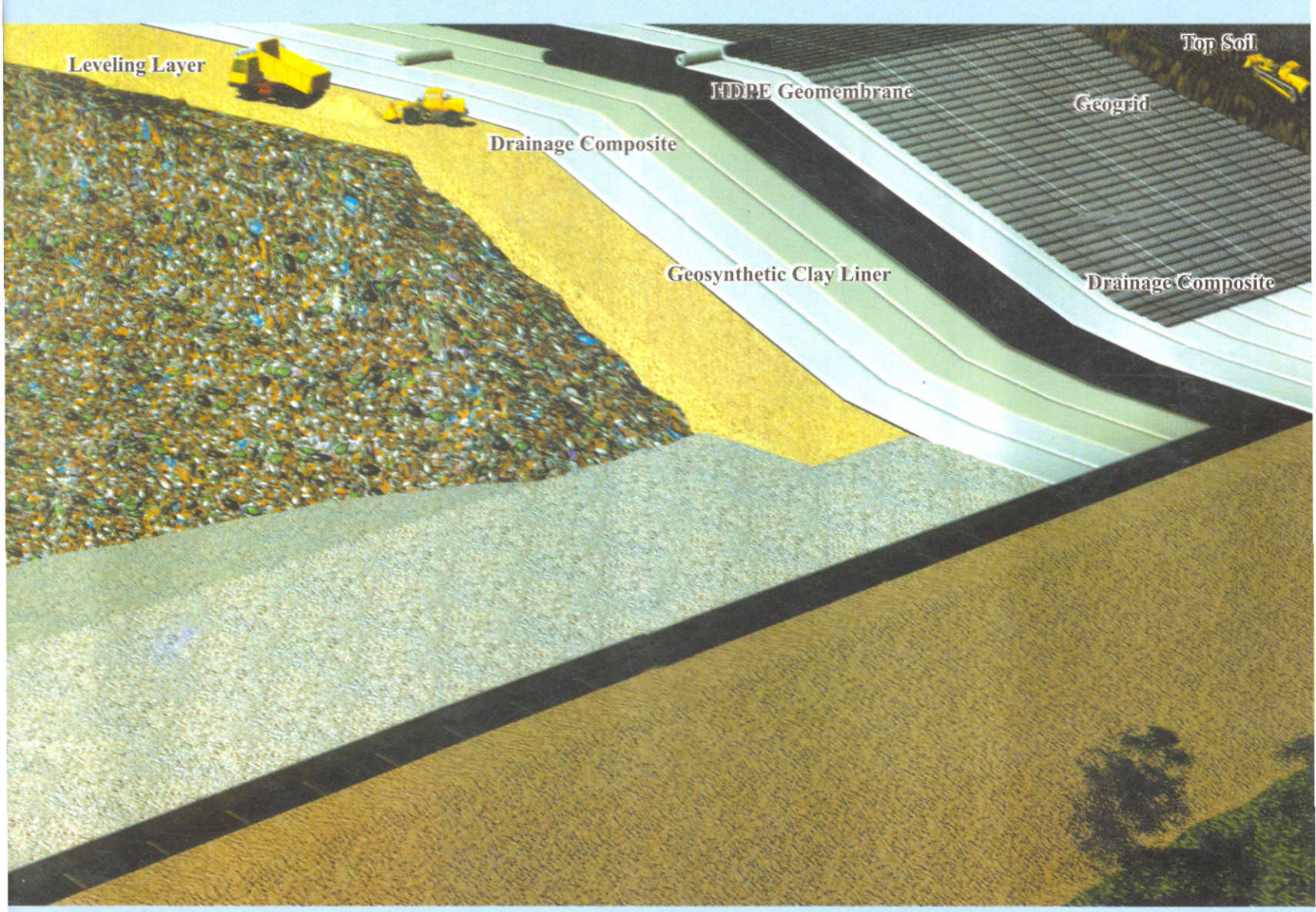
Hazardous Waste Management
Series : HAZWAMS/17/2000-01

CRITERIA FOR HAZARDOUS WASTE LANDFILLS



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CRITERIA FOR HAZARDOUS WASTE LANDFILLS

CENTRAL POLLUTION CONTROL BOARD
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FOREWORD

The Ministry of Environment & Forests, Government of India, has notified the Hazardous Waste (Management & Handling) Rules, in July 1989 under the Environment (Protection) Act, 1986. On 6th of January, 2000, major amendments to these rules with re-defined categories of hazardous wastes and harmonising them with the international laws, were notified. In order to facilitate implementation it is felt necessary to provide a set of guidelines on the Criteria for Hazardous Waste Landfills for the use of industries, implementing agencies and the general public.

The task of preparation of the guidelines was entrusted to a group comprising Prof. Manoj Datta, Indian Institute of Technology, New Delhi, Dr. D.B. Boralkar, Assistant Secretary, Central Pollution Control Board, Delhi and Ms. Sanchita Jindal, Joint Director (HSMD), Ministry of Environment & Forests, New Delhi. Useful criticism and suggestions were provided by National Productivity Council, New Delhi. The draft document was discussed and finalised by an Expert Committee under the Chairmanship of the Chairman, CPCB. The Expert Committee opined that secured disposal facilities need to be properly designed, constructed, commissioned and operated and that such facilities may not serve for the disposal of high-volume low-toxic waste. The present document provides guidance in respect of criteria for location, site selection and investigation, planning and design, waste acceptance, landfill liner system and cover, construction and operation, inspection, monitoring & record keeping, post-closure, financial assurance and contingency plan for emergencies.

This document on criteria for hazardous waste landfills has been brought out for use by implementing agencies, operators of landfills and others concerned.

(Dilip Biswas)

February, 2001

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CRITERIA FOR HAZARDOUS WASTE LANDFILLS

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CRITERIA FOR HAZARDOUS WASTE LANDFILLS

1.0. APPLICABILITY

The criteria stated hereafter apply to owners and operators of facilities that dispose hazardous waste in landfills. The term 'hazardous waste landfill' (HW Landfill) is used to designate a waste disposal unit. designed and constructed with the objective of minimum impact to the environment. This term encompasses other terms such as "secured landfill", "engineered landfill", "waste mounds", "waste piles" etc.

2.0. LOCATIONAL CRITERIA

HW Landfills shall not be located within a certain distance of the following : lakes, ponds, rivers, wetlands, flood plains, highways. habitation, critical habitat area, water supply wells, Airports, coastal zone. If it is absolutely essential to site a landfill within the restricted zone. then appropriate design measures are to be taken and prior permission from the SPCB/PCC should be obtained :

(a) Lake or Pond : No landfill shall normally be constructed within 200 m of any lake or pond. Because of concerns regarding runoff of waste contaminated water, a surface water monitoring network with approval of SPCB/PCC shall be established.

(b) River : No landfill shall be constructed within 100 m of a navigable river or stream.

(c) Flood Plain : No landfill shall 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 shall be constructed within 500 m of the right of way of any state or national highway.

(e) Habitation : A landfill site shall be atleast 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 shall be constructed within 500 m of a public park.

(g) Critical Habitat Area : No landfill shall be constructed within critical habitat areas including reserved forest areas. A critical habitat area is defined as the area in which one or more endangered species live. It is sometimes difficult to identify a critical habitat area. If there is any doubt then the SPCB/PCC shall be consulted for clarification.

(h) Wetlands : No landfill shall be constructed within wetlands. It is often difficult to identify 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 SPCB/PCC shall be consulted for clarification.

(i) Airports : No landfill shall be constructed within a zone around Airports as notified by the regulatory authority or the aviation authority.

(j) Water Supply Well : No landfill shall be constructed within 500 m of any water supply well.

(k) Coastal Regulation Zone : No landfill shall be sited in a coastal regulation zone.

(l) Ground water table level : No landfill shall be located in areas where the ground water table will be less than 2 m below the base of the landfill.

(m) Other criteria may be decided by the planners in consultation with SPCB/PCC commensurate with specific local requirements such as presence of monuments, religious structures etc.

3.0. SITE SELECTION

Hazardous waste landfills should preferably be located in areas of low population density, low alternative land use value, low ground water contamination potential and at sites having high clay content in the subsoil.

A HW landfill will be selected following the guidelines published by MoEF The step by step procedure will be as follows :

(i) Earmarking a 'search area' taking into account the location of the waste generation units and a 'search radius' (typically 5 to 250 km). The search area will be so chosen that it minimises the number of HW landfills in any region or state.

(ii) Identification of a list of potential sites on the basis of:
(a) availability of land
(b) collection of preliminary data
(c) restrictions listed in the locational criteria (section 2.0).

(iii) Collection of preliminary data as follows :

(a) Topographic Maps : 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 may be procured from Indian Agricultural Research Institute.

(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. 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. 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 geological map. Such maps can be procured from Geological Survey of India.

(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.

(m) 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.

(n) 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.

(iv) Selection of two best ranked sites from amongst the list of potential sites on the basis of the ranking system stipulated by MoEF (1991).

(v) Environmental Impact Assessment for the two sites for the following parameters :

(a) ground water quality; (b) surface water quality; (c) air quality - gases, dust, litter, odour; (d) land use alteration; (e) drainage alteration; (f) soil erosion; (g) ecological

impacts (h) noise; (i) aesthetics - visual, vermin, flies; (j) traffic alteration; and (k) others.

(vi) Assessment of public perception for the two sites.

(vii) Selection of final site.

(viii) The above site selection procedure shall not be applicable for location of facility within industrial areas of State Industrial Development Agencies. However EIA requirement will apply.

4.0. SITE INVESTIGATION CRITERIA

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 in Section 3.0 (iii) on "preliminary data" be collected for site characterisation. If some data has not be collected, the same should be obtained before site investigations are undertaken for site characterisation. The following additional data will be collected through a detailed site investigation programme at the chosen site.

A detailed site investigation programme will comprise of subsoil investigation, ground water/hydrogeological investigation, hydrological investigation, topographical investigation and geological investigation. The output expected from each investigation is listed below :

(a) Subsoil Investigation : A detailed investigation plan may be drawn up in consultation with a geotechnical engineer. The output from such an investigation should yield the following :

(i) Stratification of subsoil - type of soil and depth

(ii) Depth to ground water table and bedrock (if located within 15m of base of landfill)

(iii) Permeability of various strata beneath the landfill.

(iv) Strength and compressibility properties of subsoil

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

(vi) Subsoil properties along approach road.

A minimum of 3 boreholes per hectare of landfill area upto 15m beneath the base of the landfill shall be drilled and insitu tests as well as laboratory tests shall be performed for permeability, strength, compressibility and classification of soils. In addition, test pits and boreholes should be drilled at borrow area for liner and cover materials as well as along approach road.

(b) Ground Water / Hydrogeological Investigation : A detailed investigation plan may be drawn up in consultation with a ground water specialist or a hydrogeologist. The output from such an investigation should yield the following :

(i) Depth to groundwater table and its seasonal variations.

(ii) Ground water flow direction

(iii) Baseline ground water quality parameters - all drinking water quality parameters.

(c) 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 qauntities precisely. A map of 0.3m contour interval is considered desirable.

(d) 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 shall 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.

(e) Geological Investigation and Seismic Investigation : Geological investigations shall 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) in seismically active areas.

5.0. PLANNING AND DESIGN CRITERIA

5.1. Essential Components :

A HW landfill shall have the following seven essential components :

(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 treatment facility, which collects and extracts leachate from within and from the base of the landfill and then treats the leachate to meet standards, notified under E(P)Act 1986.

(c) A gas collection and treatment facility (optional) 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 infiltration of 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 (optional) 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.

5.2. Design life

A landfill design life will comprise of an 'active' period and an 'closure and post-closure' period. The 'active' period shall comprise of the period for which waste filing is in progress at the landfill and typically range from 10 to 25 years depending on the availability of land area. The 'closure and post-closure' period for which a landfill will be monitored and maintained shall be 30 years after the 'active period' is completed.

5.3. Waste Volume, Waste Compatibility 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 waste per annum and (b) the anticipated increase in rate of waste generation on the basis of past records.

A landfill will comprise of separate 'units'. In each unit, only compatible wastes will be disposed. Table 1 gives guidelines regarding compatibility of wastes. Incompatible wastes will be stored in separate units.

The actual capacity of each landfill unit will be computed taking into account the volume occupied by the liner system and the cover material [daily/weekily (optional) 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 (if any) shall also be taken into account.

The total landfill area should be computed on the basis of the designed height of the landfill (usually between 5 to 20m). Approximately 15 to 20% area more than the area required for landfilling should be adopted to accommodate all infrastructure and support facilities as well as to allow the formation of a green belt around the landfill. This additional area shall be computed separately and may be as high as 30% of the total area in case of small to medium landfills. The total landfill area is computed on trial and error basis.

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 areas
Large size landfill	:	greater than 20 hectare area.

5.4. 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. The area in which waste is to be filled may comprise of separate landfill units with each unit, accommodating a group of compatible wastes. Within each unit work may proceed in phases with only a part of the area under active operation. A typical site layout is shown in Fig.1. Such a layout must be prepared for all landfills. 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 facility (if used); (f) temporary waste storage and/or disposal sites for special wastes; (g) demarcation of the landfill areas and areas for stockpiling cover material and liner material; (h) location of surface water drainage facilities; (i) location of landfill leachate management facilities; (j) location of gas management facilities (optional); (k) location of monitoring wells/environmental monitoring facilities, (l) fencing and green belt along the peripheral boundary and (m) emergency exit.

It is essential that for each landfill site, a layout be designed incorporating the above mentioned facilities.

5.5. 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; (b) below ground landfill; (c) slope landfills; (d) valley landfills (canyon landfills); and (e) a combination of the above. Fig.2 shows some typical landfill sections.

It is recommended that the landfill section be arrived at keeping in view the topography, depth to water table and availability of liner and cover material. Above ground landfills shall be preferred to below ground landfills, as leachate collection in the former is by gravity flow and does not require the use of pumps.

Slope landfills and valley landfills are normally adopted in hilly areas; above-ground landfills in flat undulating ground and below-ground landfills in low-lying areas, depressions or pits.

5.6. 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.

For each landfill unit, a phased operation plan will be drawn up.

The term 'phase' describes a sub-area of the landfill. A 'phase' consists of cells, lifts, daily/weekly (optional) or intermediate cover, liner and leachate collection facility, gas control facility (optional) and final cover over the sub-area (Fig.3).

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.4 shows a simplified sequence of phased operation.

A 'phase plan' shall be drawn up for the active life of the landfill as soon as the landfill layout and section are finalised. It must be ensured that each phase reaches the final cover/intermediate cover level at the end of its construction period and that it is capped before the onset of monsoons.

During the monsoon months the waste may stockpiled in a temporary holding areas (covered with roof). During this period and the landfill may be kept capped with the final cover/intermediate cover and landfilling operations suspended to reduce infiltration of rain water into the landfill. However, if the incoming waste quantity is too large for temporary stockpiling or the monsoon period lasts for a long period, special phases may have to be designed with high leachate handling capacity and special operating procedures adopted.

5.7. Estimation of Leachate 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. 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 quantity generated. Precipitation depends on geographical location.

Significant quantity of leachate is produced from the 'active' phases of a landfill under operation. The leachate quantity from those portions of a landfill which have received a final cover is minimal. Fig. 5 shows the components of a water balance approach for estimating leachate quantity.

For design, computer simulated models (e.g. HELP) have to be used for estimation of leachate quantity generation. It is recommended that such studies be conducted to estimate the quantity of leachate and design the leachate drainage, collection and removal facility.

5.8. 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 side of the landfill and removal of the leachate from within the landfill.

On a basis of review of liner systems adopted in different countries and in consideration with Indian conditions, it is recommended that for all HW landfills the liner system criteria listed in Section 7.0 be adopted in consultation with SPCB/PCC and commensurate with local area specified needs.

5.9. Leachate Drainage, Collection and Removal

A leachate collection system shall be designed at the base of all landfills. It shall comprise of a drainage layer, a perforated pipe collection system, sump collection area, and a removal system.

The leachate collection layer (drainage layer) will usually be a 30 cm thick sand-gravel layer with a slope of 2% or higher and a permeability of greater than 10^{-2} cm/sec (10^{-4} m/sec). A system of perforated pipes and sumps is provided within the drainage layer. The pipe spacing will be governed by the requirement that the leachate head shall not be greater than the drainage layer thickness. Fig. 6 shows a typical layout of pipes and sumps.

Leachate will be removed from the landfill (Fig. 7) by (a) pumping in vertical wells or chimneys (b) pumping in side slope risers, or (c) by gravity drains through the base of a landfill in above-ground and sloped landfills. Side slope risers may be 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. The

leachate may be stored in a holding tank (for a few days) before being sent for treatment.

The design of following components should be undertaken :

(a) leachate pipe and leachate trench network

(b) leachate sumps and pumps

(c) leachate wells/side slope riser

(d) leachate holding tank

(e) backwashing/backflushing arrangement to prevent clogging/ choking/headloss.

The material used for pipes etc., should be such that it is not affected by the leachate quality.

5.10. Leachate Management

The following alternatives shall be considered for leachate management :

(a) Offsite treatment of leachate : This involves storage, pretreatment and transportation of leachate to off-site facilities not associated with the landfill e.g. industrial effluent treatment facility etc. This will be feasible where offsite facilities are available at a reasonable distance and where pretreatment requirements for the leachate (such as adjustment of pH, reduction in concentration etc.) are not very stringent. Transportation of leachate to offsite facility will be undertaken through a manifest system in accordance with HWM rules of MoEF.

(b) Onsite treatment of leachate : This involves complete treatment of the leachate at the landfill site to meet discharge standards for lined drains. Treatment processes may be biological, chemical or physical processes. Processes, which have been judged as having been "demonstrated", should be adopted.

(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. Leachate recirculation has been used in some municipal waste landfills. Information on its efficacy in HW landfills is scanty.

5.11. Gaseous Emissions Management

Landfill gas is generated as a product of waste biodegration or on account of presence of VOCs in the waste. Gas generation can be reduced or eliminated by avoiding disposal of biodegradable/organic wastes. For HW landfills where gaseous emissions are anticipated (as in the case of mixed waste having biodegradable components), the gas management strategy shall be (a) controlled passive venting or (b) controlled collection and treatment/reuse.

5.12. Final Cover System

A final landfill cover, comprising of several layers, each with a specific function shall be installed after each landfill phase reaches the full height. The final cover system shall enhance surface drainage, minimise infiltration, support vegetation to prevent erosion and control the release of landfill gases. On the basis of a review of HW landfill covers adopted in different countries [#] and in consideration with Indian Conditions the cover system criteria listed in Section 7.0 be adopted in consultation with SPCB/PCC and commensurate with local area specified needs.

5.13. 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 waterlogging/ponding on covers of landfills. A surface water drainage system comprising of channels, drains, culverts and basins (Fig.8) shall be designed to ensure the following :

(a) Rainwater running off slopes above and outside the landfill area shall 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 shall 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 and are not actively being used for waste disposal shall be diverted in drainage channels away 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 shall be able to accommodate settlement, resist erosion and cope with localised storm conditions.

(e) The horizontal surface of the final cover shall be provided a slope of 3 to 5% for proper surface water drainage. The slope of the cover on the sides will be higher and governed by slope stability considerations.

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

(g) It shall be ensured that water collected by surface water drainage system and leachate collected by the leachate collection system do not get intermixed at any stage of collection or storage. This shall apply to the 'active' and 'post closure' periods of the landfill.

The design of following components shall be undertaken :

(a) stormwater drains, diversion channel
(b) stormwater basin
(c) culverts

5.14. Base stability, Slope stability and Seismic Aspects

For landfills constructed on loose/soft soil, the base will be checked for stability against bearing failure or excessive settlements.

The stability of side slopes of a landfill shall be checked for the following cases (Fig. 9).

(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 shall 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 horizontal : 1 vertical)
(b) Temporary waste slopes	(3.0 horizontal : 1 vertical)
(c) Final cover slopes	(4.0 horizontal : 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 shall be conducted taking into account seismic coefficients as recommended by BIS codes.

5.15. Materials Balance

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

5.16. Site Infranstructure

The following site infrastructure shall be provided at each HW landfill :

(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.
(c) A properly landscaped entrance area with a green belt of 20m containing tree plantation for good visual impact.
(d) Proper direction signs and lighting at the entrance gate
(e) A perimeter fencing of atleast 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, hence good quality weighbridges shall be used. For sites receiving more than 400 tons per day of waste, 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 office should be elevated and the weighbridge operator should be able to see entering vehicles as well as speak to drivers.

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.

5.17. Environmental Monitoring System

Monitoring at a landfill site (Fig. 10) shall be 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 :

(a) long-term movements of the landfill cover;
(b) leachate head within the landfill;
(c) leachate quality within the landfill;
(d) gas quality (optional) within the landfill;
(e) quality of pore fluid in the vadose zone;
(f) quality of pore gas (optional) in the vadose zone;
(g) quality of groundwater in the saturated zones and
(h) 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 probable composition of leachate and gas likely to be generated and the geotechnical as well as hydro-geological features of the area.

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

The following instruments/equipment shall be used for monitoring :

(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 recomemended that the location of each type of instrument/equipment be finaised 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.11).

5.18. Closure and Post-Closure Maintenance Plan

A statement on the end-use of 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 parking area, recreational area etc. A closed landfill should be aesthetically landscaped.

A closure and post-closure plan for HW landfills must be evolved and should indicate the following components :

- Plan for vegetative stabilization of the final landfill cover and side slopes
- Plan for management of surface water run-off with an effective drainage system.
- Plan for periodical inspection and maintenance of landfill cover and facilities.
- Plan for post-closure management of leachate and gas
- Plan for post-closure environment monitoring.

6.0. WASTE ACCEPTANCE CRITERIA

A waste acceptance criterion shall be formulated for each landfill site. The following guidelines for waste acceptance are suggested :

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

(b) Bulk or non-containerised liquid hazardous waste or slurry-type hazardous waste containing free liquid or waste sludge, which has not been dewatered, shall not be placed in landfills. Such waste, (usually transported in pipelines) shall be placed in Hazardous Waste Impoundments designed specifically for liquid hazardous waste.

(c) Incinerable/compostable waste or any other type of waste from which energy/material recovery is feasible, shall not be placed in HW landfills.

(d) Incompatible wastes shall not be placed in the same landfill unit. Compatible wastes will be grouped together and placed in the same landfill unit (each such unit shall have its own phase, cells etc). Incompatible waste group shall be accommodated in separate landfill units (each such unit shall have its own phases, cells etc).

(e) Wastes which are incompatible with the liner material shall either be containerised and placed in the landfill (ensuring adequate container safety, or placed in a separate landfill unit made of alternate compatible liner material).

(f) Extremely hazardous waste (e.g. radioactive waste) shall not be disposed off in HW landfills but in specially designed waste disposal units.

(g) Non-hazardous waste (e.g. municipal solid waste) shall not be deposited in HW landfills. However such waste can be deposited in a MSW landfill units in the vicinity of HW landfills.

(h) Residue of treated biomedical waste (e.g. incinerator ash etc) can be deposited in HW landfills.

7.0. LANDFILL LINER AND COVER CRITERIA

7.1 Liner Criteria

The liner system shall be designed, constructed and installed to satisfy the following:

(a) Prevent migration of waste, leachate or gas to the adjacent subsurface soil or ground water or surface water.
(b) Constructed of materials that have adequate chemical properties, physical properties and engineering properties to prevent failure on account of loads, climatic conditions, and contact with waste or leachate.
(c) Placed in a stable manner on the base and side slopes.
(d) Installed to cover all surrounding soils likely to come in contact with the waste or leachate.

The base of the liner system (at the lowest point in a landfill) shall be atleast 2.0 meter above the highest anticipated ground water table level.

7.1.1. Minimum Specifications

The liner system shall be designed specifically for each site to meet the criteria stated in Section 7.1.

The liner system must include the following components. However, depending on the design requirements, the number of components as well as the specifications of the components can exceed the minimum specifications listed below. The components listed below are waste downwards (Fig. 12).

(a) A leachate collection layer of thickness 30 cm or more and coefficient of permeability in excess of 10^{-2} cm/sec (10^{-4} m/sec.).

(b) A single composite liner comprising of

  (i) A HDPE geomembrane of thickness 1.5 mm or more (see specification* below) and
  (ii) A compacted clay (or compacted amended soil) layer of thickness 150 cm or more having a coefficient of permeability of 10^{-7} cm/sec (10^{-9} m/sec) or less. At locations where availability of clay is limited, amended soil will be constituted by mixing bentonite or any other suitable clay to locally available soil to achieve the desired permability.

In regions where rainfall is high and/or subsoil is highly permeable (e.g. gravel, sand, silty sand) and/or the water table is within 2.0 m to 6.0 m beneath the base of the landfill, the liner system shall be a double composite liner and shall include the following components, waste downwards (Fig. 13) :

(a) A primary leachate collection layer of thickness 30 cm or more and coefficient of permeability in excess of 10^{-2} cm/sec (10^{-4} m/sec).

(b) A primary composite liner comprising of

  (i) A HDPE geomembrane of thickness 1.5 mm or more (see specification* below) and
  (ii) A compacted clay (or compacted amended soil) layer of thickness 45 cm or more having a coefficient of permeability of 10^{-7} cm/sec (10^{-9} m/sec) or less.

(c) A secondary leachate collection layer (also called leak detection layer) of thickness 30 cm or more and coefficient of permeability in excess of 10^{-3} cm/sec (10^{-5} m/sec).

(d) A secondary composite liner comprising of

(i) A HDPE geomembrane of thickness 1.5 mm or more (see specification* below) and
(ii) A compacted clay (or compacted amended soil) layer of thickness 45 cm or more having a coefficient of permeability of 10^{-7} cm/sec (10^{-9} m/sec) or less.

**Specification : [The geomembrane must have (a) Tensile Strength at yield > 18 kN/m, (b) Tensile Strength at break > 30 kN/m, (c) Tear Resistance > 150 N and (d) Puncture Resistance > 250 N].*

The liner materials listed above can be substituted by equivalent materials only if the following is satisfied :

(a) the liner system components continue to function as 'composite' liners; and
(b) the use of such components has been demonstrated over a 10 year period in different HW landfill and approved by a regulatory agency
(c) the design, construction and quality control specifications of such materials have been approved by a regulatory agency and are available for implementation.

For extremely hazardous waste, the number of composite liner layers shall, if necessary, exceed two and these will be finalised by the design engineer in consultation with SPCB/PCC as per site specific conditions.

7.1.2. Design Requirements

The liner system shall meet the following design requirements :

(a) Requirement of adequate stability at the base of the landfill (in soft soil)
(b) Requirement of adequate stability along the sides of the landfill
(c) Requirement of adequate strength to withstand construction loads/vehicle loads
(d) Requirement of permeability and material properties as specified in Section 7.1.1.
(e) Requirement of compatibility with leachate and waste
(f) Requirement of transition filters between waste and leachate collection layer to prevent clogging of the leachate collection layer.

(g) Requirement of protection layer/transition layer between each component of the liner system (A protection layer between a leachate collection layer and the HDPE geomembrane may sometimes be required if coarse/angular sand or gravel is used in the leachate collection layer. The protection layer may comprise of silt/local earth (15cm thick or a geotextile).

(h) Requirement of adequacy of clay additive in amended soils.

Guidelines for design are indicated in "Manual for Design, Construction & Quality Control of Liners & Covers" (to be prepared).

7.1.3. Construction Requirements

The liner system shall be constructed to ensure that :

(a) the compacted clay (or compacted amended soil) layer has a co-efficient of permeability of 10^{-7} cm/sec (10^{-9} m/sec) or less, is devoid of clods and shrinkage cracks; and achieves the desired strength.

(b) the geomembranes is laid in intimate contact with the compacted clay/compacted amended soil layer; is properly joined/welded at the seams; and is not punctured by construction vehicles/tools

(c) the leachate collection layer has a coefficient of permeability of 10^{-2} cm/sec (10^{-4} m/sec) or more and does not become clogged by intermixing or migration of fine particles.

On side slopes, the horizontal width of the 150 cm thick clay liner will normally exceed 300 cm and the clay can be compacted in horizontal layers using standard compaction equipment or in inclined layers using slope compactors.

Guidelines for construction are indicated in "Manual for Design, Construction & Quality Control of Liners & Covers" (to be prepared).

7.1.4. Quality Control

A quality assurance programme shall be drawn up by the owner/operator during construction of the liner system. Such a programme will include :

(a) Regular performance of quality assurance test in the field for each component of the liner system – one set of field and laboratory tests for each soil component per 500 to 1000 cubic meters of earthwork and one set of field and laboratory tests for the geomembrane per 200 sq.m. of installed area.

(b) Approval by the regulatory authority of the lists of tests, their frequency and the acceptance criteria.

(c) Periodical visits by representatives of the regulatory authority (or their nominee) during construction of the liner.

(d) Complete documentation of all quality control records and their submission to the SPCB/PCC alongwith statistical analysis showing satisfactory achievement of acceptance criteria.

The quality control tests for compacted clay layer (or amended soils) as well as the leachate collection/drainage layer shall include (i) in-situ density tests, (ii) in-situ moisture content tests, (iii) compaction tests, (iv) permeability tests, (iv) grain size distribution tests and (v) Atterberg's limits tests (vi) others.

The quality control tests for geomembrane liners shall include (i) thickness tests, (ii) density tests, (iii) strength tests, (iv) toughness tests, (v) durability tests, (vi) chemical resistance tests, (vii) field seam strength tests, (viii) overlap check tests, (ix) others.

Guidelines for quality control are indicated in "Manual for Design, Construction & Quality Control of Liners & Covers" (to be prepared).

7.2. Cover Criteria

The cover system shall be designed, constructed and installed to satisfy the following :

(a) Prevent infiltration of precipitation into the closed landfill.
(b) Promote drainage of surface water accumulated on the cover.
(c) Minimise erosion of the cover.
(d) Withstand or accommodate settlement of the cover to maintain its integrity
(e) Have a permeability less than or equal to the liner system
(f) Function with minimum maintenance for the post-closure period of 30 years.

7.2.1. Minimum Specifications

The cover system shall be designed specifically for each site to meet the criteria stated in Section 7.2.

The cover system must include the following components. However, depending on design requirements, the number of components as well as the specification of the components shall exceed the minimum specifications listed below. The components listed below are from top surface downwards to the waste (Fig. 14).

(a) A surface soil layer of local top soil which supports self-sustaining vegetation and which has a thickness not less than 60 cm.

(b) A drainage layer of thickness 30 cm or more having a coefficient of permeability in excess of 10^{-2} cm/sec (10^{-4} m/sec).

(c) A single composite barrier comprising of

(i) A HDPE geomembrane of thickness 1.5 mm or more and
(ii) A compacted clay (or compacted amended soil) layer of thickness 60 cm or more having a coefficient of permeability of 10^{-7} cm/sec (10^{-9} m/sec) or less. At locations where availability of clay is limited, amended soil will be constituted by mixing bentonite or any other suitable clay to locally available soil to achieve the desired permeability.

(d) A regulatory layer (optional) of thickness 30 cm having coefficient of permeability greater than 10^{-2} cm/sec (10^{-4} m/sec). Such a layer shall be provided whenever there is requirement of (i) gas collection or (ii) transition filter between waste and soil.

The drainage layer shall be replaced by the local top soil, if the coefficient of permeability of the local top soil is greater than 10^{-4} cm/sec. In such a case the total thickness of the surface soil layer (of top soil) will be 90 cm.

In dry arid regions, where self sustaining vegetation is not possible, special erosion control measures shall be adopted for the stability for the cover soil layer.

The cover materials listed above can be substituted by equivalent materials if the following is satisfied :

(a) the use of such components has been demonstrated over a 10 year period in different HW landfills and approved by aregulatory agency or SPCB/PCC.
(b) the design, construction and quality control specifications of such materials have been approved by a regulatory agency or SPCB/PCC and are available for implementation.

7.2.2. Design Requirements

The cover system shall meet the following design requirements:

(a) Requirement of stability/integrity of cover under settlement through design/maintenance/repair.
(b) Requirement of stability of steep side slopes of cover
(c) Requirement of establishment of self-sustaining vegetative cover for long-term stabilisation/or special measures in dry arid regions.
(d) Requirement of adequate strength to withstand construction loads/vehicle loads.
(e) Requirement of permeability and material properties as specified in Section 7.2.1.

(f) Requirement of surface water drainage as specified in Section 5.13.
(g) Requirement of transition filter between waste and the layer immediately above it.
(h) Requirement of protection layer/transition layer between each component of the liner system.

Guidelines for design are indicated in "Manual for Design, Construction & Quality Control of Liners & Covers" (to be prepared).

7.2.3. Construction Requirements

The cover system shall be constructed to ensure that

(a) the surface soil layer is adequately compacted and prepared to allow vegetative growth.
(b) the compacted clay/compacted amended soil layer has a coefficient of permeability of 10^{-7} cm/sec (10^{-9} m/sec) or less; is devoid of clods and shrinkage cracks; and achieves the desired strength.
(c) the geomembranes is laid in intimate contact with the compacted clay/compacted amended soil layer; is properly joined/welded at the seams; and is not punctured by construction vehicles/tools.
(d) the drainage layer has a coefficient of permeability of 10^{-2} cm/sec (10^{-4} m/sec) or more and does not become clogged by intermixing or migration of fine particles.
(e) the final cover slopes are as specified in section 5.13.

Guidelines for construction are indicated in "Manual for Design, Construction & Quality Control of Liners & Covers" (to be prepared).

7.2.4. Quality Control

A quality assurance programme shall be drawn up by the owner/operator during construction of the cover system. Such a programme shall include :

(a) Regular performance of quality assurance tests in the field for each component of the cover system – one set of field and laboratory tests for each soil component per 500 to 1000 cubic meters of earthwork and one set of field and laboratory tests for the geomembrane per 200 sq.m. of installed area.
(b) Approval by the regulatory authority of the lists of tests, their frequency and the acceptance criteria.
(c) Periodical visits by representative of SPCB/PCC (or their nominee) during construction of the cover
(d) Complete documentation of all quality control records and their submission to the SPCB/PCC alongwith statistical analysis showing satisfactory achievement of acceptance criteria.

The type of quality control tests for the drainage layers, compacted clay layer and geomembrane shall be the same as those indicated in Section 7.1.4. for the liner system.

Guidelines for quality control are indicated in "Manual for Design, Construction & Quality of Liners & Covers" (to be prepared).

8.0. Construction and operational criteria

The construction and operation of a landfill shall consist of the following steps :

(a) Site Development
(b) Phase Development
(c) Phase Operation
(d) Phase Closure
(e) Landfill Closure
(f) Post-closure vegetative stabilisation

8.1. Site Development

The following construction activities shall be undertaken during site development :

(a) Construction of perimeter fence, entrance gate, and green belt
(b) Construction of main access road near the entrance gate with parking area
(c) Construction of 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 (if needed)
(m) Construction of waste recovery/incineration/waste processing facility (if so planned)
(n) Construction of emergency exit gate.

8.2. Site Procedures : Record Keeping & Waste Inspection

Record keeping procedures as well as waste acceptance procedures to be followed at the landfill site shall be formulated.

Records shall be kept on a daily, weekly and monthly basis. In addition a site Manual shall 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.

(i) Site Manual : The site manual shall 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 (optional)
(j) Environmental monitoring program
(k) Closure and post-closure plan
(l) All permissions/licences from concerned authorities.

(ii) **Site Reports :** The daily, weekly and monthly reports shall 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.

(iii) Vehicle Inspection :

Each vehicle carrying the waste shall be checked for :

(a) Incoming weight (full)
(b) Outgoing weight (empty)
(c) Availability of relevant docuemnts
(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 shall 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 shall be taken to the waste inspection facility, the waste down-loaded, inspected visually and sampled (if necessary). Vehicles having non-conforming waste shall be held-up and matter reported to engineer or manger at site.

8.3. Phase Development

Development of each phase shall be done in 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 berms 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

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.

(a) **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 shall be evolved. A study of the landfill base contour maps

and the final cover levels of the phase allows such a plan to be devloped. 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.

(b) **Waste discharge and inspection :** Waste shall be discharged by tipping at the working area of a landfill, within the area demarcated for the cell. Every discharged load shall be visually inspected by a designated operator. Working area personnel shall 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 shall inform the waste reception facility and/or the site manager immediately and the consignment shall be isolated pending further inspection.

(c) **Waste placement (spreading) and compaction :** Once waste has been discharged it shall 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 :

(i) Face tipping method : Waste is deposited on top of existing surface and spread horizontally by tipping over an advancing face.
(ii) Inclined layering method (onion skin tipping) : Similar to (a) but inclined layering (gentle slope) done instead of advancing of face.
(iii) Working upwards : Waste is deposited on the lower surface and pushed upwards.

It is necessary to level and compact the waste as soon as it is discharged at the working area. Steel wheeled mobile landfill compactors (smooth / cleated / spiked / special wheels) are generally accepted as the best equipment for this purpose. They have largely replaced the small crawler-tracked machines which were previously in general use.

(d) **Daily / Weekly Cover :** Daily / Weekly cover (optional) is primarily used for prevention windblown dust, litter and odours, deterrence to scavengers, birds, reduction of infiltration (during unseasonal rian) and in improving the site's visual appearance. Soil used as daily / weekly cover shall give a pleasing uniform appearance from the site boundary. To achieve this a thickness of about 150 mm is usually adequate and shall be adopted.

(e) **Operation in Monsoons :** During the monsoon month, high rainfall results in excessive generation of leachate. Hence, before the onset of monsoons, the phase must be capped with a cover. Waste received

during monsoon months shall be stockpiled in temporary holding area (covered). Alternatively special "monsoon phases" may be designed with high leachate holding capacity and operated using daily covers / temporary covers.

8.5. Pollution Prevention and Safety During Operation

The following measures are needed to ensure that the landfill operation shall not adversely affect local environment within and outside the landfill.

(i) **Traffic :** Heavy lorry traffic shall give rise to nuisance, damage to road surface and verges and routing problems. The following measures are helpful :

(a) routing to avoid residential area
(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.

(ii) **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 shall be adopted.

(iii) **Odour :** Offensive odours at landfill sites may emanate from a number of sources, including waste material, which have decomposed significantly prior to landfilling, leachates and leachate treatment systems, and landfill gas. Good landfill practices shall 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.

(iv) **Litter :** Poor litter control both on and off site is particularly offensive to neighbours. Good operational practice shall be adhered to in terms of temporary fencing, waste discharge, placement, compaction and covering to minimise the occurrence of windblown litter.

(v) **Bird Control :** Birds are attracted to landfill sites in large numbers where sites receive appreciable amounts of bio wastes. Measures which can be used to mitigate birds 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.

(vi) **Vermin and Other Pests :** Landfills have potential to harbour flies, rodents and vermin, particularly where the waste contains bio materials. Modern landfilling techniques including prompt emplacement, compaction and covering of wastes in well defined cells are effective in the prevention of infestation by rodents and insects.

(vii) **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; (d) covering powder type waste with daily soil cover.

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

(ix) **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 shall be treated as a potential emergency and dealt with accordingly.

(x) **Landfill Safety Aspects :** Training of employees shall 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 shall be laid down. Landfill sites shall be regarded as potentially hazardous locations and the operator shall 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 shall be made aware of the potential hazards and the safety procedures to be implemented including fire safety.

8.6. Phase Closure

After the last set of cells of a phase are placed (on the highest lift), an intermediate or final cover shall be 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 shall be 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 all criteria are discussed in Section 7.0.

8.7. 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.

8.8. Post Closure Vegetative Stabilisation (Long Term)

If a landfill cover is intended to be used for a specific purpose e.g. park or vehicle parking area, then the cover shall 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, revegetation 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 difficult and costly process and alternative techniques may be examined for vegetative stabilisation.

While the specific procedures are unique to each landfill and climatic regime, the following representative elements of the process shall be adopted in all procedures.

(a) Seedbed Preparation : Seedbed preparation is necessary to set the stage for establishment of the short-term community. Initial operations shall 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 achieve 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 shall depend on the success of previous short term efforts and on the ultimate intended land use of the reclaimed area. All vegetation efforts, however, shall work toward self generation and minimum management in the long term. Fig. 15. illustrates the sequential steps in vegetation growth after landfill closure.

9.0. INSPECTION, MONITORING & RECORD KEEPING CRITERIA

9.1. During Construction of Liners and Covers

(a) During the construction of liners and covers, inspection shall be carried by the SPCB/PCC (or its nominee) atleast twice during each phase to ensure that construction procedures and quality control procedures isted in section 7.0 are being followed.

(b) Immediately upon the completion of construction of a liner in each phase, the complete set of construction records and quality control test results as listed in Section 7.0 will be provided by the

owner/operator to the SPCB/PCC for verification and record keeping. The same will also be done upon the completion of cover system in each phase.

9.2. During Operation

(a) The owner/operator shall monitor and keep a record of the following in the operation period :

(i) Functioning of the leachate management system (including levels in leachate holding tank) (weekly)

(ii) Functioning of the surface water run-off system (weekly)

(iii) Functioning of the gas management system (if any) (weekly)

(iv) Waste filling records shall be kept on daily basis as specified in Section 8.2 on site procedure

(v) Environmental monitoring shall be done, 1 to 2 times a month, and all parameters listed in Section 5.17 shall be recorded and compared with the permissible limits provided by the SPCB/PCC

(vi) After a major storm, the occurence of the storm and functioning of various systems shall be recorded.

(b) The SPCB/PCC (or its nominee) shall inspect all facilities atleast twice a year. The owner/operator shall provide a copy of the environmental monitoring record to the SPCB/PCC on a yearly basis.

9.3. During Closure and Post Closure Period

Period inspection and routine maintenance at a closed landfill site shall be carried out for a period of 30 years after closure. The SPCB/PCC shall inspect all facilities during the closure and post closure period atleast once a year. The owner/operator shall provide a copy of the environmental monitoring record to the SPCB/PCC once a year. The following components of a closed landfill shall be inspected visually after landfill closure to confirm that all functional elements are working satisfactorily and inspection report will be recorded. A maintenance schedule with specified reporting formats is drawn up after each inspection.

(a) 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. Atleast one inspection shall be carried out during or immediately after the peak of the monsoon season.

Closed landfills show significant settlement. Rectification measures shall not only re-establish the initial slope of the cover (for proper surface water run-off) but shall also ensure that all the components of the landfill cover system continue to perform as originally envisaged. Site managers shall 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, regrading of cover slopes and re-vegetation must be routinely undertaken.

(b) 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 shall be excessive, it shall become necessary to make sumps and operate storm water pumps for removal of accumulated water in the drainage system.

(c) Gas and Leachate Management Systems : A weekly operating record of leachate and gas management systems shall be kept in the post-closure period. Periodic inspection of the leachate and gas collection systems (2 to 4 times a year) is undertaken to identify broken pipes, leaking gas (if any) and damaged or clogged wells/sumps. Repair work requires skilled manpower and shall 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 irrepairable.

9.4. Environmental Monitoring Systems

Ground water monitoring wells, air quality monitoring systems and vadose zone monitoring instruments shall be periodically inspected 2-4 times a year 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. Wherever possible, monitoring instruments must be periodically re-calibrated. Sampling devices shall be routinely detoxified and also regularly checked for proper functioning of the opening and closing of valves or spring loaded mechanisms.

10.0. Post-Closure Criteria

(a) After closure of the landfill, the owner/operator of the landfill shall maintain the integrity of the final cover systems inclduing making repair, as necessary, to rectify the settlement, subsidence or erosion of the cover.

(b) After closure of the landfill, the owner/operator shall continue to operate all leachate, gas and surface water management systems as well as continue environmental monitoring of the landfill for a period of 30 years or until such time that harmful leachate is not produced for 5 continuous years.

(c) If after a few years of closure, the leachate is observed to meet all discharge standards, the same shall be discharged directly to lined drains.

(d) The landfill shall be abandoned after 30 years of closure, if concentrations of contaminants in all liquid and gaseous emissions from the landfill are observed to be below prescribed limits. However, if the emissions continue to be hazardous, the landfill management strategy shall have to be evolved for future years.

11.0. FINANCIAL ASSURANCE CRITERIA

The owner/operator shall prepare detailed financial estimates for the following :

(a) the fixed initial cost for setting up the landfill facility

(b) the recurring annual costs for operating the facilities

(c) the cost of hiring a third party to close the landfill

(d) the cost of hiring a third party to conduct post-closure care for 30 years after closure of the landfill

(e) the cost of hiring a third party to undertake corrective action in case of an emergency resulting in loss of ecology due to the failure of the system during the active, closure and post-closure periods.

The owner/operator shall demonstrate the funds needed for (c), (d) and (e) above will be available whenever they are needed in the form of options such as trust funds, surety bonds, letter of credit, insurance etc.

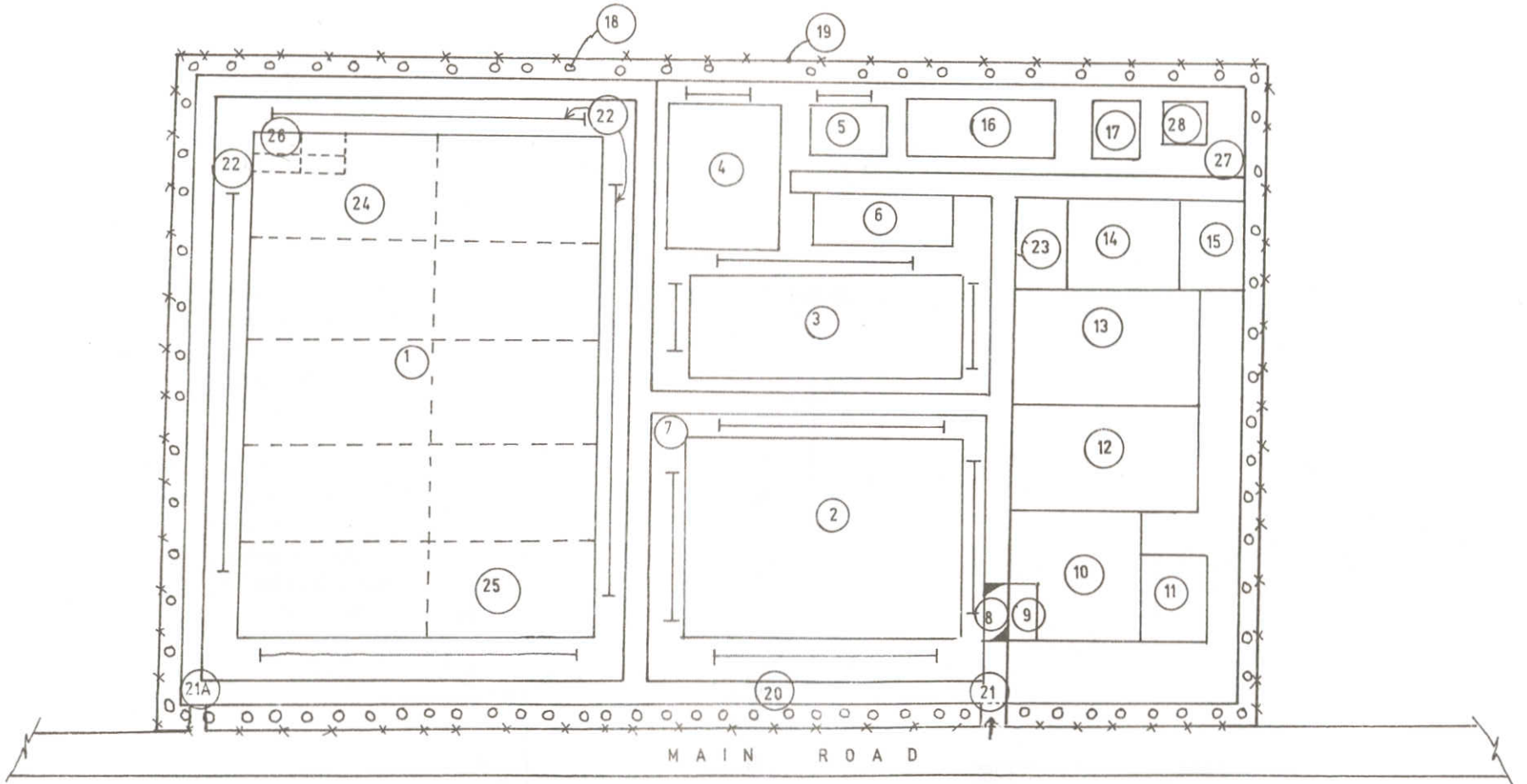
12.0. CONTINGENCY PLAN FOR EMERGENCIES

The owner/operator of a HW landfill shall prepare a contingency plan listing procedures to be executed immediately whenever there is fire, explosion or unexpected release of hazardous waste at the landfill site during the active period as well as during the closure and post-closure periods. Such a contingency plan shall be approved by the SPCB/PCC.

1	Oxidising Mineral Acids	1										
2	Caustics	H	2									
3	Aromatic Hydro-carbons	H_F		3								
4	Halogenated Organics	$H_{F\ GT}$	H_{GF}		4							
5	Metals	$GF_{H\ F}$			H_F	5						
6	Toxic Metals	S	S				6					
7	Sat Aliphatic Hydro-carbons	H_F						7				
8	Phenols and Cresols	H_F							8			
9	Strong Oxidising Agents		H	H_F		H_F		H		9		
10	Strong Reducing Agents	$H_{F\ GT}$			H_{GT}				GF_H	$H_{F\ E}$	10	
11	Water and Mixtures containing water	H			H_E		S				GF_{GT}	11
12	Water Reactive Substances ←			Extremely reactive, do not mix with any chemical or waste material →								12

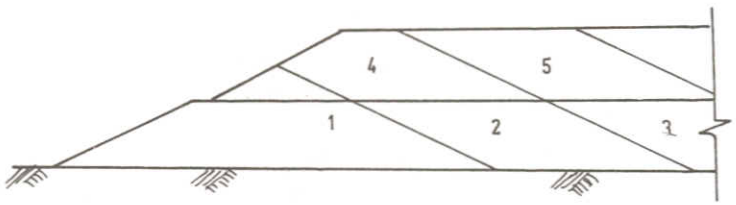
E Explosive
F Fire
GF Flammable Gas
GT Toxic Gas
H Heat Generation
S Solubilisation of Toxins

Table 1 : Compatibility of Selected Hazardous Wastes

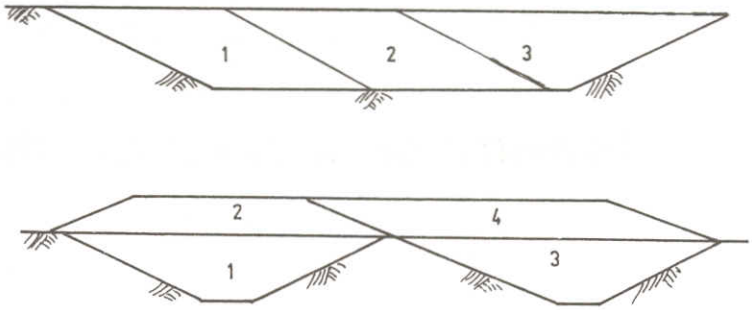


(1) Landfill Unit 1
(2) Landfill Unit 2
(3) Landfill Unit 3
(4) Landfill Unit 4
(5) Landfill for Special Hazardous Waste
(6) Area for Stockpiling Cover and Liner Material
(7) Mobile Site Office
(8) Weigh Bridge
(9) Reception/Security
(10) Administrative Office
(11) Environmental Laboratory
(12) Open Lorry/Tanker Parking Area
(13) Temporary Waste Storage Shed
(14) Equipment Shelter
(15) Workshop
(16) Landfill Leachate Management Facilities
(17) Storm-water Collection/Sedimentation Tank
(18) Green belt
(19) Fencing
(20) Approach Road/Arterial Roads
(21) Site Entrance
(21A) Emergency Exit
(22) Environmental Monitoring Facilities
(23) Vehicle Washing
(24) Phase (1) of Landfill Unit 1
(25) Phase (10) of Landfill Unit 1
(26) Cell (1) of Phase (1) of Landfill Unit 1
(27) Air Quality monitoring Station to be located at 120° from each other
(28) Space for Waste Recovery/Incineration/Waste Processing Facilities

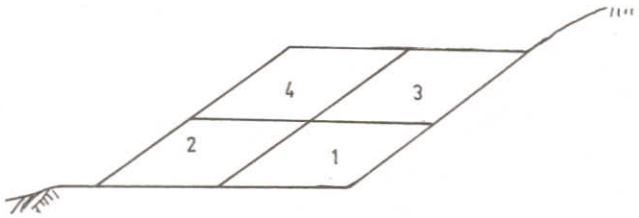
FIG. 1: TYPICAL LAYOUT OF HAZARDOUS WASTES LANDFILL



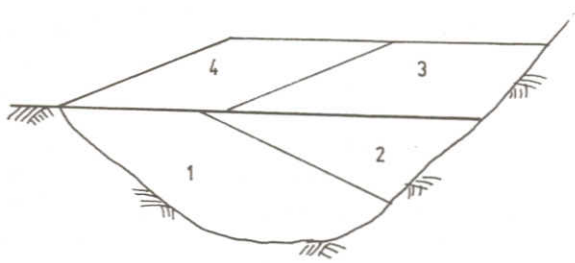
(a) Above ground landfill



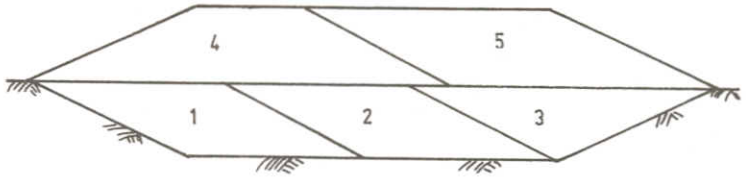
(b) Below ground and trench landfill



(c) Slope landfill



(d) Valley landfill



(e) Above and below ground landfill

FIG. 2: TYPICAL SECTION OF H W LANDFILLS

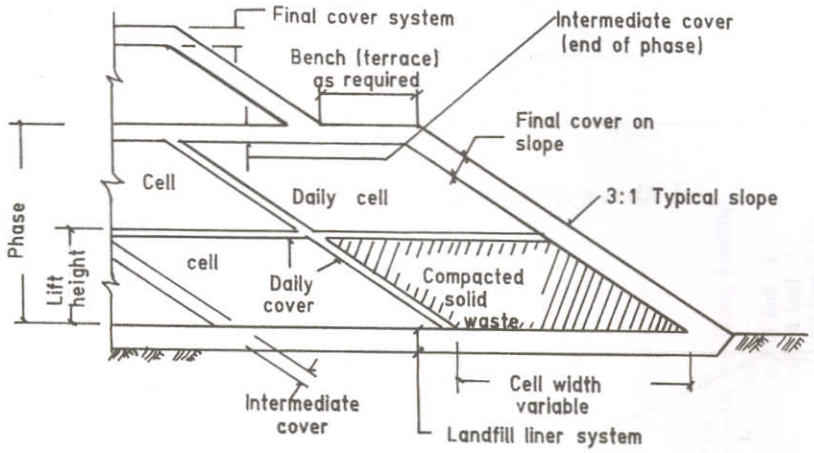


FIG. 3: COMPONENTS OF A LANDFILL PHASE

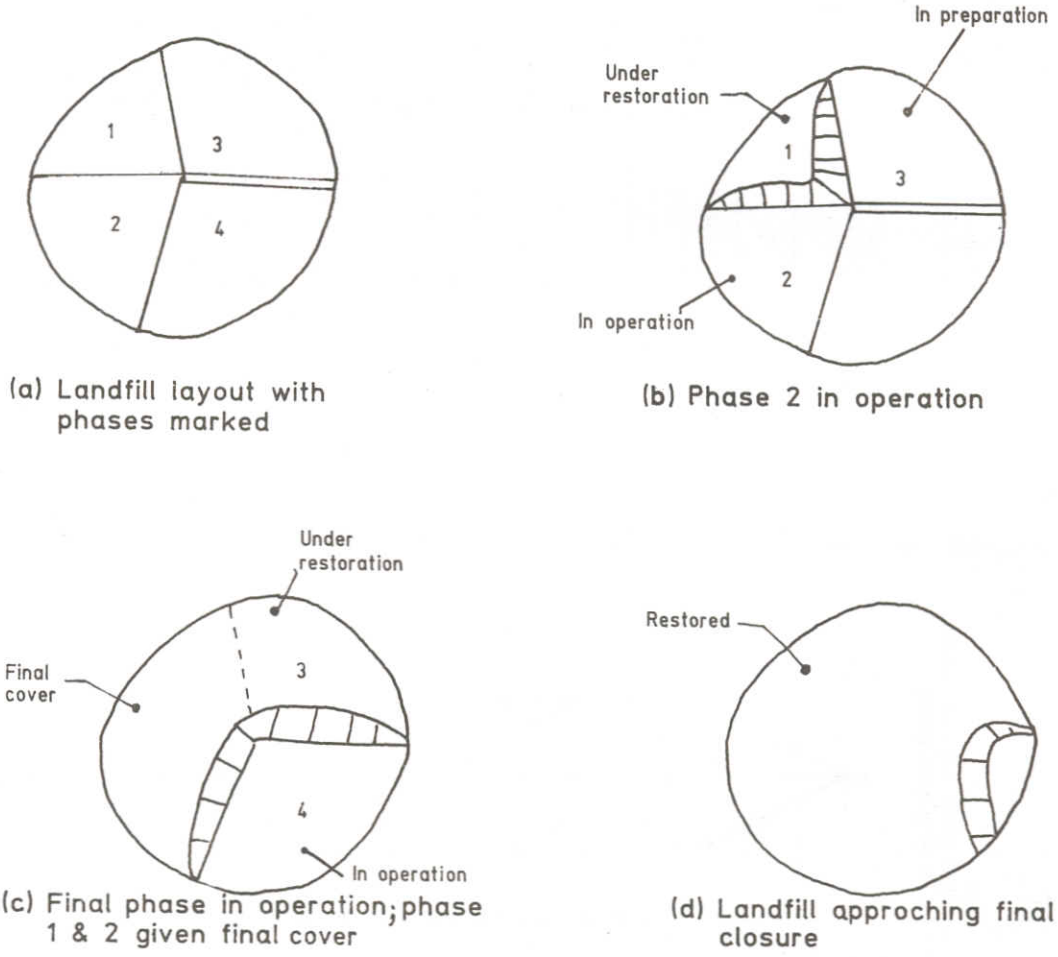


FIG. 4: OPERATION OF A LANDFILL IN PHASES

- Precipitation conditions (P)
- Evaporation transpiration (E_T)
- Surface water runoff (R)
- Infiltration and precipitation over the landfill site (P_i)
- Changes in the water storage in the sealing layer (ΔU_S)
- Overland water flow from surrounding terrain (R_1)
- Ground water flow from surrounding land (I_G)
- Decomposition of waste generating small volumes of water (b)
- The moisture content of the waste when it is deposited(S)
- Leakage of leachate volume (L_1)
- Collected leachate volume (L_R)
- Changes in the moisture content of the waste (ΔU_W)

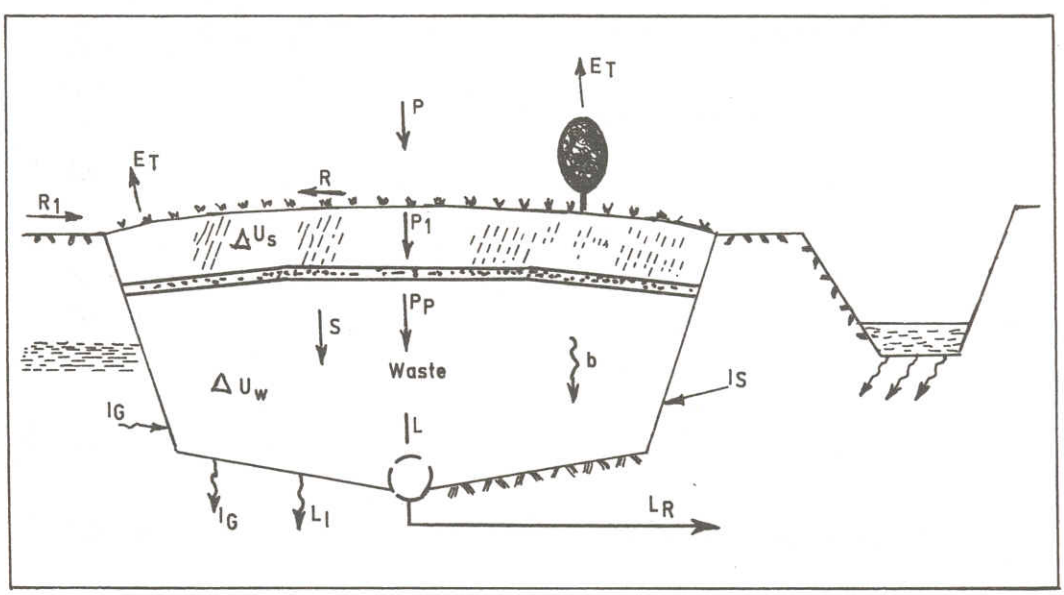
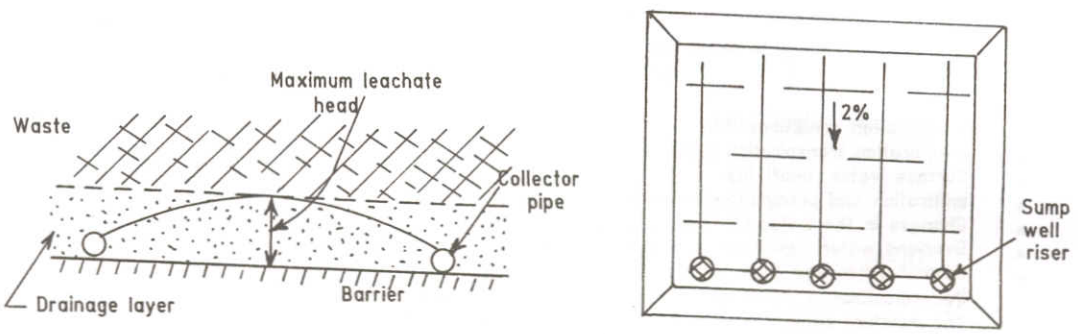


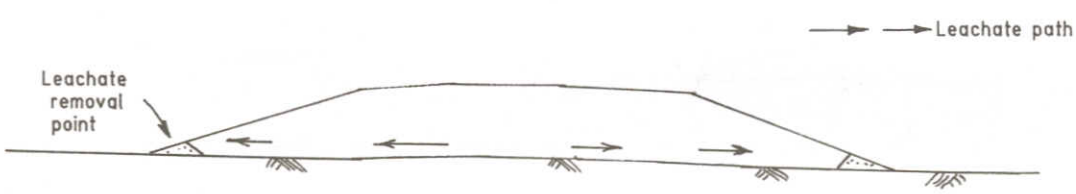
FIG. 5: WATER-BALANCE FOR ESTIMATION OF LEACHATE QUANTITY



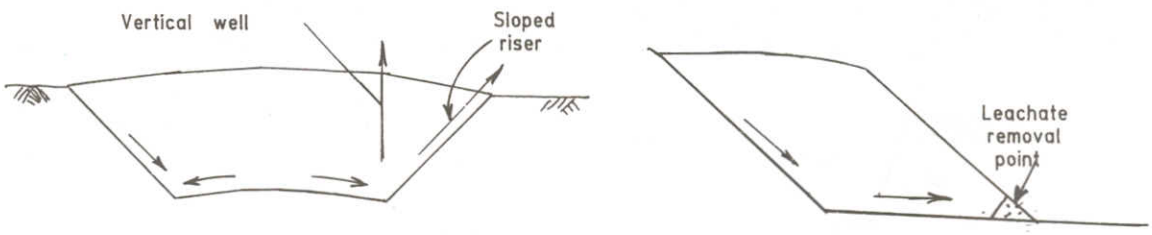
(a) Leachate mound

(b) Pipe network (plan) at base of Landfill

FIG. 6: LEACHATE COLLECTION PIPE NETWORK



(a) Above - ground Landfill



(b) Below ground landfill

(c) Sloped landfill

FIG. 7: LEACHATE PATH AND LEACHATE REMOVAL

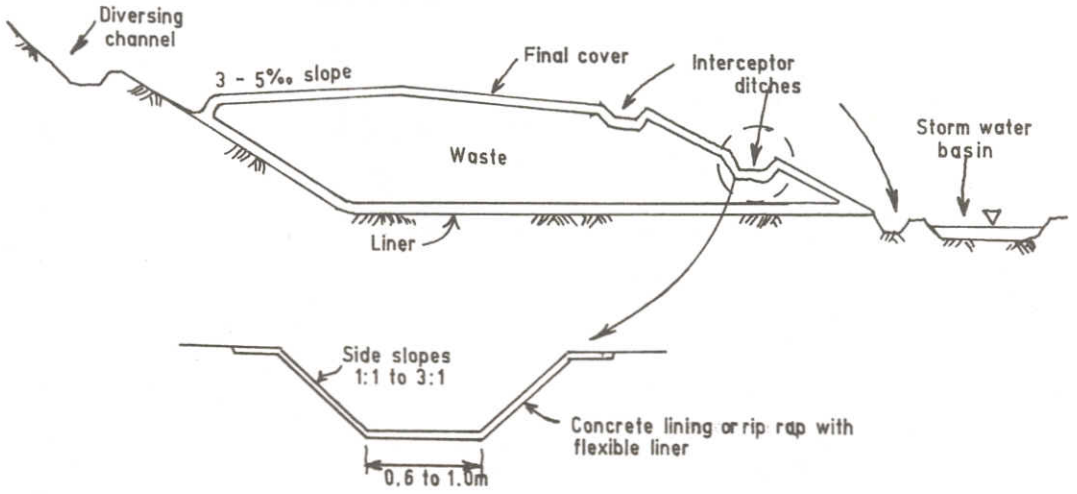


FIG. 8: SURFACE WATER DRAINAGE SYSTEM FOR A COMPLETED LANDFILL

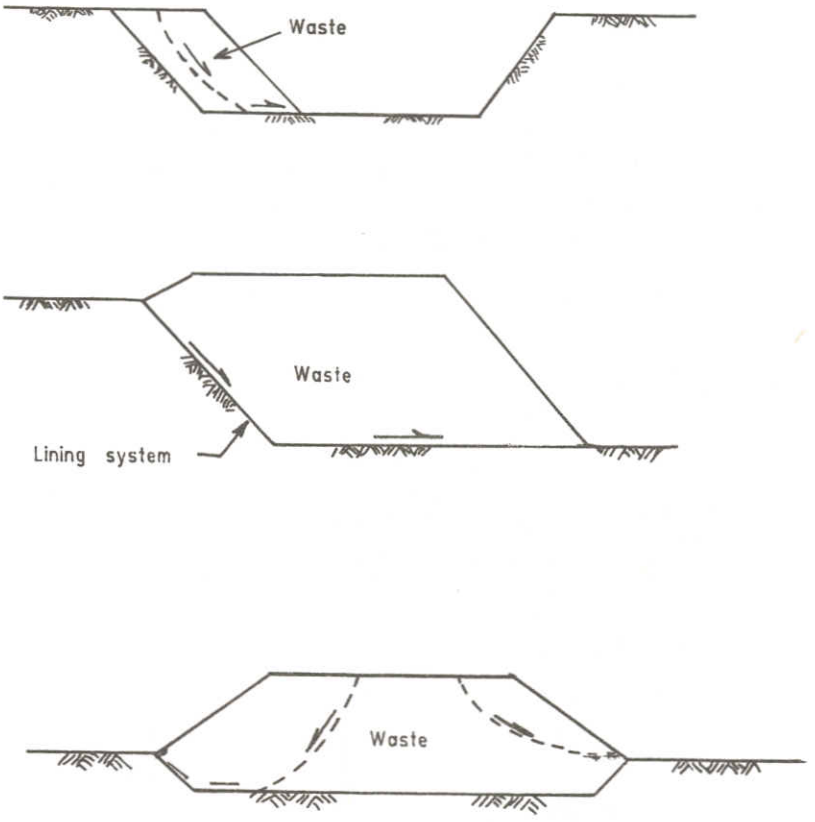


FIG. 9: SOME TYPICAL FAILURE MECHANISMS FOR SLOPES IN LANDFILLS

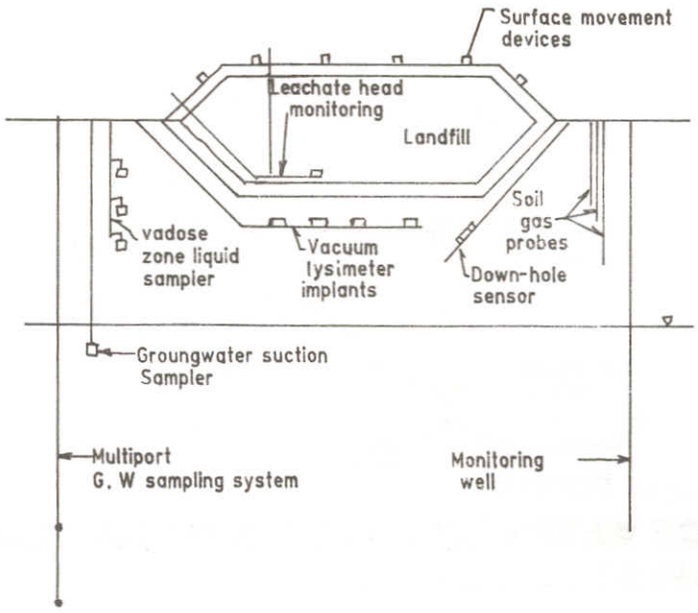


FIG. 10: TYPICAL LANDFILL INSTRUMENTATION

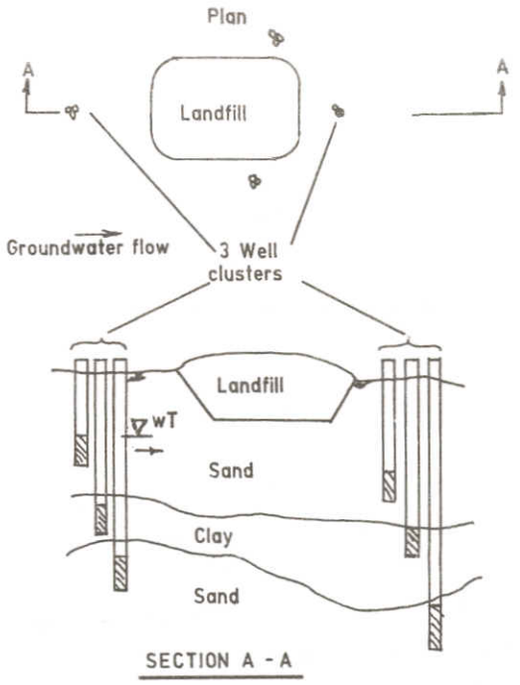


FIG. 11: GROUND WATER MONITORING WELLS AROUND A LANDFILL

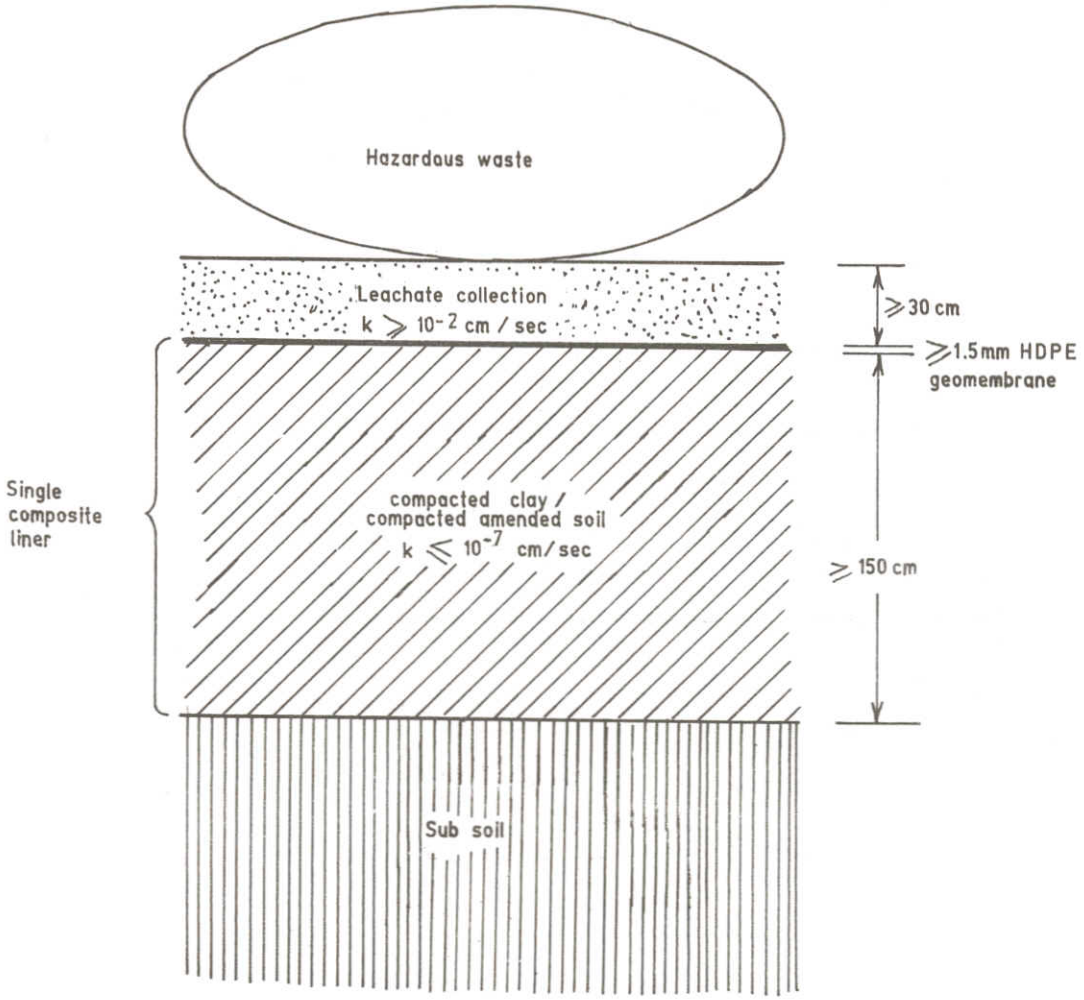


FIG. 12 : SINGLE COMPOSITE LINER SYSTEM

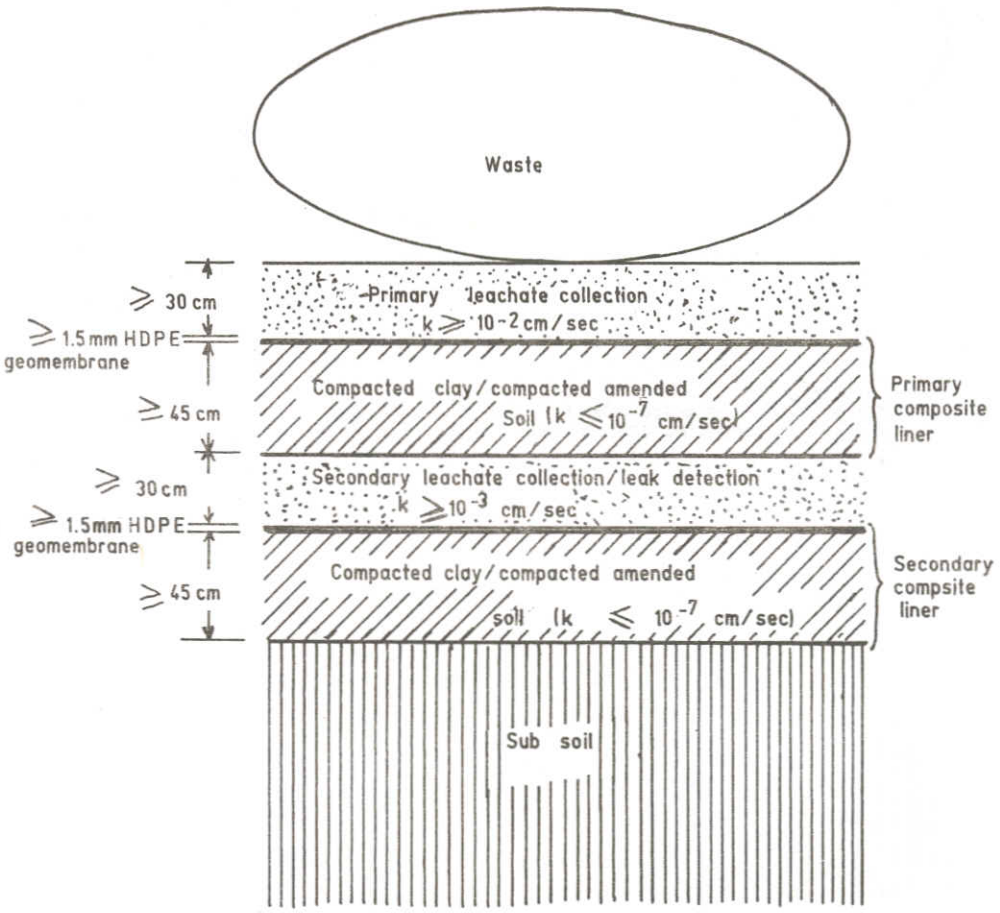


FIG. 13 : DOUBLE COMPOSITE LINER SYSTEM

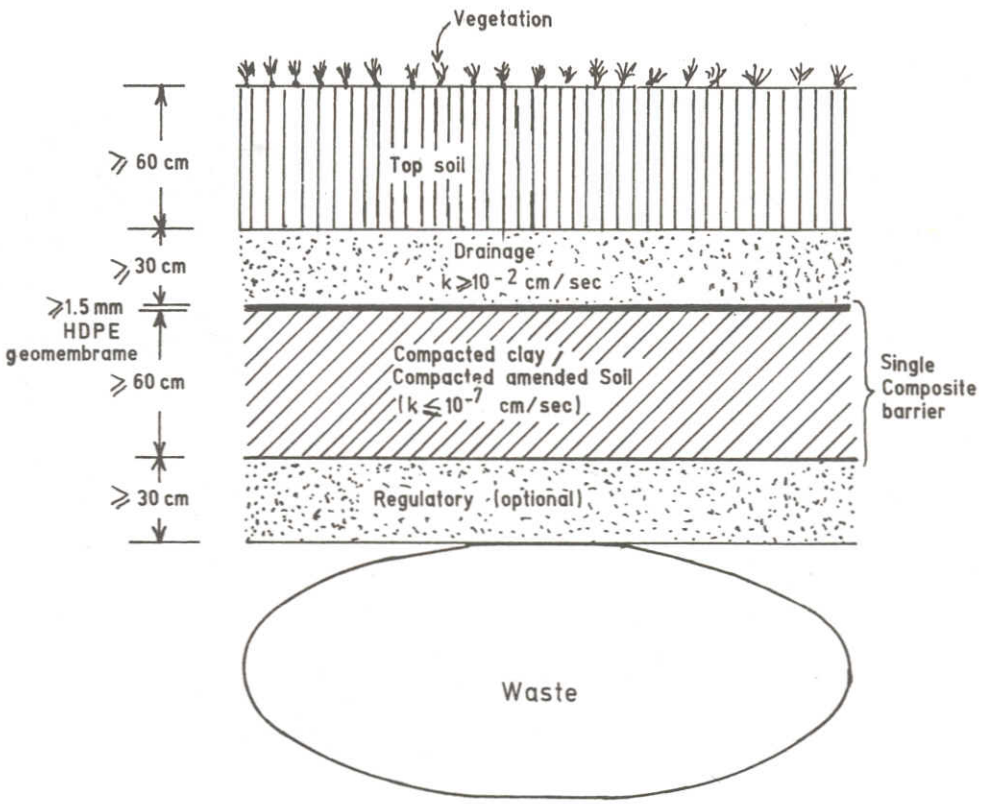
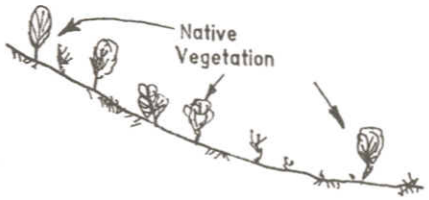
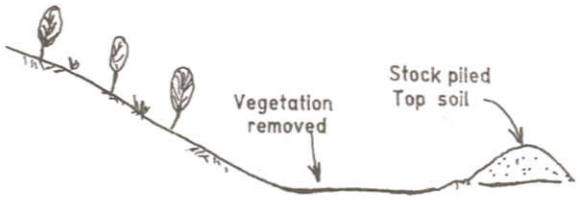


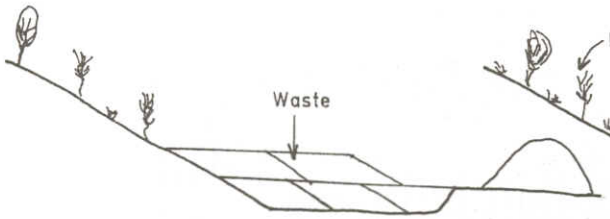
FIG. 14 : COVER SYSTEM



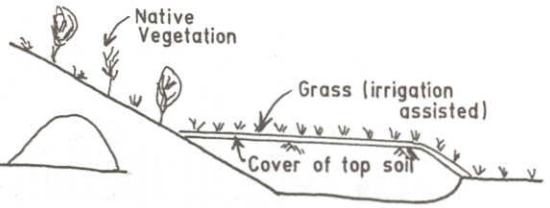
(a) Original Landform



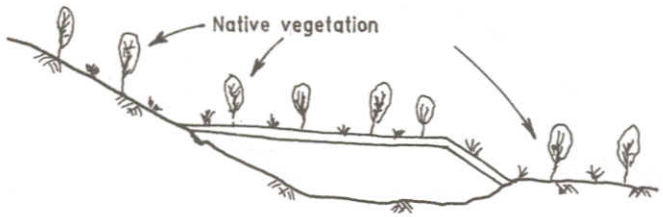
(b) Excavation for Landfill



(c) Landfilling in Progress

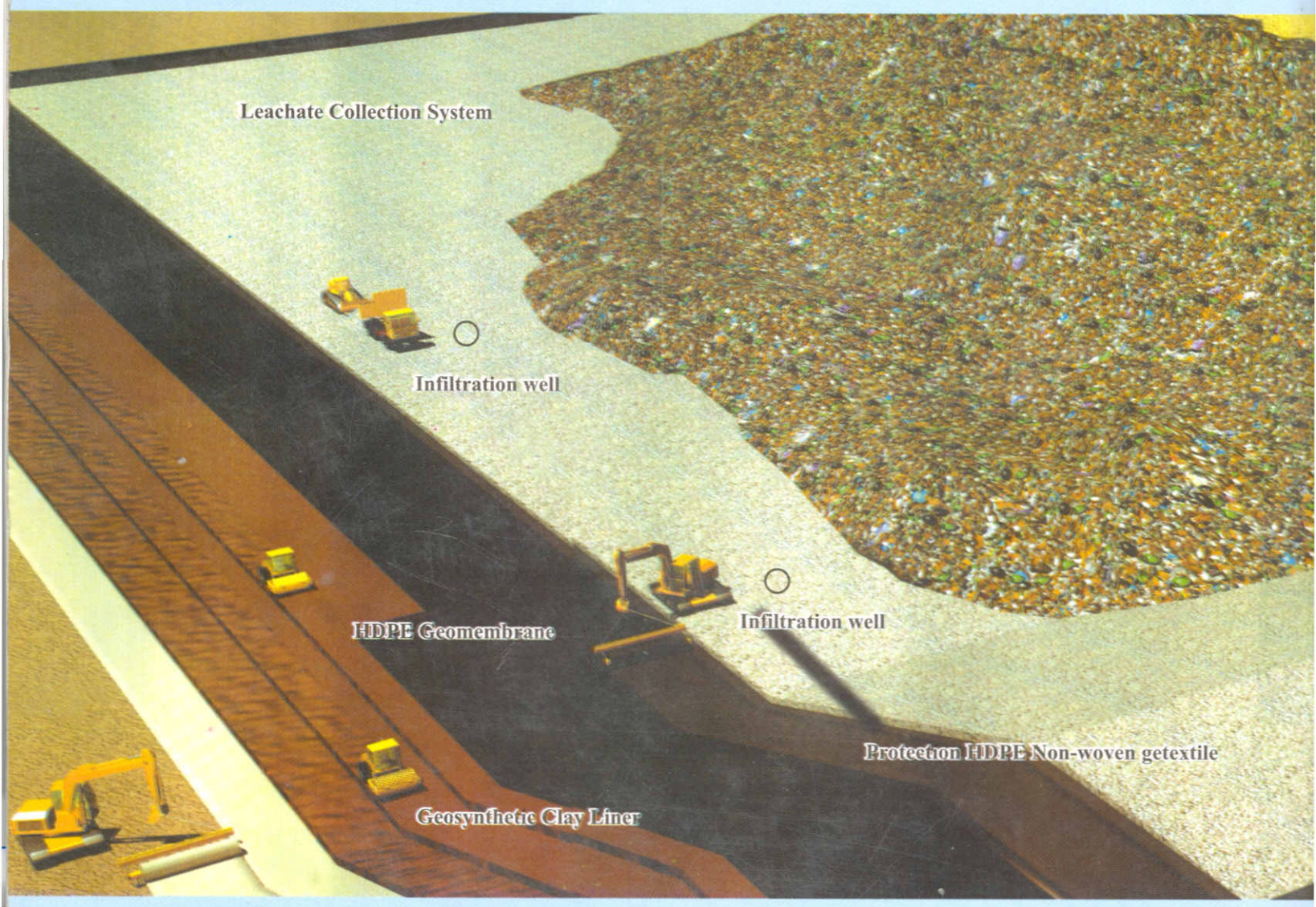


(d) Short-Term Vegetation on Landfill Cover



(e) Long-Term Vegetation on Landfill Cover

FIG. 15 : LONG-TERM VEGETATIVE STABILISATION OF CLOSED LANDFILL


Leachate Collection System
Infiltration well
HDPE Geomembrane
Infiltration well
Protection HDPE Non-woven getextile
Geosynthetic Clay Liner