CHAPTER THREE

METHODOLOGY

3.1 Introduction of VHELP Program

In this study, a computer program called Visual Hydrologic Evaluation of Landfill Performance (VHELP) was used to obtain the results. The program was developed to conduct water balance analysis of landfill cover systems, and the waste containment facilities. The model facilitates rapid estimation on the amount of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected from the operation based on the water balances.

The VHELP program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of the landfill. The model accepts weather, soil, and design data and uses solution techniques that take into account the effects of water storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, unsaturated vertical drainage and leakage through soil barrier. The geosynthetic liner may also be modeled to compute leakage (Schroeder *et al.,* 1994a).

The VHELP model required data on the climate including growing season, average relative humidity, mean monthly temperatures, maximum leaf area index, evaporative zone depth and latitude. Default values for these parameters were compiled from climates of the states. Nevertheless, daily rainfall data may be input by user or generated stochastically, taken from model's historical database. The VHELP model provides default values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of numerous soil and waste materials, as well as, geosynthetic materials.

The default value of soil material types were compiled for program usage (Schroeder *et al.,* 1994). In addition, VHELP model requires landfill design for which includes slope surface, maximum drainage distance, layer thickness and subsurface materials characteristics. These parameter values were taken and used to compute WBCs for the model of cover systems tested.

The VHELP computer program was developed by United States Engineers Waterways Experiment Station (WES) for the United States Environmental Protection agency (USEPA) in response to the requirement of Resource Conservation and Recovery Act (RCRA). The primary purpose of the model is to compare alternatives of landfill design based on the water balance and hydrologic performance (Schroeder *et al.,* 1994). The VHELP model accepts weather, soil and design data to execute the analysis.

3.1.1 Limitations of the Software VHELP

The major limitations of the program are summarised below:

- The program does not consider the affects of drifting in its accounting of snow behavior.
- The program assumes that areas adjacent to the landfill do not drain onto the landfill. The time distribution of rainfall intensity is not considered. The program cannot be expected to give accurate estimates of runoff volumes for individual storm events on the basis of daily rainfall data.
- The evaporation zone depth is assumed to be constant throughout the simulation period. However, outside of the growing season, the actual depth of evapotranspiration is limited to the maximum depth of evaporation of soil water, which is a function of the saturated hydraulic conductivity.

- The HELP program assumes Darien flow for vertical drainage through homogenous, temporally uniform soil and waste layers. It does not consider preferential flow through channels such as cracks, root holes or animal burrows. As such, the program will tend to overestimate the storage of water during the early part of the simulation and overestimate the time required for leachate to be generated.
- Vertical drainage is assumed to be driven by gravity alone and is limited only by the saturated hydraulic conductivity and available storage of lower segments. If unrestricted, the vertical drainage rate out of a segment is assumed to equal the unsaturated hydraulic conductivity of the segment corresponding to its moisture contents, provided that moisture content is greater than the field capacity of the segment directly below.
- Leakage through geomembrane is modeled by a family of theoretical an empirical equations. In all cases, leakage is a function of hydraulic head. The program assumes that holes in the geomembrane are dispersed uniformly and that the average hydraulic head is representative of the head at the holes. The program further assumes that the holes are predominantly circular and consist of two sizes. Pinholes are assumed to be 1mm in diameter while installation defects are assumed to have an cross-sectional area of 1 cm^2

3.1.2 Water Balance Components

The components of water balance are surface runoff, evapotranspiration, and subsurface water routing which include lateral drainage and leachate generation. These will be explained in the following section.

i) Surface Runoff

Daily surface runoff is equal to the sum of rainfall, minus the sum of infiltration, and evapotranspiration. Infiltration and evapotranspiration are functions of interception. Furthermore, according to Daniel (1994), interception is modeled in the method of Hotton (1919). VHELP model uses the Soil Conservation Service (SCS) curve number method to estimate surface runoff. This method correlates daily runoff with daily rainfall for watersheds with a variety of soils, level of vegetation, land management practices and antecedent moisture condition.

ii) Evapotranspiration

The VHELP model uses a modified Penman method to compute evapotranspiration (Ritchie, 1972). The method involves a two-stage square-root-of-time routine. In stage one, the soil evaporation equals the evaporative demand placed on the soil. Demand is based on energy and is equal to the potential evapotranspiration discounted for surface evaporation and shading from ground cover. A vegetative growth model is used to compute the total quantity of active and dormant vegetations that provide shades.

iii) Subsurface Water Routing

Subsurface water routing includes vertical unsaturated drainage, percolation through saturated soil liners, leakage through geomembrane, and lateral drainage in drainage layers. The soil moisture controls the rate of subsurface water movement, but the rate of movement also affects the moisture content. Thus, an analytical procedure is used, and water flow is assumed to follow the Darcy's Law (Daniel *et al.,* 1994).

3.2 Input Data and Parameters

VHELP required data and parameters to execute the water balance analysis. In the following subsection, both input data and parameters are described and the parameters defined.

3.2.1 Input Data

Three input data are required for VHELP program to accomplish the analyses of the water balance components (WBCs). Table 3.1 VHELP Model Input Data extracted from McBean (1995) provides a summary of the required data. The weather data, design data and soil data are elaborated below.

Table 3.1 VHELP Model Input Data Required.

Category	Details
Climatic Data	Daily precipitation-three options exist: 1. Use a default precipitation option 2. Input precipitation data; 3. Generate a sequence of precipitation events
Soil Data	Saturated hydraulic conductivity Soil porosity Evaporation coefficient Field capacity Wilting point Minimum infiltration rate SCS runoff curve number Initial soil water content
Vegetation data	Crop type Crop cover Leaf area indices Evaporative zone depth
Design data	Numbers of layers Layer thickness Layer slope Lateral flow distance Surface layer of landfill Leakage fraction Runoff fraction from waste

Mc Bean (1995): Landfill Engineering and Design

i) Weather data

The VHELP program required weather data such as precipitation, mean air temperature and solar radiation to accomplish the water balance analysis. Hence the program input used the data for the input of the volumetric inflow of water reaching landfill to simulate surface runoff, evapotranspiration and infiltration during the periods. For the purpose of this analysis, specific site weather data of Petaling Jaya will be entered into the program. The daily values for precipitation, air temperature and solar radiation are also required and entered. The weather data obtained from Petaling Jaya for year 2001 and 2002 were entered into the VHELP program to suit the modified Canadian weather data generator.

ii) Design Data

The VHELP program required design input data which included: drainage length, surface slope, number of layers, layer thickness of soil conservation service (SCS), runoff curve number of landfill catchments area, the percentage of landfill surface where runoff is possible, and percentage of leachate recirculation from the layer. The above parameters are used in the simulation of the water balance analysis. Therefore, it is important to provide brief definitions on the parameters used. Soil conservation service (SCS) is required for describing general site condition with regards to moisture contents. The (SCS) runoff curve number is derived from the field study of the amount of runoff measured from various soil cover combinations. SCS normally used the following moisture condition AMC I, AMC II and AMC III. AMC I relates to the lowest runoff potential and is used when soils in the catchments are dry. AMC II is the average condition. AMC III has the highest runoff potential and is used when soils in the catchments are almost saturated from antecedent rains. The rainfall-runoff processes are modeled using the USDA Soil Conservation

Service curve-number method, which can adjust the runoff calculation to variety of soil types and land management practices.

The curve number method was developed using rainfall-runoff data for intensive storm on small catchments such as landfill. The curve number (CN) is defined with respect to the runoff retention parameter (S), which measures the maximum retention of rainwater after runoff starts.

iii) Soil Data

Soil data include porosity, field capacity, wilting point, saturated hydraulic conductivity, initial moisture storage, and SCS runoff curve number for antecedent moisture condition II (Schroeder *et al.,* 1994b, Qian 2002). The VHELP model provides default values for the total porosity, field capacity, wilting point, and saturated hydraulic conductivity of numerous soil and waste materials, as well as, for geosynthetic materials.

3.2.2 Parameters Used

The following soil parameters were used in the simulation and are defined as;

Porosity-Porosity of the material used is the ratio of void volume to the total volume.

Field Capacity-is moisture storage content after a prolonged period of gravitational drainage which correspond to a certain value.

Wilting point- the lowest moisture stored that can be achieved by plant transpiration.

Saturated Hydraulic Conductivity - is the permeability of the materials under saturated condition.

The hydraulic conductivity values for topsoil, drainage materials and soil barrier layer used were extracted from VHELP soil data files.

i) Topsoil Saturated Hydraulic Conductivity Value

Table 3.2 Soil material used and saturated hydraulic conductivity

Soil type	Hydraulic conductivity (cm/s)
Silty loam	0.00019
Loam	0.00037
Fine sandy loam	0.00052
Sandy loam	0.00072
Loamy fine sand	0.00100
Loamy sand	0.00172

Source: Extracted from VHELP soil data files (1997)

ii) Saturated Hydraulic Conductivity Value for Drainage Materials

Table 3.3 Type of drainage materials used

Drainage material	Hydraulic conductivity (cm /s)
Fine Sand	0.0031
Sand	0.0058
Coarse sand	0.0100
Super coarse sand	0.0500
Gravel (or super gravel)	0.3000
Geonet	10

Source: Extracted from VHELP soil data files (1997)

iii) Saturated Hydraulic Conductivity Value for Soil Barrier Layer

Table 3.4 Barrier soil type and saturated hydraulic conductivity

Barrier Soil Type	Saturated hydraulic conductivity (cm/s)
Clay (moderately compacted)	68×10^{-7}
Silty clay (moderately compacted)	120×10^{-7}
Clay loam	360×10^{-7}
Silty loam (moderately compacted)	900×10^{-7}
Sandy clay	3300×10^{-7}
Clay loam	6400×10^{-7}

Source: Extracted from VHELP soil data files (1997).

Pinhole Density - the number of defects per unit area resulting from manufacturing flaws. It is assumed that the diameter of the hole is equal to, or smaller than, the geomembrane thickness. Holes are estimated to be one millimeter in diameter.

Installation Defects - the number of defects per unit area as a result to installation. Holes are estimated to be one square centimeter in area.

Placement Quality - quality of contact between the geomembranes liner and the under soil.

The level of vegetation parameter can take on the following values:

1. Bare Soil

2. Poor Stand of Grass

3. Fair Stand of Grass

4. Good Stand of Grass

5. Excellent Stand of Grass

3.2.3 Output of VHELP

The output of the VHELP analysis in the Output Data File is generated daily, monthly and yearly, for all years. The WBCs that appeared in the output tables in Appendix A are defined. It was an output example when model type T-4 cover system tested with every layer properties specified;

Precipitation - Inflow in the form of rainfall.

Surface Runoff - Water from precipitation that does not infiltrate into the landfill.

Evapotranspiration- Evaporation from the leaves and soil surface

Evaporative Zone Water - Water storage that can be extracted by evapotranspiration.

Change in water storage - Total change in the amount of water stored in the profile.

Annual water budget balance - Inflow water minus outflow water

Soil water - The amount of soil water at the end of the year.

Snow water- The amount of snow water at the end of year.

Lateral drainage from Layer 'x' The amount of water drained, by pipe or slope drainage, from the lateral drainage layer 'x'.

Percolation or leakage through layer 'x'- The amount of water percolated through the barrier soil liner 'x' of a geomembrane liner if it is not under laid the barrier soil liner.

Average Head on top of layer 'x' - The mean head on top of a geomembrane liner

Deviation of head on top of layer 'x'-The standard deviation of the head on top of a geomembrane liner.

3.3 Procedures of Study

The study was carried out using the software VHELP. The Weather data taken from Metrological Department of Petaling Jaya for year 2001 and 2002 was entered into the program. The average value of precipitation was 3364.05 mm. This value was used to simulate the study of performance for landfill final-cover systems. Beside this value, mean daily temperature and solar radiation were also required for the input of weather data. The input parameters value from VHELP data files were used to quantify WBCs collected at every layer of cover system tested.

Input weather and design data were used for all types of cover systems tested in this study. The study of landfill cover system performance included;

i) Type of cover systems design - Five models of landfill cover systems were tested and studied for their performance based on leachate generated. After determining the best performance of landfill cover system, the specific model was selected for further tested to find out the effectiveness of every layer on other parameters as listed below;

ii) Level of vegetation, from bare soil to excellent stand of grass.

iii) Topsoil thickness, from 0.2 m to 1.0 m at interval 0.2 m.

iv) Surface slope, from 0% to 30% increase at interval of 5%.

v) Hydraulic conductivity of topsoil while the values of hydraulic conductivity are fixed, and similar procedures followed. for lateral drainage and barrier soil layer as well.

vi) Hydraulic conductivity of lateral drainage materials, when hydraulic conductivity value of topsoil and barrier soil layers were fixed and,

vii) Hydraulic conductivity of barrier soil layer.

Parameters which included level of vegetation, topsoil thickness, and surface slopes were tested accordingly. Furthermore when soil properties were tested, the topsoil materials with different hydraulic conductivity values, lateral drainage materials and barrier soil layer hydraulic conductivity values were held constant. Similarly when hydraulic conductivity values of lateral drainage materials was tested, the hydraulic conductivity values of topsoil and barrier soil layer were held constant. The same procedure was carried out when hydraulic conductivity values of barrier soil layer was tested, both of the topsoil and lateral drainage hydraulic conductivity values were held constant.

For the purpose of parametric studies, type T-4 final-cover system was selected for further investigation. Figure 1.1 showed the final-cover profile of type T-4. The final-cover system consisted of a topsoil cover, lateral drainage layer, geomembrane layer, and soil barrier layer. The parameters studied were soil thickness, surface slopes, and hydraulic conductivity values. The required value of parameter tested was varied to find the effects on WBCs. Thus, from the above parametric study, results on the WBCs were obtained. From the results, an evaluation of the efficiency of landfill final-cover systems performance can be established.

The common values of weather and design data given below were used throughout this simulation.

i) Weather Data

Evaporative and Weather Data

Station Latitude:	3.12 Degree
Maximum Leaf Area Index:	2.50
Start of Growing Season (Julian Date):	138
End of Growing Season (Julian Date):	273
Evaporative Zone Depth:	30.0 cm
Average Annual Wind Speed:	20.80 Km/h
Average First Quarter Relative Humidity:	52.00%
Average Second Quarter Relative Humidity:	54.00%
Average Third Quarter Relative Humidity:	50.00%
Average Third Quarter Relative Humidity:	51.00%

ii) Design Data

Design and Evaporative Zone Data

SCS Runoff Curve Number:	75.00 (user specified)
Fraction of Area allowing Runoff:	100.00%
Area Projected on Horizontal Plane:	1.00 Hectares
Evaporative Zone Depth:	30.0 cm
Initial Water in Evaporative Zone:	7.338 cm
Upper Limit of Evaporative Storage:	14.190 cm
Lower Limit of Evaporative Storage:	3.120 cm
Initial Snow Water:	0.00 cm
Initial Water in Layer Materials:	288.393 cm
Total Initial Water:	288.393 cm
Total Subsurface Inflow:	0.00 mm/year

3.3.1 Study of Landfill Cover Systems Performance

i) Type of Cover Systems Design

The cover systems models namely T-1, T-2, T-3, T-4 and T-5 were illustrated below in Figure 3.1.

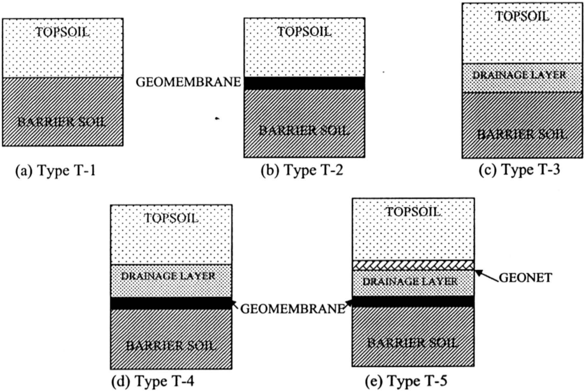

Figure 3.1 Types of cover system

Five cover systems from T-1 to T-5 were tested as shown in Table 3.5. Each of these model was tested and it was assumed that the excellent stand of grass and surface slope of 5% were adopted. Topsoil of thickness 0.4 m and saturated hydraulic conductivity values were also tabulated.

The efficiency of these cover systems were tested based on the quantity of leachate generation in the landfill. All dimension of thickness of each layer of cover system of the same materials was assumed to be consistent for every type of cover model as shown in Table 3.5. Beside this, it was also assumed that the surface area of the landfill is constant throughout study.

Model T-4 cover system was selected for further tested to determine the functions required. Among the parameters studied were topsoil thickness, surface slope, level of vegetation, saturated hydraulic conductivity of topsoil, saturated hydraulic conductivity of lateral drainage and saturated hydraulic conductivity of soil barrier layer.

Table 3.5 Model of landfill cover systems tested from T-1 to T-5

Cover system tested / Parameters Fixed	T-1	T-2	T-3	T-4	T-5
Topsoil Thickness (m)	0.4	0.4	0.4	0.4	0.4
Surface Slope (%)	5	5	5	5	5
Level of Grass Vegetation	Excellent Stand	Excellent Stand	Excellent Stand	Excellent Stand	Excellent Stand
Sat. hyd. con topsoil (cm /s)	0.00052	0.00052	0.00052	0.00052	0.00052
Sat.hyd.con.lateral drainage materials (cm/ s)	-	-	0.05	0.05	0.05
Sat.hyd.con. barrier soil layer (cm/s)	0.68E-5	0.68E-5	0.68E-5	0.68E-5	0.68E-5

Layer Properties of Cover System

The simulation study was carried out for every type of cover system model with the properties of the layer given. Type T-1 as shown in Figure 3.2, consisted of two layers namely topsoil and barrier soil layer with their properties layer specified below. Similarly for other cover systems type T-2, T-3, T-4, and T-5 as shown in Figure 3.3 to Figure 3.6 respectively and followed by layer properties.

i) Profile Properties for Type T-1

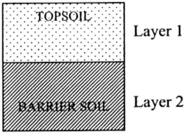

Figure 3.2 Type T-1

Layer 1

Vertical Percolation Layers

Material Name	Fine Sandy Loam (Material Texture Number 7)
Thickness	40.0 cm
Porosity	0.4730 vol/vol
Field Capacity	0.2220 vol/vol
Wilting Point	0.1040 vol/vol
Initial Soil Water Content	0.02575 vol/vol
Effective Sat. Hyd. Cond.	0.52E-03 cm/sec

Layer 2

Barrier Soil Layer

Material Name	Silty Clay (Material Texture Number 7)
Thickness	40.00 cm
Porosity	0.4790 vol/vol
Field Capacity	0.3710 vol/vol
Wilting Point	0.2510 vol/vol
Initial Soil Water Content	0.4790 vol/vol
Effective Sat. Hyd. Cond.	0.68E-05 cm/sec

ii) Profile Properties for Type T-2

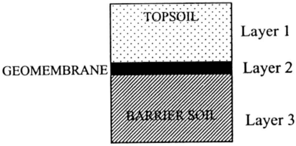

Figure 3.3 Type T-2

Layer 1

Vertical Percolation Layer

Material Name	Fine Sandy Loam (Material Texture Number 7)
Thickness	40.0 cm
Porosity	0.4730 vol/vol
Field Capacity	0.2220 vol/vol
Wilting Point	0.1040 vol/vol
Initial Soil Water Content	0.02575 vol/vol
Effective Sat. Hyd. Cond.	0.52E-03 cm/sec

Layer 2

Flexible Geomembrane Layer

Material Name	Low Density Polyethylene (Material Texture Number 7)
Thickness	0.10 cm
Porosity	0.0000 vol/vol
Field Capacity	0.0000 vol/vol
Wilting Point	0.0000 vol/vol
Initial Soil Water Content	0.0000 vol/vol
Effective Sat. Hyd. Cond.	0.40E-12 cm/sec
FML Pinhole Density	2.00 holes/hectare
FML Installation Defects	4.00 holes/hectare
FML Placement Quality	4 – Poor

Layer 3

Barrier Soil Layer

Material Name	Silty Clay
	(Material Texture Number 7)
Thickness	40.00 cm
Porosity	0.4790 vol/vol
Field Capacity	0.3710 vol/vol
Wilting Point	0.2510 vol/vol
Initial Soil Water Content	0.4790 vol/vol
Effective Sat. Hyd. Cond.	0.68E-05 cm/sec

iii) Profile Properties for Type T-3

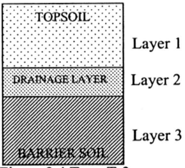

Figure 3.4 Type T-3

Layer 1

Vertical Percolation Layers

Material Name	Fine Sandy Loam
	(Material Texture Number 7)
Thickness	40.0 cm
Porosity	0.4730 vol/vol
Field Capacity	0.2220 vol/vol
Wilting Point	0.1040 vol/vol
Initial Soil Water Content	0.02575 vol/vol
Effective Sat. Hyd. Cond.	0.52E-03 cm/sec

Layer 2

Lateral Drainage Layer

Material Name	Coarse Sand
	(Material Texture Number 1)
Thickness	30.0 cm
Porosity	0.4170 vol/vol
Field Capacity	0.0450 vol/vol
Wilting Point	0.0180 vol/vol
Initial Soil Water Content	0.1215 vol/vol
Effective Sat. Hyd. Cond.	0.50E-01 cm/sec

Layer 3

Barrier Soil Layer

Material Name	Silty Clay
	(Material Texture Number 7)
Thickness	40.00 cm
Porosity	0.4790 vol/vol
Field Capacity	0.3710 vol/vol
Wilting Point	0.2510 vol/vol
Initial Soil Water Content	0.4790 vol/vol
Effective Sat. Hyd. Cond.	0.68E-05 cm/sec

iv) Profile Properties for Type T-4

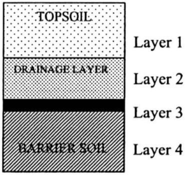

Figure 3.5 Type T-4

Layer 1

Vertical Percolation Layers

Material Name	Fine Sandy Loam
	(Material Texture Number 7)
Thickness	40.0 cm
Porosity	0.4730 vol/vol
Field Capacity	0.2220 vol/vol
Wilting Point	0.1040 vol/vol
Initial Soil Water Content	0.02575 vol/vol
Effective Sat. Hyd. Cond.	0.52E-03 cm/sec

Layer 2

Lateral Drainage Layer

Material Name	Coarse Sand
	(Material Texture Number 1)
Thickness	30.0 cm
Porosity	0.4170 vol/vol
Field Capacity	0.0450 vol/vol
Wilting Point	0.0180 vol/vol
Initial Soil Water Content	0.1215 vol/vol
Effective Sat. Hyd. Cond.	0.50E-01 cm/sec

Layer 3

Flexible Geomembrane Layer

Material Name	Low Density Polyethylene
	(Material Texture Number 7)
Thickness	0.10 cm
Porosity	0.0000 vol/vol
Field Capacity	0.0000 vol/vol
Wilting Point	0.0000 vol/vol
Initial Soil Water Content	0.0000 vol/vol
Effective Sat. Hyd. Cond.	0.40E-12 cm/sec
FML Pinhole Density	2.00 holes/hectare
FML Installation Defects	4.00 holes/hectare
FML Placement Quality	4 – Poor

Layer 4

Barrier Soil Layer

Material Name	Silty Clay
	(Material Texture Number 7)
Thickness	40.0 cm
Porosity	0.4790 vol/vol
Field Capacity	0.3710 vol/vol
Wilting Point	0.2510 vol/vol
Initial Soil Water Content	0.4790 vol/vol
Effective Sat. Hyd. Cond.	0.68E-05 cm/sec

v) Profile Properties for Type T-5

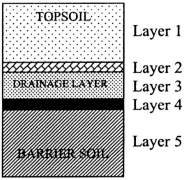

Figure 3.6 Type T-5

Layer 1

Vertical Percolation Layer

Material Name	Fine Sandy Loam
	(Material Texture Number 7)
Thickness	40.0 cm
Porosity	0.4730 vol/vol
Field Capacity	0.2220 vol/vol
Wilting Point	0.1040 vol/vol
Initial Soil Water Content	0.02575 vol/vol
Effective Sat. Hyd. Cond.	0.52E-03 cm/sec

Layer 2

Lateral Drainage Layer

Material Name	Geonet
	(Material Texture Number 43)
Thickness	0.5 cm
Porosity	0.8500 vol/vol
Field Capacity	0.0100 vol/vol
Wilting Point	0.0005 vol/vol
Initial Soil Water Content	0.1185 vol/vol
Effective Sat. Hyd. Cond.	10.0 cm/sec

Layer 3

Lateral Drainage Layer

Material Name	Coarse Sand
	(Material Texture Number 1)
Thickness	30.0 cm
Porosity	0.4170 vol/vol
Field Capacity	0.0450 vol/vol
Wilting Point	0.0180 vol/vol
Initial Soil Water Content	0.1215 vol/vol
Effective Sat. Hyd. Cond.	0.50E-01 cm/sec
Drainage Length	3.0

Layer 4

Flexible Geomembrane Layer

Material Name	Low Density Polyethylene
	(Material Texture Number 7)
Thickness	0.10 cm
Porosity	0.0000 vol/vol
Field Capacity	0.0000 vol/vol
Wilting Point	0.0000 vol/vol
Initial Soil Water Content	0.0000 vol/vol
Effective Sat. Hyd. Cond.	0.40E-12 cm/sec
FML Pinhole Density	2.00 holes/hectare
FML Installation Defects	4.00 holes/hectare
FML Placement Quality	4 – Poor

Layer 5

Barrier Soil Layer

Material Name	Silty Clay
	(Material Texture Number 7)
Thickness	40.00 cm
Porosity	0.4790 vol/vol
Field Capacity	0.3710 vol/vol
Wilting Point	0.2510 vol/vol
Initial Soil Water Content	0.4790 vol/vol
Effective Sat. Hyd. Cond.	0.68E-05 cm/sec

ii) Level of Vegetation

Various level of vegetation was studied to find the effect on WBCs within landfill. The level of vegetation tested were bare soil, poor stand of grass, fair stand of grass, good stand of grass, and excellent stand of grass. Table 3.6 explained how the level of vegetation were tested while other parameters were held fixed.

Table 3.6 Level of vegetation of model T-4 cover system

Level of Vegetation Tested / Parameters fixed	Bare soil	Poor stand	Fair stand	Good stand	Excellent stand
Topsoil thickness(m)	0.4	0.4	0.4	0.4	0.4
Slope surface (%)	5.0	5.0	5.0	5.0	5.0
Sat. hyd. con. topsoil (cm /s)	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4
Sat.hyd.con.lateral drainage materials (cm/ s)	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2
Sat.hyd.con. barrier soil layer (cm/s)	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6

iii) Topsoil Thickness

The topsoil parameter was tested. Its thickness was varied from 0.2 m, to 1.0 m at an interval of 0.2m as shown in Table 3.7. The parameters fixed were surface slope at 5 %, level of vegetation at excellence stand, saturated hydraulic conductivity values for topsoil (5.2E-4 cm/s), lateral drainage materials (5.0E-2 cm/s) and barrier soil layer (6.8E-6 cm/s).

Table 3.7 Topsoil thickness of model T-4 cover system

Topsoil Thickness Tested (m) / Parameters Fixed	0.2	0.4	0.6	0.8	1.0
Surface slope (%)	5	5	5	5	5
Level of Grass Vegetation	Excellent Stand	Excellent Stand	Excellent Stand	Excellent Stand	Excellent Stand
Sat. hyd. con. topsoil (cm /s)	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4
Sat.hyd.con.lateral drainage materials (cm/ s)	5.2E-2	5.2E-2	5.2E-2	5.2E-2	5.2E-2
Sat.hyd.con. barrier soil layer (cm/s)	6.8E-06	6.8E-06	6.8E-06	6.8E-06	6.8E-06

iv) Surface Slope

The next parameter tested was surface slope. The surface slope was varied from 0 % to 30 % at the interval of 5 % to find the effects of WBCs as shown in Table 3.8.

Table 3.8 Surface slope of model T-4 cover system

Surface Slope Tested (%) / Parameter fixed	0.0	5.0	10.0	15.0	20.0	25.0	30.0
Topsoil thickness (m)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Level of Grass Vegetation	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand
Sat. hyd. con. topsoil (cm /s)	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4
Sat.hyd.con.lateral drainage materials (cm/ s)	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2
Sat. hyd. con. barrier soil layer (cm/s)	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6

v) **Saturated Hydraulic conductivity of Topsoil**

Table 3.9 showed the types and values of topsoil materials were tested while other parameter fixed.

Table 3.9 Saturated hydraulic conductivity of topsoil materials

Topsoil Materials Tested / Parameter fixed k cm/s	Silty Loam 1.9E-4	Loam 3.7E-4	Fine Sandy Loam 5.2E4	Sandy Loam 7.2E-4	Loamy Fine Sand 1.0E-3	Loamy sand 1.72E-3
Topsoil thickness(m)	0.4	0.4	0.4	0.4	0.4	0.4
Slope surface (%)	5.0	5.0	5.0	5.0	5.0	5.0
Level of vegetation	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand
Sat.hyd.con.lat. drain materials (cm/ s)	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2
Sat.hyd.con.soil barrier layer (cm/s)	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6

vi) **Saturated Hydraulic Conductivity of Lateral Drainage Materials**

The type and value of saturated hydraulic conductivity of lateral drainage materials were tested while other parameter were fixed as shown in Table 3.10.

Table 3.10 Saturated hydraulic conductivity of lateral drainage materials

Drainage Materials Tested / Parameters fixed k cm/s	Fine Sand 3.1E-3	Sand 5.8E-3	Coarse Sand 1.0E-2	Super Coarse Sand 5.0E-2	Gravel 3.0E-1	Geonet 10
Topsoil thickness(m)	0.4	0.4	0.4	0.4	0.4	0.4
Slope surface (%)	5.0	5.0	5.0	5.0	5.0	5.0
Level of vegetation	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand
Sat.hyd.con. topsoil (cm/ s)	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4
Sat.hyd.con.soil barrier layer (cm/s)	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6	6.8E-6

vii) Saturated Hydraulic Conductivity of Barrier Soil Layer

Further tested was conducted on different soil barrier layer materials with corresponding saturated hydraulic conductivity values as shown in Table 3.11 below.

Table 3.11 Saturated hydraulic conductivity of soil barrier layer materials of

Soil Barrier Materials Tested k cm/s / Parameters fixed	Clay 6.8E-6	Silty Clay 1.2E-5	Clay Loam 3.6E-5	Silty Loam 9.0E-5	Sandy Clay 3.3E-4	Clay Loam 6.4E-4
Topsoil thickness(m)	0.4	0.4	0.4	0.4	0.4	0.4
Slope surface (%)	5.0	5.0	5.0	5.0	5.0	5.0
Level of vegetation	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand	Excel Stand
Sat.hyd.con. topsoil (cm/ s)	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4	5.2E-4
Sat.hyd.con. drainage materials (cm/s)	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2	5.0E-2

Results of these studies were disclosed and discussed in the next Chapter.

3.4 Statistical Analysis

The SPSS program is used for statistical analysis. The program is run in the Windows environment. The analysis of variance (ANOVA) is used to determine the relationship of the variables under study. ANOVA is used in this statistical test to compare the means of more than two groups of independent variable. The results of the tests obtained are shown in the Appendix D, Appendix E, and Appendix F for ANOVA and Appendix G for Correlation. The interpretation of these tests are further discussed to make the finding verified.