes constructed to their full height (usually at the end of a phase)

(d) stability of slopes of above-ground portion of completed landfills

(e) stability of cover systems in above-ground landfills.

The stability analysis should be conducted using the following soil mechanics methods depending upon the shape of the failure surface: (a) failure surface parallel to slope; (b) wedge method of analysis; (c) method of slices for circular failure surface and (d) special methods for stability of anchored geomembranes along slopes.

In preliminary design of a landfill section, the following slopes may be adopted:

(a) Excavated soil slopes (2.5 Hor : 1 Vertical)

(b) Temporary waste slopes (3.0 Hor : 1 Vertical)

(c) Final cover slopes (4.0 Hor : 1 Vertical)

Slopes can be made steeper, if found stable by stability analysis results. Acceptable factors of safety may be taken as 1.3 for temporary slopes and 1.5 for

permanent slopes. In earthquake prone areas, the stability of all landfill slopes will be conducted taking into account seismic coefficients as recommended by BIS codes.

17.6.16 Materials Balance

A materials balance should be prepared for each material required for construction of a landfill, phase-by-phase, indicating materials required, materials available and deficient material to be imported or surplus material to be exported. If a borrow area is located within the landfill site it should not become a part of an early phase to avoid stockpiling and double handling.

17.6.17 Site Infrastructure

The following site infrastructure should be provided:

(a) Site Entrance and Fencing

(b) Administrative and Site Control Offices

(c) Access Roads

(d) Waste Inspection and Sampling Facility

(e) Equipment Workshops and Garages

(f) Signs and Directions

(g) Water Supply

(h) Lighting

(i) Vehicle Cleaning Facility

(j) Fire Fighting Equipment.

Site entrance infrastructure should include:

(a) a permanent, wide, entrance road with separate entry and exit lanes and gates.

(b) sufficient length/parking space inside the entrance gate till the weighbridge to prevent queuing of vehicles outside the entrance gate and on to the highway. A minimum road length of 50 m inside the entry gate is desirable

(c) A properly landscaped entrance area with a green belt of 20 m containing tree plantation for good visual impact

(d) Proper direction signs and lighting at the entrance gate

(e) A perimeter fencing of at least 2m height all around the landfill site with lockable gates to prevent unauthorised access

(f) Full time security guard at the site.

An accurate record of waste inputs is essential. Twin weighbridges to weigh both entry and exit weights may be located on either side of an island on which a weighbridge office room is located. The weighbridge should be located well inside the entrance gate to avoid congestion and queuing at the gate. The weighbridge office should be elevated and the weighbridge operation should be able to see entering vehicles as well as speak to drivers. Raised platforms weighbridges with computerised output and with facility for manual recording of displayed readings are recommended. Such weighbridges should remain operative during power supply failure.

Administrative and site control offices should include: administrative office building (permanent); site control office (portable) near the active landfill area; stores (permanent) within or near administrative office; welfare facilities – toilets, shower room, first aid room, mess room, small temporary accommodation; infrastructural services – electricity, drinking water supply, telephone, sewerage and drainage system and communication services (telephone etc.) between site control office and administrative office and weighbridge office.

The provision of well maintained, high quality site roads is necessary to ensure the free flow of traffic and a fast turn around of vehicles. The construction details of three types of roads are required: main access road (permanent); arterial road (permanent) and temporary road.

17.6.18 Landfill Equipment

The following equipment is required at a landfill site:

(a) Dozers – for spreading waste and daily cover

(b) Landfill Compactors – for compaction of waste

(c) Loader Backhoes – for loading of waste (internal movement), for excavating trenches etc., for embankment construction

(d) Backhoes and front end loaders (instead of (c) above)

(e) Tractor trailors – for internal movement of waste or daily cover soil

(f) Poclains or heavy duty backhoes for large excavation and embankment construction

(g) Soil compactors – sheepsfoot rollers and smooth steel drum rollers (for finishing passes)

The recommended numbers of each type of equipment required at a landfill is indicated in Table 17.4.

TABLE 17.4 : EQUIPMENT AT LANDFILLS

Waste Received At Landfill per day	Buldozers	Loaders	Excavators	Compactors	Water tankers	Tractor Trailers/ Tippers
upto 200 tons	2	2	2	2	1	2
200 to 500 tons	3	3	3	3	1	4
500 to 1000 tons	5	4	3	5	2	6

(a) Productivity of each equipment should match waste handling per day in 8 hour shift or earthwork handling per day in 8 hour shift with atleast one standby equipment.

(b) Loader - Backhoes can be purchased to perform the functions of loaders and excavators.

(c) Compactors are steel wheeled compactors with cleated/spiked wheels having operating weight ranging from 12 tons to 30 tons. These should be equipped with a trash blade.

17.6.19 Design of Environmental Monitoring System

The objective of an environmental monitoring system is (a) to find out whether a landfill is performing as designed; and (b) to ensure that the landfill is conforming to the regulatory environmental standards.

Monitoring at a landfill site is carried out in four zones: (a) on and within the landfill; (b) in the unsaturated subsurface zone (vadose zone) beneath and around the landfill; (c) in the groundwater (saturated) zone beneath and around the landfill and (d) in the atmosphere/local air above and around the landfill.

The parameters to be monitored regularly are:

(i) leachate head within the landfill;

(ii) leachate and gas quality within the landfill;

(iii) long-term movements of the landfill cover;

(iv) quality of pore fluid and pore gas in the vadose zone;

(v) quality of groundwater in the saturated zones and

(vi) air quality above the landfill, at the gas control facilities, at buildings on or near the landfill and along any preferential migration paths.

The indicators of leachate quality and landfill gas quality must be decided after conducting a study relating to the type of the waste, the age of the waste, the composition of leachate and gas likely to be generated and the geotechnical as well as hydro-geological features of the area. Typical leachate and gas constituents have already been indicated in sections 17.6.6 and 17.6.10. All monitoring programmes must first establish the baseline/background conditions prior to landfill monitoring.

The frequency of monitoring will vary from site to site but it must be so fixed that it is capable of detecting unusual events and risks in the initial phases of their appearance so as to give time to diagnose and localise the cause and enable early steps to be taken for containment or remediation. Usually a monthly or a bi-monthly monitoring frequency is considered suitable during the operational phase of a landfill as well as for 3 to 4 years after closure; this frequency can be decreased to 2-3 times a year in later years, if all systems perform satisfactorily. The monitoring frequency may have to be increased if higher concentrations than expected are detected, if control systems are changed or if drainage systems become clogged/non-functional. The frequency of monitoring may also be increased during those periods in which gas generation or leachate generation is higher, such as during the monsoon periods.

A monitoring programme must specify (i) a properly selected offsite testing laboratory capable of measuring the constituents at correct detection levels, (ii) a methodology for acquiring and storing data; and (iii) a statistical procedure for analyses of the data.

The following instruments/equipment will be used for monitoring (Fig. 17.25):

(a) Groundwater samplers for groundwater monitoring wells

(b) Leachate samplers for leachate monitoring within the landfill and at the leachate tank

(c) Vacuum lysimeters, filter tip samplers, free drainage samplers for leakage detection beneath landfill liners.

(d) Surface water samplers for collection of sample from sedimentation basin.

(e) Downhole water quality sensors for measuring conductivity, pH, DO, temperature in leachate wells, groundwater wells and sedimentation basins.

(f) Landfill gas monitors (portable) for onsite monitoring of landfill gases.

(g) Active and Passive air samplers for monitoring ambient air quality.

It is recommended that the location of each type of instrument/equipment be finalised in conjunction with an expert on the basis of the topography of the area and the layout of the landfill. A minimum of 4 sets of ground water monitoring wells (one up-gradient and three down gradient) for sampling in each acquifer are considered desirable at each landfill site (Fig. 17.26).

17.6.20 Closure and Post-Closure Maintenance Plan

Determination of the end-use of a landfill site is an essential part of the plan for landfill closure and post-closure maintenance. Some possible uses of closed landfill sites near urban centres include parks, recreational areas, golf courses, vehicle parking areas and sometimes even commercial development.

A closure and post-closure plan for landfills involves the following components:

- Plan for vegetative stabilization of the final landfill cover.
- Plan for management of surface water run-off with an effective drainage sytem.
- Plan for periodical inspection and maintenance of landfill cover and facilities.

These aspects are covered in Section 17.9.

17.6.21 Waste Acceptance Criteria

A waste acceptance criteria must be formulated for each landfill site. Presence of small hazardous waste industries in municipal boundaries, if any, should be taken note of.

The following waste acceptance criteria is suggested:

(a) All waste will be routinely accepted if the truck/tipper carries authorised documents indicating the source of waste. Such waste will be routinely inspected visually at the tipping area in the landfill site.

(b) All waste coming in authorised trucks from non-conforming areas (such as unauthorised colonies with micro-industries) will be visually inspected at waste inspection facilities and sampled randomly. Waste may be rejected if found to contain hazardous material.

(c) Non-hazardous small quantity waste may be accepted from industrial zones if certified as non-hazardous by the regulatory authority (Pollution Control Board) and if the quantity is less than 10% of the MSW waste received daily.

(d) All waste rejects from thermal and biological processing of MSW waste will be accepted at the landfill provided it is certified that no additives have been added during the waste processing which render the rejects as hazardous.

(e) Liquid wastes and sludges with high water content will not be accepted at MSW landfill sites.

(f) Dewatered sludges duly certified as non-hazardous will be accepted at landfill sites provided they are less than 10% of MSW received daily.

(g) Ash from incinerators of biomedical waste or industrial waste will not be accepted unless certified as being 'non-hazardous' by the regulatory authority; otherwise it will be disposed in hazardous waste landfill.

(h) Large quantity non-hazardous industrial solid waste (more than 10% of MSW generated daily) should not be accepted at a MSW landfill (or should be stored in separate cells/phases).

(i) Construction and demolition debris be accepted for daily cover requirements or for storage in separate cells/phases in a landfill.

17.7 DESIGN AND CONSTRUCTION OF LANDFILL LINERS

The liner system at the base and sides of a landfill is a critical component of the landfill which prevents ground water contamination. The recommended minimum specification of such a liner is discussed in Section 17.6.7. Design and construction procedures of two elements of the liner system – the compacted clay/amended soil and the geomembrane – are discussed hereafter.

17.7.1 Compacted Clays and Amended Soils

The selection of material to be used a soil barrier layer will usually be governed by the availability of materials, either at site or locally in nearby areas. The hierarchy of options will usually be as follows:

(a) Natural clay will generally be used as a mineral component of a liner system where suitable clay is available on site or nearby.

(b) If clay is not available, but there are deposits of silts (or sands), then formation of good quality bentonite enhanced soil/amended soil, may be economical.

Compacted Clays: Wherever suitable low permeability natural clay materials are available, they provide the most economical lining material and are commonly used. The basic requirements of a compacted clay liner is that it should have permeability below a pre-specified limit (10^{-7} cm/sec) and that this should be maintained during the design life. Natural clay available in-situ is usually excavated and re-compacted in an engineered manner. If clay is brought from nearby areas, it is spread in thin layers and compacted over the existing soil. The quality of the in-situ clay may be good enough to preclude the requirement of a compacted clay liner, only if it has no dessication cracks and is homogeneous as well as uniformly dense in nature.

Amended Soils: When low-permeability clay is not available locally, in-situ soils may be mixed with medium to high plasticity imported clay, or commercial clays such as bentonite, to achieve the required low hydraulic conductivity. Soil-bentonite admixtures are commonly used as low permeability amended soil liners. Generally, well-graded soils require 5 to 10 percent by dry weight of bentonite, while uniformly graded soils (such as fine sand), may typically require 10 to 15 percent bentonite. The most commonly used bentonite admixture is sodium bentonite. Calcium bentonite may also be used, but more bentonite may be needed to achieve the required permeability, because it is more permeable than sodium bentonite.

It is not necessary that the bentonite should be the only additive to be considered for selection. Medium to high plasticity clays from not too distant areas, can also be imported and mixed with the local soils. Usually high quantities of clays (10 to 25 percent) are required to achieve the required permeability. Nevertheless, these may sometimes prove to be more economical than bentonite amended soils and their permeabilities may not be significantly influenced by leachate quality.

17.7.1.1 Specifications

A competent barrier made of compacted soils - clays or amended soils - is normally expected to fulfil the following requirements:

(a) hydraulic conductivity of 10^{-7} cm/sec or less;

(b) thickness of 100 cm or more;

(c) absence of shrinkage cracks due to desiccation;

(d) absence of clods in the compacted clay layer;

(e) adequate strength for stability of liner under compressive loads as well as along side slopes; and

(f) minimal influence of leachate on hydraulic conductivity.

Clays of high plasticity with very low values of permeability (usually well below the prescribed limit), exhibit extensive shrinkage on drying, as well as tend to form large clods during compaction in the relatively dry state. Their permeability can also increase on ingress of certain organic leachates. Well compacted inorganic clays of medium plasticity, either natural or amended, appear to be most suitable for liner construction.

According to various investigators, soils with the following specifications would prove to be suitable for liner construction: Percentage fines - between 40 and 50%; plasticity index - between 10 and 30%; liquid limit - between 25 and 30%; clay content - between 18 and 25%. It is necessary to perform detailed laboratory tests and some field trial tests prior to liner construction to establish that the requirements pertaining to permeability, strength, leachate compatibility and shrinkage are met.

17.7.1.2 Design Process

The design process for a compacted soil liner consists of the following steps:

(j) Identification of borrow area or source of material - in-situ or nearby.

(ii) For in-situ soils, conducting field permeability tests to assess suitability of the natural soil in its in-situ condition.

(iii) Laboratory studies on liner material (from in-situ or nearby locations), comprising of soil classification tests, compaction tests, permeability tests, strength tests, shrinkage tests and leachate compatibility tests.

(iv) Identification of source of additive, if natural soil does not satisfy liner requirements - natural clay from not too distant areas or commercially available clay such as bentonite.

(v) Laboratory studies (as detailed in (iii) above) on soil- additive mixes using different proportions of additive to find minimum additive content necessary to achieve the specified requirements.

(vi) Field trial on test pads, to finalise compaction parameters (layer thickness, number of passes, speed of compactor), as well as to verify that field permeability of the compacted soil lies within pre-specified limits.

17.7.1.3 Laboratory Studies

For amended soils, the following tests should be conducted to arrive at the minimum additive content.

Additive Composition: Grains size distribution, plasticity tests and mineralogy tests, are performed to identify the clay content, activity and clay mineralogy of the additive.

Host Material Composition: Grain size distribution and plasticity tests are performed on the host material, to assess that the host material will mix readily with the additive. Clean sands, silty sands and non-plastic silts, usually mix readily with clays and bentonites. Cohesive hosts are more difficult to mix due to balling effect yielding uneven mixing. The host material must be sufficiently dry for proper mixing.

Soil-Additive Compaction Tests: Standard Proctor (or modified) tests are undertaken with variable quantities of additives mixed to the soil, usually in increments of 2 to 5 percent. The influence of the additive on dry density and optimum moisture content are evaluated [Fig. 17.27(a)].

Soil-Additive Permeability Tests: Permeability tests are conducted on as-compacted-then-saturated samples of amended soil with different percentages of additive, each sample compacted to maximum density at optimum water content. The hydraulic conductivity usually decreases with increasing additive content (Fig. 17.27(b)). It is possible to identify a minimum additive content, from a series of tests, which may be required to achieve the desirable hydraulic conductivity.

Analysis of Laboratory Results: Field engineers usually require a compaction specification, which states the minimum acceptable dry density as well as the acceptable range of water content. It is usually possible to arrive at a narrow

acceptable range of water content and dry density as shown in Fig. 17.28. A step-by-step process of elimination is to be adopted to identify this acceptable range of water content and dry density, which should then be communicated to the field engineer.

17.7.1.4 Field Trial Test Pads

The construction of a field trial test pad prior to undertaking construction of the main liner has many advantages. One can experiment with compaction equipment, water content, number of passes of the equipment, lift thickness and compactor speed. Most importantly, one can conduct extensive testing, including quality control testing and hydraulic conductivity tests, on the test pad. The test pad should have a width which is significantly more than the width of the construction vehicles (> 10 m) and greater length. The pad should ideally be the same thickness as the full-sized liner, but may sometimes be thinner. The in-situ hydraulic conductivity may be determined by the sealed double ring infiltrometer method. In in-situ tests on test pads, the hydraulic conductivity is measured under zero overburden stress. Hydraulic conductivity decreases with increasing overburden stress. The hydraulic conductivity measured on a test pad, should be corrected for the effects of overburden stress, based on results of laboratory conductivity tests performed over a range of compressive stresses.

17.7.1.5 Construction Aspects

Compacted Clays: The typical sequence of construction for compacted clay liners is as follows:

(a) Clearing of borrow area by removal of shrubs and other vegetative growth.

(b) Adjustment of water content in the borrow area - sprinkling or irrigating for increasing the water content and ripping and aerating for lowering the water content.

(c) Excavation of material.

(d) Transportation to site in haulers or through conveyor systems (short distance).

(e) Spreading and levelling of a thin layer (lift) of soil (of thickness about 25 cm).

(f) Spraying and mixing water for final water content adjustment.

(g) Compaction using rollers.

(h) Construction quality assurance testing.

(i) Placement of next lift and repetition of process till final thickness is achieved.

The two fold objectives of soil compaction are (a) to break and remould the clods into a homogeneous mass, and (b) to densify the soil. If the compaction is performed such that the required density at the specified moisture content is obtained, the required permeability will be achieved in the field. Regulations generally require that a minimum 100 cm thick compacted clay liner be constructed. This thickness is considered necessary so that any local imperfections during construction will not cause hydraulic short-circuiting of the entire layer. Compacted soil liners are constructed in a series of thin lifts. This allows proper compaction and homogeneous bonding between lifts. Generally, the lift thickness of clay liners is 25 to 30 cm before compaction and about 15 cm after compaction. It is important that each lift of clay liner be properly bonded to the underlying and overlying lifts. If this is not done, a distinct lift interface will develop, which may provide hydraulic connection between lifts.

Sheepsfoot rollers are best suited for compacting clay liners. Rollers with fully penetrating feet have a shaft about 25 cm long. Unlike partially penetrating rollers (pad-footed rollers), the fully penetrating sheeps foot roller (Fig. 17.29) can push through an entire soil lift and remold it. In addition to increasing bonding between lifts, one should maximize the compactive energy by considering factors such as roller weight, area of each foot, number of passes and the speed of the roller.

The lifts are typically placed in horizontal layers. However, when liners are constructed on the side slopes, the lifts can be placed either parallel to the slope (for slopes up to 2.5 Horizontal:1Vertical, due to limitations of compaction equipment) or in horizontal lifts(Fig. 17.30). Horizontal lifts require a width which is at least the width of one piece of construction equipment (usually 3 to 4 m).

Amended Soils: The process of construction of amended soil liners is similar to that for compacted clay liners with the modification that the additive is introduced into the soil after the excavation stage. Additives such as bentonite can be introduced in two ways - by in-place mixing or by central plant method. In the latter technique, soil and additive are mixed in a pugmill or a central mixing plant. Water can also be added in the pugmill either concurrently with bentonite or in a separate processing step. The central mixing plant method (Fig. 17.31) is more effective than in-place mixing and should be adopted. The use of small truck mounted concrete batching plants for mixing bentonite can also be examined.

The quality of the mix must be checked to ensure uniformity and correctness of the additive. A minimum of five trial runs should be made to check the quality of the mix visually and using grain size analysis. The permeability should also be checked using the field mix, compacted in the laboratory.

17.7.1.6 Construction Control

During construction, quality control is exercised to ensure that the constructed facility meets the design specifications.

Borrow area material control and amended soil control involves the following tests: (a) grain size distribution; (b) moisture content; (c) Atterberg's limits; (d) laboratory compaction tests; and (e) laboratory permeability tests. The frequency of testing varies from one test per 1000 cu.m, to one test per 5000 cu.m.

Compacted soil liner control involves the following tests: (a) in-situ density measurements; (b) in-situ moisture content measurements; (c) laboratory permeability tests on undisturbed samples; (d) in-situ permeability tests; (e) grain size distribution and Atterberg's limits of compacted samples. The frequency of testing for in-situ density and moisture content may be as high as 10 tests/hectare/lift whereas the other tests may be conducted at a lower frequency of about 2 tests/hectare/lift [Sharma and Lewis (1994)].

17.7.2 Geomembranes

A High Density Poly ethylene (HDPE) geomembrane of minimum thickness of 1.5 mm is to be laid over the compacted clay/amended soil with no gaps along the surface of contact.

17.7.2.1 Specifications

The geomembrane is normally expected to meet the following requirements:

(a) it should be impervious

(b) it should have adequate strength to withstand subgrade deformations and construction loads

(c) it should have adequate durability and longevity to withstand environmental loads

(d) the joints/seams must perform as well as the original material.

Typical specifications for geomembrane liners are given in Table 17.5. The specifications are only suggestive and need to be refined by a geosynthetics specialist for each landfill site.

TABLE 17.5 : TYPICAL VALUES FOR GEOMEMBRANES MEASURED IN PERFORMANCE TESTS

S.No.	Property		Typical Value
1	(a)	Thickness	1.5 mm (60 mil)
	(b)	Density	0.94 gm/cc
2.	Roll Width x Length		6.5 m x 150 m
2.	Tensile Strength		
	(a)	Tensile Strength at yield	24 kN/m
	(b)	Tensile Strength at Break	42 kN/m
	(c)	Elongation at Yield	15%
	(d)	Elongation at Break	700%
	(e)	Secant Modulus (1%)	500 MPa
3.	Toughness		
	(a)	Tear Resistance (initiation)	200N
	(b)	Puncture Resistance	480N
	(c)	Low Temperature Brittleness	-94^0F
4.	Durability		
	(a)	Carbon Black	2%
	(b)	Carbon Black Dispersion	A-1
	(c)	Accelerated Heat Ageing	Negligible strength changes after 1 month at 110^0C
5.	Chemical Resistance		
	(a)	Resistance to Chemical Waste Mixture	10% strength change over 120 days
	(b)	Resistance to Pure Chemical Reagents	10% strength change over 7 days
7.	Environmental Stress Crack Resistance		1500 hrs.
8.	Dimensional Stability		$\pm$ 2%
9.	Seam Strength		80% or more (of tensile strength)

17.7.2.2 Design Aspects

The following components have to be designed/checked for in the case of geomembranes:

(a) anchor trench

(b) sliding along slopes

(c) allowable weight of vehicle

(d) uneven settlement

(e) panel layout plan.

Design details are provided by Bagchi (1994).

17.7.2.3 Construction/Installation of Geomembranes

Although the construction activities for geomembrane installation are not as time consuming as clay liner construction, the quality control tests are intensive. The surface of compacted clay/amended soil must be properly prepared for installation of synthetic membrane. The surface must not contain any particles greater than 1.25 cm (0.5 in.) size. Larger particles may cause protuberance in the liner. The panel layout plan should be made in advance so that travel of heavy equipment on the liner can be avoided. In no case should it be allowed on the liner. Seaming of panels within 1.0 m of the leachate collection line location should be avoided if possible; this issue can be finalized during the layout plan. The subbase must be checked for footprints or similar depressions before laying the liner. The crew should be instructed to carry only the necessary tools and not to wear any heavy boots (tennis shoes are preferred). Laying of the synthetic membrane should be avoided during high winds [24 kmph or more]. Seaming should be done within the temperature range specified by the manufacturer.

Several types of seaming methods are available. The following are some of the commonly used seaming techniques: thermal-hot air, hot wedge fusion, extrusion welding (fillet or lap), and solvent adhesive. The manufacturer usually specifies the types of seaming to be used and in most cases provides the seaming machine. Manufacturer's specifications and guidelines for seaming must be followed. Seaming is more of an art even with the automatic machines. Only persons who are conversant with the machine and have some actual experience should be allowed to seam. For HDPE, hot wedge fusion and extrusion welding type seaming are commonly practised.

Geomembranes must be covered with protective soil as soon as possible. Enough volume of soil should be stockpiled near the site so that it can be spread on the finished membrane as soon as the quality control test results are available and the final inspection is over. Synthetic membranes can be damaged by hoofed animals. Bare membrane should be guarded against such damage by fencing the area or by other appropriate methods.

At least 30 cm of fine sand or silt or similar soil should be spread on the membrane as a protective layer. The soil should be screened to ensure that the maximum particle size is 1.25 cm or less. The traffic routing plan must be carefully made so that the vehicle(s) does not travel on the membrane directly. Soil should be pushed gently by a light dozer to make a path. Dumping of soil on the membrane should be avoided as much as possible. One or two main routes with extra thickness of soil (60-90 cm) should be created for use by heavier equipment for the purposes of soil moving. Even the utmost precaution and quality control during installation will be meaningless if proper care is not taken when covering the membrane. Slow and careful operations are the key to satisfactory soil spreading.

The geomembrane bid specification should include warranty coverage for transportation installation and quality control tests. The cost of a project may increase due to the warranty. The experience of the company (both in manufacturing and installation), quality control during manufacturing and installation, physical installation should be asked in the bid so proper comparisons among different bidders can be made.

17.7.2.4 Quality Control Before and During Geomembrane Installation

Tests of several physical properties of the membrane must be performed before installation. Usually most of these tests are performed at the time of manufacturing in the manufacturer's laboratory. The owner may arrange for an independent observer to oversee the tests, conduct the tests in an independent laboratory, or use a "split sampling" technique. This issue of responsibility for preinstallation quality control tests must be clearly mentioned or resolved during the biding process. The following are tests used for quality control purposes: (a) sheet thickness, (b) melt index, (c) percentage carbon black, (d) puncture resistance, (e) tear resistance, (f) dimensional stability, (g) density, (h) low-temperature brittleness, (i) peel adhesion, and (j) bonded seam strength.

The quality control tests that are performed during installation include the following:

(a) Inspection of surface of compacted clay/amended soil layer.

(b) Verification of the proposed layout plan.

(c) Check roll overlap.

(d) Checking anchoring trench and sump.

(e) Testing of all factory and field seams using proper techniques over full length.

(f) Destructive seam strength test.

(g) Patch up repair.

17.7.3 Drainage Blanket

A drainage larger is constructed over the protective soil layer placed on a geomembrane. It must have permeability greater than 10^{-2} cm/sec. The 0.074 mm or less fraction content of the drainage blanket material should not be more than 5%. A clean coarse sand is the preferred material for the drainage blanket, however, gravel may also be used for this purpose. When a layer of gravel is used as a drainage blanket; the fines from the waste may migrate and clog the blanket. A filtering medium design approach may be used in designing a graded filter over a gravel drainage blanket.

The quality control tests include tests for grain size analysis and permeability. Usually one grain size analysis for each 1000 cu.m and one permeability test for each 2000 cu.m of material used is sufficient. For smaller volumes a minimum of four samples should be tested for each of the above properties. The permeability of the material should be tested at 90% relative density.

Sand blanket will be placed in leachate collection trenches as specified by the designer of leachate collection pipes.

17.8 CONSTRUCTION AND OPERATIONAL PRACTICE

The construction and operation of a landfill consists of the following steps:

(a) Site Development

(b) Phase Development

(c) Phase Operation

(d) Phase Closure

(e) Landfill Closure

17.8.1 Site Development

The following construction activities are undertaken during site development:

(a) Construction of perimeter fence and entrance gate

(b) Construction of main access road near the entrance gate with parking area

(c) Construction of main access road along the perimeter of the site and well as construction of arterial load to tipping area of the first phase

(d) Acquisition and installation of weighbridges

(e) Construction of weighbridge room/office; administrative office and site control office

(f) Construction of waste inspection facility, equipment workshop and garage, vehicle cleaning area

(g) Installation of direction signs, site lighting, fire fighting facilities, communication facilities

(h) Construction of water supply and waste water/sewage disposal system

(i) Construction of surface water drainage system

(j) Construction of main leachate pipe, tank and treatment facility

(k) Installation of environmental monitoring facilities

(l) Construction of gas collection pipe and treatment facility.

17.8.2 Site Procedures

It is important to formalise and document the record keeping procedures as well as waste acceptance procedures to be followed at the landfill site.

17.8.2.1 Record Keeping

Records will be kept on a daily, weekly and monthly basis. In addition a Site Manual will be kept at the site office giving all site investigation, design and construction details – these are necessary as landfill design may get modified during the operational phase.

Site Manual: The site manual will contain the following information:

(a) Data collected during site selection

(b) Environmental impact assessment report

(c) Site investigation and characterisation data

(d) Detailed topographical map

(e) Design of all landfill components

(f) Landfill layout and its phases

(g) Construction Plans

(h) Details of Leachate Management Plan

(i) Details of Gas Management Plan

(j) Environmental Monitoring Program

(k) Closure and Post-Closure Plan

(l) All permissions/licences from concerned authorities.

Site Reports: The daily, weekly and monthly reports will comprise of the following:

(a) Weighbridge data (daily inflow and outflow for each vehicle)

(b) Waste inspection data (daily)

(c) Materials, stores etc. (daily)

(d) Bills/accounts (daily)

(e) Visitor record (daily)

(f) Complaints record from nearby areas (daily)

(g) Topographic survey at operating phase (daily/weekly)

(h) Photographic record at operating phase (daily/weekly)

(i) Environmental monitoring data (weekly/monthly)

(j) Wastefilling plan and actual progress i.e. cell construction (daily/weekly) and review (monthly)

(k) Leachate generation and gas generation (weekly/monthly/extreme events)

(l) Weather/climatic data (extreme events)

(m) Accidents etc. (adhoc)

(n) Others

17.8.2.2 Waste Inspection Procedure

Each vehicle carrying the waste must be checked for:

(a) Incoming weight (full)

(b) Outgoing weight (empty)

(c) Availability of relevant documents

(d) Visual check at weigh-in (if feasible)

(e) Visual inspection after discharge at tipping area (inspection report to be filed for each vehicle). A visual inspection checklist must be framed which should list visual features for identification of unacceptable material. This checklist must be filled for every unloading by a vehicle in tipping area at the working phase in the landfill.

If there is reason to doubt the presence of unacceptable waste, the vehicle will be taken to the waste inspection facility, the waste down-loaded, inspected visually and sampled (if necessary). Vehicles having non-conforming waste will be held-up and matter reported to engineer or manager at site.

17.8.3 Phase Development

Development of each phase is done is stages. These stages are:

(a) Clearing the area of all shrubs and vegetation,

(b) Excavation (if required),

(c) Stockpiling of excavated material and material imported from borrow area,

(d) Levelling of base and side slopes of landfill and achieving desirable grades at the base of the landfill,

(e) Construction of embankment and temporary terms along the perimeter of the phase,

(f) Construction of temporary surface water drains,

(g) Installation of monitoring instruments,

(h) Liner construction,

(i) Leachate collection and removal system.

17.8.4 Phase Operation

At the design stage the phases of a landfill are clearly demarcated. Operation of a phase requires planning and execution of daily activities – daily waste filling plan and demarcation, waste discharge and inspection, waste placement, waste compaction, daily covering of waste, prevention of pollution and fires.

17.8.4.1 Daily Waste Filling Plan and Demarcation at Site

On the completion of a phase and before the start of a new phase, a waste filling plan for daily cells must be evolved (Fig. 17.32). A study of the landfill base contour maps and the final cover levels of the phase allows such a plan to be developed. If a phase is to be operational for 365 days, all 365 cells must be marked in plan and in sectional drawings. These may require revision as a landfill is constructed because waste quantities may vary in an unforeseen manner.

The area and height proposed to be filled every day should be demarcated at the site on a daily or weekly basis using temporary markers or bunds.

17.8.4.2 Waste Discharge and Inspection

Waste must be discharged by tipping at the working area of a landfill, within the area demarcated for the cell. Every discharged load should be visually inspected by a designated operator. Working area personnel should be trained and competent at waste identification in order that they can recognise waste which may be non-conforming. In the event of reasonable doubt as to the waste acceptability, the operator should inform the waste reception facility and/or the site manager immediately and the consignment should be isolated pending further inspection.

17.8.4.3 Waste Placement (Spreading)

Once waste has been discharged it must be spread in layers and compacted in a well defined manner to ensure that the completed slopes of a daily cell are at the designed gradients.

Waste placement (spreading) can be done by the following methods (Fig. 17.33):

(a) Face tipping method: Waste is deposited on top of existing surface and spread horizontally by tipping over an advancing face.

(b) Inclined layering method (onion skin tipping): Similar to (a) but inclined layering (gentle slope) done instead of advancing of face.

(c) Working upwards: Waste is deposited on the lower surface and pushed upwards.

17.8.4.4 Waste Compaction

It has become conventional practice to level and compact the waste as soon as it is discharged at the working area. Steel wheeled mobile landfill compactors (cleated/spiked/ special wheels) are generally accepted as the best equipment for this purpose. They have largely replaced the small crawler-tracked machines which previously were in general use. These steel wheel compactors have been developed specifically for landfill operations with different patterns of cleated wheels designed to break up and compact waste. For small sites receiving low volumes of waste, a compactor alone may be adequate to spread and compact the waste as well as handle and place cover material. However, a compactor is not designed to be a multi-purpose machine and at busy sites it is more usual to provide a tracked dozer or wheeled bucket loader for spreading followed by a compactor for densification. Compactors help to (a) chop and homogenise the waste; (b) reduce the void fraction of the waste; (c) produce an even and stable surface; and (d) pin down waste to minimise litter and make the site less attractive to birds and vermin.

Landfill compactors are not manufactured in India. However, they are available overseas in a wide range of sizes and operating weights (typically ranging from 12 tons to 30 tons). Apart from size, the differences between machines are the cleat patterns on the wheels and the wheel configuration. The wheel configuration is relevant when determining the number of passes required to achieve the desired amount of compaction.

17.8.4.5 Daily Cover

The advantages of using daily cover are primarily in preventing windblown litter and odours, deterrence to scavengers, birds and vermin and in improving the site's visual appearance. It is also advocated as a means of shedding surface water during the filling sequence, thereby assisting in leachate management by reducing infiltration, although its effectiveness in this respect is doubtful.

It is important that site location and waste inputs are taken into account when considering the type and application of daily cover. Soils used as daily cover will give a pleasing uniform appearance from the site boundary. To achieve this a thickness of about 150 mm is usually adequate and should be adopted. About 300 m.m. needs to be used to avoid paper, etc being seen from close proximity. This is excessive for other purposes and the visibility of waste through daily cover should not be regarded as the sole criterion of effectiveness.

At sites where daily covered is spread by machines such as dozers etc., a thickness less than 150 mm will not be feasible, keeping in view the uneven surface of the waste. At sites where daily cover is spread manually, a thickness of 100 mm can be attempted if soil is used; this thickness should not be less than 150 mm if construction debris is used.

Cover material takes up valuable void space for primary wastes and if a 150 mm deep layer is placed over every 2 m layer of waste, about 7.5% of the void space is lost. The covering of faces and flanks will cause even more less of void space and most operators estimate that the total loss of void space is between 10% and 20%.

If compacted, daily cover can have a relatively low permeability which results in the partial containment of each layer of waste. As a result leachate becomes perched and difficult to extract. Landfill gas then moves preferentially sideways giving greater potential for migration off-site and both gas and leachate become difficult to extract. Hence daily cover way not be compacted by rollers.

Traditionally soil material has been used for daily cover. Whenever possible daily cover is obtained by planned excavation from within the landfill area and thereby causes no net consumption of space. This will optimise the commercial value of the waste accepted. Where a site is deficient in appropriate resources, daily cover may come through the gate from construction activities. Construction waste is now also used to form screening bunds and for landscaping at the construction site.

Results so far have failed to identify any single material which can be used as a simple substitute for soil materials and all of them have given rise to secondary problems.

17.8.4.6 Pollution Prevention During Operation

Measures are needed to ensure that the landfill operation does not adversely affect local environment within and outside the landfill. Operators may appoint community liaison officers to be available to visit complainants and establish the nature and source of the problem. This is reported to the site manager so that corrective measures can be taken.

Traffic: Heavy lorry traffic can give rise to nuisance, damage to road surface and verges and routing problems. The following guidelines are helpful:

(a) routing to avoid residential areas

(b) using one-way routes to avoid traffic conflict in narrow roads

(c) carrying out road improvements, for example strengthening or widening roads, improved provision of footpaths, improvement of sight lines, provision of passing places, provision of new roads

(d) Limiting the number of vehicle movements

(e) Restrictions on traffic movement hours which are staggered with respect to peak traffic hours.

Noise: Adverse impacts on the local community from noise may arise from a number of sources including - throughput of vehicles and fixed and mobile plant, for example compactors, generators at the site. Peripheral noise abatement site measures should be adopted.

Odour: Offensive odours at landfill sites may emanate from a number of sources, including waste materials, which have decomposed significantly prior to landfilling, leachates and leachate treatment systems, and landfill gas.

Good landfill practices will greatly reduce general site smell and reduce impact from odours which could lead to complaints from the local community, site users and site staff. Good practice includes: (a) adequate compaction; (b) speedy disposal and burial of malodorous wastes; (c) effective use of appropriate types of daily cover; (d) progressive capping and restoration; (e) effective landfill gas management; (f) effective leachate management and (g) consideration of prevailing wind direction when planning leachate treatment plants, gas flares, and direction of tipping.

Litter: Poor litter control both on and off site is particularly offensive to neighbours. Good operational practice should be adhered to in terms of waste discharge, placement, compaction and covering to minimise the occurrence of windblown litter. Measures for controlling litter include:

(a) consideration of prevailing wind direction and strength when planning the filling direction and sequence

(b) Strategically placed mobile screen close to the tipping area or on the nearest downwind crest

(c) Temporary banks and bunds immediately adjacent to the tipping area

(d) Permanent catch fences and netting to trap windblown litter

(e) Restricting incoming vehicles to only those which are sheeted and secured will reduce litter problems on the highways.

Litter pickers should be employed to collect litter which escapes the preventative measures. Litter screens, fences, nets and perimeter ditches should be maintained free of litter.

Bird Control: Birds are attracted to landfill sites in large numbers, particularly where sites receive appreciable amounts of food wastes. Usually only large birds such as eagles, gulls are regarded as a nuisance. Bird control techniques should be carefully planned taking into account the species likely to be affected. Measures which can be used to mitigate bird nuisance include the employment of good landfill practice, working in small active areas and progressive prompt covering of waste, together with the use of bird scaring techniques. Measures involving explosions or distress calls have inherently adverse environmental impacts in terms of noise.

Vermin and Other Pests: Landfills have potential to harbour flies and vermin, particularly where the waste contains food materials. Modern landfilling techniques including prompt emplacement, consolidation and covering of wastes in well defined cells are effective in the prevention of infestation by rodents and insects. Rats and flies are the main pests which require control. Sites with extensive non-operational land can become infested with rabbits.

Effective measures to deal with rodent infestation include regular visits by pest control contractors or fully trained operatives. The use of insecticides on exposed faces and flanks of the tipping area, by spraying and fogging, is an effective means of exterminating insects.

Dust: Dust from landfill operations is mainly a problem during periods of dry weather but can also arise from dusty waste as it is tipped. Dust is generally associated with (a) site preparation and restoration activities; (b) the disposal of waste comprising of fine particles, for example powders; and (c) traffic dust. Dust suppression can be effected by (a) limiting vehicle speed; (b) spraying roads with water; and (c) spraying site and powder type waste with water.

Mud on the Road: Mud on the public highway is one of the most common causes of public complaint. It is, therefore, in the interests of the landfill operator to provide adequate wheel cleaning facilities to ensure that mud is not carried off site by vehicles.

17.8.4.7 Landfill Fire Management

Fires in waste on landfill sites are not uncommon and it is important for site operators to be aware of the dangers, how to treat fires and to address the problems associated with them. All fires on-site should be treated as a potential emergency and dealt with accordingly.

All sites should have an emergency tipping area set aside from the immediate working area where incoming loads of material known to be on fire or suspected of being so can be deposited, inspected and dealt with.

Waste that is burning on delivery should be doused with water or more preferably covered progressively with adequate supplies of damp soil/cover followed by cooling and finally removal to its disposal point. It should not normally be allowed to burn itself out as this will give rise to nuisance from smoke and odour and may constitute a health risk. Fire fighting techniques should be appropriate for the waste type.

Fires within the operational area are either surface fires or deep-seated fires. The former usually occur in recently deposited and as yet uncompacted materials adjacent to the current working area, whilst the latter are found at depth in material deposited weeks or months earlier. Site operators should have a plan to deal with each type of fire and have a code of practice for their operators stating exactly how to tackle any outbreak. Regardless of the circumstances, no individual should ever tackle a landfill fire alone. Deep-seated fires require expensive remediation techniques including vertical cut-offs.

17.8.4.8 Landfill Safety Aspects

Training of employees should include site safety, first aid and the handling of dangerous materials where appropriate. Since landfill sites can pose dangers to both site operator and users, emergency plans should be laid down. Landfill sites should be regarded as potentially hazardous locations and the operator should have a written safety plan for the site.

Safety hazards present at landfill sites may include: (a) moving plant and vehicle; (b) steep slopes; (c) bodies of standing water; (d) contaminated, putrescible, toxic, flammable or infective material and (e) noxious, flammable, toxic or hazardous gas.

All employees and visitors to the site should be made aware of the potential hazards and the safety procedures to be implemented including fire safety.

17.8.5 Phase Closure

After the last set of cells of a phase are placed (on the highest lift), an intermediate or final cover is constructed. If another phase is to be placed over the just completed phase, an intermediate cover is provided. However if the just completed phase has reached the final height of the landfill, the final cover system and surface water drainage system is provided.

An intermediate cover is made of locally available soil (preferably low-permeability) and is 45 to 60 cm thick. It is compacted with smooth steel drum rollers and provided a suitable gradient (3 to 5%) to encourage surface water to run-off from the cover and thus minimise infiltration. The side slopes of the intermediate cover are compacted by the crawler tracked dozer moving up and down the slope.

Final cover construction and quality control issues are similar to those for liner construction and therefore will not be discussed here. The layer below the low-permeability layer, referred to as the grading layer or gas venting layer, should be constructed using poorly graded sand. A grain size analysis for every 400 cu.m of material used is recommended for quality control purposes. The layer should be compacted to above 75% relative density to provide a firm sub-base for the low-permeability layer above. The density should be tested at 30 m grid points.

Laying of the topsoil layer should be done as soon as the protective layer construction is finished. Heavy construction equipment should not be allowed on the finished surface. The nutrient and liming requirements for the topsoil should be assessed from a competent agricultural laboratory. In the absence of a regulatory recommendation/requirement regarding seed mix, a horticulturist or soil scientist should be consulted. A combination of grass and bush type vegetation capable of surviving without irrigation water should be planted (see section 17.9.1). At least five samples of topsoil per hectare (2.4 acres) should be tested for nutrient and liming requirements. Nutrient and seed mix application rates should be supervised on site for quality control purpose. For landfill cover is which gas events are provided extreme are exercised in installation of the vents.

The final cover is provided a gradient of 3 to 5 percent to assist surface run-off. Lined ditches or channels are constructed on the final cover to intercept and carry surface water off the cover to the storm water basin.

On the cover of each phase, settlement devices are installed for monthly measurement of settlement of the landfill cover. This helps in identifying the quantity of soil required periodically for repair of the landfill cover.

17.8.6 Landfill Closure

As each phase is completed and as the final cover level is reached in successive phases, the following interconnectivities are established:

(a) the leachate collection system of each phase is sequentially connected (if so designed)

(b) the surface water drainage system at the cover of each phase is sequentially connected (if so designed)

(c) the temporary surface water drainage system constructed at the base of each completed phase is dismantled.

(d) the gas collection system (if provided) of each phase is sequentially connected.

Upon completion of all phases a final check is made of the proper functioning of all inter connected systems.

An access road is provided on the landfill cover to enable easy approach for routine inspection of the landfill cover.

17.9 POST-CLOSURE STABILISATION, OPERATION AND CARE

17.9.1 Long-Term Vegetative Stabilisation

If a landfill cover is intended to be used for a specific purpose e.g. park or golf course or vehicle parking area, then the cover will be stabilised in such a manner that the end-use is achieved.

However, if no specific end-use is envisaged, then long-term vegetative stabilisation will be undertaken to return the land to its original and natural vegetative landform.

Vegetation is by far the most common and usually the preferred stabilisation option after closure of landfills. If a self-perpetuating vegetative cover can be established, not only can wind and water erosion be minimized, but also the landfill can be returned to some semblance of its original appearance and land use. In favourable climates, re-vegetation may require only modest effort or may occur by natural process during a reasonably short period of time. However, in arid climates or a harsh environment, establishment of vegetation may be a lengthy, difficult and costly process.

Typically, vegetation efforts follow a series of steps. While the specific procedures are unique to each landfill and climatic regime, the following are usually representative elements of the process:

(a) **Seedbed Preparation**: Seedbed preparation is necessary to set the stage for establishment of the short-term community. Initial operations may include grading, furrowing, or grouping to enhance microclimate and addition of nutrients and soil amendments, if required.

(b) **Short-Term Vegetation**: It is common practice, in both humid and dry environments, to rely largely on grasses for the primary initial source of short-term land cover. Usually several species are included in the initial seeding mixture to increase diversity and reduce the chance of total community failure. Short-term vegetation is usually assisted by irrigation.

(c) **Long-Term Vegetation**: To achieved the ultimate goal of attaining a self-sustaining and stable community, a transition between short-term and long-term vegetation must occur. In some cases, this may be left to invasion by native species after short-term vegetation is assured and soil development is well under way. In other cases – for example, when irrigation has been used temporarily to establish the short-term community – it may be necessary or desirable to enhance the natural succession process by replanting with a more diverse mix of species suited to the next stage of community succession, such as shrubs. The need for artificial enhancement of the successional process will depend on the success of previous short-term efforts and on the ultimate intended land use of the reclaimed area. All vegetation efforts, however, should work toward self-generation and minimum management in the long term. Fig. 17.34 illustrates the sequential steps in vegetation growth after landfill closure.

Several factors limit the growth of plants on landfills. These include toxicity of landfill generated gases (methane and carbon dioxide) to root systems, low soil oxygen due to heavy compaction, thin cover layer inhibiting root penetration, low nutrient status of cover soil, high soil temperatures and poor soil structure. Some of these factors can be eliminated or their effect on plant growth reduced. Active gas extraction or proper use of gas barriers with venting system prevent gas migration to the root zone. Waste may be removed from certain areas to enable planting of islands of trees. By separating biodegradable waste from non-biodegradable, it may be possible to create zones free of toxic gases.

17.9.2 Operation after Closure

The following facilities will be operated routinely after closure:

(a) leachate management system;

(b) surface water management system;

(c) environmental monitoring system;

(d) cover rehabilitation and repair system.

The operating methodology will depend on the type of system adopted at the landfill.

17.9.3 Landfill Monitoring

The landfill monitoring programme will be designed and developed as indicated in section 17.6.19.

Quantitative parameter to be monitored will be: (a) leachate quantity; (b) gas quantity; (c) surface water run-off quantity and (d) cover system settlement quantities.

Qualitative parameters to be monitored will be:

(a) leachate quality within the landfill (at the base)

(b) leachate quality after treatment

(c) ground water quality (up gradient and down gradient)

(d) surface water quality at the exit of landfill

(e) gas quality within the landfill

(f) air quality above the landfill and at gas vents

(g) air quality at gas control facilities.

The regulatory limits for various parameters of quality will be prescribed by the regulatory authorities. The monitoring frequency will be as indicated in section 17.6.19.

17.9.4 Periodic Inspection and Maintenance

Periodic inspection and routine maintenance at a closed landfill site should be carried out for a period of 25 years after closure. The following components of a closed landfill are inspected visually after landfill closure to confirm that all functional elements are working satisfactorily. A maintenance schedule with specified reporting formats is drawn up after each inspection.

Cover System: The final cover is inspected 2 to 4 times a year (a) to check that vegetation growth is occurring satisfactorily and that plants are not showing stunted growth, (b) to detect if any erosion gullies have been formed thereby exposing the barrier layers, (c) to earmark depressions that may have developed with time and (d) to identify ponding of water on the landfill cover. At least one inspection should be carried out during or immediately after the peak of the monsoon season.

Closed landfills show significant settlement. Rectification measures must not only re-establish the initial slope of the cover (for proper surface water run-off) but must also ensure that all the components of the landfill cover system continue to perform as originally envisaged. Site managers must have sufficient equipment and funds to periodically carry out maintenance work in the form of soil filling, re-grading the cover and revegetating the landfill cap.

In areas where extensive erosion gully formation is observed, filling of cover material, regarding of cover slopes and revegetation must be routinely undertaken.

Surface Water Drainage System: The surface water drainage system is also inspected 2 to 4 times a year (a) to identify cracks in drains due to settlements, (b) to delineate clogged drains requiring immediate clean-up and (c) to study the level of deposited soil in the storm water basin and initiate excavation measures. Broken pipes and extensively cracked drains may require replacement after filling soil beneath them to establish slopes for gravity flow. In extreme cases where long-term settlement may be excessive, it may become necessary to make sumps and operate storm water pumps for removal of accumulated water in the drainage system.

Gas and Leachate Management Systems: Periodic inspection of the gas and leachate collection systems is undertaken to identify broken pipes, leaking gas (if any) and damaged or clogged wells/sumps. Repair work for gas and leachate management systems requires skilled manpower and should be carried out by the agencies operating the gas treatment and leachate treatment facilities. One may often have to install new gas extraction wells and leachate collection wells if the damaged/clogged facilities are inaccessible and irreparable.

Environmental Monitoring Systems: Ground water monitoring wells, air quality monitoring systems and vadose zone monitoring instruments are periodically inspected to check that all systems are functioning satisfactorily and that well caps and sampling ports are not subjected to damage due to excessive settlement or vandalism.

Environmental monitoring systems have to be maintained during the entire post-closure period as per the requirements of the local environmental regulatory agencies. Wherever possible, monitoring instruments must be periodically re-calibrated. Sampling devices must be routinely detoxified and also regularly checked for proper functioning of the opening and closing of valves or spring loaded mechanisms.

17.10 LANDFILL QUALITY ASSURANCE AND QUALITY CONTROL

Quality assurance should be applied at each stage of the landfilling process to ensure that:

(a) the landfill design is of a high standard

(b) effective mechanism are in place to ensure that construction and operation will not deviate from design

(c) documentation is carried out during design, construction, operation, closure, monitoring and post closures care for purposes of satisfying regulations and legal liability.

(d) public has access to and is assured about the acceptability of landfilling quality.

Quality control programmes should be drawn up for all construction and operation related activities and an independent engineer should oversee the implementation of these programme.

Advice may be taken from a Quality Assurance Agency for incorporation of quality control conditions in award of all contracts relating to siting, planning, design, construction, operation, monitoring and maintenance.

17.11 LANDFILLING COSTS

The total cost of landfilling can be broken into the following components:

(a) Initial Costs

- (i) site acquisition cost
- (ii) site selection and environmental impact assessment studies cost
- (iii) site investigation and characterisation costs
- (iv) design and detailed engineering costs (including laboratory studies)
- (v) site development (construction) costs (including infrastructure facilities and leachate/gas treatment facilities)
- (vi) landfill equipment costs (if purchased and not hired).

(b) Operative period-yearly costs (one year phase)

- (i) phase development costs (including liner and leachate collection system costs)
- (ii) phase operation costs
- (iii) phase closure costs
- (iv) interconnectivity of phases costs.

(c) Closure and Post Closure period-yearly costs

- (i) vegetative stabilisation costs
- (ii) operation costs
- (iii) monitoring costs
- (iv) maintenance and Repair costs.

Proper design of phases ensures that initial costs remain low and yearly expenditures remain of the some order of magnitude during operating period and thereafter during post closure periods. The preliminary estimation of landfill costs is indicated in Annexure 17.3.

On the basis of studies conducted at Indian Institute of Technology, Delhi (including the example in Annexure 17.3), it is observed that annual costs for setting up and operating MSW landfills (which have been designed and constructed as per guidelines in this chapter) lie in the range of Rs. 200 to 300 per ton of waste received at the landfill at 1998 prices (land acquisition cost excluded). These costs are similar to those reported for MSW landfills in developing countries in the report “International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management” compiled by UNEP International Environment Technology Centre, Osaka, Japan in 1998 where MSW landfilling costs are indicated to be between US$ 3-10 per ton for low income group countries and between US$ 8-15 per ton for middle income group countries.

17.12 MANPOWER REQUIREMENT

The organisational and administrative structure for municipal solid waste management in a city depends upon the size of the municipal agency. Landfilling activity should be the responsibility of an independent sectional authority which should report directly to the Director/Chief Engineer/Head of Solid Waste Management.

A senior engineer should be incharge of landfilling activity. He should be supported by assistant engineer(s), junior engineer(s), foremen, technicians and workers. The level of the engineer incharge will be dependant on the scale of work (i.e. waste received at the landfill and the following is recommended.

Waste Received at Landfill (tons/day)	Engineer Incharge of Landfilling
Upto 200	Junior Engineer
200 to 500	Assistant Engineer
500 to 1000	Executive Engineer
Above 1000	Superintending Engineer

The number of supporting officers and staff for the engineer incharge should be evaluated as per CPWD norms for earthwork projects of similar magnitude.

17.13 TYPICAL EXAMPLE (PRELIMINARY DESIGN)

A typical example (preliminary design) for MSW generation of 1000 tons per day is given in Annexure 17.2.

17.14 REMEDIATION OF OLD LANDFILL SITES

Old landfill sites will be investigated as indicated in paragraphs (e) and (f) of section 17.1.2. Whenever contamination is observed and is expected to continue, detailed site investigations for remediation will be undertaken and a feasibility study conducted for the choice of appropriate technology. Options such as provision of vertical cut of, impermeable covers, peripheral surface water drains, waste excavation, soil treatment, ground water treatment will be examined.