PREPARATION OF A SET OF TOOLS FOR THE SELECTION, DESIGN AND OPERATION OF HAZARDOUS WASTE LANDFILLS IN HYPER-DRY AREAS

GUIDELINES FOR HAZARDOUS WASTE LANDFILL DESIGN IN HYPER ARID AREAS

Prepared by

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Editorial Note

The present document was compiled jointly by Dr. **Ashraf M. El Mhagraby** in collaboration of the Project Team; **Dr. Said Dahroug and Geologist Ahmed Farouk**.

Prof. Dr. **Mortada Murad El Aref** reviewed the technical contents of the document.

Participants (Annex-1) of the Expert Group Meetings contributed much to the ideas developed in the present document.

Foreword

The BCRC-Cairo as the implementing agent of the project “Preparation of a set of tools for the selection, design and operation of hazardous waste landfills in hyper-dry areas” funded by the United Nations Environment Programme (UNEP) with the financial and technical support from the Secretariat of the Basel Convention has the honor to release as an output of the project, a set of three guidelines entitled:

- Guidelines for hazardous waste landfill site selection and EIA in hyper-dry areas.
- Guidelines for hazardous waste landfill site design in hyper-dry areas, and
- Guidelines for hazardous waste landfill site operation, monitoring and aftercare in hyper-dry areas.

These guidelines have been prepared with the overall objective of promoting principles and practices for environmentally sound management of hazardous waste in the Arab Countries. They address the specific, but widespread problem of hazardous waste and the need for their containment and disposal. They offer guidance on site-selection, EIA, design, operation, and monitoring of hazardous waste landfills in hyper-dry areas. They also warn against improvised disposal methods that may cause severe environmental and health problems, as the cost of mitigating the effects of irresponsible disposal can be many times higher than the cost of safe and environmentally sound disposal as recommended in these guidelines.

The guidelines are published in Arabic and English with easy to use indexing and/or relevant decision support charts. The guidelines are designed to be used by those who are engaged in careers that address hazardous wastes, such as landfill designers, engineers from the chemical and process industries, waste treatment system managers and designers, and public officials interested in waste management planning. They are also of interest to government departments responsible for hazardous waste management and chemical pollution control. The guidelines should be regarded as a further instrument to enhance implementation by the local agencies and municipalities, even though; the guidelines should not be used as a substitute for consultation with professional and competent advisors.

The technical information and recommendations presented in these guidelines have the status of “**Final**” which means it has been reviewed by a panel of experts nominated by BCRC-Cairo as well as by the Experts of the Arab Countries participated in the project and the Secretariat of the Basel Convention. Even though, these guidelines will be updated regularly with the intention to revise or to issue addenda when important new disposal methods and technologies become available to be used safely and cost-effectively in Arab Countries. I am pleased to release these documents which now supersede the draft version.

Prof. Dr. M.M. El Aref
Director BCRC-Cairo

PREFACE

Hazardous waste management policies and strategies in many countries of the Arab region is still underdevelopment. Most of the countries focus in dealing with hazardous wastes on the land disposal option. Few consider cleaner technology alternatives. When it comes to institutions and regulating bodies for the implementation of immediate actions or policy directives, one finds that the problem of financing prevails. Many donors provide assistance towards developing policies and strategies, capacity building training and occasionally towards pilot projects implementing hazardous waste management components including basic infrastructures.

The problem of implementing efficient and/or successful waste management policies and strategies in the Arab region is noted to belong to three main issues

1- Lack of financial resources.
2- Lack of the know-how and technical resources.
3- Political well against awareness/ and priority actions.

The problem of financial resources varies from one country to another. For example, sophisticated technology and industrial plants that comply with the international environmental standards can be found in some of the Gulf States of the Arab region for their good economic status. In countries with economic problems like many countries in the region, the problem for allocating proper funds for implementing environmental protection policies (including sound management of hazardous wastes) and cleaner production alternatives is still outstanding.

Technology is always a refulgent word that attracts the attention of decision makers especially in developing countries. Many decision makers encourage and give incentives to investors to import technology under the temptation of improved quality and quantity seeking economic development. However, assessment of cleanliness of technology exported is still a challenging issue in developing countries. Failure of technology and associated accidents recorded in the past two decades in developed and developing countries have inflected serious environmental impacts. As a result, big tolls and occasionally total losses have been noted. Technology and know-how link all the times to financial and technical resources. They also, very often; link to monopolization.

Even countries (capitals) of the region that have the financial resources should deal with industrial technologies very carefully because of the lack of local technical resources and expertise for maintenance. Fears emanate from the fact that the operation and maintenance cost of technology, in the absence of the know-how, can be highly exaggerated; and can stress budgets that in some cases closing or suspending business and lose the investment.

Having understood the different variables that impede the enthusiastic shift towards technology and towards sound management of hazardous wastes, the Cairo BCRC decided to compromise the situation regarding hazardous waste management via addressing the option of waste disposal by landfilling. The center encourages waste disposal option as a short and intermediate term policy which is thought to be popular in the region under the above mentioned circumstances.

Considering the conditions of the region and current undefined practices in dealing with different types of wastes, the Cairo BCRC decided with the SBC to develop the region's guidelines for the hazardous waste disposal by landfilling, in their quest for improved waste disposal practice, and to contributing to the sound management of hazardous wastes as the ultimate objective of the Basel Convention.

The need to develop the guidelines for the landfill disposal option as a short term policy is expressed by several member countries in the region as stated in the feasibility study conducted by the Basel convention (1996) for the establishment of the region BCRC. The Guidelines are outputs of a project awarded by the SBC to the center. The project tackles the problem of lacking technical guidelines proper for the region economic and geographic conditions.

Acknowledging the geographic, demographic, geomorphic and meteorological conditions of the region the project concentrated on developing standards for the landfill option in hyper- dry areas as the main natural characteristic of the region. The project concept has been prepared and presented for finance to the Open-Ended Technical Working Group of the Basel Convention in late 2002. The project was approved in late 2003 and started implementation at the beginning of March 2004.

The project aimed at developing Guidelines for the landfill option in hyper- dry areas including:

- Guidelines for site selection and EIA of landfills
- Guidelines for landfill design
- Guidelines for landfill operation, monitoring and aftercare

These guidelines are prepared and approved in three expert group meetings held sequentially over 14 months of the 18 month project total duration. These meetings contributed a lot to the capacity building and information share among countries of the region which participated in the meetings. Also, they helped in raising the awareness regarding hazardous waste management.

The present guidelines represent one out of three documents published by the project. The standards appeared in the guidelines are the result of a continuous work by the project staff since the start of the project, the heated discussions during the expert group meetings held in connection with the project; and finally, the scrutiny revision of renowned consultants. The document was meant to be comprehensive but still simple, that can be used both by technicians and non technicians; and also for training purposes. It is worth noted here that this document and the other guidelines published by the project will remain open files for update and improvements as information and knowledge increased, and the Cairo BCRC will appreciate receiving feedback from users of these guidelines so that future editions can be more useful.

The document is divided into independent sections to facilitate quick and concentrated reading. These sections take the reader from basic concepts to approaches and to the technical issues. All documents contain for further readings and for easy reference a bibliography of the subject.

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ACRONYMS

ACAP Alternative Cover Assessment Program
AFC Alternative Final Cover
ALCD Alternative Landfill Cover Demonstration
BCRC Basel Convention Regional Centre
BOD Biological Oxygen Demand
CB Capillary Barrier
CERCLA Comprehensive Environmental Response, Compensation, and Liability Act
CCL Compacted Clay Liner
CL Clay Liner
COD Chemical Oxygen Demand
CQA Construction Quality Assurance
CQC Construction Quality Control
EIA Environnemental Impact Assessment
EIA-R Ethylene Interpolymer Alloy-reinforced
EPA Environment Protection Agency
ET Evapotranspiration
EPS Expanded Polystyrene
FIDs Flame Ionization Detectors
FML Flexible Membrane Liner
GC Geocomposite
GCL Geosynthetic Clay Liner
GM Geomembrane
GN Geonet
GT Geosynthetic Textile
HDPE High-density Polyethylene
HELP Hydrologic Evaluation of Landfill Performance
HW Hazardous Waste
LCRS Leachate Control and Removal System
LFG Landfill Gas, Including any Volatile Organic Compounds.
MSWLF Municipal Solid Waste Landfill
MSW Municipal Solid Waste
NA Natural Attenuation
NMOCs Non-Methane Organic Compounds
PCB Polychlorinated Biphenyl
PET Potential Evapotranspiration
PIDs Photoionization Detectors
PI Soil Plasticity Index
PVC Polyvinyl Chloride
RCRA Resource Conservation and Recovery Act
SBC Secretariat of the Basel Convention
TDS Total Dissolved Salts
TOC Total Organic Carbon or Total Organic Compound
VOC Volatile Organic Compound

1. INTRODUCTION

The present guidelines provides for Minimum Requirements for environmentally sound design that considers all site specific conditions (especially geology and aridity). The state- of- the art construction of hazardous waste landfills, in the sense of using sophisticated synthetic liners, is beyond the scope of the present document, however, the design criteria and guidelines presented in this document place an emphasis on system designs that will not only satisfy the minimum regulatory requirements but will yield environmental protection at minimum construction and operation cost.

The present document deals with the criteria that must be considered when designing a hazardous waste landfill in an arid site pertaining to the Arab Region. Therefore, the main objective of the guidelines presented herein is to improve the ability to identify and pursue dramatically simpler but still cost effective designs and alternatives than typical prescriptive ones.

A first step in the design strategy is to specify the design basis upon which the landfill will be constructed. The design basis is a tabulation of the general performance requirements that the facility must satisfy to achieve project goals which we may call conceptual design. It includes the facility’s capacity, waste flow rates, traffic counts and principal environmental controls. Tabulating the design basis in this manner communicates to the project design team and others, such as regulatory review specialists, about the nature and size of the proposed landfill. The design basis may require revisions if unforeseen circumstances cause significant changes in the landfill plan.

This document provides guidance to engineers for the design of hazardous wastes disposal facilities and associated systems at arid regions. It is an essential and indispensable working tool for landfill engineers. It identifies the main components of a hazardous waste landfill and presents methods and procedures for the detailed design of each part of such containment systems. The document is split up into various sections that are designed to make it easy to read and learn from. There are five major sections that allow the reader to skip through, those are introduction, design steps, design features, alternative concepts and materials, and design report. Each section consists of a set of subsections.

The document is designed to be used by those who are engaged in careers that address hazardous wastes, such as landfill designers, engineers from the chemical and process industries, waste treatment system managers and designers and public officials interested in planning, designing, constructing, or managing the most effective waste management facility possible.

Although the information presented in this document is believed to be reliable and accurate, they are provided without warranties of any kind, either express or implied, including but not limited to warranties of the accuracy or completeness of information contained in the document. The presented technical implications of any information or guidance contained in this document may vary widely based on the specific facts involved and should not be used as a substitute for consultation with professional and competent advisors.

1.1 Design Goals

Although the design guidelines presented herein for hazardous waste landfills represent the minimum requirements, they should be met to fulfill the following goals:

- § To serve the disposal needs of a specific community or region.
- § To be capable of being characterized, modeled, analyzed, and monitored.
- § To use landfill space efficiently and extend site life as much as is practical.
- § To protect groundwater quality by eliminating leachate discharge.
- § To protect air quality and generate energy by installing a landfill gas recovery system (when applicable).
- § To minimize dumping time for site users to reduce potential nuisance conditions for neighbors.
- § To make construction, operation and closure less technically difficult and more cost-effective
- § To provide flexibility for innovation and alternatives.
- § To provide a plan for using the land once the site is closed.

1.2 Design Approaches

Initially, attempts were made to locate landfill sites in areas where natural mechanisms would attenuate or "treat" escaping leachates, but by the 1980's, the philosophy of landfill management shifted more towards containment, rather than any form of controlled release. The modern or "dry tomb" landfill is a highly engineered system involving multiple stages of intense planning and design before installation. As long as "dry tomb" type landfills are constructed for hazardous waste management, it will be necessary to design, construct, operate and especially close these types of landfills to properly consider the inevitable failure of the landfill waste containment system (liners) (Lee and Jones-Lee, 1993b).

Design approaches can be divided into two main trends namely Engineering Design Standards and Performance Based Design Standards (Stephens and Coons 1994). The engineering standards although provide State-of-the art performance, they are usually prescriptive and don't offer much flexibility. In addition, they endorse strict environmental regulations and cost a lot of money. The Basel Convention, a giant treaty in waste management, has produced technical guidelines on specially engineered hazardous waste landfills (SBC, 2002) to the aim of providing guidance to countries who are building their capacity to manage waste in an environmentally sound and efficient way.

On the other hand, performance based design standards allow for some design flexibility provided the standard is met, usually cost effective, and require a certain level of environmental control. In addition, they allow re-used of some waste streams in the construction and operational materials and thus provide a market for some of the feedstock.

Geotechnical engineering is now pervading almost all aspects of landfill design. In general the design criteria are tailored according to the nature of the 25-50 m subsurface lithology, arid versus humid conditions, and the capability of applying expensive highly engineered systems and designs. Accordingly and on a design basis, there are three types of landfills (Blight,1996), those are:

- "natural control landfills" which utilize the attributes of the site's natural setting (e.g. low permeability soils) to control flow out such as leachate or landfill gas
- "engineered landfills" which use engineered systems (e.g. leachate and gas collection systems) to compensate for inadequacies in the natural abilities of the site to restrict off-site environmental impacts
- "arid exempted landfills" for which many requirements are exempted. Secure hazardous waste landfills in arid areas will not fall into these precise types but will contain components of each. The classification of hazardous waste landfills does not take size into account, but is based only on the hazard rating of the waste (Department of Water Affaires and Forestry, DWAF1994).

1.2.1 Natural Control Landfills

Natural control landfills do not rely on leachate containment/collection/disposal systems. The bottom-most waste cell is to be at least 1.5 meters above the seasonal high water table. Greater separation depths based on soil permeability and the leachate renovation capability of the soil should be considered. There is to be at least a 2 meters thick layer of low permeability soil with a hydraulic conductivity of 1×10^{-6} cm/s or less (i.e. silt or clay), below each of the bottom-most waste cells. Lesser thicknesses or no layer of low permeability soil may be approved based on the potential for leachate generation and the unsaturated depth, permeability and leachate renovation capability of the existing soil, ground water quality and/or usage.

1.2.2 Arid Exempt (AE) landfills

A prevalent assumption is that little or no precipitation will percolate to buried wastes at an arid site, if properly located. Thick unsaturated zones, which are common to arid regions, also are thought to slow water movement and minimize the risk of leachate or waste migration to the underlying water resources. On the basis of these assumptions, it is possible that a hazardous waste landfill unit located in an arid climatic zone would not produce leachate from sources of water (e.g., precipitation) other than that existing within the waste at the time of disposal. In such an environment, the water may evaporate fast enough that no discharge and, hence, no treatment is required and significant quantities of leachate would not be produced.

Blight and Fourie (1999) claimed that, in arid and semi-arid climates, engineering calculations show that the potential for leachate generation can be very low, or zero, and does not warrant the installation of costly leachate management systems. They showed how a small leachate flow can be stopped completely by slightly increasing the field moisture capacity of the landfill. Currently, there are many proposals that endorse a more pragmatic approach to regulation in which the standards for liners and leachate management systems are relaxed in these regions. Reliance is commonly placed on the natural system (the site geology privilege) to isolate contaminants at waste-burial sites in the arid regions.

1.2.3 Engineered Landfills

Engineered landfills are designed to have leachate containment/ collection/ disposal systems. The minimum liner specification for leachate containment systems is a 1 meter thick, compacted soil liner with a hydraulic conductivity of 1 x 10^{-7} cm/s or less. Minimum bottom slopes of the liner are to be 2 percent on controlling slopes and 0.5 percent on the remaining slopes. Natural, in- situ, low permeability soils, geomembranes, or composite liners (consisting of a geomembrane and a soil layer) which provide the same level of leachate containment are acceptable equivalents. Liners with higher hydraulic conductivities may be approved depending on the leachate generation potential and the unsaturated depth, permeability and leachate renovation capability of the existing soil. Minimum specifications for leachate collection systems are a 0.3 meter thick sand drainage layer having a hydraulic conductivity of 1 x 10^{-2} cm/s or greater. Synthetic drainage nets which provide an equivalent hydraulic conductivity are an acceptable alternative.

If there is any concern for the precipitation of leachate constituents causing a plugging problem, the leachate collection system is to be designed to prevent such precipitation from occurring. The drainage layer is to be designed with appropriate grades and collection piping so that the leachate hydraulic head on the liner does not exceed 0.3 meter at any time.

1. 3 Strategies for Landfills Design in Economically Developing Countries of Arid Regions

Most of those responsible for the management of the wastes have faced difficulties due to the lack of readily available, reliable information on the subject. Furthermore, municipalities do not have criteria or guidelines available on the subject, while in some cases, there is a tendency to adopt guidelines or regulations promulgated by industrialized countries, without modifying or adapting these to local conditions. Until now waste dumping is a prevailing practice of municipal as well as hazardous solid waste disposal. Dump sites or unsanitary landfills are usually badly sited, non-engineered, lacking design, and are generally operated with consequent adverse environmental and health impacts.

Many efforts have been attempted to help build safe landfills for the disposal of the different waste materials, particularly in developing arid countries (Al-Yaqout[1] and Townsend, 2001). Strategies included landfill classification, lab and field tests on natural soils to determine their applicability as liner and cover systems, and finally examining the effectiveness of the design models for the primary tools using different computer programs such as Pollute-v6, HELP (Hydrologic Evaluation of Landfill Performance), etc, are now common. Testing and evaluation of the applicability of using high-density polyethylene (HDPE) and compacted clay liners and covers reveal that those options are generally not recommended in designing landfills in arid region sites (Lee and Jones-Lee,1995). Other options and alternatives that must be economically feasible and utilizing natural controls should be used as tools for constructing safe sites. Those alternatives will help in reducing the high cost of such containment systems and will encourage countries with economic in transition to switch from open dumping to controlled, sanitary and secured landfills and to better manage hazardous wastes. Environment and waste generation data as will as local environmental legislations and guidelines are key issues to examine and implement the effectiveness of such strategies.

1.4 Conceptual Design

Within the framework of a site development plan, that establish the overall goals for the landfill facility design, a conceptual design must be included. The conceptual design should describe the methods and procedures for establishing appropriate criteria and selecting technologies that will satisfy the construction, operation, and sound environmental monitoring requirements and performance objectives. The conceptual design requires preparation of detailed drawings of all major landfill components.

The drawings must show typical cross-sections of the proposed liner system including layer types and thicknesses, minimum slopes, and hydraulic conductivities of each soil layer. The drawings must also describe the liner system components, including the soil and geosynthetic materials, potential sources of these materials, and the overall design basis.

The conceptual design should also describe the Leachate Collection and Removal System (LCRS) design basis, including key assumptions and design criteria on how the (LCRS) will control appropriate leachate depths. A conceptual design of the LCRS must be prepared and include drawings showing typical cross-sections and a plan-view of system layout, manholes, cleanouts, and sumps.

The conceptual design must include preliminary engineering drawings showing the landfill gas control system features such as gas extraction wells locations and spacing, condensate drains, storage and treatment methods, and mechanical equipment complex

2. DESIGN STEPS

Fundamental design assumptions and criteria established during **conceptual design** should be reevaluated and refined at the outset of the detailed design stage. At this point, additional site characterization data, materials testing results, input from reviewing agencies, permit requirements, and other available information should be incorporated into the design. The detailed design phase must address the following criteria and information.

2.1 Determine Hazardous Waste Generation, Quantities, and Characteristics

The purpose of this inventory is to review both existing and projected data on hazardous waste generation, quantities, and characteristics for the region serviced by the proposed landfill. It is very important that the reported figures are based on the same definitions and classifications of hazardous waste catagories. The common classification used is the Hazardous Waste List, which is a part of the European Waste Catalogue (Environment Agency 2003). In general, the industrial structure is an important factor in explaining the variations of hazardous waste quantities in the different countries and regions.

After identifying the waste, the hazardous waste may be characterized on the basis of risk they pose. According to Misra and Pandey (2004) such wastes are of three categories. *High-risk wastes,* contain significant concentrations of constituents that are highly toxic, mobile, persistent and/or bio-accumulative, e.g. chlorinated solvents, waste from metal degreasing, cyanide waste, dioxin-based waste, PCB (poly-chlorinated biphenyl) waste. *Intermediate risk wastes* contain metal hydroxide sludge (excluding Cr^{6+} which is under the high-risk waste due to its extreme toxicity). The toxic metals of this category are relatively insoluble with low mobility. *Low risk wastes,* include primarily high volume low hazard wastes and some putrescible wastes. One may add to such characterization what we call extremely hazardous.

Waste characteristics will provide important design information:

- Hazardous waste ratings have different disposal requirements.
- Special storage areas for certain types of waste streams that might be further used in daily cover or final cover operations
- Waste preparation for landfill disposal
- Waste type affects the handling techniques.
- Waste type affects daily operating procedures
- The size of the waste stream affect the consequent size of the operation and hence the design.
- Determine the need for disposal capacity. Capacity is a function of present and future waste generation.
- Waste type affects cover requirements.

- Leachate treatment may be more complex due to the wide variety of waste types and constituents.
- Due to volatility or for other reasons, hazardous materials may require immediate cover.
- Segregation by type and chemical characteristics of wastes is usually practiced to prevent undesirable reactions within the landfill.
- Some wastes are not amenable to detoxification may be encapsulated in some permanent material prior to landfill disposal. Encapsulation materials include concrete, molten asphalt and plastics (polyethylene).

2.2 Compile Information for Potential Sites

All design relevant information together with the site selection priorities for the potential sites must be gathered and compared to achieve a satisfactory election of a candidate site based on site-selection issues, design issues, and the proposed conceptual model. The base map should also define exclusionary criteria for the siting of the proposed landfill that particularly affect the design and consequent implementation of the conceptual model. An exclusionary criterion is defined as "a criterion that prohibits a potential area from further consideration as a candidate area" (Landfill Advisory Committee 2003). Exclusionary criteria reflect both international and local regulatory requirements and policies. This information includes the following:

2.2.1 Preparation of Base Maps of Existing Conditions on and Near Sites

Base maps usually show the landfill location in relation to surrounding waste generation and communities, roads and other features. Contour maps show drainage patterns adjacent to and through the proposed disposal sites must be prepared or purchased. Areas with excessive slope or potential direct overland flow from a site to surface waters must be carefully evaluated.
A site base map typically includes information and shows the following feature:

- Contour lines drawn at 50 cm to 1 m intervals.
- Clearly delineated property boundaries.
- Utility corridors, buildings, wells, roads and other features.
- Drainage ways.
- Surface water and wetlands.

2.2.2 Compile Hydrogeological Information

Water movement in the unsaturated zone of soil in arid regions is complex. Several variables including water content, water potential, humidity, and temperature; must be monitored to define rates and directions of water movement. Water content indicates directions of water movement and how tightly the water is held by the soil matrix. Water moves through soil in liquid and vapor forms, and the two forms can move simultaneously as a consequence of water-potential, humidity, and temperature gradients in the soil.

Evaluation of the general hydrologic conditions at and near the waste-burial site in arid and hyper-arid regions suggested that low average annual precipitation and high average annual evaporation would prevent water from percolating downward more than one meter or so below land surface. This assumption, however, did not consider the extreme annual and seasonal variations in a desert climate. Some water-balance modeling in arid and hyper-arid regions have demonstrated that, under particular climate and soil-moisture conditions, the potential for deep percolation does exist, in spite of high annual evaporative demands (Nichols, 1987).

Water movement monitoring in arid and hyper-arid regions, particularly between the depths of 10 and 50 meter has shown that water movement, as liquid and as vapor, is consistently upward. Preliminary evidence indicates that upward flow of water vapor through the thick unsaturated zone may potentially serve as a contaminant release pathway (Prudic, 1994b; Prudic and Striegl, 1994). Therefore, the importance of vapor flow as a potential transport mechanism and as a contaminant release pathway should be considered in any water balance modeling during the process of evaluating a proposed waste site in arid region.

Computer numerical simulations can be used to predict the water balance. It is advisable that a realistic set of input parameters be developed for the simulations based on measurements from the actual soil, values from the literature, and expert opinion. A commonly used numeric simulation for conducting water balance analyses as well as conventional hydraulic-barrier cover systems is the EPA HELP computer model (Schroeder et al., 1994).

For purposes of designing a hazardous waste landfill in an arid site, the following hydrogeological information are required, those information include but not limited to soil characteristics, bedrock, and groundwater.

Soil characteristics

Because arid regions are dry, there will be no plants or bugs, and thus little organic matter, so soils do not form. Dryland soils are often relatively immature, so are much harder to spot in the rock record. And, as with so many other aspects of drylands, soils in such settings are much more poorly understood and documented than those in temperate and humid regions. Therefore a minimum of two meter deep test pits should be dug per hectare of the site, and the soils tested and photographed to confirm their suitability for supporting the facility.

The soil plasticity index (PI) should be greater than 10 percent. However, soils with very high PI (above 30 percent), are cohesive, sticky and difficult to work with in the field. When high PI soils are too dry, they may form clods that are difficult to break down during compaction. Preferential flow paths may form around the clods, increasing the liner's permeability. Large soil particles or rock fragments can also form preferential flow paths.

Bedrock

Bedrock characteristics such as depth, type, and presence of fractures are important parameters in the design process. The higher the depth to bedrock the better will be the site from a design point of view. A depth between 10 to 15 meters ranking the sites as 'excellent' from depth to bed rock consideration. It is generally desirable that the nature of the subsurface strata underlying the landfill is homogeneous, it is difficult or even impossible to properly monitor the groundwater parameters in heterogeneous subsurface lithologies.

Groundwater

Groundwater conditions will influence the landfill's design features of the leachate collection system and liner requirements. Groundwater parameters such as average depth, seasonal fluctuations, hydraulic gradient and direction of flow, rate of flow, quality, and uses are important for designing a landfill. The ten-year high level of the groundwater as well as the ten-year groundwater recharge area for current or future water supply development are important parameters to determine the depth to the lower most cells.

It is necessary to design the landfill in such a way that in case of failure of the liner system the groundwater flow gradient and groundwater flow direction impact at downstream villages is minimal. Groundwater quality may not directly influence the design of the landfill. If the groundwater does not conform to the drinking water quality standards, or can not be used for any useful purpose, then some relaxation regarding the liner system might be approved.

2.2.3 Compile Climatological Data

Weather conditions are important considerations in the design of landfills. Surface water control is directly dependent on precipitation, infiltration and evaporation. Leachate control will also be directly influenced by precipitation, along with evaporation and transpiration. Site access may be affected by wet or foggy weather conditions. Wind patterns should be considered in the establishment of windbreaks to control blowing debris. Climatological data can usually be obtained from the local or national weather observers. It is particularly important that recent, accurate precipitation data representative of the landfill site be obtained since the design of surface water and leachate management facilities is so dependent on this information. Important climatological data include:

- Precipitation
- Evaporation
- Temperature, and
- Wind direction.

2.3 Identify Local Regulations and Design Standards

Regulations and design standards for landfill constructions, include but not limited to loading rates, frequency of cover, distances to residences, roads, surface water and airports, monitoring, groundwater quality standards, building codes, and contents of application for permit should be consulted with concerned department.

2.4 Site Layout Development

The landfill's layout will be strongly influenced by the site's geology. The site layout begins with geotechnical information, which includes data on the surrounding site geology, hydrology and soils. This data usually is collected during the site selection process, then supplemented during subsequent investigation. Soil-boring logs and other data describing subsurface formations and groundwater conditions are diagrammed to present an interpretation of the subsurface conditions at the planned site. Soil-boring logs help to show the extent of each formation extrapolated between the boreholes. The depths to bedrock and the groundwater table also are shown. Many more boring logs and additional cross sections at regular coordinate intervals in several (minimum of two) directions typically are required to properly locate the waste disposal area within the developing site.

2.5 Design of Filling Area

Designing the working face requires consideration of the following:

- landfilling method .
- Cell width, depth, length, fill depth, liner thickness, interim cover soil thickness, and final soil cover thickness.
- operational features such as use of cover soil, method of cover application, need for imported soil, equipment requirements, and personnel requirements.
- daily quantity (tons/day), traffic volumes (vehicles/day), and landfill equipment.

3. DESIGN FEATURES

Figure 1 is a simplified landfill cross section showing the different aspects of landfill design.

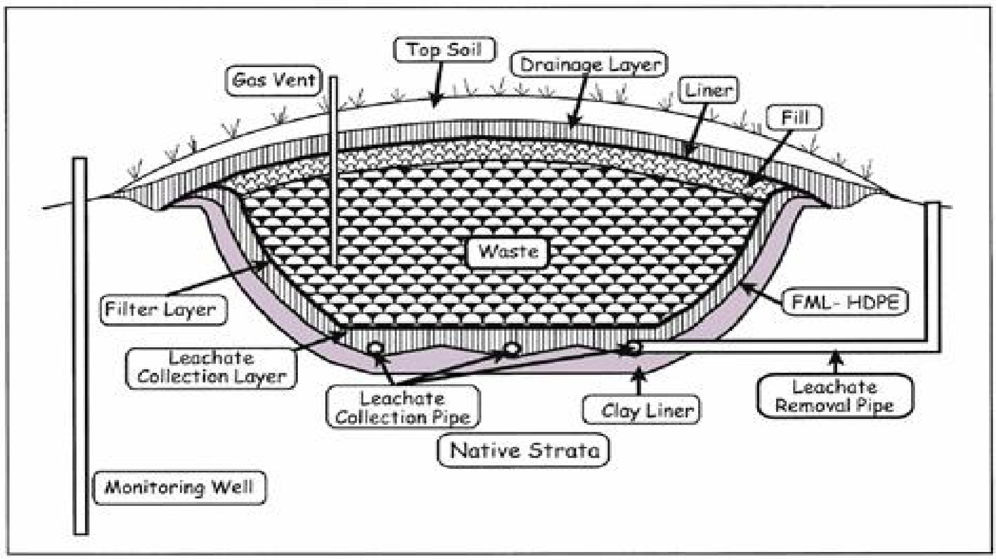

Figure 1: Simplified Landfill Cross Section

3.1 Leachate Controls

Leachate generation depends on the availability of water, landfill surface conditions, waste conditions, and underlying soil conditions (Sharma and Sangeeta 1994). Landfills are classified according to their potential of generating leatchate into two types. Those are landfills with sporadic leachate generation and landfills with significant leachate generation. Sporadic leachate generation is the result of unusual wet periods or poor site drainage. In this case, the leachate is controlled by other economical means rather than the installation of a costly leachate management system. On the other hand, in the case of significant leachate generation, a leachate management system would be a minimum requirement in landfill design.

To decide on whether or not a landfill will generate significance quantities of leachate, a climatic water balance (B) is used as $B = R - E$ where R = rainfall; and E = evaporation from the landfill cover surface. As to arid region conditions runoff from the landfill surface is ignored. Similarly the moisture storage capacity of the waste are is assumed null as the waste is not municipal but actually solid hazardous waste which do not contain much organics. B is calculated for the wet season of the wettest year on record. If the value of B is positive for less than one year in five for the years for which data is available, the landfill will be considered to generate sporadic leachate and the site is classified as B^-. However, if the value of B is positive for more than one year in five for the years for which data is available, significant leachate will occur and the site is classified as B^+.

A computer program is attached to this document that assess the climatic water balance.

3.1.1 Possibilities of Leachate Generation in Arid Regions Landfills.

Due to the fact that the amount of leachate generated in landfills located in arid areas is generally less than in wetter areas, landfill designers prepare their design packages based on the assumption that a leachate collection system and even bottom liner installation can be waived. They mistakenly claim that landfills located in arid areas do not generate leachate. Such claims are frequently based on an inappropriate water balance analysis for the landfill in which the net annual water flux for the landfill is calculated. Typically in arid areas the net annual water flux direction is from the surface layers of the soil to the atmosphere (Lee, et al., 1995). However, even areas which on the average only receive a couple of inches of rain per year do experience periods of time in which large amounts of rainfall occur in a short period of time. During this time there is significant transport of the precipitation that occurs on the surface of the soil to the ground waters and can be a highly significant cause of groundwater pollution (Lee, et al., 1995).

Another mistake that is frequently made in analyzing the potential for a hazardous waste landfill to cause groundwater pollution in arid areas is the assumption that the moisture-holding capacity of the wastes has to be exceeded before leachate generation occurs. Such an approach ignores accidental rainfalls and the unsaturated transport of leachate-derived constituents within the wastes and in the aquifer system above the water table. Transport of hazardous waste components can readily occur in the wastes and in the aquifer without exceeding the moisture-holding capacity of the wastes associated with unsaturated transport (Lee, et al., 1995).

3.1.2 Design Criteria for the Leachate Collection and Removal System (LCRS)

If a leachate collection and removal system had to be installed, the collection system should be sized in accordance with a water balance calculation, or by another accepted engineering method. The leachate management system should include a detection system located at the lowest elevation of the fill area. and throughout the fill area to monitor any build-up in leachate. In addition, clean-out units should be part of the system. The design of the system should include the preparation of a water balance, sump pumps, and piping of sufficient diameter to remove the leachate and allow cleaning. The piping and fittings should be manufactured of a material resistant to the mechanical, biological thermal and chemical stresses that may occur in the landfill environment (including settlement), or may be caused by the leachate. Filters should be used to control clogging of the pipes.

The leachate collection and removal system (LCRS) should be designed to meet the following criteria.

- Granular drainage layer percent fines: < 5% passing No. 200 sieve.
- Granular drainage layer hydraulic conductivity: 1 x 10-2 cm/sec.
- Granular drainage material should consist of carbonate-free, rounded gravel or non-angular rock.

- Leachate collection pipe minimum 6-inch diameter, schedule 80 or equivalent strength pipe.
- Minimum slopes for collection pipes: 1% after predicted settlement; comply with the local guidelines for sewer pipelines design (enough slope to maintain scouring velocity).
- Minimum slopes for leachate drainage layer: 2% after foundation settlement.
- Manhole/cleanout spacing: Should be compatible with available cleanout equipment. At a minimum, provide cleanouts at both ends of all leachate collection pipes and sweep bends to accommodate cleanout equipment.

The Oregon Department of Environmental Quality has recommended the following design procedures for a leachate collection and removal system (DEQ 1998):

- Prepare scaled drawings of the leachate collection system layout (fig.2) and construction details
- Specify properties, characteristics and performance criteria of granular drainage layers, including Unified Soil Catalogues, grain size distribution, maximum particle size, maximum percent passing No. 200 sieve, thickness, and hydraulic conductivity at anticipated field density
- Specify properties, characteristics and performance criteria of geosynthetic drainage layers, including polymer type, transmissivity and evidence of chemical compatibility. Analyze requirements for geosynthetic drainage material to determine allowable properties
- Specify properties and characteristics of any granular filter layers, including Unified Soil Classification, grain size distribution and thickness
- Specify properties and characteristics of any geosynthetic layers used for filtration or for liner protection. By analysis, determine allowable properties for protection or filtration layers
- Describe leachate collection pipe configuration, dimensions and properties, and analyze pipe loading and structural strength
- Identify minimum slope specifications for drainage layers and collection
- Prepare leachate collection sump capacity and design
- Prepare manhole/cleanout design details, describe cleanout equipment capability and procedures, and analyze manhole-foundation design
- Identify the location and minimum spacing of manhole
- Conduct a filtration analysis to evaluate the primary LCRS's clogging potential
- Conduct an analysis of primary LCRS performance

Figure 2 shows a typical leachate collection system layout (after Kinet, 1994).

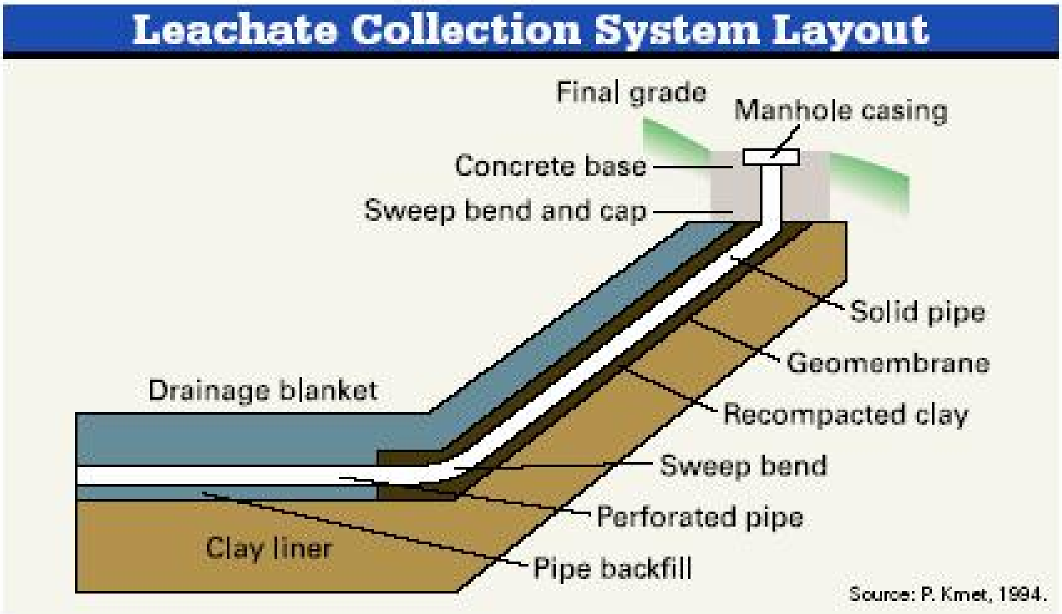

Figure 2: Typical layout of a leachate collection system (after Kinet, 1994).

3.1.3 Leachate Holding Tanks and Conveyance Pipelines

Leachate holding tanks are impoundments connected with the leachate pipeline system and in which the leachate is collected for sometime to be further conveyed to a leachate treatment unite to be prepared for final disposal or reuse. The leachate holding tanks have more advantages over conventional leachate evaporation lakes or leachate collection ponds. The later represent a threat to air, soil and groundwater quality. Leachate evaporation lakes and ponds may also have adverse impacts on the biodiversity particularly birds.

The conveyance pipelines are usually designed following the same guidelines for designing conventional sewer pipelines.

Design leachate holding tanks and conveyance pipelines to be:

- watertight
- composed of landfill-leachate compatible materials
- located on a flat, stable foundation, and
- sized to support the LCRS and leachate management practices
- consistent with the Departments' guidelines for sewer pipelines
- pipelines should be capable of withstanding in-service conditions, physical loads, stresses

3.1.4 Leachate Treatment and Storage Impoundments

Design leachate treatment and storage impoundments to meet the following criteria:

- Leachate treatment and storage impoundments are designed taking into consideration the available storage capacity which reflects the adopted leachate management practices.
- Impoundment liners should be equal to or exceed the landfill liner design safeguards.
- A leak detection system underlies the impoundment liner must be installed to account for the substantial liquid depths within such impoundments
- Impoundments must have sufficient freeboard to contain and prevent overflow due to accidental storms.

3.1.5 Leachate Treatment Process

The leachate treatment system can be located either on-site or off-site. The leachate treatment and disposal system must be designed to achieve the desired effluent quality (leachate strength) objectives as appropriate for direct discharge or for pretreatment followed by discharge to another treatment facility. Designing the leachate treatment process is based on the results of the site characterization studies, a feasibility study, and the conceptual design report. The design of a leachate treatment and disposal system should consider the following :

- Leachate composition and flow rates
- treatability studies on site-specific leachate before committing to a particular leachate treatment process or technology.
- leachate treatment goals and design criteria (e.g., effluent quality, treatment efficiency) consistent with final disposal requirements and raw leachate characteristics.
- Additional testing needed to assess the leachate's variability and treatability

3.2 Liner System

Landfill liners are designed to minimize the infiltration of leachate into subsurface soils below the landfill thus eliminating the potential for ground-water contamination, and at the same time limit the movement of landfill gases from the landfill site (Tchobanoglous et al. 1993). New hazardous waste landfill units and lateral expansions of existing landfill units must be equipped with either a composite liner, or a site-specific alternative design that meets the environmental performance criteria. The design documents of the liner system should address technical considerations such as

- Performance criteria
- Construction details (anchoring, penetrations)
- Material properties
- Dimensions

- Bottom and sidewall slopes
- Site operations (particularly the cell filling sequence and configuration),
- Interface friction properties of liner system components, and
- Subgrade conditions such as groundwater levels and soil properties

The conventional liner systems must include a soil liner component and a geomembrane liner component. Figure 3 shows the design aspects of a conventional liner systems.

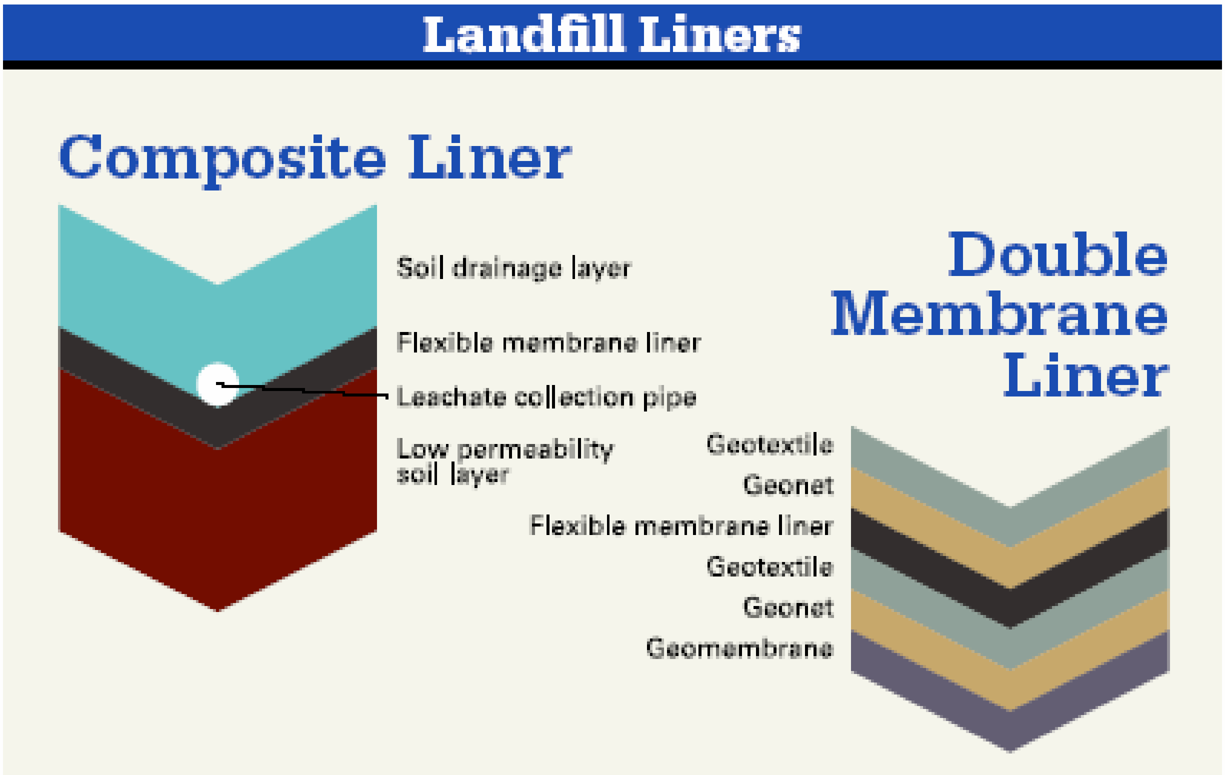

Figure 3: Landfill Liner Systems.

Source: Landfill Cover and Liner Systems for Water Quality Protection By Philip O'Leary and Patrick Walsh: 2002

3.2.1 Liner System: Soil Liner Component

Soil liners should be constructed in a series of compacted lifts. To specify lift thickness, soil characteristics, compaction equipment, foundation characteristics, compaction requirements and liner permeability must be considered. The compactor must reach the lower portions of the lift to establish good, homogeneous bonding between lifts. Test methods such as grain size distribution, Atterberg limits, and moisture/density relationships are necessary to characterize prospective liner soils.

A soil liner is designed to meet the following criteria:

- Maximum saturated hydraulic conductivity (permeability) 1 x 10^{-7} cm/sec
- (may be relaxed for arid sites)
- Minimum compacted thickness: at least 60 cm
- Atterberg limits: plasticity index 10%;
- Percent fines: 50% passing a #200 sieve;
- Percent coarse material: 10% retained on a #4 sieve;
- Maximum particle size including clods: 2.5 to 5 cm

3.2.2 Liner System: Geomembrane Liner Component

Geomembrane specifications is a necessary requirement to identify the geomembrane's function and to specify desired properties for the geomembrane to perform its intended function, construction survivability, and in-service durability (i.e., resistance to temperature variations, UV radiations, leachate, mechanical stress). The geomembrane component of the landfill liner is designed to meet the following criteria:

- HDPE geomembranes of at least 60 mils (0.15 cm) thick be installed in direct and uniform contact with the underlying soil liner. Thinner geomembrane liner may be considered or even exempted for arid region sites depending on the potentiality of leachate formation.
- The geomembrane should be chemically compatible with leachate, landfill gas, and other expected environmental conditions within the landfill
- The geomembrane should be physically compatible with the proposed subgrade and backfill properties
- The geomembrane should be capable of withstanding the anticipated short-term and long-term stresses due to facility construction and operation.
- The number of pipe penetrations through the geomembrane should be minimized to the extent possible
- The geomembrane's friction properties should be compatible with other components of the liner system to minimize mechanical stresses on any component

A common procedure for the design of the geomembrane liner component is listed below

- Specify performance criteria and material properties for geomembranes and associated geosynthetics.
- Perform a geomembrane design analysis to determine acceptable geomembrane properties.
- Analyze the liner system's stability in side-slope areas.
- Analyze geomembrane runout or anchor trench requirements and prepare design details.
- Prepare design details for sumps, pipe penetrations, mechanical attachments, etc.
- Specify Construction Quality Control (CQC) and Construction Quality Assurance (CQA) requirements.

3.2.3 Applicability of Flexible Membrane Liners (FML) in Arid Area.

In arid areas, the unusual high temperatures in the summer (more than 57 °C) and the change in weather during the winter may cause critical alterations in geomembrane properties. Therefore, the mechanical integrity of the geomembrane must be maintained for the design life of the landfill. Flexible membrane liners are composed of plastic developed from several types of polymers and a wide variety of additives to impart special properties to the liner. The major types of flexible membrane liners are listed below (Forseth and Kmet, 1983):

- Butyl rubber
- Chlorinated polyethylene (CPE)
- Chlorosulfonated polyethylene (CSPE)
- Elasticized polyolefin (ELPO)
- Ethylene-propylene rubber (EPDM)
- Neoprene
- Polyethylene-low density (LDPH)
- Polyethylene-high density (HDPE)
- Polyvinyl chloride (PVC)

Major factors to consider in membrane selection include the following (Forseth and Kmet, 1983):

- Weathering resistance
- Soil compatibility
- Resistance to biological attack
- Physical suitability
- Compatibility with waste

The principal concern with membrane liners is whether they can maintain their low permeabilities for the life of the landfill. Permeabilities can increase because of membrane rupture or degradation. Merry and Bray (1997) stated that geomembranes are expected to deform due to settlement of the underlying material. Weathering of membrane liners occurs during construction. The liner is subject to ultraviolet light and potential temperature extremes which can cause liner degradation. Selected liner materials must resist these effects or be covered by a soil layer.

Some soil constituents may degrade membrane liners (Forseth and Kmet, 1983). Those are oxides of metals, chloride compounds, sulfur compounds, organic compounds, acidic soil pH, and man-made compounds like petroleum products.

If on-site soils contain these compounds at abnormal levels or are very acidic ($pH<5$) they should be removed or covered. Membranes resistant to these effects could also be used. Biological resistance is important in landfill application. The principal degradation will likely result from microbial attack. Other biologic problems may include insects, rodents and plants whose activities may rupture the membrane. The physical properties a membrane liner must have include the following (Forseth and Kmet,1983):

- Adequate tensile strength
- Tear, puncture and creep resistance
- Adequate thickness
- Adequate elongation properties
- High seam strength
- Low permeability
- Base of field seaming

The required minimum thicknesses for membrane liners is 2 millimeters. Thicker membranes are stronger and more resistant to chemical degradation, but also more costly. Decisions to use liners thicker or thinner than the required minimum would be made on a site specific, case-by-case basis. Seam strength is very important since it is often the weak link for the liner. Selection of a liner must include consideration of field seaming techniques. Manufacturers will recommend techniques for joining membrane sheets. These techniques must be evaluated to ensure they are compatible with expected conditions in the field. Common problems include temperature restrictions and the presence of dust and dirt in the field.

3.3 Final Cover System

Cover systems are designed to minimize leachate generation by minimizing water infiltration from precipitation, limit the uncontrolled release of landfill gases, and repress the generation of vectors (Sharma and Lewis Sangeeta 1994; Tchobanoglous et al. 1993). Liner and cover systems consist of different components that serve the purposes of the landfill design method. Other important design issues related to the design of the final cover include landfill gas containment and control, settlement, erosion, long-term maintenance requirements, and slope stability.

Designing the final cover system must meet the following criteria:

- Minimum slopes of 2% and maximum slopes of 30%
- Accommodate anticipated settlements
- Contain landfill gas and enhance gas collection and recovery efforts
- Minimize erosion
- Minimize surface water infiltration
- Promote efficient surface water drainage and runoff
- Maintain stability on side slopes, and
- Enhance site aesthetics

Design the final cover system by following the procedure below

- Prepare typical cross-sections of the cover system design for top and side slope
- Use (whenever available) the latest version of U.S. EPA's Hydrologic Evaluation of Landfill Performance (HELP) Model to estimate infiltration.
- Analyze slope stability
- Analyze potential settlement

Describe each layer of the cover system, including:

§ Foundation layer
§ Low permeability layer
§ Drainage layer
§ Protective layer
§ Topsoil layer
§ Vegetative layer

3.3.1 Foundation Layer

The foundation layer will serve as a base for either a low-permeability soil layer, or a geomembrane layer. The foundation layer must support and protect the cover during and after the construction phase.

3.3.2 Low Permeability Layer

Design the low permeability layer to minimize moisture infiltration, to enhance landfill gas containment and control, and to accommodate site specific physical and environmental conditions. The use of soil moisture storage and evapotranspiration to reduce leachate generation appears to be particularly valuable in arid regions. Increasing soil depth and available water capacity has significant impacts on the water balance because it causes actual evapotranspiration to approach the high potential evapotranspiration rates typical for this climate.

3.3.3 Drainage Layer

Design the drainage layer to minimize infiltration, leachate generation, slope stability problems, erosion, and to enhance access for maintenance equipment. Design the drainage layer of the final cover system by following the procedures below.

§ Specify properties, and performance criteria of granular drainage layers, including Unified Soil Classification, grain size distribution, maximum particle size, maximum percent passing No. 200 sieve, thickness and hydraulic conductivity.
§ Specify properties, and performance criteria of geosynthetic drainage layers, including polymer type and transmissivity.
§ Identify properties of granular filter layers, including Unified Soil Classification, grain size distribution and thickness.

- Specify properties of geosynthetics used for protective or filter layers.
- Analyze filter layer performance.
- Specify configuration, dimensions and properties of the collection pipe system.
- Develop exit drain design.
- Analyze drainage layer performance.

3.3.4 Protective Layer

An additional soil layer may be used to protect low-permeability layers from physical or environmental damage. Specify the protective layer's properties and dimensions, including Unified Soil Classification, grain size distribution, thickness, hydraulic conductivity and maximum particle size. If the protective layer is placed directly on a geomembrane layer, the design the protective layer must meet the following:

- Provide adequate rooting depth and soil moisture storage for selected vegetation.
- Protect the low-permeability layer against root penetration, freezing, drying and desiccation, and
- Protect geosynthetic layers from puncture and other physical damage.

3.3.5 Topsoil Layer

The primary function of the topsoil layer is to provide an optimal growing medium for desirable vegetation. Topsoil may be amended with wood waste, sewage sludge, or compost if applied appropriately at agronomic rates. Soil amendments should not cause odors, air-born contaminants or surface water quality problems. The top soil characteristics must be specified based on a thorough analysis of vegetation alternatives and fertilizer requirements.

3.3.6 Vegetative Layer

The vegetative layer's main functions are to minimize erosion and long-term maintenance, and to maximize evapotranspiration. The vegetative layer should be compatible with other cover-system components and easy to maintain. The vegetation to be planted must have the following creiteria:

- Shallow-rooted.
- Locally adapted.
- Resist drought and temperature extremes.
- Thrive in low nutrient soil with minimum nutrient addition.
- Establish dense growth to minimize cover soil erosion (limit is no more than 2 tons/acre/year), and
- Survive and function with little or no maintenance.

3.3.7 Alternative to Vegetative Layer

A vegetative layer may be incompatible with site climatic conditions or end use plan. If an alternative layer is planned, assess soil erosion, long-term maintenance requirements, and compatibility with other cover system components. The specified material should:

- Accommodate settlement without compromising function.
- Maintain positive slopes to promote surface drainage off the cover.
- Be stable and erosion resistant during extreme precipitation and/or wind, and
- Limit soil erosion to no more than 2 tons/acre/year.

3.3.8 Typical Cover System Design

The cover system for hazardous waste landfills recommended in the 1989 EPA guidance consists of the following:

- A top layer consisting of two components: (1) either a vegetated or armored surface component, selected to minimize erosion and, to the extent possible, promote drainage off the cover, and (2) a soil component with a minimum thickness of 60 cm (24 in.), comprised of topsoil and/or fill soil as appropriate, the surface of which slopes uniformly at least 3 percent but not more than 5 percent.
- Either a soil drainage (and flexible membrane liner [FML] protective bedding) layer with minimum thickness of 30 cm (12 in.) and a minimum hydraulic conductivity of 1 × 10-2 cm/sec that will effectively minimize water infiltration into the low permeability layer, and will have a final slope of at least 3 percent after settlement and subsidence; or a drainage layer consisting of geosynthetic materials with equivalent performance characteristics; and
- A two-component low-permeability layer that provides long-term minimization of water infiltration into the underlying wastes, consisting of (1) a 20-mil (0.5-mm) minimum thickness FML component and (2) a compacted soil component with a minimum thickness of at least 60 cm (24 in.) and a maximum in-place saturated hydraulic conductivity of 1 × 10-7 cm/sec.

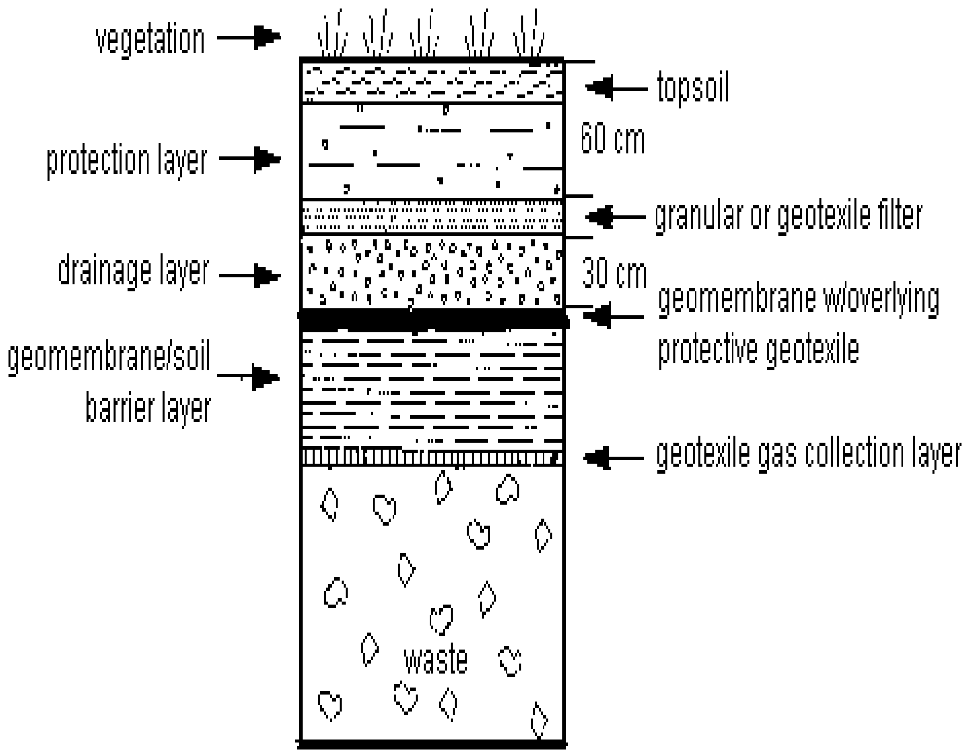

Figure 4: Typical Landfill Cap System.

Source: Landfill Cap: Environmental Expert article Published: October 1997

Table 1 summerizes the thickness, slope and specifications of a typical final cover system design (DEQ 1998).

Layer	Construction material	Thickness	Slope	Specifications
Top layer	vegetation	15 cm	---	persistent, drought resistant, adapted to local conditions, shallow-rooted
	on soil	45 cm	$\geq$ 2%	erosion rate < 2 tons/acre/year
Drainage layer	Soil (sand and gravel mixes)	$\geq$ 30 cm	$\geq$ 2%	soil K > 10^{-2} cm/sec
	geosynthetic	variable	$\geq$ 2%	performance equivalent to soil, hydraulic transmissivity > $3x10^{-5}$ m^2/s
Low-permeability layer	geomembrane (HDPE)	$\geq$ 1.5 mm	$\geq$ 2%	other types of FMLs should be at least 0.5 mm in thickness
	on low-permeability soil	$\geq$ 60 cm	$\geq$ 2%	in place K < 10^{-6} cm/sec

3.4 Gas Controls

By definition hazardous waste landfills contain negligible amount of organic waste, therefore the potential for gas emissions is not likely. However, mixing of waste categories is a common practice. Hazardous wastes, whether intentionally or not, are mixed with municipal solid wastes in many waste disposal practices, particularly in developing countries. To a leaser extent municipal wastes might also be mixed with wastes categorized as hazardous. For this reason elimination of municipal and/or organic wastes is not guaranteed consequently gas emissions are a valid probability.

The designer of a hazardous waste landfill in a developing country must take into consideration such misaction. On the light of this assumption a gas recovery and management system has to be installed just for conservative purposes particularly if the total capacity of the landfill exceeds 100,000 tonnes. For landfills exceeding this total capacity, an assessment of the potential emissions of methane gas emissions and the non-methane organic compounds (NMOCs) shall be carried out. If the assessment indicates that the emission of NMOCs exceeds or is expected to exceed 150 tonnes/year, the installation and operation of landfill gas recovery and management systems are mandatory.

Where a gas recovery and management system is installed, direct venting to the air of gases collected must be avoided. Combustion, even by incineration or flaring, should be encouraged over direct venting to the atmosphere to reduce odours and greenhouse gas emissions. Designing the system for landfill gas control must accommodate a wide range of operational and environmental variables, withstand harsh physical and/or environmental conditions, and function as long as needed.

The applied technologies for the landfill gas control system must be appropriate and fulfilling the following requirements:

- Flexible operationally
- Easy to construct and modify
- Durable (physically and chemically)
- Easy to monitor, and
- Easy to maintain and repair

Designing the landfill gas control system must meet the following design criteria:

- Handle the maximum gas flow rate predicted for the landfill
- Accommodate variability in gas generation, composition, and other operational parameters
- Expand as needed to collect gas from future cells

3.5 Surface Water Controls

Designing the surface water control system must meet the following criteria:

- Prevent run-on flow onto active or inactive portions of the landfill (assuming peak discharge from the 50-year storm).
- Collect and control run-off from active and inactive portions of the landfill (assuming a 24-hour, 50-year storm).
- Comply with the provisions of the storm water discharge.
- Control sediment transport and remove suspended solids as necessary.
- Collect and contain leachate contaminated stormwater that accumulates in active fill areas.
- Temporarily store excess run-off from peak flows until it can be discharged at a lower, controlled rate.
- Minimize site erosion.
- Protect the integrity and effectiveness of the landfill cover system, and
- Minimize post-closure maintenance requirements.

3.6 Access Roads

An appropriately constructed and maintained access road to and from the site, in addition to a road system within the landfill site capable of supporting all vehicles hauling waste are required during the operating life of the landfill. Various specifications and manuals from the local transportation authority must be available to assist in the design and construction of all-weather access roads. An all-weather access road should be provided from the public road to the site. This road, designed to safely accommodate the anticipated volume of vehicular traffic, should consist of two lanes of sufficient width and strength to carry the delivery vehicles. The grade of the access road should be maintained at 8 percent or less and its intersection with the existing public road should be carefully designed to reflect traffic volumes and safety requirements (Solid Waste Landfill Design Manual, Washington State Department of Ecology, 1987}.

Roads should be laid out to eliminate crossing of traffic and consequent tie-ups. Waiting space should be provided near the scales and parking areas should be provided for employee vehicles and landfill equipment. The access road generally terminates at the scale or other delivery control facility. Temporary roads utilized for transporting wastes from this point to the unloading area may be constructed of on-site soil with a topping of suitable material, such as gravel, crushed aggregate, cinders, broken concrete, or demolition wastes. Lime, portland cement, or asphalt may be used as binders to maintain stability and control dust.

3.7 Fencing and Signs

Fencing is required around the perimeter of the landfill as fending controls to limit the access to the landfill site. The type and extent of fencing will depend on topographic features. Woven and chain link fencing is commonly used for this purpose. All access points are to have locking gates. The site entrance should be locked when the site is unattended or otherwise closed to users. The entrance should be attractively designed and landscaped. A sign prominently located should identify the landfill site, the hours of operation, fees, and any restrictions on users or materials acceptable for delivery.

3.8 Buffer Zone

The site design plan must include a zone around the perimeter of the landfill site to buffer adjacent property, to limit access by unauthorized. persons and prevent litter, dust and noise from the site. The working area of the landfill should be visually separated from adjacent property by natural vegetation or by the use of plantings and berms which also reduce the problems of litter, noise and dust.

3.9 Buildings

A building should be provided for office space and employee facilities at most landfills. Very small sites may not require these facilities. Equipment used at the site should be provided with a shelter. A single building or shed may be used both for equipment maintenance and storage, as well as for the office purposes. Appropriate sanitary facilities must be provided for landfill employees and users of the site. Portable chemical toilets can be used for this purpose. At larger sites, employees should be provided with shower and lunchroom facilities. Buildings on sites that will be used for less than 10 years may be temporary types and may be movable. The design and location of all structures should consider gas movement and differential settlement caused by the decomposing solid waste.

3.10 Utilities

Hazardous waste landfills should be provided with power, water, and telephone. Power is required for maintenance of on-site operating equipment and for lighting. An electric generator may be installed rather than extending power lines to the site. Water in sufficient quantities and under adequate pressure is needed in the event of a fire, for machine maintenance, and for dust control. Potable water should be made available for site personnel. A telephone or radio should be provided for communications.

4. ALTERNATIVE CONCEPTS AND MATERIALS

An important objective of this document is providing speculations for applicable design alternatives and operating options for hazardous waste landfills in arid region to meet the cost effectiveness and successful performance. Landfill Engineers adopting alternative approaches have an important job ensuring that each part of a hazardous waste landfill new project demonstrates due diligence and that the finished project is functional, reliable, maintainable and safe.

Once potential alternatives have been developed, it may be necessary to screen out certain options to reduce the number of alternatives that will be analyzed. The screening process involves evaluating alternatives with respect to their effectiveness, implementability, and cost. It is usually done on a general basis and with limited resources, because the information necessary to fully evaluate the alternatives may not be complete at this point in the process.

Alternative approaches allowing for alternative construction and operational materials in certain components of the landfill liner and final cover system are now evolving and adopted particularly in arid region sites. The USA Sandia National Laboratories, have lunched The Alternative Landfill Cover Demonstration (ALCD) which is a developing technology to improve upon current landfill cover systems. The project provide alternatives to the EPA's landfill cover designs that would work more effectively and be easier and less expensive to install in arid and semiarid climates. The Technical Guidance for RCRA/CERCLA Final Cover Systems (Bonaparte et. al. 2003) addresses a number of alternative concepts, materials, and designs (including evapotranspiration (ET) barriers and capillary barriers). The guidance also highlights the development of new types of geosynthetics (such as geosynthetic clay liners (GCLs).

Over the past decade, the international regulatory process of constructing, operating, and monitoring landfills has matured, allowing for more flexibility particularly those landfills that are in remote arid region sites. In some countries municipalities and environmental affairs agencies, presently, are switching to more flexible regulations based on performance standards. Implementing performance-based standards need to have a regulatory staff that is capable of reviewing the detailed hydrogeology and modeling reports to prove that the landfill containment system's performance still meets the international and local standards.

It is realized that, during the past decade, improved construction materials relating to hazardous waste landfills, particularly landfill liners and final cover systems, continue to evolve. These provisions allow for future landfill construction to take advantage of alternative concepts and materials. This ability to use alternative materials may provide a market for some of the feedstock coming from communities recycling programs. For example, in Madison County, New York, using glass scraps to construct the landfill's primary drainage layer has saved the county $35,000 per acre in construction costs. Using tire chips in the landfill's leachate collection and removal system, and the gas venting layer also has reduced costs.

The alternative design concepts differ from designs with hydraulic barriers alone in that they are intended to emphasize the following:

- unsaturated hydraulic conductivities of the soil components;
- low hydraulic conductivity of fine-grained soil layer(s), even at high degrees of soil saturation;
- relatively high water storage capacity of fine-grained soil layer(s) with eventual removal of stored water primarily by evapotranspiration.
- increased transpiration through the use of diverse native vegetative; and
- ease of construction and/or substantial cost savings through the use of locally-available materials.

In this subsection some alternative criteria are presented which primarily based on some modifications to fit the needs of a 'typical' community in an economically developing country. Specifically, address the critical issues that should be considered for the design, operation, and monitoring of hazardous waste landfills along with other relevant topics. The alternative approaches described below are intended to help regulators and others develop a consistent approach to their evaluation, regulatory approval, and deployment of specific technologies at specific sites.

4.1 Landfill Caps

Most landfill cover requirements, which include a foundation layer, a barrier layer with a permeability of 10^{-6}, and a vegetative layer, don't function well in an arid climate. The cover of those landfills in arid climates dried and that the low permeability barrier layer was very expensive to construct. After three or four years, through wetting and drying cycles, the layer may break down and become ineffective. Some of the facilities in arid regions that complied with the international regulations are not now functioning as they initially were intended.

Typically, the most critical components of a landfill cap are the barrier layer and the drainage layer. The barrier layer can be low-permeability soil (clay) and/or geosynthetic clay liners (GCLs). A flexible geomembrane liner is placed on top of the barrier layer. Geomembranes are usually supplied in large rolls and are available in several thickness, widths, and lengths. The candidate list of polymers commonly used is lengthy, which includes polyvinyl chloride (PVC), polyethylenes of various densities, reinforced chlorosulfonated polyethylene (CSPE-R), polypropylene, ethylene interpolymer alloy (EIA), and many others. Soils used as barrier materials generally are clays that are compacted to a hydraulic conductivity no greater than 1 x 10^{-6} cm/sec. Compacted soil barriers are generally installed in 15-cm minimum lifts to achieve a thickness of 60-cm or more. A composite barrier uses both soil and a geomembrane, taking advantage of the properties of each. The geomembrane is essentially impermeable, but, if it develops a leak, the soil component prevents significant leakage into the underlying waste. All covers should be designed to prevent the "bathtub" effect. The bathtub effect occurs when a more permeable cover is placed over a less permeable bottom liner or natural subsoil. The landfill then fills up like a bathtub.

4.2 Alternative Landfill Caps

The design of an alternative landfill cover typically proceeds with a five-step process (ITRC, 2003).
(1) selection of performance criteria. (2) preliminary/conceptual design, (3) site characterization, (4) design sensitivity analysis/computer modeling, and (5) final design. Inclusion of all these steps is not required. For example, facility owners, operators, consultants, and regulators should determine the need for modeling early in the design process. In some situations, a risk-based approach may be more appropriate than a landfill cover percolation approach. Existing site data or data from similar sites, may make modeling unnecessary.

The most common landfill covers currently being used are the Environmental Protection Agency (EPA) Resource Conservation and Recovery Act (RCRA) C or D caps. These multi-layered cap systems are usually very expensive when compared to alternative solutions. Rough industry cost are $175k/acre for RCRA Subtitle D, and $225k/acre for RCRA Subtitle C).

Research has led to a variety of alternative landfill caps which are being field tested to gain regulatory approval (ALCD, 1992). There are many designs and components for these caps, including capillary breaks, geosynthetic clay liners (GCL), geo-membranes, vegetative caps, enhanced runoff, soil or evapotranspiration (ET) caps, or combinations of these.

Important questions to be addressed when designing an alternative barrier layer include the following:

- What materials should be used to construct the barrier?
- How thick should the barrier be to store the required amount of water?
- Are materials uniform and have appropriate placement methods been determined to minimize preferential pathways for percolation?
- What surface treatments should be applied to control erosion?
- Which plants should be established to promote transpiration and stabilize the cover surface?
- How and at what frequency should the barrier be maintained?
- What type and frequency of monitoring should be employed?

Alternative covers should be easier to build and should require a lesser amount of quality assurance (QA)/quality control (QC) during construction than conventional designs with hydraulic barriers.

4.2.1 Evapotranspiration (ET) Cover

This is the simplest type of alternative covers used instead of the traditional RCRA multilayered cover. It is composed primarily of a mono-layer consisting of native alluvium. Conceptually, the cover consists of two soil types, a topsoil layer to promote vegetative growth and reduce the potential for erosion by water or wind. The topsoil layer is underlined by a thick barrier layer that consists of relatively fine-grained. Soil

The principle upon which an ET cover works is that the soil layer holds incoming precipitation until it is removed by evapotranspiration. If the soil layer has sufficient storage capacity to hold the water until it can be removed by evapotranspiration, then no deep percolation will penetrate past the cover (Hauser, Weand, and Gill 2001a; Chadwick et al. 1999; Somasundaram et al. 1999). These covers usually employ a layer of soil on top of the landfill where grass, shrubs, or trees grow for the purpose of controlling erosion and removing water from the soil. Recent studies indicate that in the arid regions, mono-layer covers may be more effective at isolating waste than layered covers, and will effectively isolate waste from infiltrating water via evapotranspiration back to the atmosphere, even during wetter-than-average years (Levitt *et al*., 1996 ; Schmeltzer *et al*., 1996).

4.2.2 Capillary Barrier Cover

The capillary barrier (Figure 5) is formed by two layers—a layer of fine soil over a layer of coarser material (e.g., sand or gravel). The name is derived from the break in pore structure that results at the interface of the two soil types. The barrier is created in this type of cover by the large change in pore sizes between the layers of fine and coarse material (Ankeny et al. 1997, Stormont 1997, Gee and Ward 1997).

Capillary force causes the layer of fine soil overlying the coarser material to hold more water than if there were no change in particle size between the layers. Soil water is held in the fine-grained layer by capillary forces and will not move into the coarse-grained layer until the fine-grained layer approaches saturation near the interface. (Stormont 1997; Jury, Gardner, and Gardner 1991). This barrier can fail if too much water accumulates in the fine-particle layer or if the desired large change in pore size is missing in spots. Quality control in constructing a capillary break layer may be particularly important to prevent mixing of the coarse-grained and fine-grained layers and to ensure that flaws in the capillary break do not cause failure (Morel-Seytoux 1996). Stability of the capillary break function is dependent on maintaining a clear separation between the fine and coarse layers (Stormont 1997). This may require a layer of geotextile (or from graded soil, coarse at the bottom and fine at the top) between the layers to prevent mixing of the fines into the coarse for the required time period.

4.2.3 Asphalt/Concrete Cap

Another cost-effective yet efficient landfill cap is the Asphalt/Concrete Cap. It is effective single-layer cap that is composed of concrete or bituminous asphalt. It is used to form a surface barrier between landfill and the environment. An asphalt concrete cap would reduce leaching through the landfill into an adjacent aquifer.

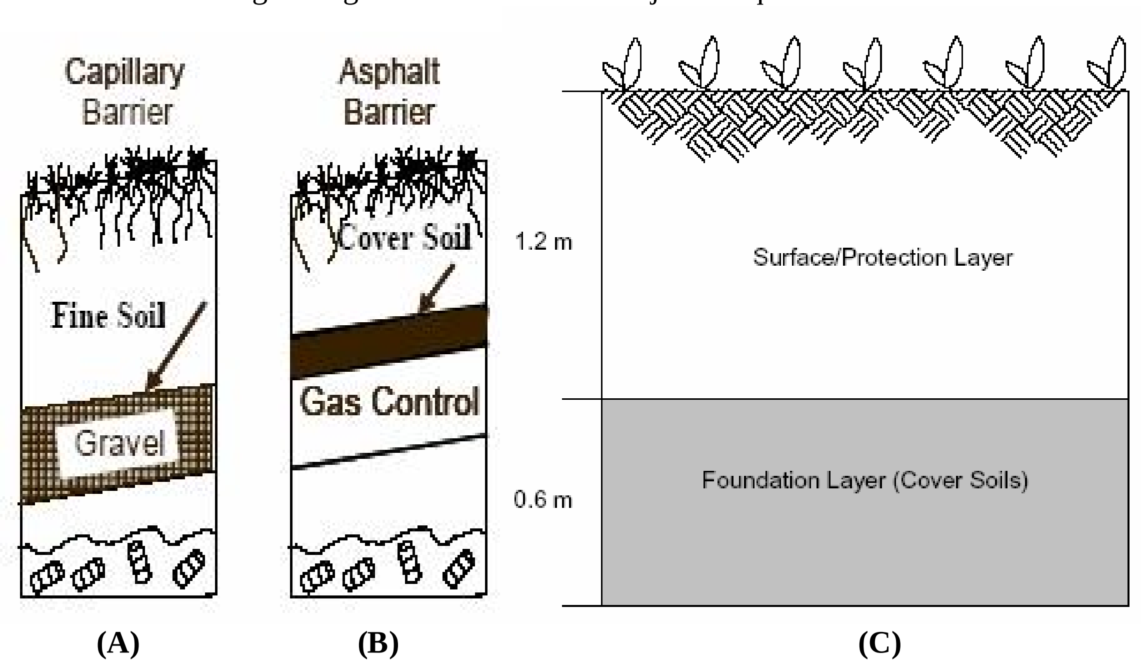

Figure 5: (A) and (B) alaternative covers with barriers, (C) evapotraspiration cover.

4.3 Alternatives Liner systems

4.3.1 Natural Attenuation (NA)

The issue of construction of a bottom liner is a difficult one for a number of developing countries. Therefore, the identification of, and justification for, any reliance on the capacity of the geological environment for natural containment and/or natural attenuation of leachate sufficient to avoid groundwater pollution is a big concern as far as cost effectiveness is considered.

To determine whether natural attenuation (NA) is appropriate as an alternative of landfill liner depends upon whether the appropriate environmental conditions are sufficient to sustain adequate rates of degradation to ensure compliance with the groundwater protection within a given period of time and also depends on the degree of confidence that the attenuating mechanisms will adequately protect human health and the environment.

To test the applicability of (NA) we have to analyze available physical, chemical and biochemical methods of degradation or attenuation of the pollutant(s). Natural attenuation involve mechanisms such as dilution, dispersion, (bio)degradation, irreversible or reversible sorption. All these mechanisms lead to a net reduction of contaminant toxicity and risk for humans and their environment.

Among the other alternatives is the use of naturally occurring liner bed such as impermeable clay layer. A natural soil liner should be at least 120 cm thick and should have a permeability less than 1 x 10^{-6} cm/sec. Cheaper natural materials such as activated clays mixed with lime have been used as a bottom liner. In altimate cases, a particular type of waste can be used directly, or with suitable processing, as a low permeability material in a bottom liner.

4.3.2 Dense Asphaltic Concrete (DAC) and Bituminous Membrane (BM) liner

Because of its versatile properties of durability, flexibility and water resistance among many others, asphalt is widely used across the entire spectrum of modern industry, and especially in construction and civil engineering. Dense Asphaltic Concrete (DAC) and Bituminous Membrane (BM) liners are now recognized as the premier lining for landfills. Compared to clay, the traditional material, DAC and BM offer considerable advantages to designers, operators and environmental regulators.

The following are the advantages of using DAC and BM as a liner for landfills:

- Thin construction which maximizes fill volume.
- Offers horizontal as well as vertical engineering freedom.
- Less haulage traffic as it require low volume of imported materials
- Does not require maintenance during filling
- No investment in haul roads - traffic runs on DAC
- Impermeable, and resistant to hydrocarbons
- Withstands stresses and shear forces caused by settlement
- Superior liner performance guaranteed by modified design of materials
- Cost-effective.

Table 2 compares the structure and properties of DAC and BM.

Material	Structure and properties	Applications
Bituminous Membranes (BM)	-Thin, watertight layers of bitumen -Sprayed or spread manually -Usually reinforced by geotextile -Impermeable -Prepared on-site or supplied in prefabricated rolls	Landfill linings
Dense Asphaltic Concrete (DAC)	-A filled mixture of crushed stones or gravel, sand and filler -After compaction, voids are nearly completely filled with bitumen (void content <3%) -Impermeable -Stable on steep slopes -Unsuitable for application under water or in the tidal zone	Landfill linings

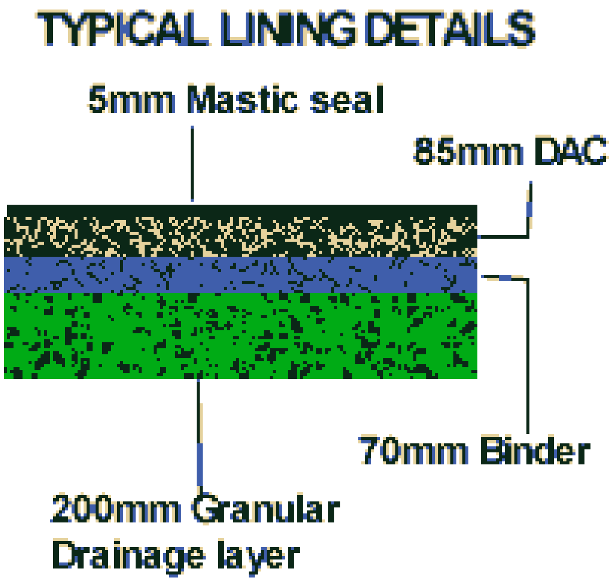

Figure 6: Design Details for DAC liner.

Source: Hesselberg Hydro 2002, see link in the references

Vertical Linings for Landfill Sites by DAC

Disused quarries are increasingly being exploited in the search for prime landfill sites. They are particularly suited to lining with asphalt. The workings generally present a large horizontal area with near-vertical sides to be sealed. An impermeable, robust and flexible vertical asphaltic lining can be constructed which is easy to build up in stages. The technique has the following advantages

- Quarry floor regulated with binder asphalt then lined with 85mm DAC
- Vertical liner typically 300mm, or more thick to withstand shear forces
- High quality joint between horizontal and vertical membranes formed by hot asphalt weld
- Paver adapted with special beam to place thin core plus transition material
- Up to three 200mm layers placed per day
- DAC is economic to install and operate for the following reasons
- One paver can install a maximum of 500m daily to a height of 600mm so the technology is economic for fairly long stretches.
- Optimal void space is achieved by raising the lining in stages, each providing the volume for six months or one year of operation. Thus, investment in liner is spread over several years, thus helping cash-flow.
- The asphaltic option is even more attractive where suitable rock is available in the quarry and/or an asphalt plant is situated nearby. Often, in operating or former quarries the developers will have their own asphalt plant on site so they can supply the material and reducing the cost of the liner considerably.

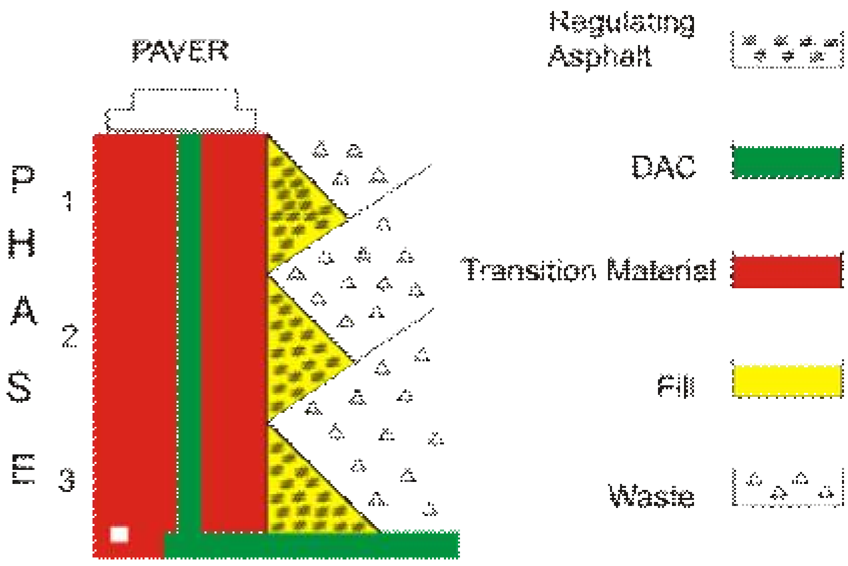

Figure 7: Design of vetrical liner using DAC.

Source: Hesselberg Hydro 2002, see link in the references

4.3.3 Natural Soil as Alternative Liner

The use of natural soil as a liner for solid waste landfills is a common practice. These soils may have a low permeability and a high adsorption capacity for certain contaminants. These soils may exist uniformly over the entire site and with grading, remolding and recompaction the standard liner design can be achieved. In some cases, on-site soils may not be suitable in their natural state, or may be concentrated in one area of the landfill requiring excavation and placement. With additional remolding and compaction, these soils may be made satisfactory. When on-site soils do not meet minimum design criteria, suitable off-site soils can be imported, remolded and compacted to form a flow impeding layer.

Thus soil for a landfill liner is potentially available from two sources, on-site and imported. On-site soils are preferable for two reasons. First, they are more economical because additional property is not needed for the source material and transportation costs are greatly reduced. Second, use of on-site excavated soils eliminates the need to find alternative uses for the soil or areas to dispose of the excess. If on-site soils of suitable characteristics are unavailable, then a borrow source off-site must be located. Proximity to the landfill site is an important factor to reduce transportation costs. Estimates of required soil volumes are based on the thickness of the liner and the area of the active fill. It is important to include side liners in this calculation as well. For every acre of active fill area, 1,475 cubic meters of compacted soil is required to achieve a liner thickness of 30 cm. Available soil volume is calculated from geologic information. Normally, geologic information is plotted on vertical cross-sections through the area of interest. Volume is calculated based on the indicated thickness of the formation and an estimate of its areal extent. In areas where there is significant heterogeneity of the soils, an adequate number of borings or other information is required to lend confidence to the volume estimates. This can be determined by an experienced geologist.

Consideration must be given to the volume differences between loose and compacted soils. Table (3) provides approximate conversions between in-place volume and loose and compacted volume.

Volumes of Loose and Compacted Soil from One Cubic meter of In-place Soil

Type of Material	No. of meters	
	Loose	Compacted
Sandy-clayey loam	1.14	0.82
Clay	1.31	0.82
Sand	1.01	0.87

Table 3: Approximate conversions between in-place volume and loose and compacted volume.

Source: D. P. Krynine and W. R. Judd (1957)

Failure to account for loss of volume by compaction for clay soils could result in underestimating required in-place volumes by over 10 percent. For a thirty-acre landfill with a 60 cm thick compacted liner, the in-place volume requirements could be underestimated by over 8105 cubic meters.

The important physical characteristics required for soil liners can be determined from grain-size distribution, Atterberg limits and permeability measurements. Grain-size distribution curves indicate the uniformity of soil particle size and the percentage of fines. Fines are defined as soil particles less than 0.074 mm in diameter (U.S. Standard Sieve No. 200). Roberts, (1984). Atterberg limits are essential factors in evaluating the behavior of clay type soils used as liner materials. Permeability is obviously an important consideration in the evaluation of the soil material because of its direct effect on the ability of the soil liner to contain the leachate.

The required engineering characteristics of the soil must be tested. Engineering characteristics refer to the ability to manipulate the soil to achieve the desired results. This is measured by the Standard Proctor compaction test and permeability tests. The Standard Proctor compaction test is preferred over the Modified Proctor test because it is more closely matches actual field compaction densities (Schaefer, 1978). Permeability measurements should be conducted at densities and moisture contents that can be achieved in the field. It is extremely important to match laboratory and field conditions as much as possible to avoid large errors in predicted soil permeabilities.

4.4 Intermittent, Intermediate Cover

An intermittent (daily) cover should be placed on all exposed waste at the end of the day. The depth of the cover should be sufficient to cover all waste completely, and if soil or a similar material is used, this should be at least 15 cm. The waste should be thoroughly compacted before the cover and new layers of waste are added. The ideal cover material is a mixture of clay and sandy soils. Daily cover operations are needed for:

- vector control

- controlling the breeding of mosquitoes and flies
- limiting access to birds, rodents and other animals to the waste
- reducing the exposure of the waste to the elements and controlling litter
- minimizing odors
- preventing and controlling the spread of fires within the landfill
- reducing the amount of water reaching the solid waste mass (from precipitation, run-on and run-off).

The use of a compacted soil cover also offers a safe and solid surface for vehicles, thus providing for adequate mobility of vehicles around the working face and limiting damage to tyres. Finally, a landfill covered with a 15 cm layer of soil is more aesthetically pleasing than one without a soil cover.

An intermediate cover of low permeability should be used on all the facility's filled surfaces if no additional waste will be deposited within 30 days. The intermediate cover should be at least 30 cm of soil or similar material is used. The cover should be properly compacted and graded, to prevent erosion and water from ponding.

4.5 Design of Monitoring Wells

Groundwater monitoring is an important technical requirement in managing hazardous waste disposal facilities. The purpose of monitoring is to assess whether and how a disposal facility is affecting the underlying groundwater system.

Groundwater monitoring wells are installed in and around a landfill site to permit water level measurement and sampling of groundwater and leachate. They are typically constructed of 50 mm diameter threaded polyvinyl chloride (PVC) plastic pipe with manufactured well screens.

All constructed wells should be tested to determine the hydraulic conductivity of the formation, and to determine if they are sufficiently responsive to the hydraulic flow system to provide reliable monitoring data.

4.5.1 Construction

Each monitoring program should be considered unique when determining monitoring well construction materials. The choice of construction material will depend on the following factors; cost, availability, strength, chemical and physical compatibility with analyte (the element or compound being tested for), groundwater and leachate. There is a variety of materials on the market with a wide price range.

Due to availability and cost, PVC tends to be the most common choice. However, recent studies investigating the adsorption and release of organic compounds by rigid PVC have led EPA to recommend the use of well construction materials made of polytetrafluoro-ethylene (PTFE) or stainless steel as opposed to PVC. Unfortunately, the costs of stainless steel and PTFE are five to seven times and ten to fifteen times, respectively, more expensive than PVC. In certain cases it may be advantageous to design a well using more than one type of material. For example, where stainless steel may be preferred in a specific chemical environment, costs may be saved by using PVC in non-critical portions of the well.

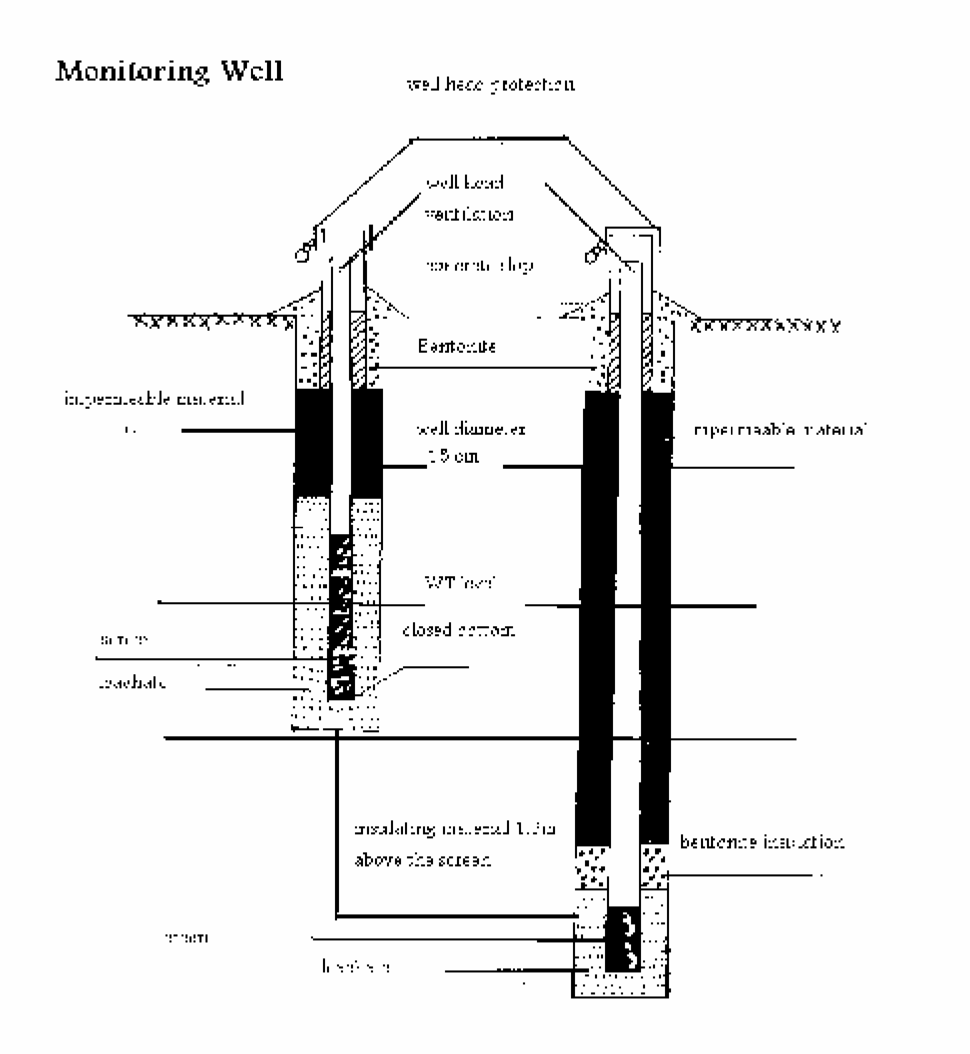

Figure (8) Typical design of a monitoring well

Source: Bagchi, A (1994)

In order to effectively detect and evaluate potential or existing groundwater contamination at a landfill, there are three principal locations for groundwater monitoring wells

- A minimum of one well upgradient from the landfill to establish background water quality, and to establish water level elevations and hydraulic gradients for determining groundwater flow into, or below, the landfill. Although one upgradient well is the minimum, it is recommended that two upgradient wells be installed to give some idea of background water quality variability.
- A well immediately adjacent to the downgradient edge of the filled area, with screen intercepting the water table to enable sampling of 'raw' leachate for chemical

constituents at the contaminant source and to measure fluid levels for determining leachate position in relation to the refuse.

§ A line of three wells situated downgradient from the landfill and perpendicular to groundwater flow in the horizontal plane to detect and determine the extent and concentrations of any leachate plumes; to assess groundwater levels, flow directions, and flow rates; and to assess leachate impacts on receptors (e.g. supply wells and receiving waters).

In arid areas where ground water level is at great depths (>50 m), we can set up the down gradient wells to be at greater distances from the edge of the landfill. Accordingly, existing nearby wells in the down gradient side can be used to monitor contamination by leachate from landfills. If the groundwater depth is greater than 100 m, it is expected that leachate will be naturally attenuated prior to reaching this depth assuming no fractures conduits exist in the subsurface layers beneath the landfill. In such a case groundwater monitoring wells can be exempted.

4.5.2 Monitoring Wells Alternatives

Several possible alternatives to full ground-water monitoring requirements, including;: as mentioned above, using existing wells to sample ground-water; reducing the list of constituents being monitored for; sampling materials in the unsaturated zone; collecting soil gas samples from the unsaturated zone, surveying the electrical resistivity of the soil beneath the landfill, and using gypsum block to detect moisture beneath the landfill. These alternatives are a subset of options that could be chosen according to local conditions.

Possible alternate ground-water monitoring constituents include the following:

§ Water quality constituents: Sodium, Potassium, Calcium, Manganese, Chloride, Sulfate, Nitrate, Carbonate

§ Constituents that are considered leachate indicators: BOD, COD, TOC, Calcium, magnesium, sodium, chloride, sulfate, Stable isotopes (e.g., "light" hydrogen is preferentially metabolized in landfills undergoing methanogenesis, ground water is preferentially enriched in deuterium), conductivity, Ph (e.g., research indicates that biodegradation of organic contaminants causes an acidification of ground water in oxidizing environments), Hardness (may be related to increasing acidity caused by degradation of organic matter), Alkalinity (may be related to increasing acidity caused by degradation of organic matter), redox potential, TDS, Phosphate, Ammonia, Microbiologic toxicity.

5. DESIGN REPORT

Prepare a design report that includes the following information:

- Executive summary, conclusions, recommendations
- Design basis, main assumptions, design criteria, and site constraints
- Descriptions of key landfill components and their design functions
- A written explanation of the detailed design drawings and specifications
- A demonstration that landfill components will function as designed
- Results of design-related materials testing
- Preliminary specifications for construction materials, and
- Engineering analyses and calculations used to develop the design

To facilitate the local authority's review, design reports, design plans and specifications and other related documents should have the same organizational format. Design documents should be sufficiently detailed to enable the local authorities to determine whether mandatory standards and performance criteria have been achieved.

Tables 4, 5, 6 represent the minimum requirements of design, Liner components, and landfill Capping adopted from (DWF, RSA 1998).

Table 4: Minimum Requirements for Landfill Design (Adopted from DWAF; RSA, 1998)

LEGEND **B- = No significant leachate produced** **B+= Significant leachate produced** **R = Requirement** **N = Not a requirement** **F = Flag: special consideration to be given by expert or Departmental representative**	**CLASSIFICATION SYSTEM**									
	G General Waste								**H Hazardous Waste**	
	C Comunal Land		**S Small Landfill**		**M Medeium Land**		**L Large Landfill**		**H:h Hazard Rating 3 & 4**	**H:H Hazard Rating 1-4**
Minimum Require	**B-**	**B+**	**B-**	**B+**	**B-**	**B+**	**B-**	**B+**		
Appoint a Responsible Person	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Conceptual Design Confirm site classificati	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Assess cover volume	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Indicate unsaturated zon after cover excavation	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Determine available airs	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Estimate airspace utilisa	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Estimate site life	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Address any impacts identified by investigati and/or by the IAPs	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Site layout design	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Surface drainage design	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Development Plan	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Closure/Rehabilitation F	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Design of leachate management system	**N**	**N**	**N**	**R**	**N**	**R**	**N**	**R**	**R**	**R**
Design of the toe drains	**N**	**R**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Monitoring system desi	**N**	**N**	**F**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
End-use Plan	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Testing of soils and mat	**N**	**N**	**N**	**F**	**F**	**F**	**F**	**F**	**F**	**F**
Technical Design Surface hydrology and drainage design	**N**	**N**	**N**	**F**	**R**	**R**	**R**	**R**	**R**	**R**
Consult lining requirem in	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**

Worksheet 2										
Water quality monitorin system	**N**	**F**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Leachate detection syste	**N**	**F**	**F**	**N**	**R**	**N**	**R**	**N**	**N**	**N**
Leachate treatment syste	**N**	**N**	**N**	**F**	**N**	**R**	**N**	**R**	**R**	**R**
Leachate management a monitoring s	**N**	**F**	**N**	**R**	**N**	**F**	**N**	**R**	**R**	**R**
Gas management and monitoring system	**N**	**N**	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**
Consult cover requireme in ***Worksheet 3***	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
Stability of slopes	**N**	**N**	**F**	**F**	**F**	**F**	**F**	**R**	**R**	**R**
Erosion control c	**N**	**N**	**F**	**F**	**R**	**R**	**R**	**R**	**R**	**R**
Design drawing specifica	**N**	**N**	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**
Approval of Tecl D	**N**	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**

Table 5: Minimum Requirements for Liner Componenets (International Standards)

LEGEND **B - = No significant leachate produced** **B+ = Significant leachate produced** **R = Requirement** **N = Not a requirement** **F = Flag: special consideration to be given by expert or Departmental representative**	**CLASSIFICATION SYSTEM**									
	G General Waste								**H Hazardous Waste**	
	C Comunal Lan		**S Small Landf**		**M Medeium Lan**		**L Large Landf**		**H:h Hazar Ratin 3 &**	**H:H Hazar Ratin 1-4**
Minimum Requiremer	**B-**	**B+**	**B-**	**B+**	**B-**	**B+**	**B-**	**B+**		
12 Waste body	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
11 Dessication protection	**N**	**N**	**N**	**N**	**R**	**N**	**R**	**N**	**N**	**N**
10 Leachate collection layer	**N**	**N**	**N**	**R**	**N**	**R**	**N**	**R**	**R**	**R**
9 Cushion layer	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**R**	**R**
8 1,5mm or 2mm geomembrane	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**R**	**R**
7 Compacted clay liner	**N**	**N**	**N**	**N**	**N**	**R**	**N**	**R**	**R**	**R**
6 Geotextile layer	**N**	**N**	**N**	**N**	**N**	**R**	**N**	**R**	**R**	**R**
5 Leakage detection layer	**N**	**N**	**N**	**N**	**N**	**R**	**N**	**R**	**R**	**R**
4 Cushion layer	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
3 1mm geomembrane liner	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**	**N**
2 Compacted clay liner	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
1 Base preparation layer	**N**	**N**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**

Note: Numbers 1 - 12 indicate order of construction.

Table 6: Minimum Requirements for Landfill Capping (International Standars).

LEGEND B_- = No significant leachate produced B_+ = Significant leachate produced R = Requirement N = Not a requireme F = Flag: special consideration to be given by expert or Departmental representative	**CLASSIFICATION SYSTEM**									
	G **General Waste**								**H** **Hazardous Waste**	
	C **Comunal Lan**		**S** **Small Land**		**M** **Medeium Lan**		**L** **Large Land**		**H:h** **Haza** **Ratir** **3 &**	**H:H** **Haza** **Ratir** **1-4**
CAPPING COMPONENTS	B_-	B_+	B_-	B_+	B_-	B_+	B_-	B_+		
5- Layer of Topsoil	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
4- Compacted Clay Layer	N	N	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**
3- Geotextile Layer	N	N	N	N	N	**R**	N	**R**	**R**	**R**
2- Gas Drainage La	N	N	N	N	N	**R**	N	**R**	**R**	**R**
1- Shaped and Compacted Waste Surface	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**	**R**

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7- Annexes

Annex (1)
Attendance Sheet for Participants of Expert Group Meetings

Email	*Third Expert group meeting 23-26/5/2005*	*Second Expert group meeting 22-25/11/2004*	*First Expert group meeting 5-8/7/2004*	*Name*	*Country*
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