Quantitative and Qualitative Assessment of Landfill Leachate

A Dissertation Submitted in Partial Fulfillment
for the Award of the Degree of

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With specialization in

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Submitted by
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CERTIFICATE

This is to certify that the project titled **“QUANTITATIVE AND QUALITATIVE ASSESSMENT OF LANDFILL LEACHATE”** being submitted by Mr. Amber Bhadani, is a bonafide record of student’s own work carried by him under our guidance and supervision in partial fulfillment of requirement for the award of the Degree of **Master of Engineering in Civil Engineering specializing in Environmental Engineering, Department of Civil and Environmental Engineering, Delhi College of Engineering, Delhi, University of Delhi.**

The matter embodied in this project has not been submitted for the award of any other degree.

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ABSTRACT

In India, groundwater represent majority of portable supply, especially 88% in rural areas. Any contamination of groundwater would pose a significant strain on the potable water-distributing unit because rehabilitation of polluted ground water is expensive, and may not be technically feasible. The aim of this project is the quantitative and qualitative assessment of landfill leachate. The study involves three aspects: first, to do the chemical analysis of landfill leachate. The leachate generated from MSW Landfills can impose detrimental affects on ground water quality, as it can percolate from the soil strata to the underlined aquifers. Second, a water balance was performed so as to predict the amount of leachate generated at the landfill site. The lack of data regarding the amount of leachate pumped and treated since the start of operation of the landfill makes it impossible to validate the calculated amount of leachate formed. It should be acknowledged that the calculations were based on many assumptions, which undeniably yield very rough results. In the third step, quantity of leachate is measured based on the concept of field capacity. Monthly meteorological data were employed with an option provided to convert them into daily average value to match the daily time step if required.

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List of Abbreviation used in equations

L	Leachates Formed
Li	Leachates Infiltration
Lc	Collected Leachates
Ig	Water from Underground
b	Water Production by biodegradation of Waste
j	Leachate Recirculation
Ron	Run on
AET	Actual Evotranspiration
Us	Water Content in soil Cover
Wv	Water lost as water Vapour
Wg	Water Consumed in the Formation of landfill Gas
R	Runoff
P	Precipitation
PET	Potential evotranspiration
Roff	Runoff Coefficient
FC	Field Capacity
MC	Moisture Content

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Chapter 1

INTRODUCTION

1.1 General

Groundwater is the largest source of freshwater on our planet, representing over 90% of the readily available freshwater reserves. It is defined as water that is found underground in cracks and spaces in soil, sand and rocks. This resource has two distinct functions: firstly, it is a significant source of both urban and rural water supply and secondly it sustains many wetland ecosystems.

In some areas of the world, people face serious water shortages because groundwater is either used faster than it is naturally replenished or it is polluted by human activities Groundwater can be polluted by landfills, septic tanks, the widespread use of road salts and chemicals, by leaky underground gas tanks, and also from overuse of fertilizers and pesticides Figure 1.1 shows some sources of groundwater contamination. Pollutants can accumulate over years in the groundwater and suddenly become mobilized when the assimilative capacity of soil is exceeded, thus steadily diminishing the amount of clean water they can yield for human use.

Ground water has unique features which render it particularly suitable for public water supply. It has excellent natural quality, usually free from pathogens, colour and turbidity and can be consumed directly without treatment. Ground water is widely distributed and can be frequently developed incrementally at points near the water demand, thus avoiding the need for large scale storage, treatment and distribution system. Ground water is particularly important as it accounts for about 88% safe drinking water in rural areas, where population is widely dispersed and the infrastructure needed for treatment and transportation of surface water does not exist. Ground water plays an important role in agriculture, for both watering of crops and for irrigation of dry season crops. It is estimated that about 45% of irrigation water requirement is met from ground water sources. Industrial demands for ground water are also high, as many of the qualities which make ground water a preferred source of potable water (low salinity, low turbidity, lack of pathogens) are also important in use of ground water in various industries. Unfortunately, the availability of ground water is not unlimited nor it is protected from deterioration. In most of the instances, the extraction of excessive quantities of ground water has resulted in drying up of wells, damaged ecosystems, land subsidence, salt water intrusion and depletion of the resource. Ground-water quality is being increasingly threatened by agricultural, urban & industrial wastes which leach or are injected into underlying aquifers. It has been established that once pollution has entered the subsurface environment, it may remain concealed for many years, becoming dispersed over wide areas of ground water aquifer and rendering ground water supplies unsuitable for consumption and other uses. The rate of depletion of ground water levels and deterioration of ground water quality is of concern in major cities and towns of the country. The National Capital Territory of Delhi is one, which is facing severe problems in management of ground water quality and quantity.

Any contamination of groundwater would be a significant strain on the water distributing unit because rehabilitation of polluted groundwater is expensive, and often may not be technically feasible. Secondly, this means that water has to be abstracted from other sources and this would result in conflicts with other uses, especially if the land is facing a drought period, which is often the case.

One way to protect aquifers is to control activities which pose a threat to groundwater quality, especially in areas where underground water is naturally poorly protected.

Very few countries have regular monitoring programs to gauge the health of their aquifers. This is partly logistical since it is extremely costly to track the health of underground water resources adequately.

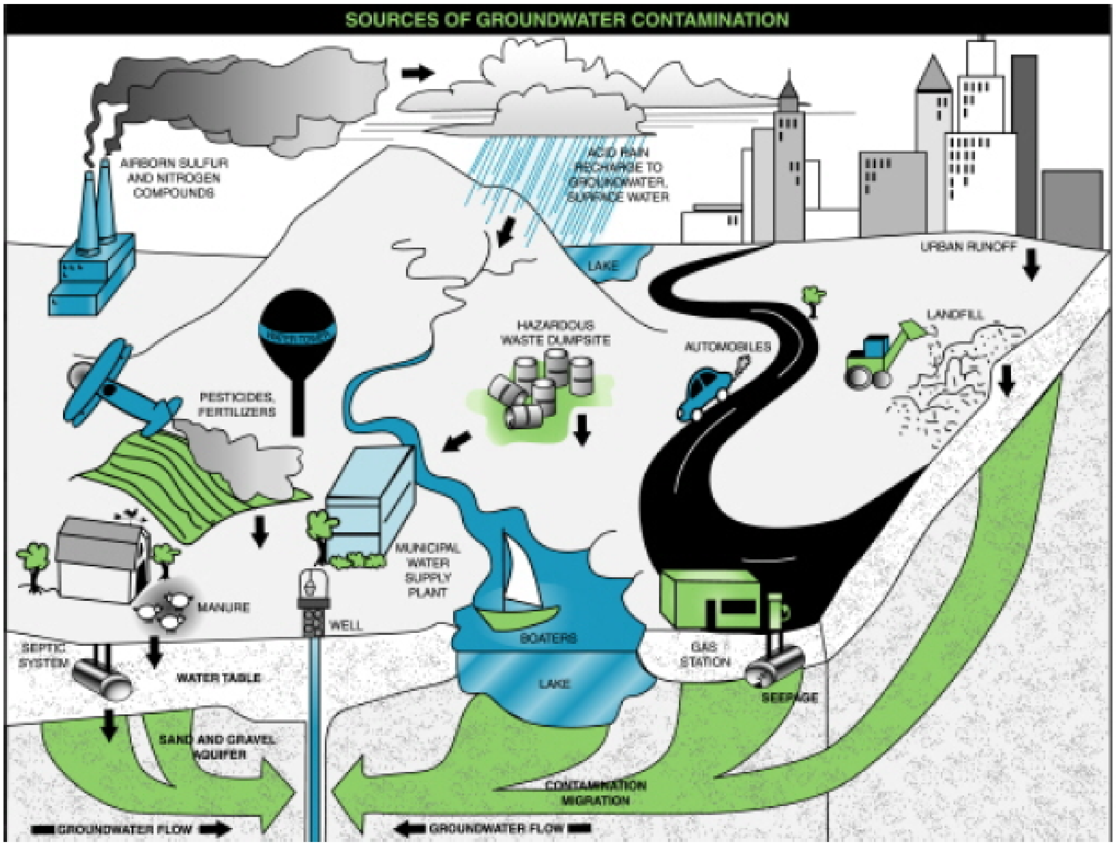

Fig.1.1 Sources of ground water contamination

1.1 Water Resources in Delhi

1.1.1 General

The water requirement of NCT of Delhi constitute mainly for the drinking water supply of its growing population. The NCT of Delhi is occupying an area of 1483 sq km and having six administrative blocks namely Alipur, Kanjhawala, Najafgarh, Mehrauli, City and Shahdara. The water supply resources in Delhi are continuously under severe pressure due to ever increasing population and industrial activities. The metropolitan city became a major centre of commerce, industry and education after independence. The growth of government departments and office complexes has contributed to the city growth. Civic amenities have not kept pace with increasing urbanisation. The unabated immigration of population has compounded the problems, resulting in flouting of land use regulations and restriction and deterioration of green cover.

The quality of ground water within Delhi varies from place to place along with the depth of water table. It also varies with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it. The kind and concentration of dissolved salts depends on their sources and nature of sub-surface environment.

In context of the above scenario, a collaborative study has been undertaken by the Central Ground Water Board and Central Pollution Control Board, to assess the ground water quality and suitability for various uses particularly drinking and irrigation purposes including pollution aspects within NCT - Delhi. Within the purview of the joint project study, the ground water samples were collected through extensive field surveys covering entire NCT - Delhi area representing various geo-hydrological and land use conditions. The ground water sampling locations represented hand pumps, dug wells and tubewells located in urban and rural areas including thickly populated, commercial, industrial, residential colonies and agricultural areas so as to obtain a comprehensive lateral and vertical representation.

The estimated water availability from surface water sources viz. Yamuna, Ganga & Bhakra system is 1150.2 mcm. The Yamuna River contributes a substantial part to this. Of the total 724 mcm water available in Yamuna river, (NCT Delhi share) the flood water is about 580 mcm, of which 50% could not being utilized but flows out of Delhi.

1.1.2 Water Utilization

The requirement of raw water in Delhi would be about 400 litres/capita/day (lpcd) considering the transmission losses in bringing raw water from distant sources. The total estimated of water in 2001 would be to the extent of 4.88 million cubic metres per day (MCM/day) considering the massive population increase.

The master plan 2001 for Delhi, suggests the water consumption norm of 364 litres per capita/day (lpcd) as detailed below:

S. No.	**Water use**	**Consumption litres/capita/day**
1.	Domestic	226
2.	Industrial, Commercial and community requirement based on 45000 litres per hectare per day	47
3.	Fire production based on 1% of total demand	04
4.	Garden based on 67 litres per day	35
5.	For floating population & special uses	52
	Total	**364**

1.1.3 Ground Water Resources

The ground water availability in the National Capital Territory - Delhi is controlled by the hydro-geological situation, characterized by occurrence of alluvial formations and quartzite hard rocks. The hydro-geological set up and the ground water occurrence is further influenced by the following distinct physiographic units

1. Alluvial plain on eastern and western sides of the ridge

2. Yamuna river flood plain deposits

3. Isolated and nearly closed Chattarpur alluvial basin

4. NNE-SSW trending Quartzitic Ridge

The Delhi ridge, which is the northern most extension of Aravali mountain range, consists of quartzite rocks and extends from southern part of the territory to western bank of river Yamuna for about 35 kilometres. The alluvial formations overlying the quartzitic bed rock have different nature of either side of the quartzitic bed rock have different characteristics on either side of the ridge. The Yamuna flood plain contains a distinct river deposits. The nearly closed Chattarpur alluvial basin covers an area of about 48 km^2, is occupied by alluvium derived from the adjacent quartzite ridge.

Table1.1 General stratigraphic sequence in NCT- Delhi

Quaternary	Newer Alluvium	Unconsolidated, inter-bedded lenses of sand, silt, gravel and clay in narrow flood plains of Yamuna river.
	Older Alluvium	Unconsolidated inter bedded, inter-fingering deposits of sand, clay and kankar, Moderately sorted. Thickness variable, at places more than 300 meters.
Pre-Cambrian	Alwar Quartzite	Well stratified, thick bedded, brown to buff colour, hard and compact, intruded locally by pegmatite and quartz veins inter-bedded with mica schist.

1.2 Purpose and Scope of Study

Quantitative and qualitative assessment of landfill leachate is the aim of this project.

The outcome of the study will provide an insight of the existing situation and can also be used to aid in decision making for planning issues such as issues related to prospective types of land use in the region, water resources development, health aspects, etc.

The amount of leachates generated from the landfill can exceed the pumping and treatment capacity of the leachates treatment plant since the landfill has not been originally designed to accept waste from the whole country. Henceforth, the risk of having a high volume of leachates and its subsequent seepage into the ground is high. The third reason is that contamination by leachate poses a great threat to groundwater resources since leachates contain multiple pollutants which might not be easy to remove or treat.

The specific objectives are to:

1 Carry out sampling and analysis of leachate around the perimeter of the landfill.

2. Carry out a water balance at the landfill to determine the amount of leachates generated and to estimate the amount seeping into the ground.

3. Collect the necessary data specific to landfill site conditions.

Chapter 2

LITERATURE REVIEW

2.1 General

The landfill, as we know it, has evolved from a long tradition of land disposal of MSW dating back to prehistoric times. Problems with land disposal began as society developed, and population density increased. land disposal of waste often as open dumps was subject to aesthetic, safety, and health problems that prompted innovations in design and operation. Environmental impacts associated with MSW landfills have complicated sitting, construction and operation of the modern landfill. Production of leachate has lead to documented cases of groundwater and surface water pollution. Landfill gas emission can lead to malodorous circumstances, adverse health effects, explosive conditions, and global warming.Traffic,dust,animal and insect vectors of diseases, and noise often are objectionable to nearby neighbors.

Modern landfills have liners at the base, which act as barriers to leachate migration. However, it is widely acknowledged that such liners deteriorate over time and ultimately fail to prevent the movement of leachates into an aquifer (Lee,1996) It can take years before groundwater pollution reveals itself; and chemicals in the leachates often react synergistically and often in unanticipated ways to affect the ecosystem.

2.2 Landfill Leachate

2.2.1 Leachate Generation and its Characteristics

Leachate is generated primarily as a result of precipitation falling on an active landfill surface, although other contributors to leachate generation include groundwater inflow, surface water runoff, moisture from emplaced waste, and biological decomposition. The quantity of leachate produced is impacted by the following factors: precipitation, type of site, groundwater infiltration, surface water infiltration, waste composition and moisture content, preprocessing of waste (baling or shredding), cover design depth of waste, climate, evaporation, evapotranspiration, gas production, and density of waste. Continuous production of leachate will occur once the absorptive capacity of waste ha been satisfied. Leachate quantity is site specific and ranges from zero in arid states to nearly 100 percent of precipitation in wet climates during active landfill operation. Leachate production from new landfills occurs at relatively low rates, and then increases as more waste is placed and larger areas are exposed to precipitation. Leachate production reaches a peak just before closure and then declines significantly with the provision of surface grading and interim or final cover.

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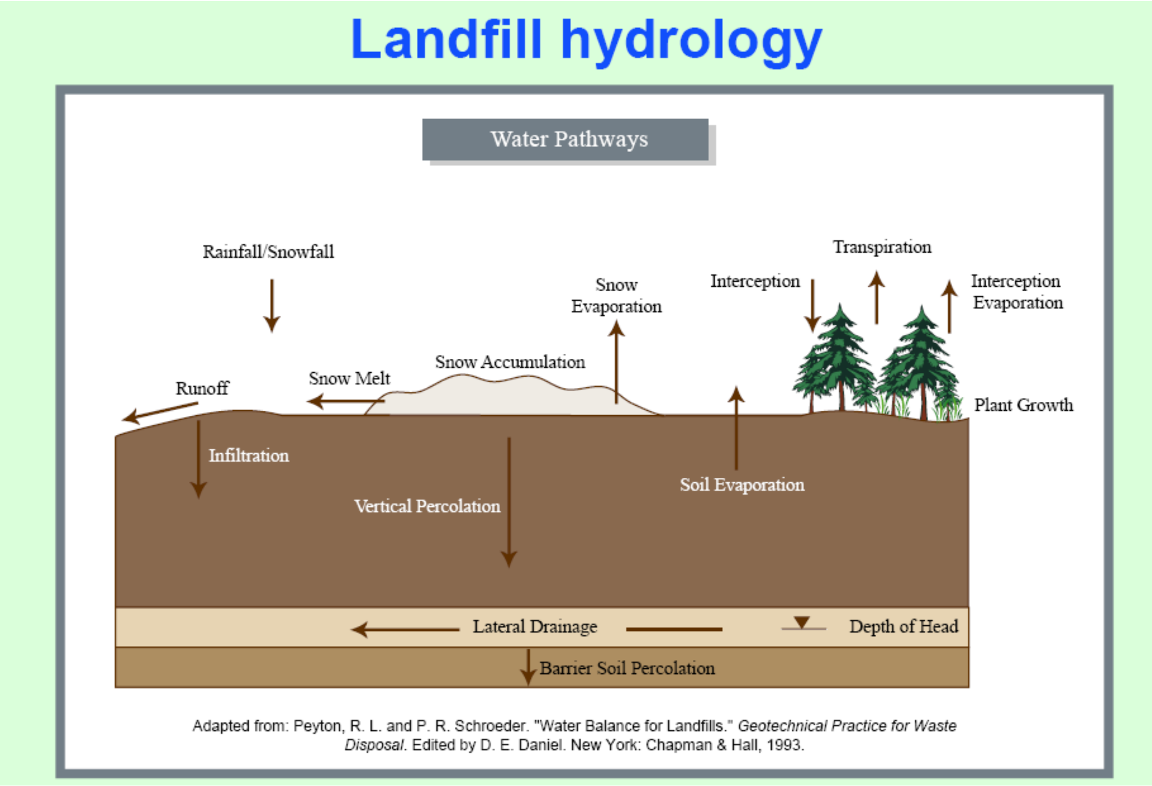

Adapted from: Peyton, R. L. and P. R. Schroeder. "Water Balance for Landfills." *Geotechnical Practice for Waste Disposal*. Edited by D. E. Daniel. New York: Chapman & Hall, 1993.

Fig 2.1 Landfill Hydrology

2.2.2 Landfill Containment System

The concepts of containment systems for modern sanitary landfills involve the use of barrier layers to prevent leachate from leaving the landfill and contaminating the underlying soil and groundwater, and to prevent water from entering the landfill to create leachate. Barrier layers are constructed of materials that possess a low permeability to water. The most common materials include compacted soil (clay) and synthetic membranes (geomembranes). The containment layer at the bottom of a landfill is known as a liner and the one at the top is referred to as a cap. While conceptually the barrier layers may be thought of as one unit, they are in reality multiple layers of different materials, and are more accurately referred to as liner and cap systems.

2.2.3 Compacted Soil Barrier Layer

Many soils naturally posse's characteristics that make them relatively impermeable to water flow. Clay soils are a good example of a naturally impermeable material. Because of the small particle size and the surface chemistry of clay minerals, a clay deposit in the environment greatly restricts the arte of water movement. Natural clay deposits sometimes are used as landfill barrier layers. In most sanitary landfills, however, clay liners are constructed by modifying the structure of the clay soil brought to the site by the addition of water and mechanical compaction to achieve optimum engineering characteristics.

A number of properties make compacted soil amenable to use as a component in a landfill containment system. These include mechanical properties such as shear strength, but most importantly, the permeability of the clay to water. The engineering parameters relating the permeability of a porous media to the flow of water is the hydraulic conductivity. Most engineered clay liners must meet regulatory requirements for hydraulic conductivity of less than 10^{-7} cm per second.

The hydraulic conductivity of a compacted soil, along with many other parameters, must be tested routinely during soil liner construction.

2.2.4 Synthetic Barrier Layers

Geosynthetic may be defined as synthetic materials, mostly plastic, which are commonly used in place of, or to enhance the function of, natural soil materials. Geosynthetics used in both municipal solid waste (MSW) and hazardous waste (HSW) landfills and other waste containment systems are geomembrane, geotextiles and geosynthetic clay liners (GCL).The function type and material properties of each of these geosynthetics are discussed.

Geomembrane

Types and functions: Geomembranes are flexible, polymeric sheets that have extremely low permeability and are typically used as liquid or vapor barrier.

In landfills, geomembranes are typically used in place of or in addition to low permeability soils as a base or cover liner, Base liners are below waste to minimize liquids expelled from and/or filtered through the waste (known as leachate) from contaminating the underlying ground and mast important, the ground water. Cover liners are placed above the final waste configuration to keep water, usually from are in or snow, from entering the waste and producing leachate. If a building or other structure is constructed on a landfill, a geomembrane may be placed under the building foundation to provide a barrier from vapors such as landfill gas.

The type of geomembrane most commonly used for landfill base and cover lining systems are PE geomembranes. This is due primarily to the high chemical resistance and durability properties of PE geomembranes.

Base lining systems typically use a highly-density polyethylene (HDPE) geomembrane. This material is somewhat rigid but generally has good physical properties and can withstand the large stresses often imposed on the geomembrane during construction and installation. Due to the large settlement that may occur in refuse, cover lining systems require a more flexible geomembrane.Very low density polyethylene (VLDPE) is often used in this application since it has many of the same properties as HDPE but is more flexible and cam more readily conform underlying refuse settlement without puncturing. PVC geomembrane are used as liners for many waste containment applications, such as contaminated soils containment and liquid storage ponds.

GEOTEXTILES

Geotextiles are synthetic fabrics used in geotechnical engineering for various applications. The majority of geotextiles are composed of polypropylene or polyester fibers; a small percentage is composed of polyamide or polyethylene. In waste containment facilities, geotextiles are most commonly used for filtration, separation, reinforcement, cushioning, and drainage. A relatively new application for geotextiles is an alternative daily cover over refuse. Typically, non woven geotextiles are used in waste containment facilities for filtrations, separation, cushioning, and drainage. Woven geotextiles are usually used for reinforcement. Both woven and nonwoven geotextiles may be used for alternative cover.

Geosynthetic Clay Liners

Geosynthetic clay liners (GCL) are very low permeability barriers consisting of a layer of unhydrated, loose granular or powdered bentonite which is chemically or mechanically adhered to a geotextile or geomembrane. The GCL are formed in panels approximately 51 feet wide by 100 feet long which are joined in the field by overlapping. They are generally used as an alternative to compacted clay liners.

Difference between GCLs and compacted clay liners are presented in table 2.1

TABLE 2.1- Difference between GCLs and Compacted Clay Liners

Characteristic	Goesynthetic Clay Liner	Compacted Clay Liners
Materials	Bentonite clay, adhesives, Geotextiles, and Geomembranes	Native soils or blend of soil and bentonite
Construction	Manufactured and then Installed in the field	constructed in the field
Thickness	Approximately 10 mm	Approximately 0.5 to 1.0 mm
Hydraulic Conductivity Of clay	10^{-7} to 10^{-8} cm/sec	10^{-8} to 10^{-7} cm/sec
Speed and ease of construction	Rapid, simple installation	Slow, complicated construction
Water content at Time of Construction Water	essentially dry; cannot desiccate during construction and produces no consolidation	Nearly saturated; can desiccate and can produce consolidation water
Cost	\$5 to \$11 per square meter	range \$8 to \$32 per square Meter

Some advantages of GCLs over their compacted clay liner counterparts are that they are flexible, somewhat self heating, and fairly easy to install. In locations where low-permeability clays are not readily available, they may offer significant construction cost savings. Also, since they are factory manufactured with good quality control, field construction quality assurance costs are typically less than with a compacted clay liner. However, since GCLs have been used in landfill applications for a short time, further research and information is still required on long tern performance of GCLs in the field application, standardized test methods, GCL hydration behavior, internal shear strength, shear strength against adjacent materials, and the hydraulic performance of overlapped seams. There has also been some expressed over the ability of GCLs to provide intimate contact with adjacent geomembranes.

Liner System Components

Lining systems are used for two purposes in landfills, as cover to minimize leachate generation and surface water contamination by providing a barrier from precipitation and other percolating waters, and as containment liners to contain leachate and minimize its downward migration into underlying groundwater. The components of these systems are similar since they are both barriers, however, there differences in regulatory requirements and other design and performances-related issues. Lining systems in surface impoundments are for containment only and are placed on the base and side slopes to minimize liquid migration into underlying groundwater. Examples of the various types of bases, side slope, and cover liners are illustrated in fig.

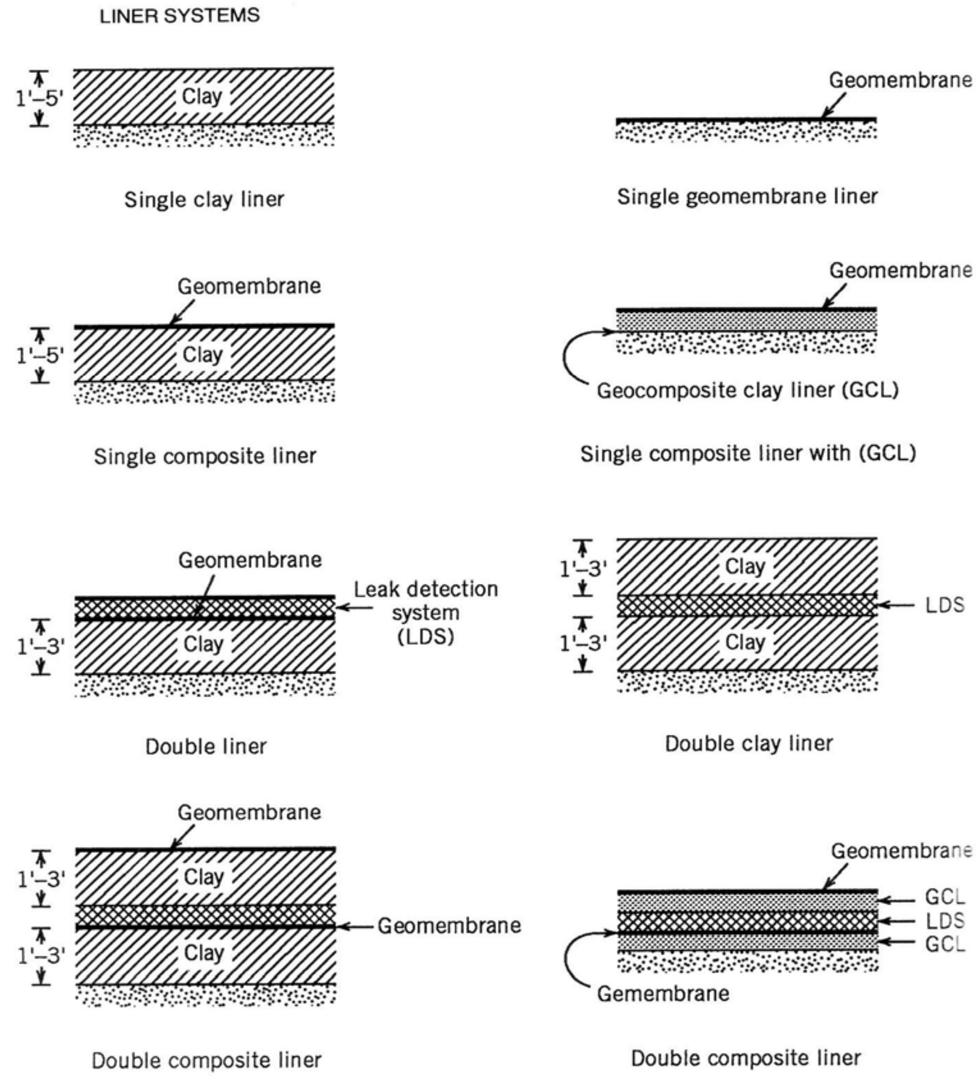

Figure 2 Base lining system configuration.

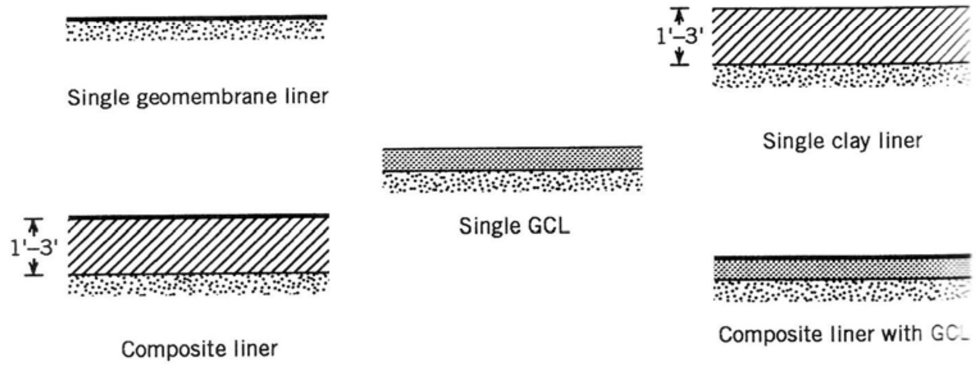

Figure 3 Cover lining system configuration.

Fig.2.2 Lining System Configuration

Containment Liners (Bases and Side-Slope Lining Systems)

Prior to the early 1980s, base liners are generally consisted of 1- to 5-foot thick compacted low permeability soil materials. Clay was and still is used, since they are natural, relatively inert, generally available barrier materials. Recommended clays are those having USCS classification of CH, CL, and MH.

Although clay or admixed liners minimize leachate flow rates, they cannot prevent leachate flow; once leachate is absorbed in the clay, it is only a matter of tome before it will migrate through the barrier. For an added factor of safety, double composite liners may be used. Double liners and double composite liners consist of two single or composite lining systems separated by a secondary LCRS or a leachate detection, collection, and removal system (LDCRS). The upper single or a composite liner is generally known as the primary liner with the bottom liner correspondingly the secondary liner. The mechanisms of containment and leakage are generally the same for both the primary and secondary liners; however, if the primary liner is a functioning adequately, there should be minimal leachate head above the secondary liner.

The current EPA prescriptive regulations for MSW landfill base liners require a 2-foot-thich clay liner with a minimum permeability of 10^{-7} cm/sec, overlain by a minimum 30-mil-thick geomembrane. If HDPE geomembrane are used, their minimum thickness must be 60 mils, since a thickness less then 60 mils may be difficult to seam. For hazardous waste landfills, double liners are required. The double liners include a top liner (e.g.; a geomembrane) designed to prevent the migration of hazardous constituents into the liner during the active life and post closure period and composite bottom liner consisting of a geomembrane underlain by at least 3 feet of compacted soil material having a hydraulic conductivity of no more than 10-7 cm/sec

Cover Lining Systems

Lining systems for the covers are different than base lining systems because they provide a barrier from water rather then leachate. The chemical resistance required for covers is therefore less than that required for base liners. Cover liner are, however, more susceptible to durability and exposure concerns, such as clay desiccation, erosion, freeze-thaw conditions, burrowing animals, and root penetration. Also, due to the high compressibility of MSW refuse, cover liners must be flexible enough to withstand damage by potentially large differential settlements. The settlement may be not be as significant in hazardous waste landfills.

Cover liners generally incorporate 1 to 2 feet of firm foundation material overlain by clay and/or geomembrane liner .The firm foundation is especially required in compressible MSW landfills to provide an adequate base for compaction of the overlying clay liner. However, even with a firm foundation, the clay liner is susceptible to potential cracking due to differential settlement of the underlying waste. More flexible barriers, such as geosynthetic clay liners (GCLs), may be used in place of clay.

The GCLs typically consist of thin hydrated bentonite mats encased in a geotextile or adhered to geomembrane. Bentonite is an extremely low permeability soil, which when hydrated swells and conforms to the surrounding topography. Its major is that it has low shear strength and therefore may create a weak plane along which a stability failure may occur. In the past, the geotextile surrounding the bentonite mats were mostly for encasement. The newer GCLs, however, reinforce the bentonite mat with geotextile fibers to increase the shear strength.

The geomembrane used in cover liners must be flexible, have high puncture resistance, withstand imposed stresses, and be durable under the condition to which they are exposed. Until the late 1980s, HDPE geoembranes were used. However, VLDPE geoembrane are now more commonly used for covers, due to their flexibility and good puncture resistance. PVC geomembranes are also commonly used.

The permeability of cover liners should be less then or equal to the permeability of the base liner. This to prevent the build up of leachate within landfill known as the bathtub effect. If leachate accumulates in a landfill, without proper removal, it may leak out the sides and potentially contaminates surface waters. This would obviously be undesirable.

To prevent desiccation and damage of the cover liner and minimize infiltration, a vegetated soil layer is placed above the cover liner. The vegetated soil layer promotes surface water runoff and protects against erosion. The vegetation should be drought resistant self supportive, dense enough to minimize soil erosion and have roots that will not penetrate the low permeability layer. In climates where vegetation cannot be maintained, rocks and cobbles may be used in place of the vegetated soil layer.

To minimize seepage of infiltration waters through the cover liner, a drainage layer may be placed between the cover liner and the vegetated soil layer. Typically, a 1- foot-thick layer granular drainage material or a geonet may be used. Toe drainage around the perimeter of the landfill is often used to collect the water from the drainage layer. Pipes may also be placed within the drainage layer to increase its efficiency; however it is important that these pipes not damage the underlying liner and are flexible enough to withstand the potential differential settlements. The drainage layer is often sandwiched between geotextile or soil filters to minimize clogging due to soil infiltration or root penetration.

As illustrated in fig. the EPA minimum guidance for hazardous waste landfill cover systems is, from bottom to top:

- Minimum 24-inch low permeability soil layer with a maximum hydraulics conductivity of 10^{-7} cm/sec
- Minimum 20-mil geomembrane
- Drainage layer consisting of either a minimum 1 foot of granular drainage material with a minimum hydraulics conductivity of 10^{-2} cm/sec or geosynthetic drainage material having the same characteristics.
- A soil or geosynthetic filter layer to prevent soil or root clogging of the drainage layer
- A minimum 2-foot-thick vegetated soil layer graded at a slope between 3 and 5 percent.

2.3 Leachate Effects

Leachate contain a host of toxic and carcinogenic chemicals, which may cause harm to both humans and the environment (Lee,1996) .Appendix 1 gives details about the health effects of contaminants in leachates. Furthermore, leachate-contaminated groundwater can adversely affect industrial and agricultural activities that depend on well water. For certain industries, contaminated water may affect product quality, decrease equipment lifetime, or require pretreatment of the water supply, all of which cause added financial expenditures. The use of contaminated water for irrigation can decrease soil productivity, contaminate crops, and move possibly toxic pollutants up the food chain as animals and humans consume crops grown in an area irrigated with contaminated water (O Leary &Walsh,1995).

2.4 Formation of Leachate Plume

Gravity causes leachates to move through the landfill, to the bottom and sides, and through the underlying soil until it reaches the groundwater zone or aquifer.

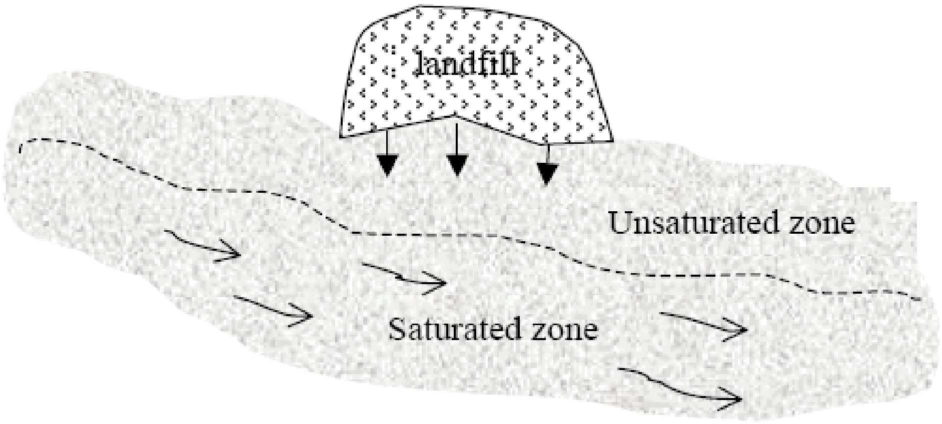

Fig. 2.3 Movement of leachate from landfill to Ground Water

As leachates move down the subsurface, they mix with groundwater held in the soil spaces and this mixture moves along the groundwater's flow path as a plume of contaminated groundwater as shown in figure

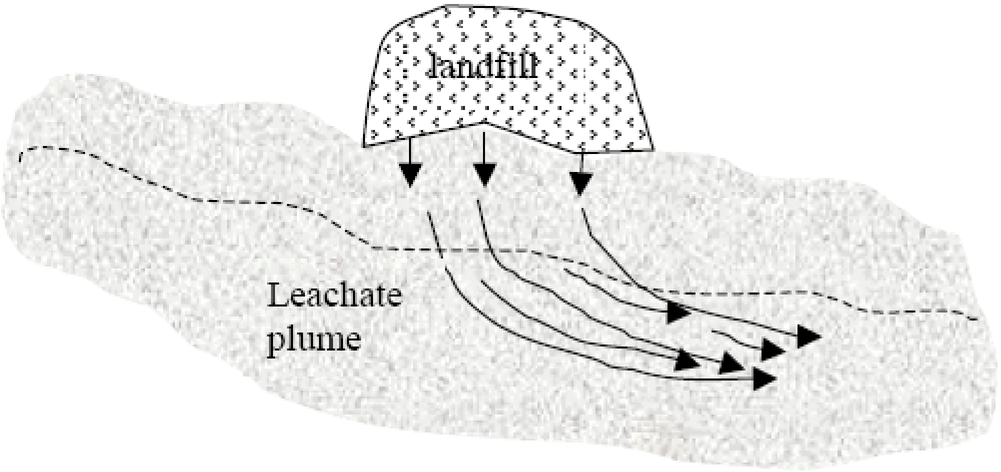

Fig. 2.4 formation of Leachate plume

The leachates contaminants first enter the unsaturated zone and eventually are transported to the groundwater table in the saturated zone Figure 2.3 gives an overview of the zones1 that exist underground

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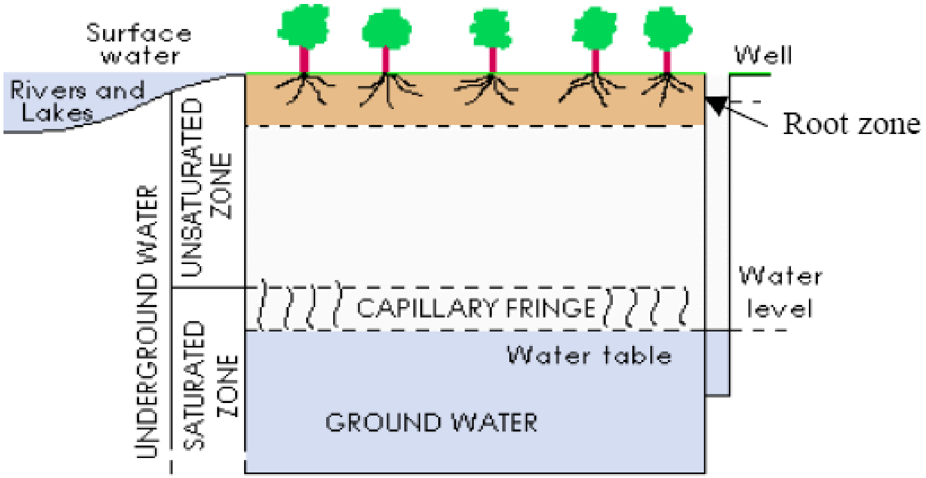

Fig 2.5 Subsurface Vertical Statigraphy

Chapter 3

GENERAL DESCRIPTION OF BHALASWA LANDFILL

3.1 Introduction

Bhalaswa landfill is located in a North West corner of Delhi, on the northern side of the G.T.K bypass. It is surrounded by localities such as Bhalaswa and Jehangirpuri.

The landfill was established and commissioned in 1990-91 and about 15 years of service is, well past its commissioned life. At the current rate, it might last for another year at maximum.

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The Bhalaswa landfill site occupies 40 hectares of land that was once used for sugar cane plantation. The total volume available for waste containment is about 2.9 million m^3. It is actually receiving 2400-2500 tons of wastes per day and at such rate, the expected active life of the landfill has almost been crossed. However, plans to extend the landfill site are underway. Thus, a risk analysis of groundwater in the surrounding of the landfill site will not only help to gauge how well the landfill site is performing but also provides some basis for further expansions of the site.

3.2 Organization

The landfill is publicly owned and is managed by MCD. The contract concerns operation and management of the site consists mainly of activities relating to receipt of the waste, processing and burial, treatment of leachate, on-going site preparation and restoration. The weighing bridge system is run by a private agency under contact with MCD. Operation and maintenance of the weighing bridge is done by the agency. The trucks arrive on the weighing bridge and the weight is automatically registered on the computer and the receipt is printed out and handed over to the driver on the way back. At the end of the day, comprehensive report is printed out which shows the truck number and the amount of garbage dumped on a trip.

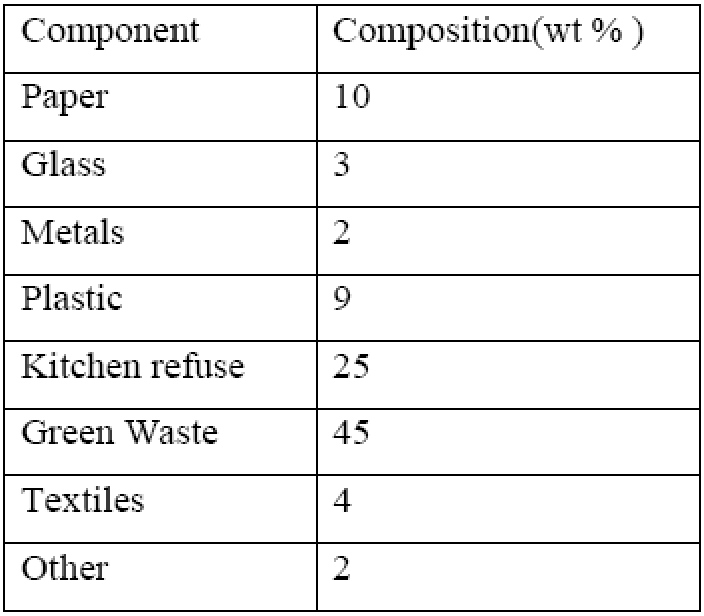
3.3 Incoming Waste: Type and Amount

The incoming wastes originate mainly from households and commercial areas, but there are also some wastes that are brought to the landfill from industries. However, before being carried to the landfill, the wastes undergo compaction at transfer stations. Sorting of wastes are neither carried out at the transfer stations nor at the landfill.

Latest figures show that about 2400-2500 tons of wastes are being landfilled daily and that figure is expected to increase significantly in the coming years. It has been estimated that about 70-75 % of the wastes can be classified as municipal waste.

It is also worth noting that waste segregation as at the point of generation is not carried out. This action would have reduced the volume of waste going into the landfill. All the waste produced are landfilled with a low percentage (4-5%) being reused or recycled. Since once in the landfill, paper, garden and food waste decompose under microbial action into various gases, water and other compounds, it can be deduced from table 3.1 that more than 70% of the wastes are biodegradable.

Table3.1 Solid Waste Composition



Component	Composition(wt %)
Paper	10
Glass	3
Metals	2
Plastic	9
Kitchen refuse	25
Green Waste	45
Textiles	4
Other	2

3.4 Physical and Geographical Conditions at Bhalaswa Landfill

3.4.1 Landfill Site Description

The landfill site is approximately square in shape with an area of about 40 hectares. The site was originally a depression in the ground-now its height is around 60 meters from NGL. The proposed height is around 30.0 meters.

The sanitary landfill is divided into a number of cells. On a particular day, any one cell is selected and all the dumping is done on that cell. A cell is demarcated by access road on its sides. A soil cover is given after about 3-4 feet of material has been dumped the soil cover is usually of Malba. One compartment of the landfill has been constructed so as to accept hazardous wastes likely to cause health and environmental problems. However, the hazardous wastes cell has not been filled because the regulations concerning the types of wastes that should be accepted at the landfill have not been finalized yet.

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3.4.2 Hydro Meteorological Conditions

Bhalaswa landfill site lies in the North West part of Delhi. The average rainfall is in the range of 611.8 mm/year. The precipitation over NCT-Delhi generates surface water runoff through streams, drains and as sheet flow. Delhi being highly urbanized area, the run off water is quite high due to extensive pavement. Considering a run off coefficient of 30% in urban areas and 12% in other areas, the total surface run off is estimated to the extent of 162 MCM. The major part of this surface run off generally contributes to Yamuna flow in the mid and down stream part of the river, while a portion contributes to sub soil water and recharge the ground water.

3.5 Leachate Characteristics of Bhalaswa MSW Landfill

The leachate generated from MSW landfills can impose detrimental affects on ground water quality, as it can percolate from the soil strata to the underlined aquifers. Hence, an attempt has been made to identify the concentration of various constituents in Leachate, at Bhalaswa MSW landfill site, which can contaminate the ground water quality of its surrounding areas. An analysis has been carried for various parameters. The results obtained are indicated the table given below Table 3.2

Table 3.2 Results of Leachate Analysis of MSW Landfill Bhalaswa

Sl.No.	Parameters	Units	Concentration
1	pH		8.04
2	Conductivity	mho/cm	28500
3	Total hardness	mg/l	1424
4	Calcium	mg/l	464
5	Alkalinity	mg/l	1361
6	Chloride	mg/l	1172
7	Fluoride	mg/l	0.853
8	Magnesium	mg/l	644
9	Phosphate	mg/l	0.347
10	Nitrate	mg/l	0.461
11	Sulphate	mg/l	196
12	Sodium	mg/l	2837
13	Potassium	mg/l	55
14	Boron	mg/l	6.12
15	Nitrate	mg/l	86
16	COD	mg/l	3613

3.6 Leachate Management at Bhalaswa Landfill

3.6.1 Barrier

Since when this landfill is came into being, no lining was done, therefore the leachate is able to percolate through the garbage and the lower soil layers and eventually mixes with the ground water. Local public has reservation about the ground water quality. However, no major disease has been reported.

3.6.2 Leachate Collection System

At the landfill there is a proper leachate pond for the collection of the leachate. However, no treatment to leachate is being provided. No recirculation of the leachate is done. Instead, it is fed off to the adjoining nallah. This creates possible contamination issue for the groundwater.

3.6.3 Gas Collection System

Gas collection system does not exist. In summer, the garbage catches fire. Even in present condition, smoke can be seen coming out of the dumps at various places. The working personnel complained of weak eyesight due to exposure to methane

3.7 Compost Plant at Bhalaswa Landfill

Composting and manufacture of manure is done at a site adjacent to Bhalaswa landfill. Fresh garbage is at first kept at yard station where actual process of composting is carried out. Each MCD truck brings about 4 tonnes of garbage. About 800 tonnes of garbage accumulates per day at this place.

At this site heap of about 200 tonnes are made. These heaps are about 16-17 m in length and 3 metre high. A culture, commonly known as culture bio column, is prepared out of the heap by mixing 3 litters of water and 500gm culture per tonne of garbage. After 2 days the temperature of the heap rises to about 40-50C in winter and to about 70-75c in summer. If the temperature rises to more than 80C water has to be sprinkled. After 7 days first turning is done during which 300gm culture /tonne of garbage is added. After another 2 days the temperature normally rises to 60 to 70 degree Celsius. Again after 7 days the aeration is done in the 3rd stage. The material will be composted after 7 days of aeration the color of waste turn brownish black and there will be no odor.

The composted material is then sent to the compost plant which was established in December 1999. The whole material is then transferred to a platform for segregation of stones etc. then the material is sent to a turmoil where particles greater then 50 mm are screened out while those less than 50 mm are passed through a conveyer to another turmoil from which particle less than 20 mm come out. After this 2nd turmoil the whole material is reduced to about 40% by weight. After this the material is sieved by 4mm sieves by vibration. Then the final material is packed in 50 kg bags which are sold at Rs 1.50 to 2.00 per kg. The final manure which is produced is about 20 to 30% of the initial volume of the garbage. On the money which comes by selling of the manure 2 to 3% royalty is given to the MCD.

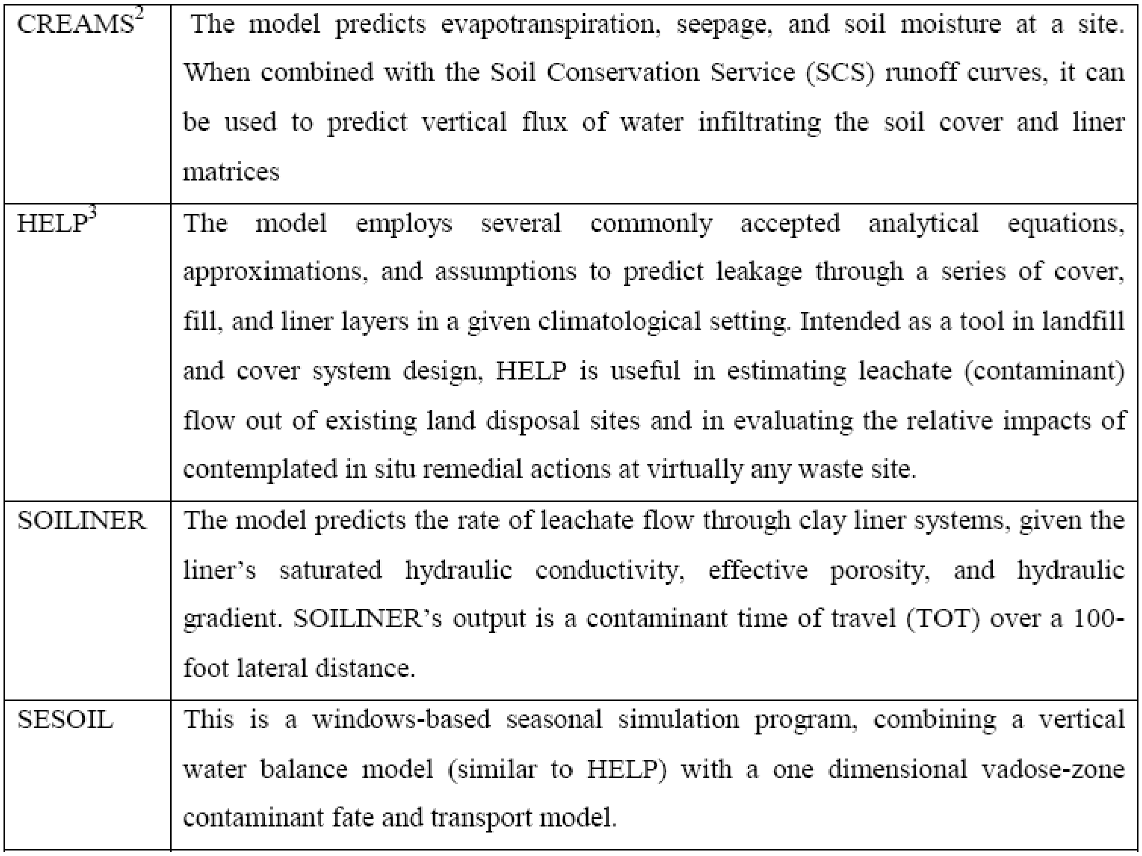
Chapter 4

METHODOLOGY AND MODELS EMPLOYED

4.1 Introduction

Analytical water balance method aims at predicting the quantity of leachate generated at solid waste disposal sites as a function of water infiltration and cell design. Some computerized models now in use to predict the generation of leachates and these are briefly described in table 4.1.

Table 4.1 Computerized Water Balance Models



CREAMS[2]	The model predicts evapotranspiration, seepage, and soil moisture at a site. When combined with the Soil Conservation Service (SCS) runoff curves, it can be used to predict vertical flux of water infiltrating the soil cover and liner matrices
HELP[3]	The model employs several commonly accepted analytical equations, approximations, and assumptions to predict leakage through a series of cover, fill, and liner layers in a given climatological setting. Intended as a tool in landfill and cover system design, HELP is useful in estimating leachate (contaminant) flow out of existing land disposal sites and in evaluating the relative impacts of contemplated in situ remedial actions at virtually any waste site.
SOILINER	The model predicts the rate of leachate flow through clay liner systems, given the liner's saturated hydraulic conductivity, effective porosity, and hydraulic gradient. SOILINER's output is a contaminant time of travel (TOT) over a 100-foot lateral distance.
SESOIL	This is a windows-based seasonal simulation program, combining a vertical water balance model (similar to HELP) with a one dimensional vadose-zone contaminant fate and transport model.

4.2 Water Balance Method

The method that has been used to predict moisture movement within the landfill is the simple water balance method. The basic configuration that is assumed for the model is that the landfill consists of an uncovered surface; a compacted waste compartment and a single clay barrier as engineering barrier system (see Figure 4.1).

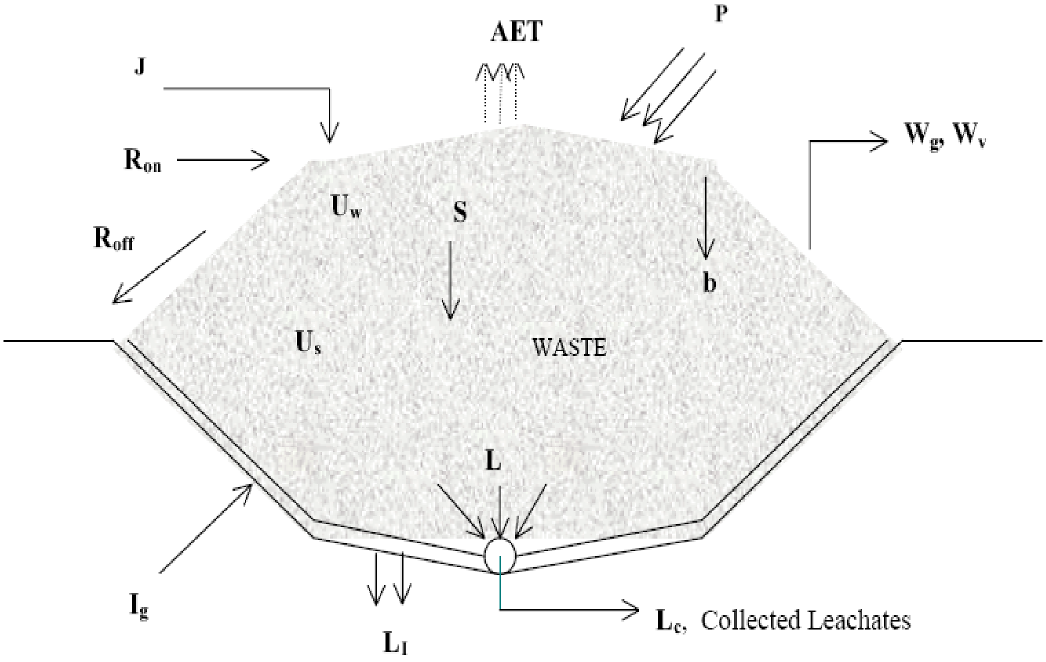
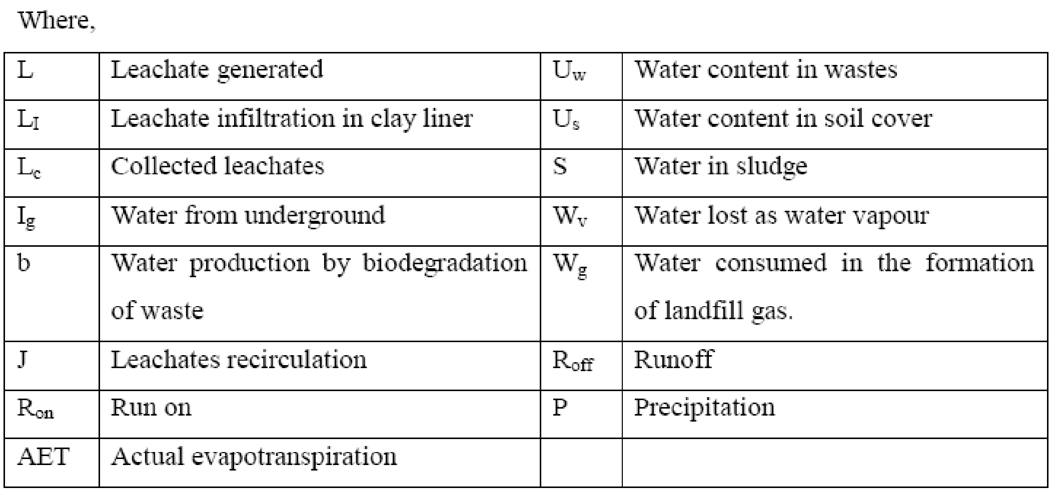


FIG.4.1 Hydrological water balance around Bhalaswa



Where,

L	Leachate generated	U_w	Water content in wastes
L_I	Leachate infiltration in clay liner	U_s	Water content in soil cover
L_c	Collected leachates	S	Water in sludge
I_g	Water from underground	W_v	Water lost as water vapour
b	Water production by biodegradation of waste	W_g	Water consumed in the formation of landfill gas.
J	Leachates recirculation	R_{off}	Runoff
R_{on}	Run on	P	Precipitation
AET	Actual evapotranspiration		

In the following section, the water balance around the Bhalaswa landfill would be derived, making use of assumptions in instances where it is applicable.

Starting with the most general equation,

The infiltration through the top of the waste pile is

$$\mathbf{I = P + J + R_{on} - R_{off} - AET \pm U_s}$$

Where,

P is the precipitation

J is the leachate recirculation

Roff is the runoff

Ron is the run on

AET is the actual evapotranspiration

Us is the water content in soil cover7

However, since there is no leachate recirculation practiced at Bhalaswa Landfill (J = 0) and assuming the following

1. The final soil cover is inexistent and the moisture content of the daily thin layers of soil is assumed to be at field capacity and is assumed not to contribute significantly in total moisture content of the cells (Us=0)

2. The landfill has been designed so that water outside the site does not enter the site (Ron = 0)

The infiltration (I) through the top part section of the waste pile becomes

$$I = P - R_{off} - AET$$

The change in water volume of the waste due to external sources (PL) is

Where,

S is the water added by sludge disposal

I_g is the water from aquifers

Assuming the following:

1. Water from aquifers entering the landfill is negligible ($I_g = 0$) since the presence of groundwater monitoring ponds take care of any water intruding into the wastes,

2. Water in incoming treatment plant sludge is assumed to be negligible (S = 0) since the sludge is dried before being dumped on the landfill.

The change in water volume of the waste (PL) due to external sources is

$$P_L = I$$

The total leachate production is

$$L = P_L \pm U_w + b$$

Where,
b is the water production by biodegradation of waste
Uw is the water content in wastes (at field capacity)

The water produced due to the biodegradation of waste is assumed to be very small and negligible (b=0) since the wastes must undergo an initial adjustment, a transition phase as well as an acid formation phase before the methane fermentation process starts, whereby water is produced. This stage can occur a couple of years after the solid wastes are first placed in the landfill.

Then,

$$L = P_L \pm U_w$$

In terms of collection and leakage

$$L = L_I + L_C$$

Where,
L is the leachate production
LI is the infiltration into aquifers
LC is the leachates collected by drains

4.3 Parameters in the Water Balance Method

1. Precipitation: This involves rain falling on the landfill site. For the water balance method, monthly rainfall data have been used.

2. Runoff: This is the portion of precipitation, which runs off the site and does not infiltrate. Runoff is a function of water retention characteristics, unsaturated hydraulic conductivity, and initial soil moisture profile and rainfall intensity. It is calculated using runoff coefficients.

3. Potential Evapotranspiration (PET)

This is the potential amount of water (usually in mm) that can be evaporated from soil and (or) refuse and transpired from vegetative cover. It is a function of temperature, wind speed, solar radiation and most importantly, humidity. Evaporation values that have been used in the water balance method are actual climatic measurements, obtained from the meteorological services.

4. Soil moisture storage

The amount of infiltration which is retained in the soil and (or) refuse up to field capacity and thus does not percolate as leachate.

4.4 Bhalaswa Landfill Water Balance Model

In working the water balance, it has been assumed that the landfill is still under aerobic phase and has barely reached the anaerobic (methanogenic) phase. This implies that there is minimal water consumption by anaerobic digestion and almost no water vapour escape from the landfill with the landfill gas.

Also, it is worth noting that water percolating through from the surface of a landfill, tends to be absorbed by the waste until the field capacity is reached. It is only when the infiltration of water exceeds this value that movement of water through the waste occurs, initially under unsaturated conditions and, finally, if sufficient water is present, under saturated conditions.

Table 4.2 The method of solution for the water balance

Step 1	Input values for evapotranspiration and precipitation
Step 2	Calculate Runoff $R_{off} = C_{RO}$ x P where, C_{RO} = runoff coefficient
Step 3	Calculate Flux – movement of water Flux = P – R_{off} – AET If flux has a negative value (-ve up): water evaporating from wastes If flux has a positive value (+ve down): water infiltrating in the wastes
Step 4	Calculate STORE = AW + Flux, where AW = actual water content in the wastes
Step 5	Determine AW: If STORE > Max Storage Capacity (FC), Then AW = Maximum Storage Capacity Otherwise, AW = STORE or AW = 0 (if STORE = ≤ 0)
Step 6	Determine PERC IF STORE > Max Storage Capacity PERC = STORE – Max Storage Capacity Otherwise PERC = 0 Note If PERC has a positive value (+ve) : Leachate formed If PERC has a negative (-ve) : Moisture deficit

1. Volume excludes final capping layer but includes 10% daily cover.
2. Surface area of Landfill covered by waste= vol. of waste and cover lifted/lift height. (Where lift height =3)
3. Runoff= Cro x P and cro is assumed to be 25%
4. I (mm)= P-Roff-AET
5. I(m3)= I(mm) x A
6. TMC= MC+ AWC
7. Actual Water content of solid= I+ TMC
8. AWS= FC x dry weight of solid waste. Assuming field capacity of 0.4

4.5 Quantity of leachate based on field Capacity

4.5.1 General

Bhalaswa landfill has been in operation for a decade with no record of the quantity of the generated leachate. Changes in field capacity and water consumed in gas generation were formulated based on empirical relationships of the nearest applicability to this site found in the literature. Monthly meteorological data were employed with an option provided to convert them into daily average values to match the daily time step if required. The model results for Bhalaswa landfill were good approximation of the amount of leachate generated. Although more reliable results can be achieved if more accurate site specific data is provided through field measurements as well as test trenches.

4.5.2 Methodology

The variation in *FC* (also referred to as water absorption capacity) of the waste is an important factor often ignored. In this paper, the different parameters influencing the amount of leachate generated considering trench method of waste disposal are discussed based on which a model is constructed and run as an example for Bhalaswa landfill site.

The model first assumes that a single cell is waste filled and covered with cover material. A water balance as proposed in this paper is applied to this single cell bearing in mind that *FC* of the waste changes rapidly during the first days of operation due to vehicle movement over the waste and placement of cover material. Thereafter *FC* decreases gradually due to waste material degradation resulting in additional settlement. The amount of leachate obtained for every single cell computed for a certain period of time (e.g. a few years) is then super imposed to that of new cells filled with MSW. This results in the overall leachate quantity estimation showing also the temporal variations. The key parameters and modelling procedure are discussed bellow.

4.5.3 Field Capacity and Time Interval

Field capacity decreases as the waste filled depth increases. Since the waste depth is a time dependent variable, therefore *FC* as well can be introduced as a function of time. The waste filled depth is directly related to the method of land filling. Different methods are well discussed in the. If a trench of H meters deep is to be occupied with daily cells of h meters high, it will then take H/h days for the whole depth to be filled. This can be considered as a reasonable time interval. *FC* is a density dependent variable and shown to decrease as the density increases. Although experimental work is required to evaluate the variation of *FC*, but it can be introduced as an exponential and/or linear function of. The exponential /linear behaviour of *FC* was introduced by Blight et al. (1996), based on a series of field measurements for fresh and older waste. Besides *FC* being a density dependent variable decreases rapidly during the first stages of compaction due to vehicle movement, cover placement etc.. Thereafter *FC* decreases gradually as the overburden pressure decreases substantially.

4.5.4 Primary leachate

Moisture content of the waste in excess of FC can be considered the main leachate generating component. This method presented by determines the moisture holding capacity using the following equation:

$$W(t)=FC(t)*D(t)$$

Where *t* denotes the time from disposal of MSW, *W* is the mass of water held in waste (kg) and *D* is dry weight of MSW (kg). Therefore the Primary leachate (*PL* in kg) will be the difference in water content at any given pair of times:

$$PL(t)=W(t-\Delta t)-W(t)$$

where *Δt* is the time interval. Equation 2 simply states that moisture content at any time step equals the amount of water held in the waste, calculated for previous time step. Therefore *W(0)* (i.e. water held in waste at the first time step) will be the same as initial moisture content.

4.5.5 Water Consumed in Gas generation

Biogas is produced within a landfill as a result of anaerobic degradation of MSW. Assuming that the organic Carbon content of the waste can partly be converted to biogas, the total amount of gas to be produced can be estimated using the following equation

$$Ge = 1.868\ C\ (0.014\ T+0.28)$$

where *Ge* is the total gas quantity (m3/ton of MSW), *C* is the Total Organic Content (TOC)(kg/ton of MSW) and *T* is temperature in degrees of Centigrade. Gas generation rate can be determined using different models, among which the two-stage model was found to be more accurate and practical. This model as introduced by Cossu et al. [1996], states that gas generation rate increases and then decreases as formulated by the following pair of equations respectively:

$$G = (Ge / 2) \exp(-k1(th - t))$$

$$L = (Ge / 2) \exp(-k2(t - th))$$

where;

G and *L* are the volumes of gas produced prior to time *th* and after *th* respectively, *k1* and *k2* are decay constants and *th* is the time for half of total gas production to occur.

Water is lost partly in anaerobic waste decomposition and partly as vapour within which gas is usually saturated] introduced the following well known chemical reaction for waste decomposition:

$$C_aH_bO_cN_d + \frac{4a-b-2c+3d}{4}H_2O \rightarrow$$
$$\frac{4a+b-2c-3d}{8}CH_4 + \frac{4a-b+2c+3d}{8}CO_2 + dNH_3$$

Using the above Equation, the amount of water consumed per unit weight of MSW ($C_a H_b O_c N_d$)

$$\frac{kgH_2O}{kgMSW} = \frac{(4a-b-2c+3d)*(18/4)*1000}{12a+b+16c+14d}$$

If *G* or *L* representing the rate of gas production are taken into account, then water consumption will be:

$$W1 = \frac{(4a-b-2c+3d)*(18/4)*1000}{(12a+b+16c+14d)Ge}$$

where *W1* is the mass of water consumed per cubic meters of gas produced and *a*, *b*, *c* and *d* can be determined if chemical analysis of

MSW is available. At any given time the amount of water consumed (*W2*) will be:

$$W2 = W1 * G$$

$$W2 = W1 * L$$

It is important to note that dry weight of MSW decreases as the gas production initiates. Therefore the dry weight at any given time can be determined by subtracting the mass of gas produced from dry weight of previous time step

$$D(t+\Delta t) = D(t) - G * d$$

$$D(t+\Delta t) = D(t) - L * d$$

Where *d* is the overall gas density.

Gas generation initiates months after land filling, therefore a lag phase should be taken into account. Lag phase is reported to vary from a few weeks and months to 1 year and more from one landfill to another.

4.5.6 Precipitation and Evaporation

The simplest method of determining the amount of rainfall associated infiltration is to employ run-off coefficient as follows:

$$Pe = (1 - c)P$$

Where *Pe* is the effective precipitation (mm), *P* is the total precipitation (mm) and *c* is the run-off coefficient. Other complicated methods are also available [Safari, 1999], which require more detailed information on the physical characteristics of the cover material and surface water drainage system. Since Bhalaswa landfill lacks any sort of surface water drainage system above equation was considered more practical.

Evaporation also can be obtained from climate data sets and corrected for application to soil and MSW using a correction factor (*cf*)

$$Ea = cf^{*}Ep$$

where *Ea* and *Ep* are the actual and pan evaporations (mm) respectively. Thus the overall mass of water (kg) entering/leaving the landfill will be

$$W4 = (Pe - Ea)A$$

where *A* (m2) is the surface area of waste receiving rainfall and subject to evaporation.

4.6 Modelling Procedure

The term “cell” used hereafter is referred to the space filled with MSW in *H/h* days. A single cell water balance is provided for any desired period of time, considering three distinct components; (1)moisture content in excess of *FC,* (2) water consumed in gas generation and water lost as gas saturated vapour and (3) water entering/leaving the landfill due to infiltration and evaporation.

Leachate generated as a result of changes in moisture content and *FC* at any given time can be determined for each cell using the following equation

$$\begin{aligned} LC_{cell}(t) &= FC_{cell}(t-\Delta t)[D - G_{cell}(t-\Delta t) * d] \\ &- FC_{cell}(t)[D - G_{gcell}(t) * d] \end{aligned}$$

where *LC* is the leachate generated at time *t* for a single *cell*, as a result of moisture content changes and the decrease in dry weight due to degradation of waste and gas generation.

Water consumed in gas generation was introduced in the above equation. The amount of water lost as vapour during gas generation, can be assumed to be about 0.01 kg per cubic meters of gas produced

Therefore the total amount of water lost through waste degradation process can be determined as follows:

$$WG_{cell}(t) = W2_{cell}(t) + 0.01d\, G_{cell}(t)$$

The overall leachate quantity at time *t* for a single cell excluding infiltration/evaporation will be:

$$\begin{aligned} LC_{cell}(t) &= FC_{cell}(t-\Delta t)[D - G_{cell}(t-\Delta t) * d] \\ &- FC_{cell}(t)[D - G_{gcell}(t) * d] + WG_{cell}(t) \end{aligned}$$

The accumulative amount of leachate as the operation progresses can be determined through superposition of the results of Equation

$$LCT(t + n\Delta t) = \sum_{i=1}^{ncell} LC(i, (n - i + 1)\Delta t)$$

where *n* counts the time steps, *ncell* is the number of cells to be waste filled. Infiltration and evaporation are independent from land filling operation and therefore are present throughout the modeling time. Therefore the resultant infiltration) must be added to *LCT* separately:

Chapter 5

RESULTS AND DISCUSSIONS

5.1 Output of Water Balance Method

The output from the water balance method provides an estimation of the amount of leachates that is being generated at the base of the landfill. High leachates generation increases the risk of groundwater contamination. **Figure 5.1** below shows the seasonality in the amount of leachates that are produced at Bhalaswa landfill.

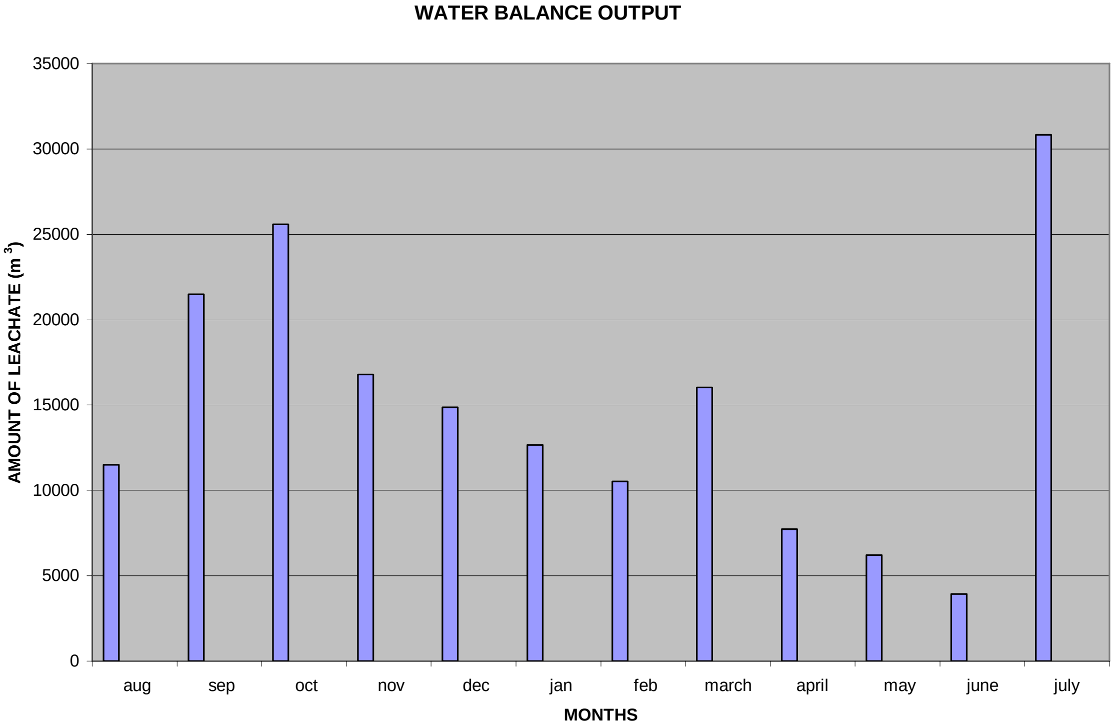


Fig 5.1 Water Balance Output

From the calculations performed, it can be deduced from the graphs above that leachates production are most likely to occur during summer with, periods of intense rainfalls. However, this tendency is not always followed because during summer time, evaporation is high and moisture tends to be evaporated from the refuse and also from the ground. Henceforth, even when it is raining significantly, no leachate is formed since infiltration is used to make up the deficit in soil moisture.

In general, the leachate flow rate increases as the surface area of the landfill increases. It should also be acknowledged that the landfill conditions are not uniform throughout the landfill at any time and that conditions change as the site ages. At any time, the refuse in the landfill ranges from new to old and will therefore be exposed to different amounts of percolation.

It should also be acknowledged that the calculations were based on many assumptions, which undeniably yield very rough results.

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Table A

	W x 10^3 kg	Cw (kg)	MC	V (m3)	Cv (m^3)	Vc (m3)	A (m2)	P (mm)
Aug	66000	66000	26400	82500	82500	90750	30250	197.4
Sept	66756	132756	26702	83445	165945	182539	60786	105.3
Oct	68354	201110	27342	85443	251388	276527	92175	19.3
Nov	69655	270765	20896	87068	338456	372302	124100	2.8
Dec	71152	341917	28461	88940	427396	470135	156712	4.3
Jan	71496	413413	28598	89370	516766	568442	189480	14.5
Feb	71882	485295	28753	89852	606618	667280	222426	13.2
March	72014	557309	28806	90018	696636	766294	255433	9.9
April	72168	629477	28867	90210	786846	865531	288510	5.5
May	72368	701845	28947	90460	877306	965036	321678	9.2
June	72572	774417	29029	90715	968021	1064823	350000	38.8
July	72696	847113	29078	90870	1058891	1164780	350000	191.6

Table A-Continued

P (mm)	R (mm)	El (mm)	I (mm)	I (m^2)	TMC	AWC	AWS	L (m3)
197.4	48	118	31.4	950	26400	27350	15840	11510
105.3	26	91	-11.7	-712	54052	53340	31862	21478
19.3	4.8	88.5	-74	-6821	80682	73861	48267	25594
2.8	0.7	84.2	-82.1	-10188	94757	84569	67770	16799
4.3	1.1	80.2	-85	-13320	113030	99710	84846	14864
14.5	3.62	82.4	-71.57	-13643	128308	114665	102005	12660
13.2	3.3	94.6	-84.7	-18840	136229	117389	106866	10523
9.9	2.5	107.5	-100	-25593	146195	120602	104562	16040
5.5	1.4	115.6	-111.5	-32024	149469	117445	109715	7730
9.2	2.3	117.8	-110.9	-35706	146392	110686	104462	6224
38.8	9.7	106.2	-87.1	-30450	139715	109265	105337	3928
191.6	48	127.5	16.1	5635	139797	145432	114613	30818

5.2 Waste Characteristics

Total amount of waste dumped at Bhalaswa Landfill site is about 2500 ton of MSW per day.

Moisture content: 42% by weight

Density of fresh waste: 500 kg/m3

Density of the waste at landfill site: 800 kg/3

Total Organic Carbon (TOC): 35% by weight

The range of variation in moisture content of the waste is about 40% to 44% depending on the season of the year. Values of other parameters are reported as single shut estimates followed by no consistent field measurements.

No data is available for FC at the site. Estimation of initial *FC* and its variation is a crucial task in modeling leachate quantity. Therefore as an example a somewhat inverse approach was employed to determine the primary leachate quantity compared to the value reported by CPCB, resulting in an initial *FC* value of about 0.55. This initial *FC* was assumed to decrease to 0.2 linearly during 12 months (i.e. 720 days) and remain constant afterwards. Clearly to validate the proposed model a series of long-term field measurements must be performed so as to obtain reliable values of *FC* and the related variations. A trench depth of 20 m was assumed to be waste filled with 2 m high daily cells within a 6 months (i.e. 180 days) operating trench.

5.2.1 Single Cell Leachate

The single cell of waste in this case example consists of 10 daily cells (i.e. 20m/2m), resulting in a *Δt* of 10 days. The waste pile will have a surface area of 1562.5m2, based on a 800 kg/m3 waste density. The primary source of leachate is the moisture content amounting to 1050000 kg (i.e. 2500,000 kg*0.42). The initial dry weight of MSW is 1450000 kg.
Gas generation is assumed to initiate after 6 (i.e. 180 days) months of land filling with the following characteristics:
Waste chemical composition:

$$C_{68} H_{111} O_{50} N$$

Average temperature: 25 °C

Ge=10297300 m3

K1=6.14 year-1

K2= 1.083 year-1

th= 1.5 years (i.e. 540 days)

d = 1.2 kg/m3

CALCULATION:

1. Total amount of biogas produced

$$Ge = 1.868 \times C\ (0.014 \times T + 0.28)$$

$$Ge = 1.868 \times 0.35 \times 2500{,}000\ (.014 \times 25 + .28)$$

$$= 10297300 m^3$$

Volume of gas produced prior to time th and after th

For t=410 days, G = (10297300 /2) x e (-6.14 (1.51.38)

=5.57 x 10^5

For t=490 days, G=2.99 x 10^6

For t=570 days, L=4.7 x 10^6

For t=650 days, L=3.7 x 10^6

For t=730 days, L=2.99 x10^6

For t=810 days, L=2.8 x 10^6

For t=890 days, L=1.79 x10^6

For t=1050 days, L=1.01 x 10^6

2. Amount of water consumed: W2= W1 x G

W2=W1 x G

For t=310 days, W1=0.1 x1.018 x 10^6

=1.1018 x 10^4

For t=430 days, W1=7.86 x 10^4

For t=490 days, W1=3.0 x 10^5

For t=570 days, W1=5.0 x 10^5

3. Change in dry weight of gas:

$D\ (t+\Delta t) = D\ (t) - G \times d$

$D\ (t+\Delta t) = D\ (t) - L \times d$

Considering a lag phase of one year

For t=10 days $D\ (t+\Delta t) - D\ (t) = 14500000$ kg

For 1=60 days $D\ (t+\Delta t) - D\ (t) = 14500000$ kg

For $t=110$ days $D(t+\Delta t) - D(t)=14500000$ kg

For $t=160$ days $D(t+\Delta t) - D(t)=14500000$ kg

For $t=210$ days $D(t+\Delta t) - D(t)=14500000$ kg

For $t=260$ days $D(t+\Delta t) - D(t)=14500000$ kg

For $t=310$ days $D(t+\Delta t) - D(t)=14500000$ kg

For $t=360$ days $D(t+\Delta t) - D(t)=14500000$ kg

For $t=410$ days $D(t+\Delta t) - D(t)=6.69$ x 105 kg

For $t=460$ days $D(t+\Delta t) - D(t)=1.5$ x 105 kg

For $t=560$ days $D(t+\Delta t) - D(t)=3.68$ x 105 kg

For $t=560$ days $D(t+\Delta t) - D(t)=5.85$ x 105 kg

For $t=610$ days $D(t+\Delta t) - D(t)=5.0$ x 105 kg

For $t=660$ days $D(t+\Delta t) - D(t)=4.34$ x 105 kg

For $t=710$ days $D(t+\Delta t) - D(t)=3.70$ x 105 kg

Fig 5.2 shows the gas generation trend based on the above assumptions for 3 years (i.e. 1080 days).

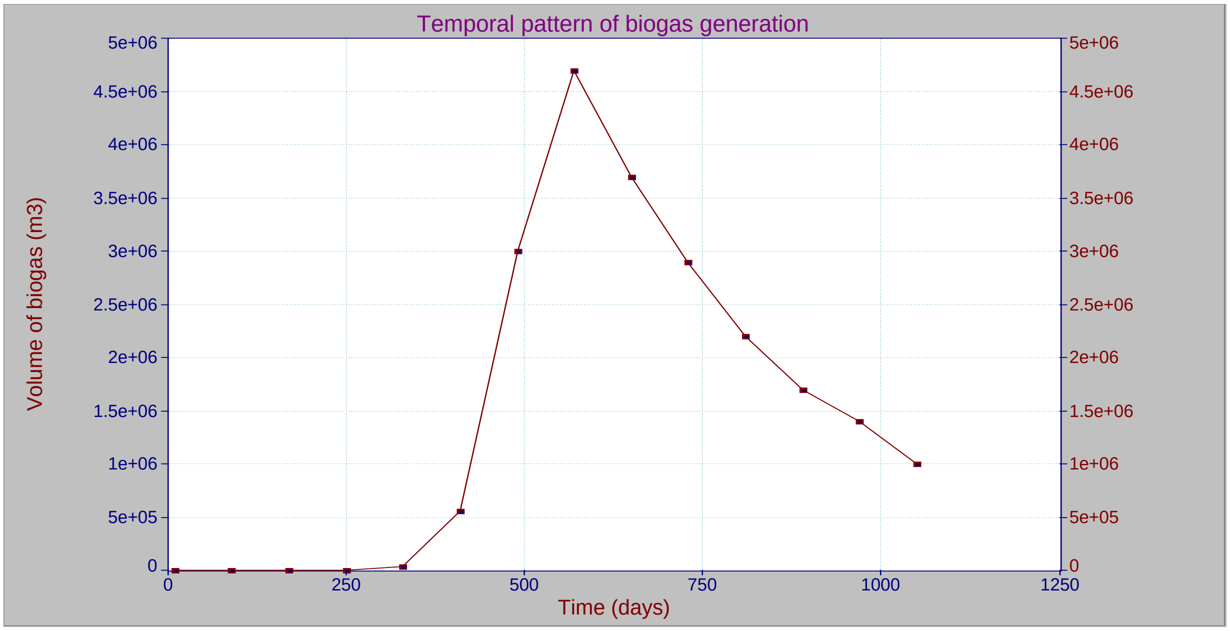

Fig 5.2 Temporal Pattern of biogas Generation of single Cell

Water consumed in gas generation process for a single cell is shown in Figure5.3. The modeling time was considered to be 2 years (i.e. 720 days). Clearly, the water lost as gas saturating vapour will follow the same pattern but 10 times smaller in magnitude. Slight changes in dry weight of MSW will start to appear at the first stages of gas generation. After quite some time, the rate of dry weight decrease will be much faster as shown in Figure 5.4 Using above equation the amount of leachate generated within a single cell can be estimated excluding infiltration/evaporation (Figure5. 4). As shown in Figure 5.4, the quantity of generated leachate is shown in m3/day assuming a uniform distribution of leachate discharge during one time interval.

The cover material at Bhalaswa landfill site mainly consists of construction and demolition waste. Based on the information a run-off coefficient of 0.5 seems to be reasonable. Since no data was available on the evaporation correction factor the amount of actual evaporation from soil was assumed to be 65% of all values recorded as pan evaporation.

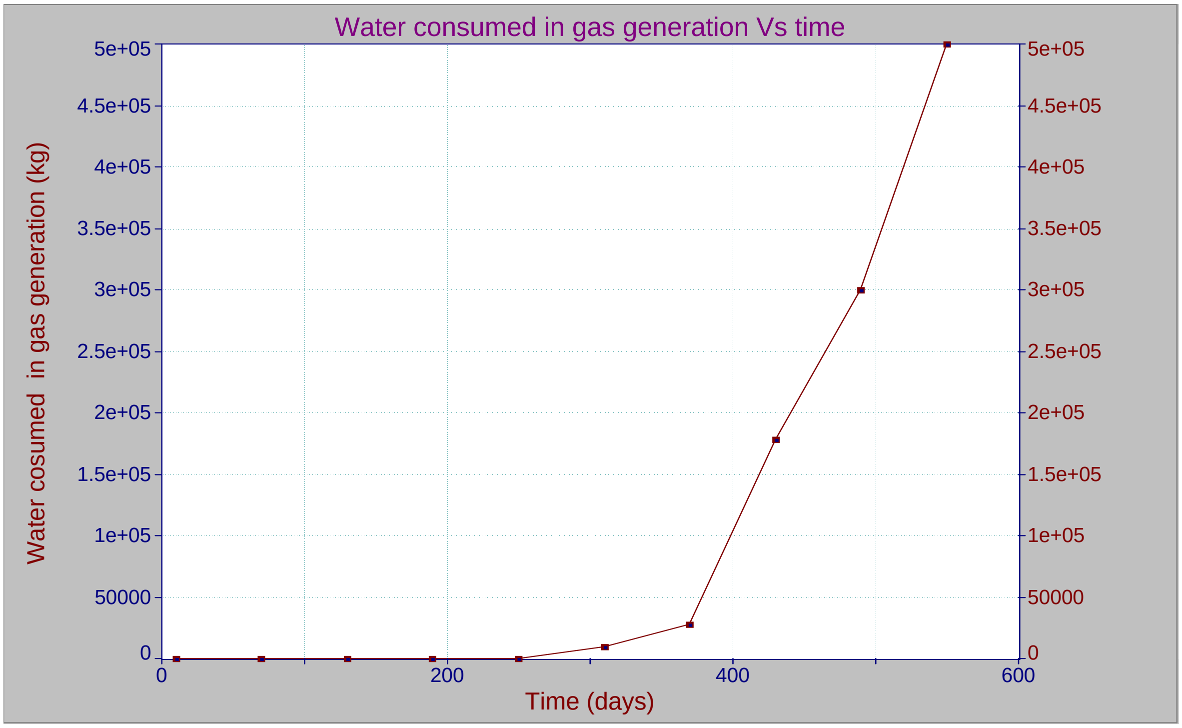

Fig5.3 Volume of water consumed in gas generation versus time.

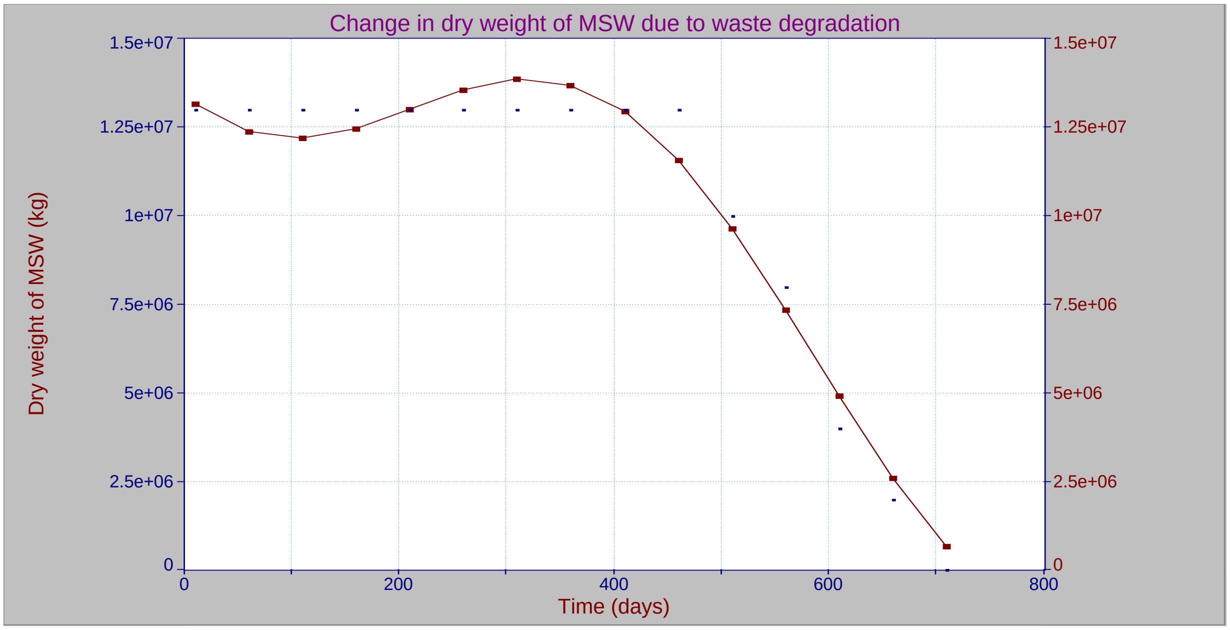

Fig 5.4 Changes in Dry weight of MSW due to Waste Degradation

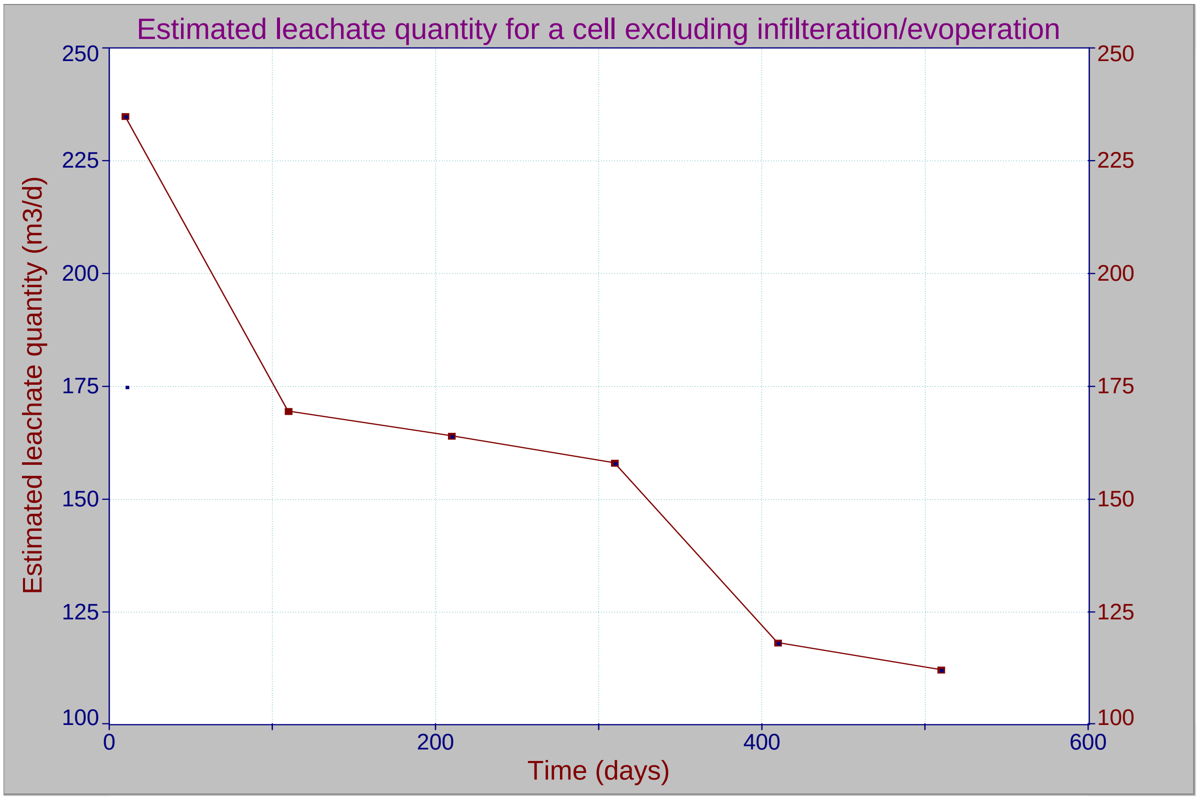

Fig 5.5 Leachate Quantity for a Single Cell

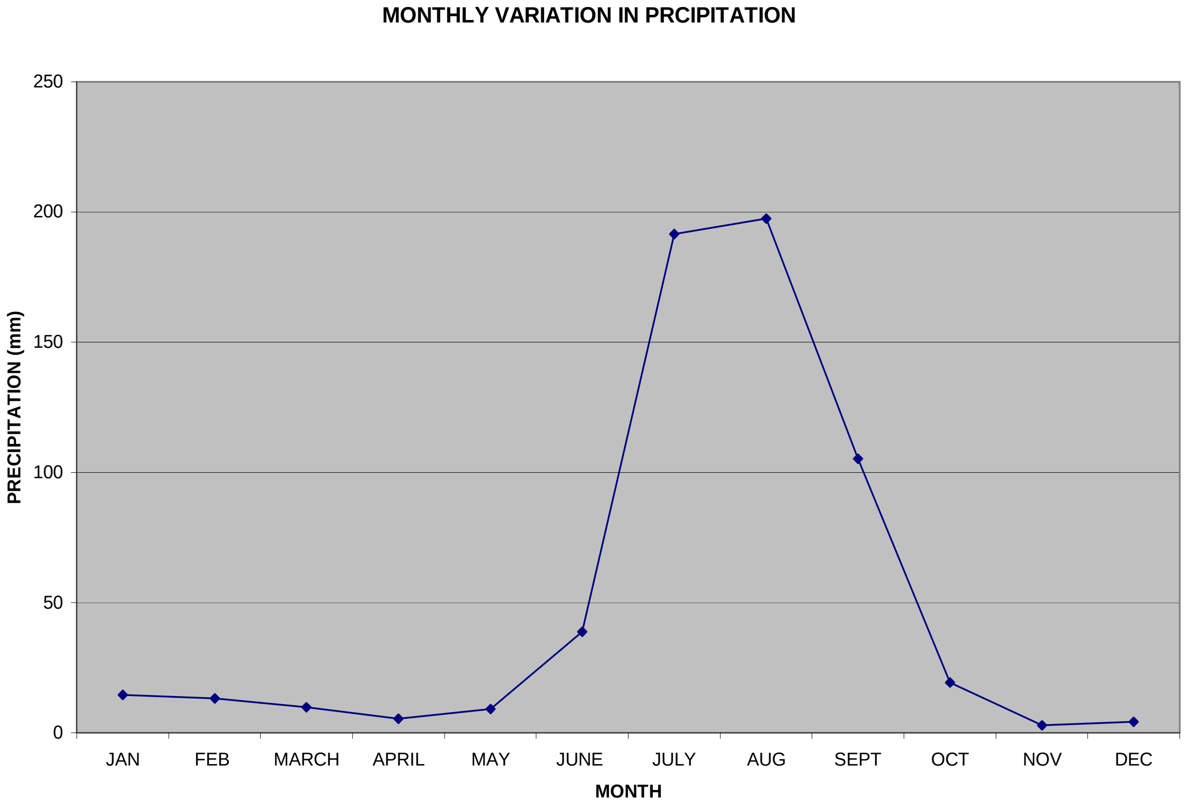

Fig 5.6 Monthly variation in Precipitation

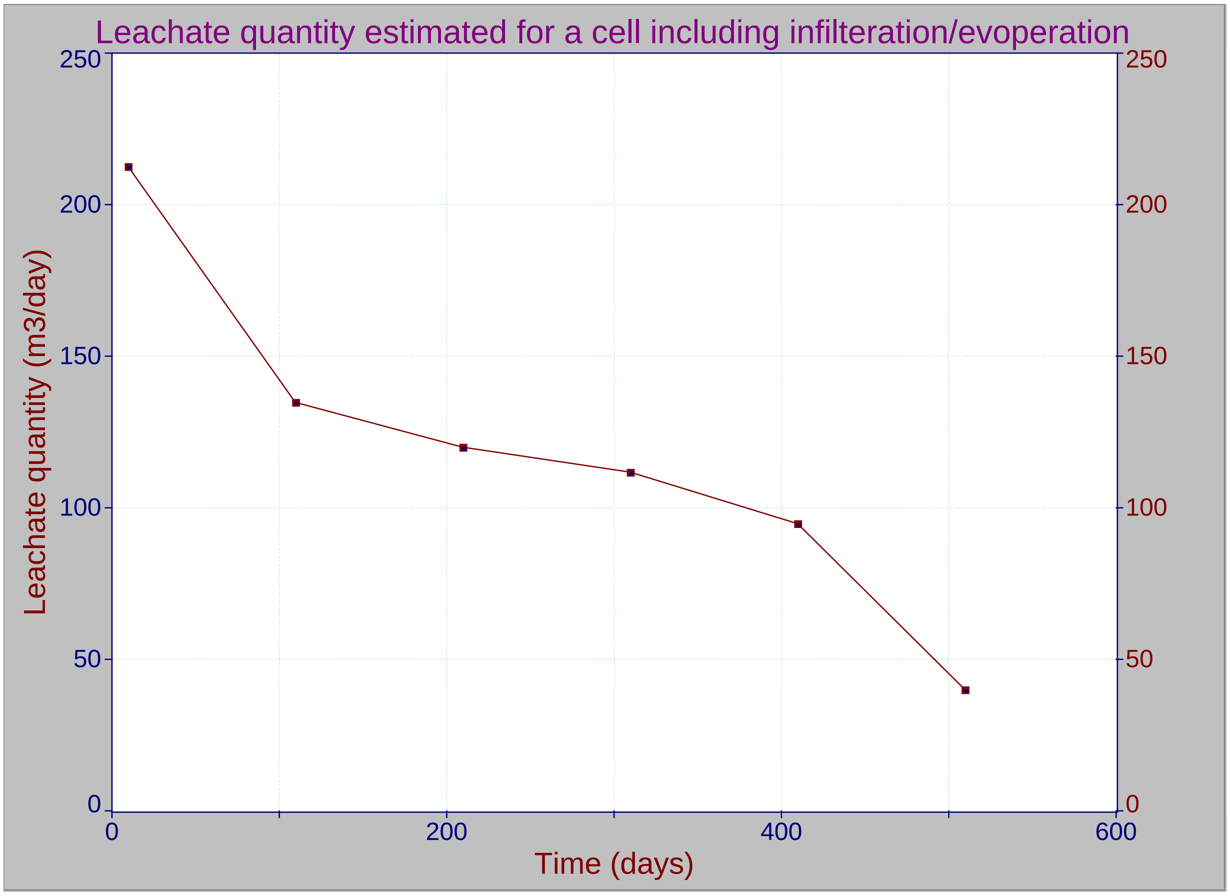

Figure5.7 Water gain/loss due to infiltration/evaporation

5.3 Accumulative leachate generation

The trench in this case example was assumed to receive MSW for six months. Therefore the trench consists of 6 cells as defined in this paper. The accumulative leachate generation was estimated using above Equation. The result is shown in Figure

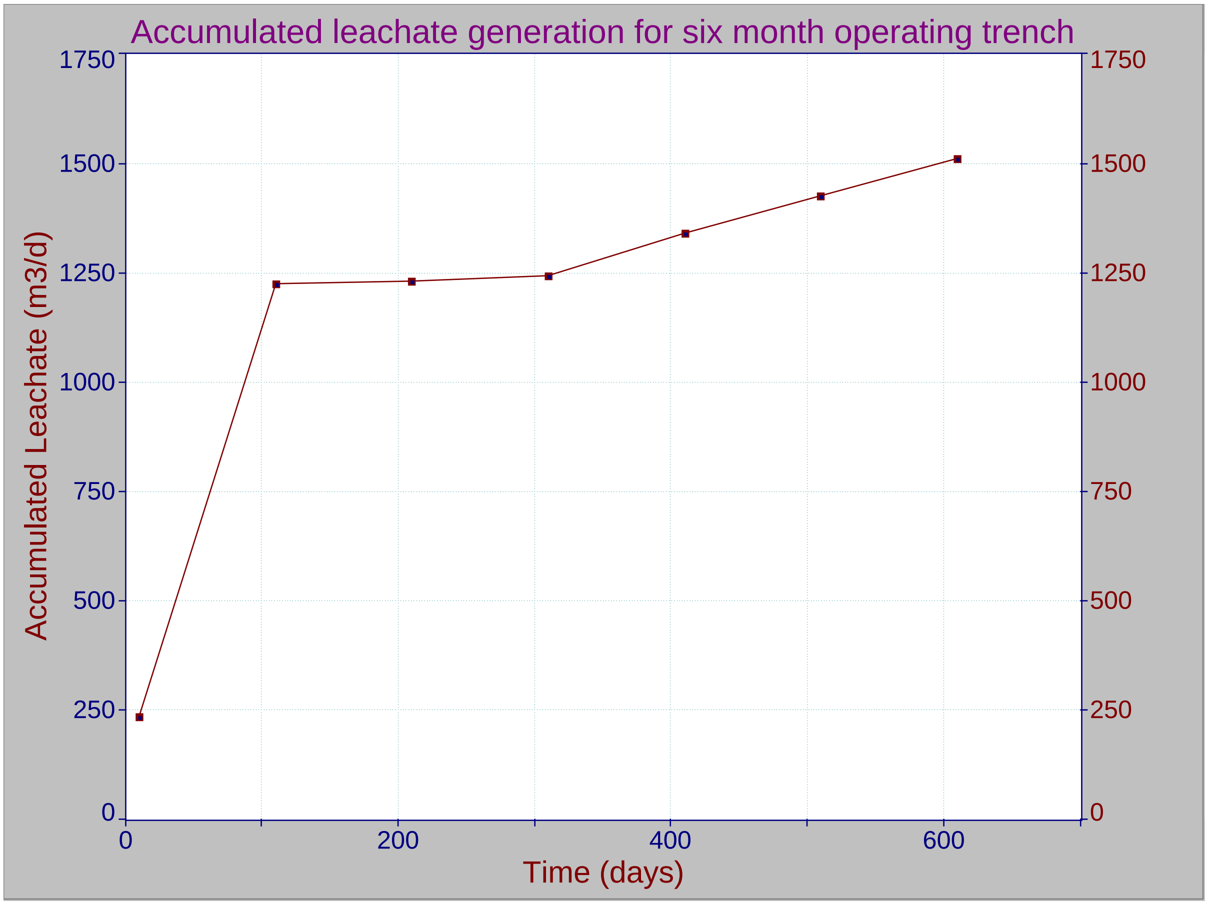

Fig 5.8 Accumulated leachate Generated

As shown in Figure 5.8 a six months operating trench can generate leachate for about 1 year after the land filling is initiated. The irregularity in leachate production with time might be associated with the relatively large time interval as well as cell dimensions. Also the starting month/season for trench operation taken as the starting time of modelling can significantly affect leachate production pattern considering the coincidence of primary leachate production (as the main part of the total leachate) with high evaporation during dry season or with infiltration occurring in wet seasons. Unfortunately no data is available on field measurements of leachate quantity of existing landfill in making the comparison of the results impossible at present.

CHAPTER 6

CONCLUSION

The following main conclusion can be drawn based on the study:

1. Relatively high moisture content of MSW disposed of at Bhalaswa landfill site was considered the key leachate generating component.

2. The working of a water balance has shown that heavy rainfall leads to high infiltration of water into the waste dump and henceforth, high leachate generation only if the site has not suffered long periods of moisture deficit period.

3. The chemical analysis of the leachate shows that the large volume of leachate if get percolated into the ground could pose a great threat to groundwater resources since it contains multiple pollutants which might not be easy to remove or treat.

4. Maximum amount of leachate was generated in the month of July i.e. in the monsoon season.

5. Minimum amount of leachate was generated in the month of June, evaporation is high and moisture tends to be evaporated from the refuse and also from the ground.

6. The values of various parameters of leachate evaluated from chemical analysis of leachate are pH=8.04, Conductivity= 28500 mho/cm, Total Hardness=1424 mg/l, Chloride=1172 and chemical oxygen (C.O.D)=3613

FUTURE SCOPE OF STUDY

1. Due to lack of data regarding the amount of leachate pumped since the start of operation of the landfill makes it impossible to validate the calculated amount of leachate formed. Key parameters mainly the field capacity remains to be determined through extensive field measurements and monitoring.
2. The quality assessment of the ground water in the vicinity of the landfill site can be done so as to ascertain weather there is any seepage of the leachate in the ground. Local public has reservation about the ground water quality.
3. Study of transport of contaminants due to seepage of Leachate in the ground water
4. The possibility of leachate collection and its recycling.
5. Risk assessment of ground water contamination due to landfill leachate.
6. Stabilization of landfill through technologies such as leachate recirculation.

REFERENCES

P.Lewis and H.D. Sharma'waste containment systems,waste stabilization and landfills',John Willey and Sons,INC.

G. Townsend and Debra R Reinhart'landfill bioreactor design and operation'Lewis

Carra,J.s and R. Cossu, Eds'International persrective on municipal solid waste and sanitoty landfilling' Academics Preaa, London, 1989.

Pohland,F.G Sanitort Landfill Stablization with leachate recycled recycle and residual treatment . U.S Environmental protection agency, Cincinnati, EPA-600/2-75-043, 1975.

U.S. Environmental Protection Agency, Solid waste disposal facility criteria;proposed rule. Fed. Reg, 53(168) 3313, 1988.

Tchobanoglous, G, H Theisen, and S.A. Vigil, Integrated Solid Waste Management Engineering Principles and Management Issues McGraw-Hill, New York, 1993.

Blight, G. E., D. J. Hojem and J. M. Ball,Production of landfill leachate in water –deficient areas, Landfilling of waste:leachate, E & FN SPON, 35-51, 1996.

Cossu, R., G. Andreottola and A. Muntoni,Modelling landfill gas production,Landfilling of waste: Biogas, E & FN SPON,237-268, 1996.

Ehrig, H. J., Prediction of landfill gas productionfrom laboratory-scale tests, Landfilling ofwaste: Biogas, E & FN SPON, 269-291, 1996.

Rhyner, C. R., J. S., Leander, R. B. Wenger andM. G., Kohrell, Waste management and resource recovery, CRC, Lewis Publishers,Chapter 9, 1995.

Safari, E., Hydraulics of drainage systems of landfill final cover and its application to arid regions of Iran, Proceedings of The second Hydraulics conference, Iran University of Science and Technology, 367-374, 1999.

Shroeder, P. R., T. S. Dozier, P. A. Zappi, B. M. McEnroe, J. W. Sjostrom and R. L. Peyton, The Hydrologic Evaluation of Landfill Performance (HELP) Model: EngineeringDocumentation for Version 3, EPA/600/R-94/168b, U.S. Environmental Protection Agency, Office of Research and Development, Washington DC.

Rowe, R.K., Fleming, I., Cullimore, R., Kosaric, N., and Quigley, R.M., "A Research Study ofClogging And Encrustation in Leachate Collection Systems in Municipal Solid WasteLandfills", Geotechnical Research Centre, UWO Research Report prepared for InterimWaste Authority Ltd., 1995.

F.G. Pohland and S.R. Harper, CriticalReview and Summary of Leachate and Gas Production from Landfills, Environmental Protection Agency, 600/S2-86/073, March 1987.

D.E. Daniel, C.D. Shackelford, W.P.Liao, and H.M. Liljestrand, Rate of Flow of Leachate through Clay Soil Liners,Environmental Protection Agency, 600/S2-91/021, July 1991.

K.G. Dotson, Migration of Hazardous Substances through Soils, Environmental Protection Agency, 600/S2-91/017, May 1991.

N.D. Williams, F.G. Pohland, K.C. McGowan, and F.M. Saunders, Simulation Leachate Generation from Municipal Solid Waste, Environmental Protection Agency, 600/S2-87/059, December 1987.

Andreas, L. and B. Bilitewski (1999). Effects of waste quality and landfill technology on thelong-term behaviour of municipal landfills. Waste Management & Research 17:413-423.

Chian, E. S. K. and F. B. DeWalle (1976). Sanitary Landfill Leachates and Their Treatment.Journal of the Environmental Engineering Division, American Society of Civil Engineering (EE2) 102: 411-431.

Cossu, R. and R. Serra (1989). 2.6 Effects of codisposal on degradation process. Sanitarylandfilling: process, technology and environmental impact. Christensen, Cossuand Stegmann, Academic press Ltd, London: 121-151.

Doedens, H. and U. Theilen (1992). Effluent requirements and related leachate treatmentprocesses. Landfilling of waste: leachate. Christensen, Cossu and Stegmann,Elsevier science publishers Ltd.: 417-428.

LIST OF SOME OF THE WEBSITE VISITED

1.www.civeng.unsw.edu.au/Internal/Subjects/Cven4229/Lectures/Lectu re -Leachates.html
2. Landfill manual, www.foe.org//ptp/chapter3.html
3. www.groundwater.com
4. www.epa.gov/ebtages/watgrounhydrogeology.html

APPENDIX 1

Selected Non-Hazardous Wastes that contain toxic chemicals

Waste Category	**Toxic Constituents**
Agricultural chemical wastes	Pesticides, fertilizers
Mining wastes	Radioactive materials, metals, acids
Wastes from energy production	Metals, organic solvents
Sewage sludge	Heavy metals, organics
Residual solids from air pollution equipment	Heavy metals

Hazardous Household Items

Household Items	**Hazardous Constituents**
Spot removers, laundry detergents and other solvents	Trichloroethylene (TCE), benzene, toluene, methylene chloride
Moth balls	100% Dichlorobenzene
Fingernail polish	Xylene, dibutyl phthalate, toluene
Plastics	Vinyl chloride, polyethylene, formaldehyde, toluene

Hazardous Metals from Household substances

	Household Items
Lead	Consumer electronics (television sets, radios, etc.), glass, ceramics, plastics, brass, bronze, used oil
Cadmium	Nickel-cadmium batteries, plastics, consumer electronics, appliances (dishwashers, washing machines, etc.), pigments, glass,

	ceramics, rubber, used oil
Mercury	Batteries, light bulbs, paint residues, thermometers, pigmentsfrom inks and plastics

Health Effects of Selected Volatile Organic Chemicals found in Landfill Leachate

Benzene	Human carcinogen, mutagen, and possible teratogen; central nervous system (CNS), peripheral nervous system, immunological and gastrointestinal effects; blood cell disorders; allergic sensitization; eye and skin irritation
Chloroform	Probable human carcinogen and possible teratogen; CNS and gastrointestinal effects; kidney and liver damage; embryotoxic; eye and skin irritation
1,1-dichlorethane	Embryotoxic; CNS effects; kidney and liver damage
Ethylbenzene	CNS effects; kidney and liver damage; upper respiratory system, eye and skin irritation
Methylene Chloride	Possible carcinogen; CNS, lung/respiratory system, and cardiovascular effects; blood disorders; eye and skin irritation
Tetrachloroethylene	Probable carcinogen; CNS and lung/respiratory effects; embryotoxic; kidney and liver damage; upper respiratory tract and eye irritation
Toluene	Possible mutagen and carcinogen; CNS and cardiovascular

	effects; kidney and liver damage; upper respiratory tract, eye and skin irritation; and allergic sensitization
Trichloroethylene	Possible carcinogen and teratogen; CNS , kidneys, liver, cardiovascular system, and lung/respiratory system effects; blood cell disorders; skin, eye and upper respiratory irritation
1,1,1-trichloroethylene	Carcinogenic; mutagenic; CNS and lung/respiratory effects; kidney and liver damage; eye and skin irritation
Vinyl Chloride	Carcinogenic; mutagenic; possible teratogen; CNS effects; kidney and liver damage; blood cell disorders; and skin irritation
Xylene	CNS and cardiovascular effects; kidney and liver damage; upper respiratory and eye irritation