QUANTITATIVE EVALUATION OF LEACHATE USING PILOT SCALE LANDFILL LYSIMETER

A DISSERTATION

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DEDICATION

Dedicated to Late Mr. Janak Raj Manandhar and Late Mrs. Ganga Devi Manandhar

CERTIFICATION

This dissertation entitled **Quantitative Evaluation of Leachate Using Pilot Scale Landfill Lysimeter** by "*Dinesh Raj Manandhar*", under the supervision of *Prof. Dr. Sanjay Nath Khanal,* DESE, Kathmandu University, Dhulikhel, Nepal and co-supervision of *Prof. Dr. William Hogland,* Linnaeus University, Kalmar, Sweden and *Prof. Dr. V. Krishnamurthy*, PES University, Bangalore, India is hereby submitted for the partial fulfillment of the PhD Degree in "*Environmental Science*". This dissertation has not been submitted in any other university or institution previously for the award of a degree.

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I, *Dinesh Raj Manandhar*, hereby declare that the research work entitled **Quantitative Evaluation of Leachate Using Pilot Scale Landfill Lysimeter** submitted herein partial fulfillment of the requirements for the Doctor of Philosophy (Ph. D) Degree in Environmental Science, is genuine work done originally by me and has not been published or submitted elsewhere for the requirement of a degree programme. Any literature, data or works done by others and cited within this dissertation has been given due acknowledgement and listed in the reference section.

Sincerely,

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ABSTRACT

The population and the economic growth and the fast urbanization lead to the generation of increasing quantities of solid as well as liquid wastes which have severe consequences to the environment. More than eight million tons of solid waste is produced per day in developing countries. Over 95% of this waste is disposed off in landfills, open dumps, on riverbanks, directly into the sea, or just combusted on site because of insufficient waste collection and final disposal systems. Meanwhile Europe and industrialized countries go for high-tech solutions (e.g. modern incineration technologies) there is still a huge demand for proper landfilling in developing countries. Landfilling is likely to be the most appropriate and cost-effective final disposal option for solid waste in developing countries. The emissions of leachate and gas from landfills are main threat to environment. One of the main concerns is water contamination by leachate from landfills. The environmental risks associated to landfilling are related to leachate generation and risks of surface and groundwater pollution and offensive odour. The biodegradable portion of waste is largely responsible for the production of leachate and landfill gas. The leachate management is thus utmost important in terms of both quantity and quality. The leachate collection and treatment system in a landfill has to be designed carefully keeping the leachate production minimum. The leachate generation depends upon the climatic conditions of specific location and can be controlled by variation of hydraulic properties of materials of layers used in any landfill and analyses of water balance. This particular research presents the outcome of the study on the water balance of landfill in Nepal using a pilot scale landfill lysimeter at Kathmandu University. The related leachate production (percolation) as an effect of variation of properties of layer materials and climatological factors has been assessed. The Hydrologic Evaluation of Landfill Performance (HELP), a computer model has been used to estimate the water balances and comparison with the actual leachate (percolation) measurement was done. The local weather data (daily values of rainfall, temperature and solar radiation), vegetative growths were collected as required and variable soil and waste data (total porosity, field capacity, wilting point, initial moisture content and saturated hydraulic conductivity of layers and materials) have been determined at laboratories and some default data were used from the model. A set of simulations were done viz; A, B and C with variations in Field Capacity values of 0.2, 0.292 and 0.35 vol./vol. for hydraulic conductivity values of 0.1, 0.01 and 0.001 cm/s of waste materials respectively and also another set of simulations using various hydraulic conductivity values at the exponential orders of E^{-3} to E^{-5} and E^{-4} to E^{-9} cm/s for cover soil and barrier soil liners respectively.

It was observed that the percolation generally follows the rainfall trend. With the results of simulations carried out, it indicates that the evapotranspiration (E_T) do not exactly follow the rainfall & percolation trend and E_T is more on horizontal trend based on average years. The annual percolation rate is high in lysimeter (78 to 86% of rainfall), which is due to small area of lysimeter. There seems to be more percolation than evapotranspiration as more infiltration occurred before evapotranspiration could take place. The daily average percolation rate is as low as 5.8 mm (only 5.4% of daily average rainfall) when the higher rainfall events are considered compared to the annual values. The percolation response is observed only after few days of rainfall instead of immediate response. This is an important design consideration for landfill. Thus, the design of landfill leachate treatment system should be done on annual leachate generation basis rather than daily data. The leachate should be directed to collection and treatment system rather than allowing percolation through barrier soil liner and to ground water or surface water bodies.

The model has been calibrated for the local situation with the observed data (from June to December 2006) of leachate generation from the pilot scale landfill lysimeter. However, the trend of leachate generation on HELP simulation and actual percolation seem to be similar during October to December season, but from June to September, the trend shows higher actual percolation rate compared to the model. This may be due to the higher value (in the range of E^{-5} cm/s) of hydraulic conductivity of barrier soil liner, which should be generally lower value (in the range of E^{-7} cm/s or more), though difficult to achieve naturally. Also higher actual percolation may be due to the rainy season (June-September) when soil is wet at most of the time.

The response of average percolation and evapotranspiration with change of hydraulic conductivity values of barrier soil liner is very important. With the change of order of E^{-6} to E^{-7} cm/s in hydraulic conductivity of barrier soil liner, there is significant change in the results. With lesser values, there is no percolation and there is significant increment in E_T value. This provides an important design consideration of landfill, where hydraulic conductivity of barrier soil liner is deciding parameter and should be in the order of E^{-7} cm/s or lesser. When less or no percolation is observed, there will be a leachate mound in the layers above barrier soil liner, which should be collected from drainage layer and sent for treatment. Another important parameter observed is Field Capacity of waste, which has been simulated under three conditions A, B and C as mentioned earlier. The FC value of 0.292 vol./vol. and hydraulic conductivity (HC) of 0.001 cm/s of waste seems to best fit during regression analyses.

The HELP model simulations results and sensitivity analyses have given a guideline for evaluation of operation and design of landfill in developing countries like Nepal. The major design considerations are the Field Capacity & hydraulic conductivity of waste and hydraulic conductivity of barrier soil liner for water balance in terms of controlling leachate generation. The estimates of the cumulative leachate volume were strongly dependent on the variation of the above parameters. The evapotranspiration component of the water balance have been underestimated, as it is dependent on solar radiation, vegetative growth, evaporative zone depth, wind speed, and relative humidity. The runoff has been considered NIL in this research and model simulations as it is a small-scale lysimeter. The runoff would also have been percolated in this small area of lysimeter even if it has been considered. This is one of the reasons that percolation is higher than evapotranspiration. The landfill cover specification for Nepal is about 60 cm and capping of 30 cm. The top cover used for lysimeter is also 30 cm in this research. The depth of cover soil and other layers do not seem to have much impact on the quantity of leachate produced. Another important consideration is the formation of cracks in the cover soil and development of wall effect and preferential pathways. The hydraulic conductivity as determined in the laboratory scale could not be achieved at the field and possibly the actual leachate (percolation) might have been overestimated. During most dry period, there is a high possibility of development of these cracks. Cracks can also develop due to poor workmanship during construction or low compaction. These will aggravate the preferential flow from sidewalls. The model also does not take into account of such cracks and fissures, and if occurs in large scale, the model result might be much under estimated than the actual percolation. Thus, this is one of the important design parameter.

Simulating with variations of other parameters of soil and waste, the performance of the HELP model could be further validated using long-term measured data. In future research, study of leachate characteristics, qualitative evaluation and leachate treatment options could be focused. Laboratory and filed scale lysimeters, lysimeters with variations in waste and other material properties, recirculation and simulations and application in real landfills could also be focused in future research works. In summary, the HELP model has been considered as a good tool for evaluation of design and planning purpose and operation of landfills in developing countries like Nepal based upon the findings of this research.

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ACRONYMS AND SYMBOLS

AEC	Aquatic Environmental Center
AIT	Asian Institute of Technology
AMC	Antecedent Moisture Condition
ARRPET	Asian Regional Research Project on Environmental Technology
CCL	Compacted Clay Liner
CED	Construction Engineering Department
CN	Curve Number
cm/s	Centimeter Per Second
cm/yr	Centimeter Per Year
^0C	Degree Centigrade
%	Percentage
DESE	Department of Environmental Science and Engineering
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organization
FC	Field Capacity
g/cc	Gram Per Cubic Centimeter
g	Gram
FILL	Field Investigation for Landfill Leachate
HDPE	High Density Polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
IFS	International Foundation for Science
KMC	Kathmandu Metropolitan City
KU	Kathmandu University
kg	Kilogram
lit	Litres
MoSTE	Ministry of Science, Technology and Environment
MSW	Municipal Solid Waste
MJ	Mega Joule
m	meter
mm	Millimeter
m/s	Meter Per Second

msl	Mean Sea Level
m^2	Square Meter
m^3	Cubic Meter
m/s	Meter Per Second
NARC	Nepal Agriculture Research Center
PVC	Poly Vinyl Chloride
PWP	Permanent Wilting Percentage
RCC	Reinforced Cement Concrete
SCS	Soil Conservation Services
SHC	Saturated Hydraulic Conductivity
SIDA	Swedish International Development Agency
SWMTSC	Solid Waste Management Technical Support Center
tons/day	Tonnes Per Day
USDA	United States Department of Agriculture
USEPA	United States Environment Protection Agency
vol./vol.	Volume Per Volume
w/w	Weight Per Weight

CHAPTER I: INTRODUCTION

1.1 General

Solid waste residues are waste components that are not recycled, that remain after processing at a material recovery facility, or that remain after the recovery of conversion products and/or energy. The population and the economic growth and the fast urbanization lead to the generation of increasing quantities of solid as well as liquid wastes which have severe consequences to the environment. As the world hurtles toward its urban future, the amount of municipal solid waste (MSW), one of the most important by-products of an urban lifestyle, is growing even faster than the rate of urbanization. Ten years ago there were 2.9 billion urban residents who generated about 0.64 kg of MSW per person per day (0.68 billion tonnes per year). The report estimates that today these amounts have increased to about 3 billion residents generating 1.2 kg/capita/day (1.3 billion tons per year). By 2025, this will likely increase to 4.3 billion urban residents generating about 1.42 kg/capita/day of municipal solid waste, about 2.2 billion tons per year (Hoornweg and Perinaz, 2012). Over 95% of this waste is disposed off in landfills, open dumps, on riverbanks, directly into the sea, or just combusted on site because of insufficient waste collection and final disposal systems. Meanwhile Europe and industrialized countries go for high-tech solutions (e.g. modern incineration technologies) there is still a huge demand for proper landfilling in developing countries. Environmental and health risks associated to open dumping are related to release of methane, carbon dioxide and other gases to the atmosphere, settlings and risks of avalanches, leachate generation and risks of surface and groundwater pollution and offensive odour. Those are also the reasons that put landfilling in the bottom of the waste management hierarchy in the industrial world. However, there is no feasible alternative to landfilling in developing countries. In a short and middle term perspective, landfilling is likely to be the most appropriate and cost-effective final disposal option for solid waste in developing countries. Facing the accelerated generation of solid waste caused by an ever-increasing population, migration from countryside, urbanization, and industrialization, the problem has become one of the primary environmental issues in low and middle-income Asian countries (Hogland et al., 2005).

Most of the disposal sites in the cities are open dumps without leachate treatment, protection at the bottom by a geo-membrane or clay-lined layer, gases treatment nor other infrastructures needed. The distances to the official most important disposal sites vary from 3 km in Hambantota to 50 km in Beijing from the city centers. Besides the official disposal sites, the cities suffer from the illegal disposal of waste in rivers, lakes, oceans, drainage channels, empty lots and roadsides (Guerrero et al., 2013).

Providing adequate disposal facilities is a challenge faced by waste managers throughout the world. Most guides on sanitary landfilling management are based on technologies and practices suited to the conditions and regulations found in high-income countries. These are often based on extremely high levels of protection for aquifers, incorporating aesthetics, low noise, low gaseous emissions and high levels of leachate treatment. Many of these technologies and practices are beyond the financial resources of middle and lower income countries. The oldest and most common way of disposing of solid wastes is open dump. Though in recent years many have been closed, many are still being used. In many cases, they are located wherever land is available, without regard to safety, health hazard, ground and surface water pollution and aesthetic degradation. The waste is often piled as high as equipment allows. At many instances, the refuse are ignited and allowed to burn. In others, the refuse are periodically leveled and compacted. As a general rule, open dumps tend to create a nuisance by being unsightly, breeding pests, creating a health hazard, polluting the air and sometimes polluting groundwater and surface water. Landfill is an engineered waste disposal site facility with specific pollution control technologies designed to minimize potential impacts (Rafizul et al., 2012; 2013).

Leachate formation and water balance: Leachate is liquid percolated through solid waste, which has extracted dissolved or suspended materials. The quantity of leachate that could be generated in a landfill can be predicted by performing a water balance. A water balance involves an accounting of liquid flows into and out of the landfill system, and of liquid stored within the system. In most landfills, the inflows are precipitation and to some extent water contained in the delivered waste, and the significant outflow is leachate. Water produced during the decomposition of waste is less than 1% and water lost, as water vapor may be of non-significance to the water balance. Such circumstances can include the case of a landfill located in an extremely arid zone. Initially, for a new volume of land filled waste, the waste will absorb some of the water inflow (from percolation into the fill). However, it is presumed that on the long run, the rate of leachate produced by a landfill becomes essentially equal to the rate of infiltration of precipitation. Following is an approach that can be used to obtain an approximation of the quantity of percolation that can be expected in a landfill by means of a simple conventional hydrological water balance (Bengtsson et al., 1997).

$$\mathbf{L = P - R - E_T - \Delta S} \qquad \mathbf{(1)}$$

L = Quantity of percolation through the cover per unit area of cover soil (mm)

P = Quantity of net rainfall per unit area (mm),

R = Quantity of runoff per unit area (mm),

E_T = Quantity of moisture lost through evapotranspiration per unit area (mm),

ΔS = Change in the amount of moisture stored in a unit volume of landfill (mm),

The total amount of moisture that can be stored in a unit volume of soil is a function of two variables; the Field Capacity (FC) and the Permanent Wilting Percentage (PWP).

Leachate management is a dire need to control surface and subsurface pollutions. For proper management, thus leachate quantity as well as quality aspect need to be given attention and estimated. The estimation will help to manage and treat the leachate in a proper way. This will help the landfill management agencies such as municipalities, private operators and other concerned organizations to develop state of art technologies and also methods that could be recommended so that optimal design and evaluation of operation of landfills could be done.

1.2 The Research

Leachate production is a result of climatological factors and the biological and chemical properties of waste being disposed at the landfill. Leachate may be defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials. In most landfills, leachate is composed of liquid that has entered the landfill from external sources, such as surface drainage, rainfall, and groundwater and the liquid produced from the decomposition of waste (Tchobanaglous et al., 1993). The organic, inorganic, chemical and biological contaminants in the waste dissolve in leachate. By preparing a water balance on the landfill, the potential for formation of leachate can be assessed. The need to understand and control leachate production at landfill sites is not a new phenomenon but it has perhaps become a more significant consideration in developing countries like Nepal. More general question like how much leachate per unit area and year might be expected on a long-term average are to be answered. Water management in a small landfill is crucial and the design of the landfill needs to be carefully done, especially with respect to total water management and the specific circumstances in developing countries (Tränkler et al., 2001). The accurate estimation of leachate production and quality is a vital aspect of landfill design. This research study focuses particularly on the leachate quantification and its analytical part for evaluation of operation of landfills. Consideration and specific conclusions are drawn from this research work using a pilot scale landfill lysimeter in Nepal, which serves as a case study for better understanding of water balance in landfills. Lysimeter is a prototype form of sanitary landfill in the sense of a control device. The word lysimeter is a combination of two Greek words "Lusis" means "Solution" and "Metron" means "Measure" and the original aim is to measure soil leaching (Rafizul, 2009). The pilot scale landfill lysimeter was constructed and leachate generated is compared using a computer based hydrological model called "Hydrologic Evaluation of Landfill Performance (HELP)" (Schroeder et al., 1994). The computer model HELP developed by USEPA is tested in Nepalese context. The outcome of the analyses is used to evaluate and predict the landfill performance and also useful to recommend design and operation of landfills in Nepalese context.

The fundamental study of the field experiment using the pilot scale landfill lysimeter is to provide the reliable data for testing and improving methods of water balance in landfill operation and design. The field experiment is expected to provide clear aspects on factors influencing parameters of the water balance in landfills. From the research, the leachate production, moisture content, percolation, soil moisture storage and evapotranspiration from landfill cover is estimated. The leachate per unit area and per year expected on a long-term average is calculated.

There have been many research projects carried out in developed countries like Sweden, Canada, German in the area of water balance of landfills (Berger, 1996; Nolting, 1995; Campbell, 1983; Ehrig, 1989; Hettiaratchi, 2009 etc.). Few studies have been done in Thailand (Visvanathan et al., 2002; Tränkler et al., 2005), Bangladesh (Rafizul et al., 2009, 2012). Only one research using HELP model has been carried out in Nepal (Mahaju, 2004).

This particular research on pilot scale landfill lysimeter and comparison with HELP model has been designed and carried out for the first time in Nepal. The lysimeter has been constructed within the premises of Kathmandu University, Dhulikhel. This research serves as a case study for better understanding of effect of water balance of landfills in its operation in developing countries like Nepal.

1.3 Objective of the Research

The main objective of this research is to have estimation of water balance on quantitative basis for recommending design and operation of landfills in developing countries. The influence of variation of hydraulic properties of layer materials and simulations in leachate generation from HELP model is to be found out and comparison to be done between model and measured data of the pilot scale landfill lysimeter.

The specific objectives are as follows:

- To estimate water balance in pilot scale landfill lysimeter on quantitative basis,
- To determine influence of variation of hydraulic properties of layer materials in leachate generation, by using HELP model simulations, and
- To recommend design and operation of a landfill in local context based on findings from the research.

1.4 Justification of the Study

One of the major urban environmental problems in the developing countries like Nepal is open dumping and the direct discharge of solid waste into the river system as it is difficult to find space for landfills. The safe and reliable long-term disposal of solid waste residues is an important component of integrated waste management. Based on the analysis and findings, it is estimated that waste from households in general contributes about 50%–75% of the total MSW generated in Nepal. Thus, the average MSW generation was found to be 317 gm/capita/day. Using these per capita waste generation rates and the population in 2011, the total MSW generation of the 58 municipalities was estimated at about 1,435 tons/day and 524,000 tons/year (ADB, 2013). This figure might have exponentially increased with many municipalities added and high population growth in a decade time frame. Many rivers in the Kathmandu city and urban areas have been seriously polluted by discharges of untreated industrial and MSW. To prevent the scarce water resources from further pollution, the municipal solid waste measures should be set as rapidly as possible with planned waste control system. Landfill has been widely used for the disposal of municipal solid waste in developing countries like Nepal. In many municipalities in Nepal, landfill sites are being planned and constructed these days. It is considered to be a reliable and cost effective method when adequate land is available. However, improper management and operation of landfills and mis-handling of leachate and landfill gas is creating a severe environmental impact such as surface and subsurface water pollution and nuisance odor. Landfills can be sources of groundwater and soil pollution due to the production of leachate and its uncontrolled migration through refuse.

The need to understand and control leachate production at landfill sites is not a new phenomenon but it has perhaps become a more significant consideration during the last two decades. However, water management in a small landfill in developing countries is crucial and the design of the landfill needs to be carefully done, especially with respect to total water management (Campbell, 1983). Leachate ponds are constructed away from landfills, which are storages of leachate from the facilities, but management of this leachate is generally not done in developing countries. Specially, the impact of leachate in water quality of downstream water bodies and water use is our concern. In Nepal, Sisdole and Pokhara landfills have leachate collection and treatment system in built, but both are not adequately functioning due to poor operation. At present in other municipalities also, landfills and leachate treatment are being planned. Thus, reduction and proper management of leachate is a crucial factor in the design and operation of landfills.

This research study on assessment of volume of the leachate stream from landfill waste cells and study of the change of leachate volume with time and the effect of properties of the landfill layers on production of leachate based upon results from the pilot scale landfill lysimeter will be useful in designing landfill operation and leachate management in Nepalese context.

1.5 Scope of Research

The scopes of the research study are as follows:

1. Composition survey of waste as disposed; field and laboratory analyses for necessary soil parameters were done. Precipitation (rainfall), temperature, sunshine hours (converted to solar radiation) data for seven years (2000 to 2006) were collected from station no 1024, Dhulikhel, Department of Hydrology and Meteorology (DHM) and used in the HELP model.
2. Construction of a pilot scale landfill lysimeter and actual leachate generation was measured.
3. Water balance simulations by using HELP model were carried out. The volume of leachate generated over time period along with the other water balance components were assessed.

4. The influence of variation of hydraulic properties of layer materials, in leachate generation, based upon the simulations in HELP model was evaluated. The HELP model values compared to the measured values from the pilot scale landfill lysimeter.

1.6 Limitations of the Study

The limitations of this research study are as follows:

1. The hydraulic properties were only modeled but not the biological properties due to limitation of the HELP model.
2. Only Quantitative analyses of leachate were carried out
3. The model default values have been used wherever data on local context are unavailable for properties of layer materials of lysimeter and HELP model.

CHAPTER II: LITERATURE REVIEW

PART I: THEORETICAL CONSIDERATIONS

2.1 General

The quantity of leachate generated in a landfill depends upon the climatic conditions in which the landfill is located, the type of waste, the moisture content of the waste at the time of deposition, and the design and operating conditions of the fill. The impact of climate on the landfill can be quantified by conducting a water balance on the landfill. Basically, the difference between the net water input and the capacity of the waste to store it (Field Capacity) will be available to form leachate.

In the situation where no significant quantities of leachate are produced, it has been suggested that it may be possible to relax the standards required for the siting and the design of a landfill, by ignoring potential pollution due to leachate and by omitting the leachate collection system and landfill liner. This however, will depend on geological and groundwater conditions at the site. In an arid climate, there are occasional wet years. If extreme weather conditions occur, some leachate may be formed and may seep into the soil beneath the landfill. Provided that this does not occur more frequently than once in five years and if the foundation strata are relatively impervious, so that there is some degree of attenuation, the consequences of such an escape may not be serious and potentially may be ignored. The climatic water balance has already been expressed earlier using Equation 1 (Bengtsson et al., 1997).

2.2 Transport of Water through Landfill

The presence of water in a landfill has both positive and negative consequences for the operation of the landfill. The greatest threat, however, stems from the generation of leachate and the dispersion of pollutants to the surroundings. Water is an excellent transport medium and solvent for the pollutants which exist in the waste and which are released in connection with their decomposition. The transport of water in a landfill site is primarily generated by the following sources:

- Infiltration of precipitation over the landfill site
- Surface water runoff/run on from surrounding terrain
- Ground water inflows and outflows from surrounding land

- Decomposition of waste, and
- The moisture content of waste when it is landfilled

When localizing a landfill site and during the management and planning of its treatment systems for leachate and the establishment of a control structure for the surface and groundwater, it is necessary to have detailed information on the hydrology of the landfill and the surroundings (Bengtsson et al., 1997).

2.3 Leachate Formation and Water Balance

The quantity of leachate that could be generated in a landfill can be predicted by performing a water balance. A water balance involves an accounting of liquid flows into and out of the landfill system, and of liquid stored within the system. The major component of the liquid phase in landfills is, of course, water. In most landfills, the significant inflows are precipitation, groundwater inflow and run on and water contained in the delivered waste, and the significant outflow is leachate. Under some special circumstances, water produced during the decomposition of waste and water lost, as water vapor may be of significance to the water balance. Such circumstances can include the case of a landfill located in a desert location. Initially, for a new volume of landfilled waste, some of the water inflow (from percolation into the fill), will be absorbed by the waste. However, in the long run, the rate of leachate produced by a landfill becomes essentially equal to the rate of infiltration of precipitation. The sources of water are, water entering the fill through the cover, moisture in the cover material, and inherent moisture in the solid waste. As a consequence of the processes of decomposition that occur in a landfill, a certain amount of moisture is converted to the gaseous constituents of the landfill gas (i.e. CH_4 and CO_2). In addition, water also leaves the landfill in the form of saturated water vapor in the landfill gas. The remaining water becomes leachate.

In typical landfills, leachate migrates to the bottom of the fill. In situations where the landfill is not lined, the leachate will have the tendency to migrate in a generally downward direction through the underlying soils. However, depending upon the type of material surrounding the fill, it is possible that a certain amount of lateral migration of the leachate will take place along the soil-waste interface. One of the major concerns associated with the uncontrolled vertical migration of the leachate is the potential contamination of the groundwater. The rate of migration of the leachate can be estimated using Darcy's law.

$$Q = KA(\Delta H / L) \qquad \textbf{(2)}$$

Where:

Q = Flow rate of leachate (mm/year.)
K = Hydraulic conductivity (mm/year)
A = Cross sectional area of the fill through which the leachate flows (m^2)
ΔH/L = Hydraulic gradient (m/m), and
ΔH = Head loss (m)
L = Length of flow (m)

2.4 Factors Influencing Water Balance

The major climatic factors responsible for the water balance are precipitation, temperature, evapotranspiration, and the hydrological parameters such as surface runoff, infiltration. Other important factors are soil and waste properties, which play a major role in effecting water balance in a sanitary landfill. The properties of concern are field capacity, porosity, wilting point and saturated hydraulic conductivity values of layer materials. Equally important is the initial moisture content of the waste being disposed off, however it is generally not significant except in quite arid zones. Moisture content is related to the field capacity and also to the density of the waste. Longer precipitation series for calculation purposes could be collected from the nearest meteorological station. Evaporation from a landfill site can be estimated by means of well-known calculation methods such as Penman, Thornthwaite & Blaney-Morins. Direct measurements of the potential evaporation can be made with evaporation vessels, such as Class A Evaporation Pan. Surface water runoff is that part of precipitation which runs on the surface of a landfill site when all other losses have been deducted. Infiltration of precipitation in a landfill site refers to the water’s immediate penetration of the surface coverings upper vegetation layer, or if the waste is not covered, its penetration of the waste’s surface layer. Infiltration capacity depends on surface covering materials, composition of the waste and degree of compaction (Bengtsson et al., 1994).

2.5 Moisture Movement through the Soil Cover

Engineered MSW landfill final covers are designed to minimize the percolation of moisture into the waste. The final cover typically consists of a vegetative layer, a protective layer, a drainage layer, and a barrier layer. The moisture percolates through the overlying vegetative and protective layer into the drainage layer. The infiltrated water starts mounding on the barrier layer. A portion of the mounded moisture flows laterally as sub-surface runoff, and the remaining portion percolates vertically downwards. Thus, the moisture percolating into the drainage layer is apportioned into sub-surface runoff (flowing laterally) and seepage (flowing vertically downwards). The drainage layer encourages sub-surface runoff and reduces the mounding depth of moisture on the barrier layer. This limits the vertical seepage of moisture through the barrier layer into the waste layers. Fig. 2.1 (Mahaju, 2004) below shows a schematic diagram of the migration of moisture through drainage layer and barrier layer of the landfill final cover.

The factors affecting the sub-surface flow are the moisture infiltration rate into the drainage layer, the hydraulic conductivity of the granular material in the drainage layer, the gradient of the barrier layer, and the hydraulic conductivity of the barrier layer (McEnroe, 1989). High moisture infiltration rate into the drainage layer, high hydraulic conductivity of the drainage layer, and high gradient of the barrier layer, decreases the mounding depth over the barrier layer and increases the sub-surface flow.

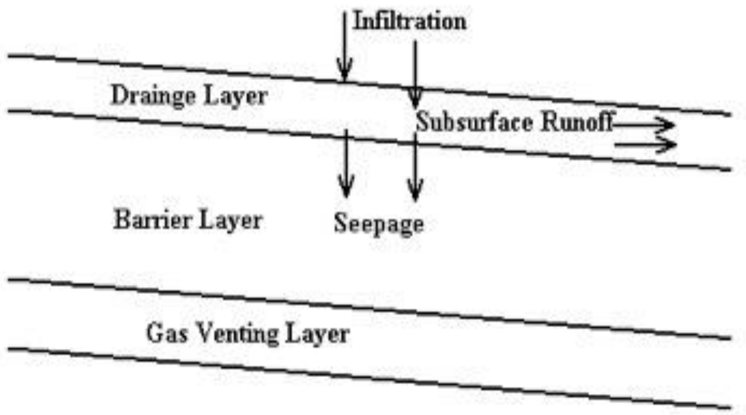

Figure 2.1: Schematic Diagram Showing the Moisture Migration

It has been found that infiltration rates of the same order of magnitude as the hydraulic conductivity of the barrier layer fail to produce a significant head over the barrier layer, thus encouraging vertical seepage and inhibiting sub-surface flow. If the hydraulic conductivity of the barrier layer is lower than the infiltration rate, significant sub-surface runoff occurs, and leachate generation rates are reduced (Sweeney et al., 1982). However, barrier layers having low gradients increase the mounding depth and decrease the sub-surface flow. Also, a higher hydraulic conductivity of the drainage layer lowers the mounding depth and vertical seepage through the barrier layer. It was observed that for coarse sand with a hydraulic conductivity of 0.01 cm/s, percolation rate was less than 110 cm/yr and the mounding depth did not exceed 30 cm (McEnroe, 1989).

Several moisture apportionment models have been developed to predict the seepage through the barrier layer. All these models assume a saturated barrier layer, and are developed for steady flow conditions. The U.S. EPA's HELP model assumes the subsurface runoff to be quasi-steady. The model assumes that the steady-state relationship between the lateral drainage rate and the average saturated depth over the barrier also holds for unsteady flow conditions existing in the landfill final cover. The model under-estimates the sub-surface runoff when the saturated depth is building up on the liner and over-estimates when the depth is falling.

2.6 Moisture Movement through Municipal Solid Waste (MSW)

Soil is a homogeneous porous matrix. Moisture flows between the solid particles of unsaturated soil as a uniform wetting front (Noble & Arnold, 1991; Khanbilvardi et al., 1995). The moisture movement through micro pores occurs due to the hydraulic head gradient consisting of elevation head and capillary pressure head. Most researchers assume that flow through unsaturated MSW also occurs as a uniform wetting front. This implies that the waste is a homogeneous porous matrix. However, MSW is heterogeneous and moisture movement occurs through preferential pathways. The flow of moisture through these preferential pathways, or macro pores, is called channeling.

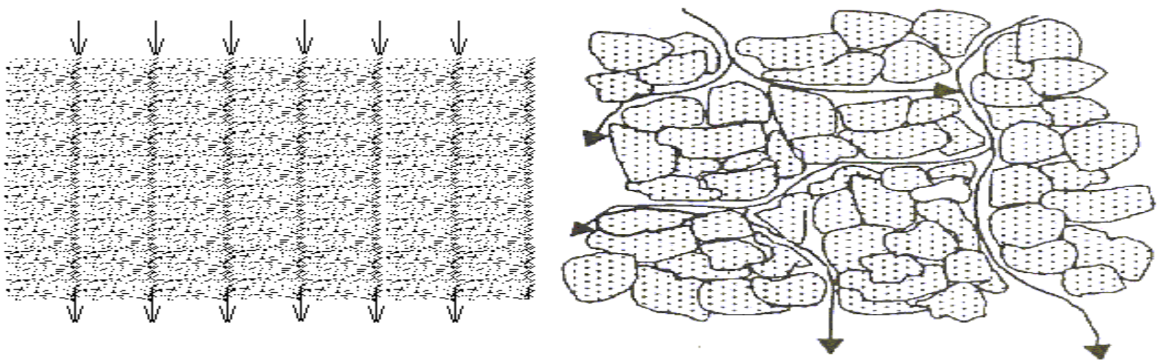

Figure 2.2: Schematic Diagram Showing Uniform Moisture Front in Soils and Preferential Flow through Channels in MSW

Moisture flows normally as unsaturated flow in micro pores and as more rapid saturated flow in macro pores. Fig. 2.2 (Mahaju, 2004) above presents the schematic diagram showing the uniform moisture front in soils and preferential flow through channels in MSW. Most flow models used to quantify leachate generated from MSW landfills, assume the waste to be a homogeneous, unsaturated, non-deformable, porous medium with uniform flow. These models assume that the moisture movement through the waste layer is an unsaturated Darcian flow through the micro pores. These models do not account for the potential occurrence of flow through macro pores of MSW due to channeling (mainly due to heterogeneous nature of municipal waste). Like most other flow models, the HELP model also assumes the waste to be a homogenous porous media with uniform flow. According to Poiseuille's equation, the volumetric flow through the porous media is directly proportional to the fourth power of radius of the pore. This means that the flow through a pore of a particular diameter is 16 times higher than the flow through an equivalent pore of half the diameter. The volume of moisture flowing through the macrospore is greater than the assumption of MSW as a homogeneous porous matrix. Also, homogenous soil matrix consists of pores of small radius, and capillary pressure head gradient governs the flow. MSW is heterogeneous and now occurs through larger pores. Elevation head gradient governs the flow through these macro pores. Therefore, a uniform moisture front is not an accurate representation of channeled flow (Chen and Wagenet, 1992).

2.7 Factors Affecting Moisture Movement in Landfills

2.7.1 MSW Composition and Properties

Typically, MSW is composed of food waste, yard waste, plastic, paper, metal, textile, lumber and others. The composition varies by location and by season. This leads to variations in MSW properties such as initial moisture content, field capacity, porosity, and saturated hydraulic conductivity. The quantity and quality of leachate generated depends on the initial moisture content of the waste, the water holding capacity of the waste, ease with which moisture flows through the MSW, climatic conditions, and land filling conditions, etc. Campbell (1983) found that reduction of particle size by crushing and powdering could increase the absorption capacity threefold. An increase of the density of the waste from 0.7 to 1 ton/m^3 can reduce it from 100 to 24 lit/ton (w/w).

2.7.2 Landfill Operating Practices

The landfill operating practices such as the type of waste accepted by the facility, and the processing of waste (such as shredding and compaction density), affect the quantity of leachate produced in a landfill. Certain types of wastes, such as food wastes, have high moisture contents. The acceptance of such waste, as well as liquid waste, by the facilities decrease the moisture storing capacity of the landfill waste. Waste processing, such as shredding, reduces the particle size of the waste, and causes garbage bags to open exposing the waste inside. The exposed waste absorbs moisture. The presence of large quantity of paper and cardboard in the waste increases the absorbing capacity of the waste. Thus, landfill-operating practice affects the amount of leachate generated.

2.7.3 Compaction Density of the Waste

Density of the waste is related to void ratio and pore geometry of the waste. Density affects the moisture absorption capacity of waste, the porosity of the waste, the hydraulic conductivity of waste, and the quantity of Leachate generated from MSW landfills. Research has shown that direct relationship exists between density and absorptive capacity of waste (Blakey, 1982). Compaction increases the density of MSW and tears open plastic "garbage bags". Compacted wastes have higher absorptive capacity due to an increase in the surface area of waste exposed to moisture by tearing of garbage bags, Zeiss & Major (1993) showed that an increase in waste density decreased the porosity (from 0.58 to 0.47 for densities in the range of 170 to 305 kg/m^3). Therefore, increased density may result in lower hydraulic conductivity and decreases the quantity of Leachate generated. The compacted MSW landfills with low waste densities have higher saturated hydraulic conductivity of about 2.5×10^{-1} cm/s (Ettala, 1987).

2.7.4 Landfill Final Cover

The final cover over MSW prevents the percolation of moisture into the underlying waste and minimizes the generation of leachate. Fig. 2.3 (Mahaju, 2004) shows a typical final cover system consisting of a surface layer, a protection layer, a drainage layer, a barrier layer,

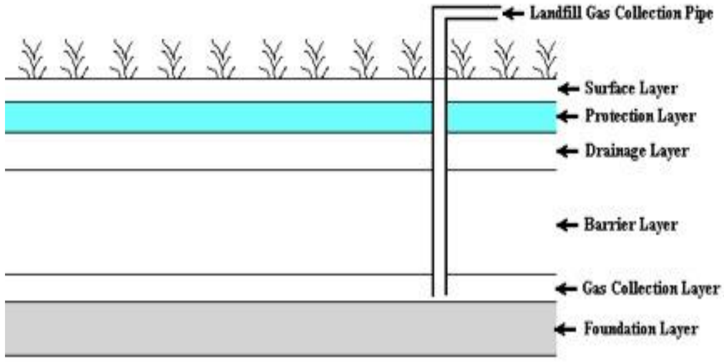

Figure 2.3 Schematic Diagram of a Landfill Final Cover System

a gas collection layer and a foundation layer. The surface layer consists of topsoil and is vegetated to minimize erosion and promote transpiration. The protection layer protects the layers underneath. The drainage layer laterally drains the rainwater and snowmelt percolating through the cover material and reduces the mounding on the barrier layer, thus minimizing infiltration into the barrier layer. The barrier layer is generally the most critical component of the final cover system. It minimizes infiltration of moisture through the cover, thereby promoting storage or drainage of moisture in the overlying layers. The gas collection layer aids in gas collection from the underlying waste. The foundation layer contours the surface of the landfill and serves as a sub-base for the overlying layer.

The percentage rainfall percolating through the landfill final cover into the waste layers depends primarily on the time of placement of final cover, and type and depth of final cover (Campbell, 1982). The final covers for MSW landfills are constructed after a landfill cell is filled to design grades. Over time, waste degrades and the cover undergoes settlement due to primary and secondary compression of the waste. Primary compression is compaction due to the dissipation of pore water and gas from the void spaces. The magnitude of primary compression is greater and masks the effects of secondary compression in the initial period of the waste placement. Secondary compression is generally due to biological decay of MSW. Settlement due to secondary compression can account for a significant portion of the total landfill settlement and can take place over many years (Wall & Zeiss, 1995). The differential settlement may result in "cracking" of the cover and the development of preferential pathways for moisture and gas. This results in an increase in infiltration into the waste layer, and an increase in Leachate production.

Generally the barrier layer is made of 60 cm thick compacted clay. Low hydraulic conductivity of the barrier layer in the final cover reduces migration of moisture into the waste. As the barrier layer is not saturated, less percolation is observed during the initial period after construction. Later on, the percolation increases with the precipitation events due to saturation. The evaporation of moisture from the surface of clay layer during the summer period reduces the moisture content of the surface layer. This results in reduction of hydrostatic pressure of the surface layer. Moisture flows from lower layers to the surface, reducing the hydrostatic pressure of lower layers. Moisture gradients are created in the clay layer, which produces stresses. These stresses cause cracking of the clay layer (Macey, 1942). Research has shown that the drying of the clay barrier in the summer period results in a many fold increase in infiltration. Freezing temperatures can also cause cracking of compacted clay barrier layers.

Cracking of final cover due to waste settlement, desiccations, and freeze-thaw allows rapid and deep infiltration of moisture into the clay layer that gradually deepens and widens with time. The swelling of fine-grained clay soil occurs during wet periods. This closes the cracks and homogenizes the soil layer. However, these cracks do not fully heal when the clay is under low overburden stress. These conditions increase the hydraulic conductivity of the barrier layer.

2.7.5 Percolation Rate through the Cover

Moisture percolating through the cover contributes to the amount of leachate produced from a MSW landfill. The more the moisture percolating into waste layers, the higher is the leachate generated. Percolation rate influences the degree of channeling that occurs within the waste; high rates result in higher degree of channeling. Uguccioni (1995) observed that precipitation rate is a more important factor affecting moisture migration through the waste, than precipitation frequency. Uguccioni (1995) showed that percolation rate had a significant effect on breakthrough time, time to reach steady state, and quantity of leachate generated. Low infiltration rates such as the low intensity rainfall, are less likely to lead to pronounced channeling than high rates, because slow application of moisture allows more time for moisture absorption into waste particles, and capillary action in the smaller pores redistributes the moisture so that the matrix flow regime in the waste layer contributes more to the overall discharge. This slow increase in moisture content forms a wetting front that moves according to the

Richard's equation for Darcy f1ow in an unsaturated zone which is given by:

$$\partial\theta/\partial t = \Delta\,(-K\,(\Psi)\Delta\,(h)) \qquad (3)$$

Where,

θ = the volumetric moisture content of the media at a given capillary pressure Ψ (m^3/m^3)

t = time (s)

K (Ψ) = the unsaturated hydraulic conductivity as a function of the suction head of the media (m/s)

Δ (h) = the hydraulic gradient (m/m)

The lower infiltration rates result in more interaction with the waste leading to increased dissolved constituents in the leachate. High infiltration rates such as high intensity rainfall increase the channeling within the waste. During periods of high infiltration, additional moisture migration pathways are developed, effectively increasing the amount of leachate transmitted. Compaction of waste reduces channeling and lessens the effect of rainfall peaks on leachate flow rates (Campbell, 1982).

2.8 Leachate Control

2.8.1 Leachate Production

Storage of any waste material in a landfill poses several potential problems. One problem is the possible contamination of soil, groundwater and surface water that may occur as leachate produced by water or liquid wastes moving into, through and out of the landfill migrates into adjacent areas. The waste landfills should be designed to prevent any waste or leachate from ever moving into adjacent areas.

In the context of a landfill, leachate is described as liquid that has percolated through the layers of waste material. Thus, leachate may be composed of liquids that originate from a number of sources, including precipitation, groundwater, consolidation, initial moisture storage, and reactions associated with decomposition of waste materials. The chemical quality of leachate varies as a function of a number of factors, including the quantity produced, the original nature of the buried waste materials, and the various chemical and biochemical reactions that may occur as the waste materials decompose. In the absence of evidence to the contrary, most regulatory agencies prefer to assume that any leachate produced will contaminate either ground or surface waters in the light of the potential water quality impact of leachate contamination, this assumption appears reasonable.

The quantity of leachate produced is affected to some extent by decomposition reactions and initial moisture content, however it is largely governed by the amount of external water entering the landfill. Thus, a key first step in controlling leachate migration is to limit production by preventing, to the extent feasible, the entry of external water into the waste layers. A second step is to collect any leachate that is produced for subsequent treatment and disposal. Techniques are available to limit the amount of leachate that migrates into adjoining areas to a virtually immeasurable volume, as long as the integrity of the landfill structure and leachate control system is maintained.

2.8.2 Design for Leachate Control

The base of the landfill should act as a liner with some minimum thickness and a very low hydraulic conductivity (or permeability). Treatments may be used on the barrier soil to reduce its permeability to an acceptable level. Above the primary liner are, geosynthetic drainage net and sand layer that serve as drainage layers for leachate collection. The drain layers composed of sand are typically at least 0.30 m thick and have suitably spaced perforated or open joint drain pipe embedded below the surface of the liner. The leachate collection drainage layer serves to collect any leachate that may percolate through the waste layers. Taken as a whole, the drainage layers and barrier soil liners may be referred to as the leachate collection and removal system (drain/liner system) and more specifically a double liner system.

After the landfill is closed, the leachate collection and removal system serves basically in a back-up capacity. However, while the landfill is open and waste is being added, these components constitute the principal defense against contamination of adjacent areas. Thus, care must be given to their design and construction. Day-to-day operation of a modern sanitary landfill calls for wastes to be placed in relatively thin lifts, compacted, and covered with soil each day. Thus, wastes should not remain exposed for more than a few hours. Although the daily soil cover serves effectively to hide the wastes and limit the access of nuisance insects and potential disease vectors, it is of limited value for preventing the formation of leachate. Thus, the drainage/liner system must function well throughout and after the active life of the landfill. When the capacity of the landfill is reached, the waste cells may be covered with a cap or final cover, typically composed of four distinct layers as shown in Fig. 2.4 below. At the base of the cap are a drainage layer and a liner system layer similar to that used at the base of the landfill. A layer of soil suitable for vegetative growth is placed at the top of final cover system to complete the landfill. A 0.60 m thick layer of soil having a loamy, silty nature serves this purpose well. The upper surface is graded so that run on is restricted and infiltration is controlled to provide moisture for vegetation while limiting percolation through the topsoil. The combination of site selection, surface grading, transpiration from vegetation, soil evaporation, drainage through the sand, and the low hydraulic conductivity of the barrier soil liner serve effectively to minimize leachate production from external water.

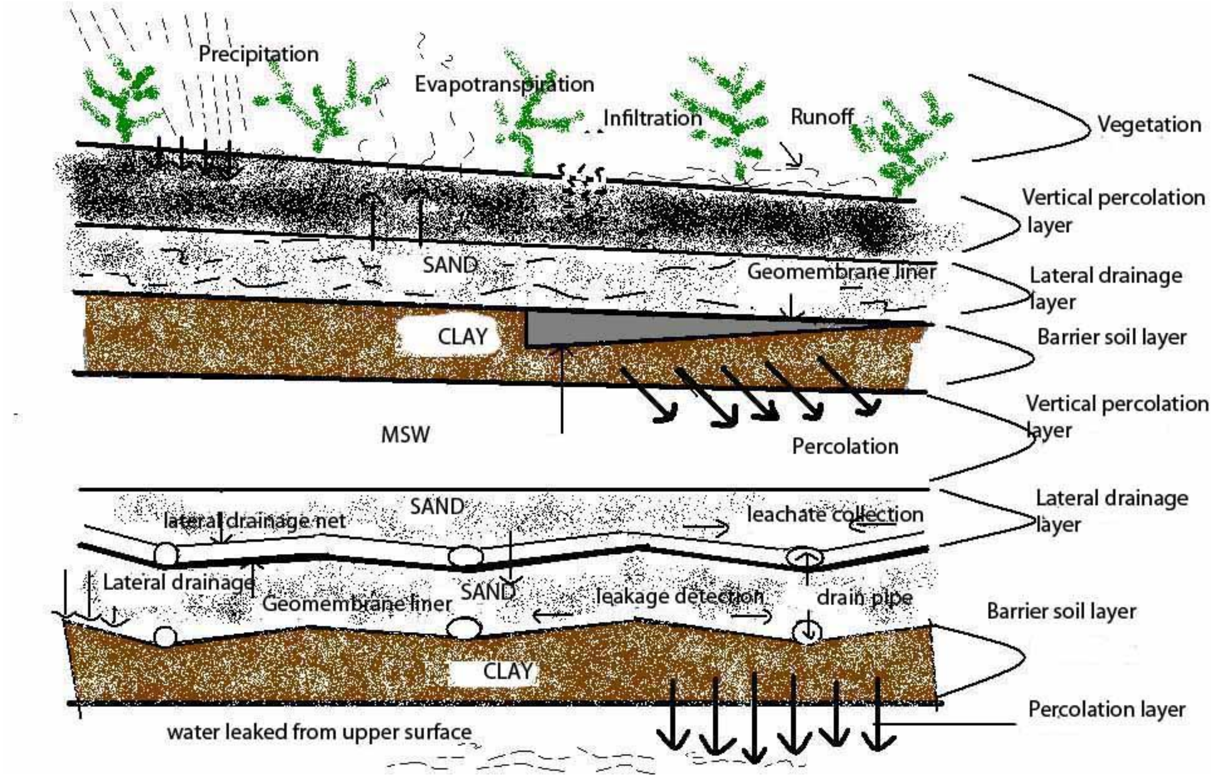

Figure 2.4: Schematic Profile View of a Typical MSW Landfill (Modified from Schroeder et al., 1994)

2.9 Parameters Needed for Modeling

The Parameters needed for modeling have been detailed in the description of model. However, some useful parameters are described here.

2.9.1 Solar Radiation and Evapotranspiration

Solar radiation values are the basis for evapotranspiration. If the solar radiation, Rs, is not measured, it can be calculated with the Ängström formula, which relates solar radiation to extraterrestrial radiation and relative sunshine duration:

The solar radiation values are determined from the equation (Richard et al., 2006) shown below

$$\boldsymbol{R_s = (0.25 + 0.50\, n/N)\, R_a} \qquad (4)$$

Where,
R_s = Solar Radiation in MJ/m^2/day
R_a = Extra terrestrial radiation in MJ/m^2/day
n = Actual measured bright sunshine in hours
N = Maximum possible sunshine in hours

2.9.2 Soil-Water Retention

Field capacity is the volumetric water content of a soil or waste layer at a capillary pressure of 0.33 bars[1]. Field capacity is also referred to as the volumetric water content of a soil remaining following a prolonged period of gravity drainage. Wilting point is the volumetric water content of a soil or waste layer at a capillary pressure of 15 bars. Wilting point is also referred to as the lowest volumetric water content that can be achieved by plant transpiration. The general relation among soil moisture retention parameters and soil texture class is shown below.

Brakensiek et al., (1984) reported the following empirical equations, which were developed using data from natural soils with a wide range of sand (5-70%) and clay (5-60%) content:

Field Capacity = 0.1535 - (0.0018)(% Sand) + (0.0039)(% Clay) + (0.1943)(Total Porosity) …(5)

Wilting Point = 0.0370 - (0.0004)(% Sand) + (0.0044)(% Clay) +(0.0482)(Total Porosity) …(6)

Sand and clay percentages should be determined using a grain size distribution chart and particle sizes defined by the U.S. Department of Agriculture textural soil classification system. According to this system, sand particles range in size from 0.05 mm to 2.0 mm, silt particles from 0.002 mm to 0.05 mm, and clay particles are less than 0.002 mm. Numerous other equations relating field capacity and wilting point to soil textural properties have been developed. Most of these equations were developed using site- specific data. However, Gupta & Larson (1979) developed empirical equations for field capacity and wilting point using data from separate and mixed samples of dredged sediment and soil from 10 geographic locations in eastern and central United States. Rawls et al. (1982) also developed empirical equations by fitting the Brooks and Corey’s (1964) soil water retention equation to soil water retention and matrix potential data from 500 natural soils in 18 states. Rawls’ (1982) equations are not applicable to soils subjected to compactive efforts. HELP users generally do not have adequate information to use models that require unsaturated water content information; therefore, Equations (5) and (6) are used to calculate the water retention of soil and waste layers.

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[1] 1 bar = $1X10^{-5}$ N/m^2

2.9.3 Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (sometimes referred to as the coefficient of permeability) is used as a constant in Darcy's law governing flow through porous media. Hydraulic conductivity is a function of media properties, such as the particle size, void ratio, composition, fabric and degree of saturation, and the kinematic viscosity of the fluid moving through the media. Saturated hydraulic conductivity is used to describe flow through porous media where the void spaces are filled with a wetting fluid (e.g. water). Permeability, unlike saturated hydraulic conductivity, is solely a function of media.

$$K_s = qL/(A^* \Delta H) \tag{7}$$

K_s = Saturated Hydraulic Conductivity in (litres/m^2/day)
q = Flow rate in (litres/day)
L = Length of sample in m
A = Area of sample in m^2
ΔH = Hydraulic gradient (m/m)

The HELP program user-defined values for total porosity, field capacity, wilting point, and saturated hydraulic conductivity can be conservatively calculated using empirical or semi-empirical methods presented. Total porosity, percent sand, silt and clay, and particle diameter are the minimum data required to calculate user-defined values using the empirical method. Total porosity and Brooks-Corey parameters are the minimum data required for the semi-empirical method. Where available, comparisons with measured values re-emphasized the fact that neither of these methods is intended to replace laboratory or field generated data.

2.10 The HELP Model

2.10.1 Introduction

The HELP model was developed at the U.S. Army Engineer Waterways Experiment Station. Use of the HELP model is recommended by the EPA and required by most states for evaluating closure designs of hazardous and nonhazardous waste management facilities. More than 2,000 private engineering offices in more than a dozen countries, and greater than 200 offices of federal, state, and municipal governmental agencies, use the model for design evaluation and regulatory permitting actions. The model is also used for training and continuing research at more than 50 universities.

HELP is a versatile model for predicting landfill hydrologic processes and testing the effectiveness of landfill designs, therefore enabling the prediction of landfill design failure resulting in groundwater contamination. HELP has become a requirement for obtaining landfill operation permits in the U.S. HELP is also effective in assessment of groundwater recharge rates. The quasi-two-dimensional hydrologic model accepts the following input data:

The input parameters for the HELP model are:

(i) Soil Properties: Porosity, Field Capacity, Wilting Point, Saturated Hydraulic Conductivity.

(ii) Vegetation Data: Evaporative Depth, Root Zone Depth, Leaf Area Index, Growing Season (Julian Day)

(iii) Climate Data: Precipitation, Air Temperature, Solar Radiation, Wind Speed, Quarterly Relative Humidity, Altitude

(iv) Engineering Design Data: Liners, Leachate and runoff collection systems, surface slope, slope length, area of landfill, Cover Data: Layer Thickness, Cover Slope

(v) Initial Boundary Conditions: Initial Moisture Content of the layers

The profile structure can be multi-layered, consisting of a combination of natural (soil) and artificial materials (waste, geo-membranes) with an option to install horizontal drainage, and change the slope of profile parts (e.g. landfill cap, leachate collection and removal systems). HELP uses numerical solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, Leachate re-circulation, unsaturated vertical drainage, or leakage through soil, geo-membrane, or composite liners.

Built-in Databases and tools:

• Weather Generator, a tool for synthetic generation for up to 100 years of daily values of precipitation, air temperature and solar radiation.

• Soil, waste and geo-membrane database which contains parameters for 42 materials.

2.10.2 Methods Used in the HELP Model

The modeling procedures developed in HELP model are based on many simple assumptions (Schroeder et al., 1994). Calculations are performed on a daily basis. Infiltration is assumed to equal the sum of rainfall and snowmelt, minus the sum of runoff, surface storage and surface evaporation. Vertical drainage is computed for each modeling segment starting at the top. No moisture is held in surface storage from one day to the next, except in the snow cover. Snowfall and rainfall are added to the surface snow storage, if present, and then snowmelt plus excess storage of rainfall is computed. The total outflow from the snow cover is then treated as rainfall in the absence of a snow cover for the purpose of calculating runoff. A rainfall-runoff relationship is used to determine the runoff. Surface evaporation is then computed. Surface evaporation is not allowed to exceed the sum of surface snow storage and intercepted rainfall. Interception is computed only for rainfall, and not for outflow from the snow cover. The snowmelt and rainfall that does not run off or evaporate is assumed to infiltrate into the landfill. Computed infiltration in excess of the storage and drainage capacity of the soil is routed back to the surface and is added to the runoff or held as surface storage.

Unsaturated vertical drainage is computed for each modeling segment starting at the top of the sub profile, proceeding downward to the liner system or bottom of the sub profile. The program performs a water balance on each segment to determine the water storage and drainage for each segment, accounting for infiltration or drainage from above, sub-surface inflow, leachate re-circulation, moisture content and material characteristics.

2.10.3 Model Application

The Hydrologic Evaluation of Landfill Performance (HELP) computer program is a quasi-two-dimensional hydrologic model of water movement across, into, through and out of landfills. The model is quasi-two-dimensional because it does not take into consideration the computation for the vertical and lateral components of flow in each layer of landfill profiles. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geo-membrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drainage layers, low permeability barrier soils, and synthetic geo-membrane liners may be modeled. The program was developed to conduct water balance analysis of landfills, cover systems and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances.

2.10.4 Overview of Modeling Procedure

The hydrologic processes modeled by the program can be divided into two categories: surface processes and subsurface processes. The surface processes modeled are snowmelt, interception of rainfall by vegetation, surface runoff, and surface evaporation. The subsurface processes modeled are evaporation from soil profile, plant transpiration, unsaturated vertical drainage, barrier soil liner percolation, geo-membrane leakage and saturated lateral drainage.

Each day, the free available water for infiltration, runoff, or evaporation from water on the surface is determined from the surface storage, discharge from the snowpack, and rainfall. Snowfall is added to the surface snow storage, which is depleted by either evaporation or melting. Snowmelt is added to the free available water and is treated as rainfall except that it is not intercepted by vegetation. The free available water is used to compute the runoff by the SCS rainfall-runoff relationship. The interception is the measure of water available to evaporate from the surface. Interception in excess of the potential evaporation is added to infiltration. Surface evaporation is then computed. Potential evaporation from the surface is first applied to the interception; any excess is applied to the snowmelt, then to the snowpack and finally to the ground melts. Potential evaporation in excess of the evaporation from the surface is applied to the soil column and plant transpiration. The snowmelt and rainfall that does not run off or evaporate is assumed to infiltrate into the landfill along with any ground melts that does not evaporate. The first subsurface processes considered are soil evaporation and plant transpiration from the evaporative zone of the upper sub-profile. A vegetative growth model accounts for the daily growth and decay of the surface vegetation. The other subsurface processes are modeled one sub-profile at a time, from top to bottom, using a design-dependent time step ranging from 30 minutes to 6 hours. A storage-routing procedure is used to redistribute the soil water among the modeling segments that comprise the sub-profile. This procedure accounts for infiltration or percolation into the sub-profile and evapotranspiration from the evaporative zone. Then, if the sub-profile contains a liner, the program computes the head on the liner. The head on the liner is then used to compute the leakage/percolation through the liner and, if lateral drainage is permitted above the top of the liner, the lateral drainage to the collection and removal system. A more detailed description of the model can be found in the HELP model user's guide and documentation reports (Schroeder et al., 1994).

2.10.5 Surface Processes

The surface processes such as snowmelt, interception of rainfall by vegetation, and surface runoff and evaporation of water affect the moisture migration into the sub-surface layers. In the HELP model, the soil is assumed to enter a frozen state when the average temperature of the previous 30 days first drops below 0°C. During the time in which the soil is considered frozen, increasing the calculated runoff reduces the infiltration capacity of the soil. The interception by vegetation is calculated daily based on the above ground biomass (CV) value using a vegetative growth model included in the HELP program. Runoff is simulated using the Soil Conservation Service (SCS) curve number method.

2.10.6 Sub-surface Processes

The sub-surface routing of moisture precedes one sub profile at a time, from top to bottom. Moisture is routed downward from one segment to the next using a storage routing procedure, with storage evaluated at the mid-point of each time step.

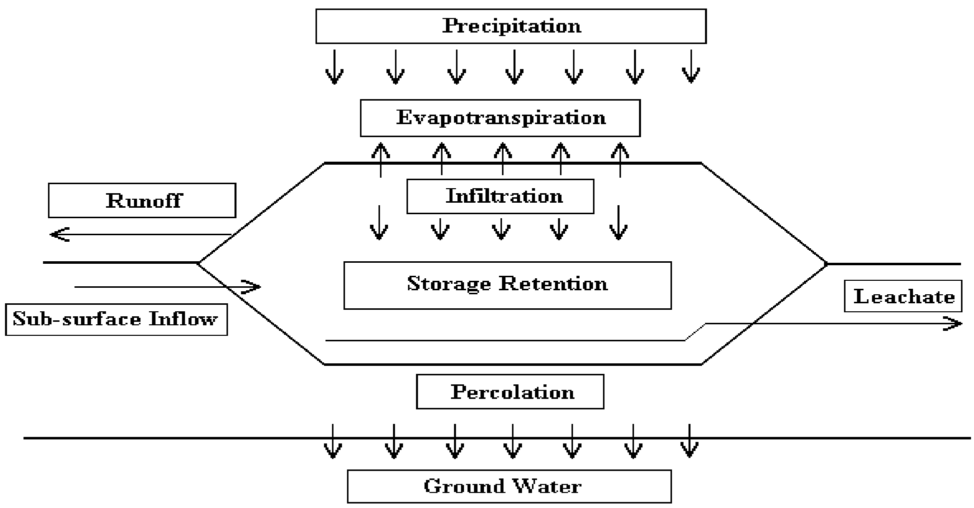

Figure 2.5 Various Water Balance Components in a Sanitary Landfill

Mid-point routing produces relatively smooth, gradual change in flow conditions, and avoids the more abrupt change that results from applying the full amount of moisture to a segment at the beginning of the time step. Mid-point routing is based on the following equation of continuity for a segment as shown in Fig. 2.5:

$$\Delta\text{Storage} = \text{Drainage In} - \text{Drainage Out} - \text{Evapotranspiration} + \text{Leachate Re-circulation} + \text{Sub-surface Inflow}$$

2.10.7 Assumptions in Field Application of Model

The model can simulate water routing through or storage in up to twenty layers of soil, waste, geo-synthetics or other materials for a period of 1 to 100 years. As many as five liner systems, either barrier soil, geo-membrane or composite liners, can be used. The model has limits on the order that layers can be arranged in the landfill profile. Each layer must be described as being one of four operational types as, vertical percolation, lateral drainage, barrier soil liner or geo-membrane liner. The model does not permit a vertical percolation layer to be placed directly below a lateral drainage layer. A barrier soil liner may not be placed directly below another barrier soil liner. A geo-membrane liner may not be placed directly below another geo-membrane liner. Three or more liners, barrier soil or geo-membrane, cannot be placed adjacent to each other. The top layer may not be a barrier soil or geo-membrane liner. If a liner is not placed directly below the lowest lateral drainage layer, the lateral drainage layers in the lowest sub-profile are treated by the model as vertical percolation layers. If a geo-membrane liner is specified as the bottom layer, the soil or material above the liner is assumed to be the controlling soil layer. No other restrictions are placed on the order of the layers. The lateral drainage equation was developed and tested for the expected range of hazardous waste landfill design specifications. The ranges examined for slope and maximum drainage length of the drainage layer were 0 or 30 percent and 7.5 m to 600 m; however, the formulation of the equations indicates that the range of the slope could be extended readily to 50 percent and the length could be extended indefinitely. Several relations must exist between the moisture retention properties of a material. The porosity, field capacity and wilting point can theoretically range from 0 to 1 in units of volume per volume, but the porosity must be greater than the field capacity, and the field capacity must be greater than the wilting point.

The initial soil moisture content cannot be greater than the porosity or less than the wilting point. If the initial moisture contents are initialized by the program, the moisture contents are set near the steady-state values. However, the moisture contents of layers below the top liner system or cover system are specified too high for arid and semi-arid locations and too low for very wet locations, particularly when thick profiles are being modeled. Values for the maximum leaf area index may range from 0 for bare ground to 5.0 for an excellent stand of grass. Greater leaf area indices may be used but have little impact on the results. Detailed recommendations for leaf area indices and evaporative depths are given in the program. For numerical stability, the minimum evaporative zone depth should be at least 7.5 cms.

The program computes the evaporation coefficient for the cover soils based on their soil properties. The default values for the evaporation coefficient are based on experimental results reported by Ritchie (1972) and others. The model imposes upper and lower limits of 5.50 and 3.30 for the evaporation coefficient so as not to exceed the range of experimental data. The program performs water balance analysis for a minimum period of one year. All simulations start on the January 1 and end on December 31. The condition of the landfill, soil properties, thicknesses, geo-membrane hole density, maximum level of vegetation, etc., are assumed to be constant throughout the simulation period. The program cannot simulate the actual filling operation of an active landfill. Active landfills are modeled a year at a time, adding a yearly lift of material and updating the initial moisture of each layer for each year of simulation.

Part II: Empirical Reviews

2.11 Lysimeter Study

A Lysimeter model have been researched under Asian Regional Research Program on Environmental Technology (ARRPET), a project on Sustainable Solid Waste Landfill Management in Asia funded by Swedish International Development Agency (SIDA) and coordinated by Asian Institute of Technology (AIT), Bangkok, Thailand. Leachate generation and composition under monsoon conditions have been studied under ambient conditions by constructed lysimeters. The settings of these lysimeters have been simulating sanitary landfills as well as dumpsites. The first period results over almost two years indicate that the open dump simulation showed highest leachate generation throughout rainy season and leachate flow terminating during the dry period. More than 60% of the precipitation emerged as leachate; accordingly storage and evaporation accounted for less than half of the sanitary landfills (Visvanathan et al., 2002, 2003).

In a lysimeter, moisture content of the waste in excess of field capacity can be considered as the main leachate-generating component. The lysimeter generated a flow based on the available moisture above field capacity due to compaction and compression of the waste bed only for a short initial period. This continued for nearly 2–3 week after the starting period (dry season). Single rainfall events, especially in the dry season, did not influence the system, which indicates that there were no short circuits or wall effects (Tränkler et al., 2005).

Considering about 65% of moisture content and 52% of organic composition of MSW in lysimeter, the amount of leachate generation was found to be strongly related to rainfall and cover system. After 450 days of entire lysimeter operation, leachate generation was also increased steady than the successively rainy season. However, for open cell, without a compacted clay liner (CCL), rain water was percolated rapidly into the lysimeter and hence produces relatively higher quantity of leachate, whereas, due to the providing a CCL having high compaction density expected to produce relatively low leachate, especially during the dry season (Rafizul et al., 2012).

Three lysimeters were filled with municipal waste and three different cover soil types i.e. sandy loam soil, silty loam soil and clay soil while another lysimeter was filled solely with municipal waste. The study was conducted in the rainy season. Leachate quantities were measured every day and leachate characteristics were determined once a week. The cumulative leachate quantity from the lysimeter filled solely with municipal waste was found to be around 27% higher than the lysimeters using cover soils (Karnchanawong & Yongpisalpop, 2009).

One of the important limitations of lysimeter is edge effect. A major potential problem in lysimeter experiments is preferential flow along the sidewalls of the lysimeters, and the use of lysimeters for studying the mobility of contaminant and evaluations of solute transport models have been criticized for that reason (Till & McCabe, 1976). Thus, efforts have been made to solve that problem (Corwin, 2000; Cameron et al., 1990, 1992 & McLay et al., 1992). Preferential flow along the walls of the lysimeter is an artificial channeling of water due to occurrence of air space between the test material and the inside wall of the lysimeter. These air spaces serve as artificial flow paths that permit the rapid flow of water and thereby the transport of solutes. Preferential flow may cause the hydraulic conductivity and the leaching rates to be overestimated, and in that case the lysimeter conditions are not representative of the field conditions (Cameron et al., 1990 & Corwin, 2000). The amounts of specific elements leached may also be underestimated due to the fact that parts of the leachate have not been in proper contact with the test material. In general, increasing the surface area of the lysimeter can minimize the relative importance of sidewall flow. Actually, many different techniques have been used to overcome that problem but unfortunately only a few investigations actually evaluate the effectiveness of the techniques used (Nordtest Technical Report 473, 2000).

2.12 Leachate Production

The estimate of leachate rate in a landfill site is of considerable importance in the design of an appropriate collection system or the treatment alternatives to reduce the offsite migration that might pollute both surface-water and ground-water resources. The hydraulics of leachate accretion in the unsaturated zone and the variation of leachate mound in the saturated zone are relatively complicated due to the heterogeneity of the landfill matrix. The portion of precipitation, that remains after surface runoff, change in soil moisture and evapotranspiration is considered to be instantaneously flowing as leachate through the landfill.

In a well-compacted landfill site (density > 0.7 ton/m^3), leachate production could be 10-20% of the annual precipitation, while a less compacted landfill has 25-50% of the annual precipitation (Campbell, 1983). Out of reported results for 15 different landfills in Germany, some of which were up to 12 years old, the leachate production rate were not greater than 20% of the site-specific rainfall and in many instances the ratio was less than 15% (Ehrig, 1989). In a site in North London, the leachate production rate was a maximum of 30%, even for a year of abnormally high rainfall (Blakey, 1989).

As per review of 36 landfills in USA, leachate production rates rarely exceeded 5% of the site-specific precipitation, especially those sites that had implemented modern construction quality assurance procedures (Bonaparte & Gross, 1993). In a landfill in Pennsylvania in the USA, leachate production rates of up to 12% of precipitation were monitored during the first year of active filling, but thereafter dropped to 0.3%, as active filling was accompanied by cover installation (Bonaparte & Gross, 1993). The leachate production rate from 12 test cells in Sweden, that contained various combinations of domestic and industrial waste, varied from 6 to 16% (Nilsson, 1995). Despite all these landfills being in the cooler, wetter climates of Northern Europe, the rate of leachate production is usually of the order of 10 to 30% of the ambient precipitation. Higher values are found in landfills in Central Europe (the Netherlands, Germany and Denmark), where leachate production rates of up to 60% were found and never fell below 40%. These results, however, appear to be exceptional. In the light of the above figures, these countries require leachate collection systems beneath all new landfills (Nolting, 1995).

Kimpo metropolitan landfill has received various kinds of wastes since January 1992. The leachate level was measured to be 10.3 m in May 1995 and the level increased to 12.2 m in August 1996. Therefore, to prove the reason for the increasing leachate level, we calibrated hydraulic conductivity of each waste and intermediate layer using the HELP (Hydrologic Evaluation of Landfill Performance) model. The leachate generation data measured from the landfill from February 1993 to October 1995 was used in the model calibration. As a result of a model calibration, we obtained an average infiltration ratio and used this in analysis of the total water balance to predict elevation of leachate level. Main causes of the elevation of the leachate level were the high water content of the waste and the degradation of the leachate-drainage system caused by the subsidence of a natural barrier layer (Dho et al., 2002).

Municipal landfill sites have neither proper liner nor leachate collection and treatment systems. The final covering is done without laying any drainage layer. All the precipitation on the landfills passes through the cover and solid waste acquiring various contaminants through physical, chemical or biological processes. Any precipitation or external source of water contributes to leachate generation. Using water balance method, the amount of leachate generated from the landfill sites in Delhi has been estimated. The amount of leachate generated is dependent on the available water, landfill constituents, its surface and the foundation soils (Oweis & Khera, 1990). The available water is affected by the moisture content in the refuse itself, precipitation, surface runoff, irrigation water moving through the landfill, rise of an otherwise low groundwater table, and water generated from the decomposition of the waste. The quantity of water infiltrating into the landfill is affected by the surface runoff, evapotranspiration, and the field capacity of the soil cover (Kumar et al., 2001).

Hydraulic properties of waste and cover soil from Kimpo Metropolitan Landfill was experimentally measured by laboratory tests. The degree of compaction was changed to identify the effect on hydraulic conductivity, field capacity, and permanent wilting point. Properties were utilized in developing a reliable numerical tool for leachate analysis. HELP, a simulation model for hydrologic evaluation of landfill performance, was adopted for that purpose. For calibration, results from simulation using the parameter values measured by laboratory tests were compared against the field data. The model was applied to predict the leachate level change according to the degree of compaction and cover soil thickness variation. It was found that the increase in the degree of compaction for intermediate cover soil and waste results in the decrease of field capacity and hydraulic conductivity, hence, the increase of leachate level. The effect of cover layer thickness on the leachate level was minor. Based on the findings from laboratory and numerical experiments, a guideline for reclamation practice was recommended (Jang et al., 2002).

2.13 Application of HELP Model

Results from a field investigation of leachate production in young landfills in semi-arid climates, with open waste layers are presented. The delay of placing final covers in semi-arid landfills, for a period of up to three years is the primary contributor to leachate production during the early stages. Rainfall intensity and duration impact the leachate production patterns. The MC/FC ratio in waste layers is proposed as an alternate parameter to assess propensity of arid climate landfills to produce leachate. The peak/average leachate flow is affected by rainfall intensity and duration. A computer simulation of leachate production in young landfills shows that HELP model may under estimate leachate production during the early stages of a landfill’s life. Laboratory studies to determine field capacity of waste were conducted in two plexi glass columns. For pilot scale field studies, a landfill lysimeter was constructed using a corrugated steel pipe of 2.4 m diameter and 4 m height (Hettiaratchi et al., 1998).

Given the location’s specific boundaries the simulation shows that leachate is generated at an average of 21% of the rainfall. However, it is not suitable to use long-term average weather data. Due to the linkage of rainfall, run-off, and evaporation individual data have to be assessed. Taking into account the annual values at great bandwidth from 17–30 % is obvious. This variation is mainly due to the intensity of rainfall and in consequence an increase of the run-off. However, the dominating factor of the overall water balance is the empirical calculated evapotranspiration in a range of 50% of the precipitation. The reduction of leachate could be best achieved by reducing the open space needed for operation and by applying a top layer of a hydraulic conductivity less than kf = $5X10^{-6}$ cm/s. The HELP model is an appropriate tool to estimate the emerging leachate as well as give recommendation for the operation and design of landfills. However, its detailed application to tropical monsoon boundaries has to be assessed. Especially the influence of evaporation and run-off on the leachate generation shall thoroughly be investigated (Manandhar & Tränkler, 2000).

Application of HELP model will give a basis for the evaluation of the landfill and also design alternatives for planning purpose. The model was applied to simulate the Leachate flow rates in Fresh Kills landfill, situated in Staten Island, New York. Comparison was made with a two-dimensional un-steady-state moisture flow model called FILL (Flow Investigation for Landfill Leachate). It has indicated the shortcomings of the HELP model in calculation of surface runoff, while using SCS curve number technique, which does not take into account the side slope, surface roughness (Khanbilvardi et al., 1995). The model was also applied in Germany where some operational difficulties for the use of this model was notified, which has been developed for the United States. The model results are tested against field data of the water balance, measured on test fields on the Georgswerder landfill in Hamburg. It has indicated that water balance components, such as evapotranspiration, lateral drainage and percolation are the three most important values to be modeled (Berger et al., 1995).

The HELP model has been used in landfill study in Nepal. The study showed that there was plenty of leachate production annually which ultimately was mixing with ground water. This study concluded that the leachate production can be controlled with the manipulation of the topsoil cover. Use of HDPE sheet of 500 micron as geo-membrane cover to the landfill site along with the provision of simple lateral drainage could minimize the leachate production up to 99.10% of the present leachate production (Mahaju, 2004).

2.13.1 Limitations of HELP Model

The past research has shown the following limitations of the HELP model:

- Peyton and Schroeder (1988) observed that the hydraulic conductivity of the cover soil affected the lateral sub-surface predictions by the HELP model. An increase in the hydraulic conductivity of the soil cover increased the sub-surface runoff. They claimed that a good agreement between predicted and measured values could be obtained by calibrating the hydraulic conductivity of the cover material while staying within the range of hydraulic conductivity values reported in the literature for those materials.
- The moisture movement through unsaturated MSW has been assumed as a uniform wetting front moving through the homogeneous media. However, as the moisture flow in MSW is through macro pores, preferential pathways are formed. MSW characteristics itself vary with source and other landfill operating conditions. These factors affect the hydraulic properties of the waste. HELP model assumes the landfill conditions to be constant over time and uses built-in default waste parameters.
- The HELP model has built-in default value for field capacity of the waste. However Zeiss and Uguccioni (1995) showed that the practical field capacity of the waste is significantly lower than the HELP model default value. Hence, leachate is produced earlier than that predicted by the HELP model.
- The field capacity values of waste have been defined based upon the water content and density of the waste and also literature values and default values have been used. Such properties, like field capacity, wilting point can be determined from the lab-scale testing.

This methodology more closely approximated the actual conditions. They demonstrated that HELP model can be calibrated to more accurately model actual field conditions with minor adjustments to the site-specific inputs, and more accurate predictions can be made without extensive additional time and cost during the design phase of a landfill.

2.14 Field Capacity of the Waste

The Field Capacity refers to the volume of water, which is absorbed, stored or held by capillary action after the possible volume of water has been drained through the influence of gravity, and after the waste has been saturated. For waste having homogeneous character, absorption capacity and Field Capacity carry the same meaning. The Field Capacity for mixed household waste could lie at 80%, which can then fall to 60-65% for 4-5 years old household waste, where decomposition is in full progress (Blight, 1996). It is possible to neglect the expiry of water, which takes place with water-saturated gases, which leave the landfill. The volume of water, which can be generated in connection with the decomposition of the organic material in the waste, is small. Some of the water can also be consumed during the anaerobic decomposition process (Bengtsson et al., 1994). The Field Capacity of the waste affects the moisture movement through the waste. A decrease in Field Capacity decreases the breakthrough time of leachate discharge. Field Capacity has been defined in a number of ways. Field Capacity is defined as the maximum moisture that the porous medium can retain against gravitational forces without producing a downward flow of liquid (Bagchi, 1994). It is the moisture content of a porous media at 0.33 atm. of pressure (Freeze & Cherry, 1979; Schroeder et al., 1994), or the moisture content corresponding to the point on the drainage curve at which free drainage of an initially saturated media ceases. It is also defined as the ratio of volume of moisture retained in the porous media after gravity drainage ceases to the total volume occupied by the soil (Schroeder et al., 1994). In a broad sense, these definitions have similar meaning.

In a homogenous soil medium, moisture flows from one layer to another as a uniform wetting front, draining or releasing moisture at field capacity. Although MSW is assumed to behave in a manner similar to soil in relation to its moisture retention and transmission capabilities, the waste particles have a greater moisture absorptive capacity than soil particles and would therefore have a greater capacity to store and retain moisture under similar conditions (Leskiw, 1992). The moisture absorption capacity of MSW depends on a variety of factors such as type and age of waste, initial moisture content, degree of compaction, pre-treatment, and infiltration of rainfall and other liquids (Blakey, 1982) and can range from 0.020 to 0.380 vol./vol. of dry waste (El-Fadel et al., 1997). Moisture content of fresh domestic waste is lower than the Field Capacity (Blakey, 1982). This results in moisture absorption until the Field Capacity is reached. Moisture contents of the waste at the time of placement have been found to range between 0.1 vol./vol., and 0.3 vol./vol., and Field Capacity to range between 0.30 vol/vol. and 0.45 vol./vol. (Leskiw, 1992). The initial moisture content and Field Capacity of MSW (excluding the daily cover soil) as reported in several studies are summarized in Table 2.1.

Table 2.1: Initial Moisture Content and Field Capacity of MSW as a Function of Density (Modified from: Bagchi, 1994)

Wet Density (Kg/m^3)	Dry Density (Kg/m^3)	Initial Moisture Content (vol./vol.)	Field Capacity (vol./vol.)	Source
314	Not Available	0.160	0.302	(Rovers et. al., 1973)
479	312	0.167	0.318	(Walsh et. al., 1979)
473	308	0.165	0.404	(Walsh et. al. 1981)
390	303	0.083	0.367	(Wigh, 1979)
334	282	0.052	0.342	(Fungaroli, 1971)

Table 2.1 indicates that average initial moisture content of 0.125 (vol./vol.); the average field capacity (absorptive capacity) of MSW is 0.345 (vol./vol.). Thus, on an average, MSW can absorb an additional 0.220 (vol./vol.) of moisture. The absorptive capacity of MSW also depends on the thickness of the waste layer (Guyonnet et al., 1998). The thicker is the waste layer, the longer is the travel path, and the greater is the absorption.

However in this research, waste of field capacity 0.292 (vol./vol.) have been used as related with density of waste of about 450 kg/m^3 (Schroeder et al., 1994). The Field Capacity is dependent on density of waste and age of waste deposition.

CHAPTER III: MATERIALS AND METHODS

3.1 Description of Study Site

The pilot scale landfill lysimeter has been set up within the premises of the Kathmandu University in Dhulikhel. Dhulikhel is situated about 27 km. east from the Kathmandu Valley. It lies in Kavre district of Bagmati zone, Nepal. Dhulikhel has a moderate and temperate climate. There are large differences in temperatures between summer and winter. Winters are cold with temperatures that are much lower than those during the summer, subzero temperatures are not uncommon during the winter sometime. During the summer it may be quite warm. Precipitation figures are low during spring. However, when temperatures start to rise precipitation figures rise as well. Summers are very wet. It lies at the latitude of 27.61^0 N and longitude of 85.55^0 E and at altitude of 1550 m above msl. The annual precipitation ranges from 1232 mm to 2228 mm with average of 1552 mm over 7 years (2000 to 2006). The condition of the study site is best characterized by a season of eventually high intensity rainfall (maximum of 220 mm/day). However, it has been observed that 215–269 days per year showed up with no rain at all and there is a distinct arid period. With an average temperature of 16ºC (range 4ºC to 27ºC) over the 7 years and an average solar radiation is computed to be 78.56 MJ/m²/day with max. 218.43 MJ/m²/day (Department of Hydrology and Meteorology, 2006).

3.2 Experimental Design and Setup

A desk study (theoretical and empirical review) was done of the similar projects carried out at various places. The lysimeter study and HELP model applications were reviewed. The methodology includes fieldwork for planning of lysimeter, installation of lysimeter, hydrological and meteorological data collections, preparation of data for model, quantitative sample collections for leachate measurements, laboratory analysis of soil, HELP model simulations, calibrations, analysis of data, interpretation of results and discussions and deriving conclusion and recommendations. The area inside KU was visited and planning was done to construct and install lysimeter, sampling and testing of soils, transportation of waste. The preparation for the waste composition survey and soil sampling was done. The laboratories at the Kathmandu University and Nepal Agriculture Research Center (NARC) were consulted for testing of the soils and drainage materials.

3.2.1 Waste Composition Survey

The waste sample of 1000 Kg (1 Tonne) was collected from 10 numbers of waste transporting trucks hauled from different wards of KMC (100 Kg from each truck) to Teku Transfer Station in Kathmandu. The waste was put together and segregated to determine waste composition. The wastes were placed in a large plastic sheet and by using quarter method (standard method used to come up with representative amount: samples of one-fourth each time after mixing) of analyses, the waste composition survey was carried out at the Teku transfer station itself. The waste sample from Teku Transfer Station in Kathmandu was brought to the KU. The mixed waste as received in the truck was used in the lysimeter without any sorting.

3.2.2 Installation of Pilot Scale Lysimeter

The research was carried out with installation of pilot scale landfill lysimeter made up of Reinforced Cement Concrete (RCC) rings with diameter (1m) and total height of 3m. The Fig.3.1 provides schematic details and photographs are shown in Appendix I. A barrier soil layer of 0.3 m thick was provided at bottom with compaction of soil. The drainage system (aggregates chip size between 5mm –10mm) of thickness of 0.5 m was provided at the bottom layer above the barrier soil (thickness of 0.3 m). A drainage channel was assembled made up of PVC pipes so as to collect the leachate generated. The wastes were brought from the Kathmandu Metropolitan City representing the waste, as it would have been landfilled. Solid waste received from Teku Transfer Station was placed inside the lysimeter at the rate of 200 to 250 mm thickness each time and compacted to a density of approximately 450 kg /m^3 until total height of 1.8 m was reached. Clay loam layer of thickness of 0.3 m was placed as the cover soil layer on top. The leachate from the lysimeter was drained into 2 numbers of storage tanks, i.e. two numbers of buckets each with a capacity of 17 litres, one leading from bottom of drainage layer and other from bottom of barrier soil layer. Diversion of leachate has been provisioned through perforated PVC pipe of 50 mm diameter installed in the drainage and barrier soil layers. The PVC pipes have been arranged at mid part of drainage layer with two pipe sections. At upper section, there are several perforations made both at upper and lower sides, while on lower section, there are only upper side perforations made. The temperature probe inserted in the lysimeter (up to middle of waste layer) provides temperature variations, which provide stages of degradation process of the wastes. The lysimeter has been installed so that it represents a real vertical landfill profile and the scale is prototype of landfill layers.

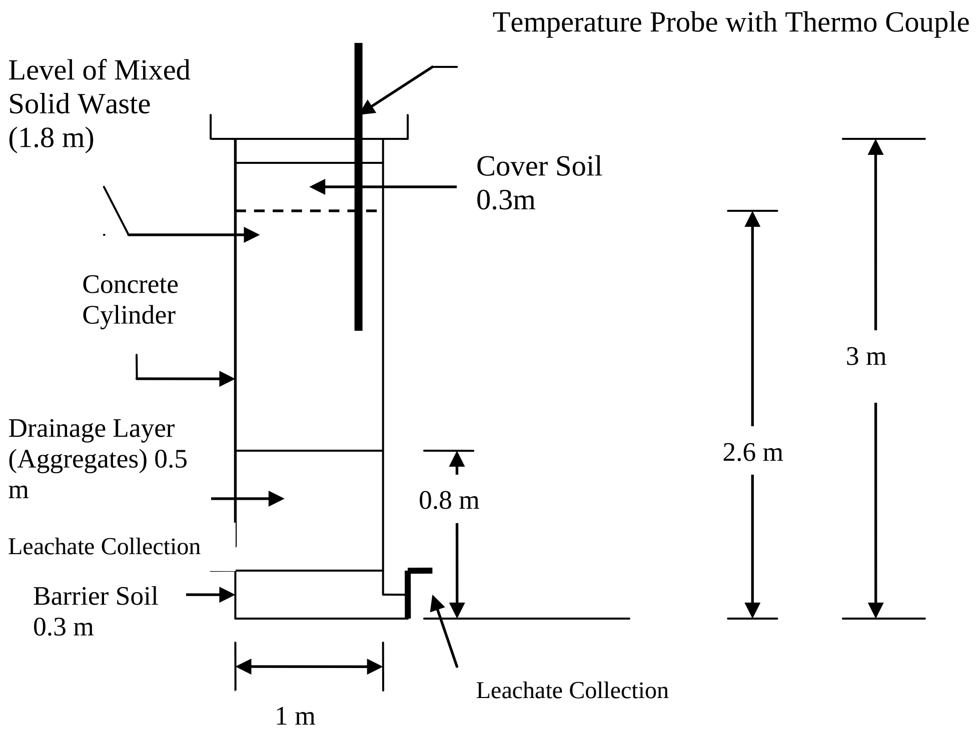

Figure 3.1: Schematic Diagram of Lysimeter Installation

3.2.3 Test Conducted for the Barrier Soil, Cover Soil and Drainage Layers

For soil testing, the required parameters like Saturated Hydraulic Conductivity, Moisture Content, Total Porosity, Field Capacity, Bulk Density and Wilting Point have been carried out. The soil tests were carried out at Nepal Agricultural Research Council (NARC), Khumaltar and the moisture content of soil were tested in Kathmandu University (KU). The key parameters for Barrier Soil layer (Clay loam) and Cover Soil layer (Sandy Loam) are tested in the NARC as per the followings;

The tested parameters were;

- Saturated Hydraulic Conductivity
- Total Porosity
- Field Capacity (FC)
- Permanent Wilting Point (PWP)

The Saturated Hydraulic Conductivity was derived from Constant Head method. The Field Capacity (FC) of soil could not be tested in NARC because of non-functioning of the instrument. The value of FC and PWP has been calculated using the sand and clay content and total porosity (Equation 5 and 6 in Chapter II). The moisture content of soils necessary for the cover and barrier soil in pilot scale model were tested in Kathmandu University.

For conducting the above tests, the soil samples from Chaukot, Banepa for the barrier soil and the soil samples taken from Kathmandu University near Aquatic Lab for cover soil were collected and tested at Nepal Agricultural Research Council (NARC), Khumaltar. The results obtained from NARC are as shown in Table 4.2 and 4.3.

For drainage layer

The drainage layer in lysimeter was filled with the aggregate chips sizes passing through 5 mm sieve and retained on 10 mm sieve. The aggregate chips passing from 5 mm sieve and retained on 10 mm was put into a 3.8 cm diameter burette of height 1.22 m. The water passing constant flow for determination of the following parameter of drainage layer (Aggregate chips with size between 5-10 mm)

- Saturated Hydraulic Conductivity
- Total Porosity
- Field Capacity
- Permanent Wilting Point

The tests were conducted at the Chemistry laboratory of the Kathmandu University. The values obtained from the laboratory tests for soil and drainage have been used in the HELP model. The waste parameters have been taken from the default values of the HELP model itself. The landfill design parameters have been used that of lysimeter representing a typical vertical section profile of a landfill.

3.3 Design Parameters for HELP Model

3.3.1 Weather and Landfill Design Data

Weather and hydrological data such as precipitation, temperature, evaporation, sunshine hours, quarterly relative humidities, wind velocity were collected from the Department of Hydrology and Meteorology, Babarmahal, Kathmandu. Data of nearby meteorological station of Dhulikhel station no. 1024 were used. The required set of data over the period of 7 years (2000 –2006) were used. These seven years data sufficiently characterize the broad range of annual precipitation (1232 – 2228 mm), temperature and solar radiation, which are input weather data for the model. The solar radiation data was calculated using the sunshine hours and relative humidity data. The data has been presented in Tables 5, 6 and 7 in Appendix III.

Other landfill design data were used as that of lysimeter. There is no runoff and run on considered as the surface area of lysimeter is too less (0.785 m^2).

3.3.2. Data Preparation and Input into the Model

Weather data have been prepared as per the HELP model requirement in a Canadian weather format. The collected data was processed and analyzed as per the requirement of the model**,** such as weather data, soil data, landfill design data. A long-term prediction of leachate (percolation) was done by modeling for various hydraulic conductivity values of cover and barrier soil and with various hydraulic conductivity and field capacity values of waste.

3.4 Modeling Procedure

The four layers of the landfill lysimeter model under this research; soil, waste, gravel and barrier soil liner as shown in Figure 3.1, placed at the site have been modeled considering the design data as well as the standard parametric values of the model. The procedure followed was as per the documentation report and user's guide on HELP program (Schroeder et al., 1994).

3.5 Simulation of Percolation of Leachate from HELP Model

For carrying out the various scenarios of the leachate drained from HELP model software, various simulations of the HELP model were carried out. There are set of simulations (viz. A, B and C as shown in section 3.7 below) based on various field capacity and hydraulic conductivity values of waste. The leachate generated is the total of leakages calculated from lateral drainage and barrier soil layer. The actual leachate (percolation) produced from the pilot scale landfill lysimeter has been compared with the values of the leachate (percolation) with different simulations using the HELP model.

3.6 Leachate Measurement from Lysimeter Model

The pilot scale landfill lysimeter was installed at the site in March 2006. Leachate measurement was done and temperature of solid waste collected starting from 7th June 2006 to 31st December 2006. The daily data measurement from the outlet was maximum of 28.03 lit. and minimum 0.13 lit.

3.7 Sensitivity Analysis

A sensitivity analyses for the model was carried out with variations of soil and waste properties of the input parameters. A set of three simulations viz; A, B and C has been modeled by using HELP model to predict the leachate generation with variations of Field Capacity of Waste as 0.2, 0.292 and 0.35 vol./vol. and Hydraulic Conductivity values (0.001, 0.01 and 0.1 cm/s). Another set of simulations was done by change of hydraulic conductivities of cover soil and barrier soil liner. A sensitivity analysis of the model was done based upon the controllable parameters of the model.

3.8 Analyses of Data

3.8.1 Data Requirement for the HELP model

The data type and use of the input parameters for the model are presented in Table 3.1 shown as below. Details of data required by model are described earlier. The matrix shown in the Table 3.1 shows the availability of real data and the boundary condition of application of the model in the lysimeter under study. This is the limitation of the model and data used by application to landfill lysimeter and landfills real set of data may be used.

3.8.2 Weather Data

The daily precipitation, sunshine hours, temperature data collected from the Meteorological Department for the nearest station (Dhulikhel, 1024) were prepared in a format acceptable to the HELP model. The continuous data available for 7 years were taken for precipitation, temperature and solar radiation (derived from available sunshine hours). These data are presented in Appendix I.

Table 3.1 Matrix of the Input Parameters for HELP model

S. N	Data Type	Real Data	Empirical/Processed	Default
1	**Precipitation**	✚		
	Daily Precipitation Values, 2000-2006	✚		
2	**Evapotranspiration Parameters**		✖	★
	Daily Solar Radiation Values, 2000-2006		✖	
	Daily Sunshine Hours Values, 2000-2006	✚		
	Daily Temperature Values, 2000-2006	✚		
	Quarterly Relative Humidity	✚		
	Wind Speed	✚		
	Maximum Leaf Area Index			★
	Evaporative zone depth			★
3	**Soil and Drainage Data**	✚		
	Saturated Hydraulic Conductivity of Topsoil, Barrier Soil and Gravel	✚		
	Field Capacity	✚		
	Wilting Point	✚		
	Porosity	✚		
4	**Waste Properties**			
	Saturated Hydraulic Conductivity			★
	Porosity			★
	Field Capacity			★
	Wilting Point			★
5	**Landfill Design Data**	✚		

Note:

✚ Parameters for which Real data were used

✖ Parameters for which Empirical/Processed data were used

★ Parameters for which built-in default model data were used

3.8.3 Extreme Rainfall Events

The daily specific data related to extreme (higher side) rain fall in seven years are on 2nd Aug. 2000, 23rd Sept. 2001, 23rd July 2002, 19th Aug. 2003, 9th July 2004, 8th Aug. 2005 and 20th July 2006 with actual field condition for cover soil hydraulic conductivity E^{-4} cm/s, that for Barrier Soil E^{-5} cm/s and Field Capacity of waste taken as 0.292 (vol./vol.) and hydraulic conductivity value of waste as 0.001 cm/s. The leachate values from model corresponding to those extreme rainfall event dates were observed and discussed in detail in the results and discussion chapter.

3.8.4 Evapotranspiration Parameter

The parameters based upon the latitude and longitude of the site, starting and ending of the growing season, maximum leaf area index, wind speed and quarterly relative humidity were taken from the same weather station and utilized by the model to generate required evapotranspiration parameter of the model.

3.8.5 Soil and Waste Data

The soil and waste data of the four layers (Fig. 3.2) and information on layer properties (Table 3.2) are derived and used as input values in to model. Some of the default values of the model have been used as indicated in Table 3.1.

Table 3. 2 Information on Properties of Layers

S. N	Parameters	Unit	Layer 1 (Cover Soil)	Layer 2 (Waste Layer)	Layer 3 (Drainage)	Layer 4 (Barrier Soil Liner)
	Type	-	Vertical Percolation Layer (Silty Loam)	Vertical Percolation Layer (MSW)	Lateral Drainage (Gravel)	Barrier Soil Liner (Silty Clay)
1	Total Porosity	vol./vol.	0.398	0.671	0.397	0.483
2	Field Capacity	vol./vol.	0.212	0.292	0.032	0.206
3	Wilting Point	vol./vol.	0.192	0.077	0.013	0.187
4	Saturated Hydraulic Conductivity	cm/s	$1.44\ E^{-4}$	$1.00\ E^{-3}$	0.25	$2.43\ E^{-5}$
5	Subsurface Inflow	cm/day	0	0	0	0
6	Top Slope	%	0	0	0	0
7	Bottom Slope	%	0	0	0	0
8	Thickness	m	0.30	1.80	0.50	0.30

Source: Laboratory Results of NARC and KU

3. 9 General Design and Evaporative Zone Data

The general evapotranspiration data of the site as per the meteorological station data are as follows. The input value used for the HELP model is given in Table 3.3.

Table 3.3 Data for HELP Model

S. N	Description	Unit	Values
1	Fraction of Area allowing to Runoff	%	0
2	Vegetation class	Class	Fair stand of grass
2	Lysimeter area projected on Horizontal plane	m^2	0.7855
3	Evaporative Zone Depth	cm	25
4	Maximum leaf area index	no	5
5	Growing season start day	day	190
6	Growing season end day	day	335
7	Average wind Speed	km/hr	8.04
8	First quarter relative humidity	%	45
	Second quarter relative humidity	%	44
	Third quarter relative humidity	%	77
	Fourth quarter relative humidity	%	54
9	Latitude	^{0}N	27.61
10	Longitude	^{0}E	85.55

Source: Department of Hydrology and Meteorology

The input value required for the evapotranspiration, such as vegetation class, evaporative zone depth and maximum leaf area index were taken from default value of model appropriate to the site condition. All other parameters were as per real data available.

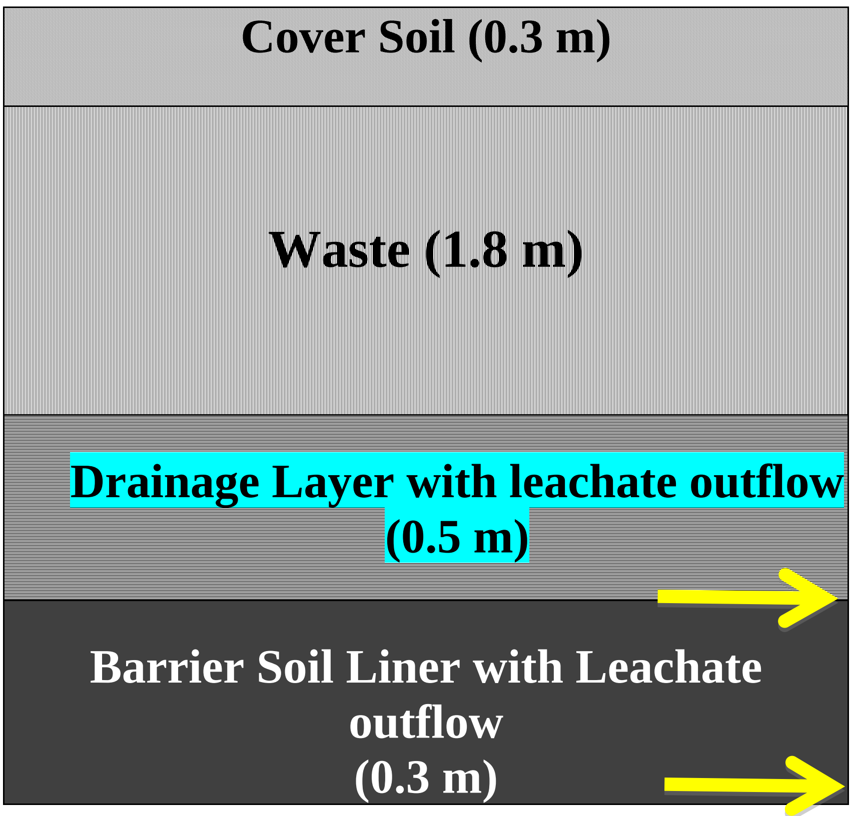

Figure 3.2 Schematic Diagram of Layers in Lysimeter

3.10 Material Layers in Lysimeter

The Fig. 3.2 above shows the schematic diagram of lysimeter with various layers and collection of percolation (leachate) at two layers; drainage and barrier soil liner as shown. There is 0.1 m clearance in the lysimeter as total height is 2.9 m and lysimeter is 3 m. The landfill lysimeter under study has been studied with different conditions with variations of hydraulic conductivities of cover soil and barrier soil liner, field capacity and hydraulic conductivity of waste with no variations in the drainage layer.

3.11 Approach for the Modeling

The simulation has been done for water balance with the given data as per Table 3.2. Numbers of simulations were also done for a total height of 2.9 meters of the lysimeter and separate water balance scenarios. The program cannot simulate for a period less than a year. The response of short period intensive rainfall are thus to be observed in the daily data of that particular year. However, based upon the per unit area of water balance output, leachate production rate can be calculated as required. However the prediction on a yearly basis as been done in this study is taken as an important indicator for further improvement and evaluation of design alternatives.

3.12 Output of the Model

The HELP model use solution techniques and with all the input parameters give a water balance of the landfill in terms of evapotranspiration, lateral drainage, percolation. The soil moisture storage has been found negligible. The lateral drainage layer in our case is gravel, at the base of which pipe network (PVC, 50 mm dia.) for collection of leachate has been installed. It was assumed that there is very less percolation from the barrier soil liner layer and almost all of the percolated water from top reaches the collection system installed, i.e. through layer 3. The output given by the model is in the time step of days, months and years. However, as we are also interested for a long-term prediction, monthly and annual rates and volume of lateral drainage collected through layer 3 and vertical drainage through layer 4 was taken into account and interpreted. The per unit surface area of the lysimeter, which has been modeled with the input of 7 years weather data and other site specific design data of soil and waste.

CHAPTER IV: RESULTS AND DISCUSSION

4.1 Results of Waste Composition and Soil Analyses

The data of waste composition shows that the organic waste is about 69% (Fig. 4.1), which is higher and generally true for organic waste content in developing countries.

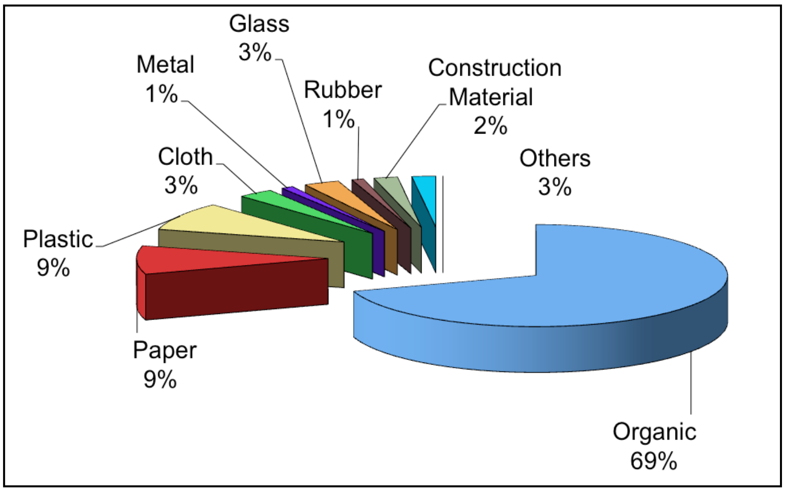

Figure 4.1: Waste Composition of Waste at Teku Transfer Station

The tables 4.1 to 4.4 below show the results of soil and gravel analyses carried out at the laboratories.

Table 4.1: Moisture Content of Soil for Cover and Barrier Soil Layer

Location of Soil Sample	**Sample No.**	**Initial Weight of Soil (Wet Weight)**	**Final Weight of Soil (Oven Dry at 105°C)**	**Moisture Content (%)**
1. Chaukot for barrier soil	Mo1	202.03g	171.21 g	29.82
2. KU premises for cover soil	Mo2	204.98 g	182.50 g	22.48

Source: Kathmandu University Laboratory

Table 4.2: Hydraulic Conductivity, Total Porosity & Wilting Point of Soil for Barrier layer

Location of Soil Sample	**Sample No.**	**Hydraulic Conductivity (cm/s)**	**Total Porosity (%)**	**Wilting Point (%)**	**FC (%)**	**Bulk Density (g/cc)**
1. Chaukot	309 A	2.41 E^{-5}	48.8	20.70	22.77	1.357
2. Chaukot	208 A	9.93 E^{-6}	47.9	17.27	18.99	1.381
3. Chaukot	301 A	3.91 E^{-5}	48.3	18.26	20.08	1.371
	Average	2.43 E^{-5}	48.33	18.74	20.61	1.37

Source: Nepal Agriculture Research Council Laboratory

Table 4.3: Hydraulic Conductivity, Total Porosity & Wilting Point of Cover Soil

Location of Soil Sample	**Sample No.**	**Hyd. Conductivity (cm/s)**	**Total Porosity (%)**	**Wilting Point (%)**	**FC (%)**	**Bulk Density (g/cc)**
1. Ku-Periphery near Aquatic Lab	8 RB	2.38 E^{-5}	36.8	14.35	15.78	1.675
2. Ku-Periphery near Aquatic Lab	9 RB	2.77 E^{-4}	39.2	21.47	23.61	1.610
3. Ku-Periphery near Aquatic Lab	302 RB	1.31 E^{-4}	43.5	22.03	24.23	1.497
	Average	1.44 E^{-4}	39.83	19.28	21.21	1.594

Source: Nepal Agriculture Research Council Laboratory

Table 4.4: Laboratory Values of Gravel for Drainage Layer

Sample No.	**Sample No.**	**Hyd. Conductivity (cm/s)**	**Total Porosity (%)**	**Wilting Point (vol./vol.)**	**FC (vol./vol.)**
1	DR1	2.83 E^{-1}	0.85	1.5	15.78
2	DR2	2.47 E^{-1}	0.91	1.1	17.85
3	DR3	2.21 E^{-1}	0.93	1.45	18.11
	Average	2.5 E^{-1}	0.9	1.35	17.25

Source: Kathmandu University Laboratory

From the above results, the average hydraulic conductivity value of barrier soil in the range of E^{-5} cm/s was found to be higher, it should have been around E^{-7} cm/s, which may have resulted actual percolation (leachate) on higher side as discussed more in sections below.

4.2 Simulations A, B and C of Waste Materials

As mentioned earlier, the three set of simulations have been carried out. The simulation A has been done for Field capacity of waste FC=0.292, simulation B for Field Capacity of waste FC=0.2 and simulation C for Field capacity of waste FC=0.35 (with hydraulic conductivity of waste as 0.001 cm/s) and kept as a constant with different values of hydraulic conductivities of cover soil designated as E^{-3}, E^{-4} and E^{-5} (in exponential order) and that for barrier soil liner E^{-4}, E^{-5}, E^{-6}, E^{-7}, E^{-8} and E^{-9} (in exponential order) representing values with decreasing order respectively (Table 1 in Appendix III). In another simulation, field capacity and hydraulic conductivities of waste are varied for actual values of cover soil and barrier soil liner, i.e. E^{-4} for cover soil and E^{-5} for barrier soil liner. From the simulations A, B and C, the percolation (leachate) could not be observed for HC values of barrier soil E^{-8}, E^{-9} corresponding to HC of cover soil E^{-3}, E^{-4} and E^{-5} cm/s. The percolation and leachate has been used as synonyms in the discussion. The values of average percolation per year were observed with not much difference from three simulations. The percolation values have been found in the range of 1270-1298 mm/m^2 for three simulations. The percolation or leachate production varied in the range of about 78-86% (83% average) per year of the rainfall amount in this research, the production rate being about 2.63 litres/m^2/day on an average, which is compared to be high (Campbell, 1983; Blakey, 1989; Ehrig, 1989; Bonaparte & Gross, 1993 & Nolting, 1995). For barrier soil hydraulic conductivity E^{-7}, percolation is only about 600 mm/m^2 (38% of rainfall, Fig. 4.2). The evapotranspiration component is in the range of 259-275 mm/m^2 (18% of rainfall) for three simulations and for barrier soil E^{-7}, it increased in the range of 703-719 mm/m^2 (47% of rainfall).

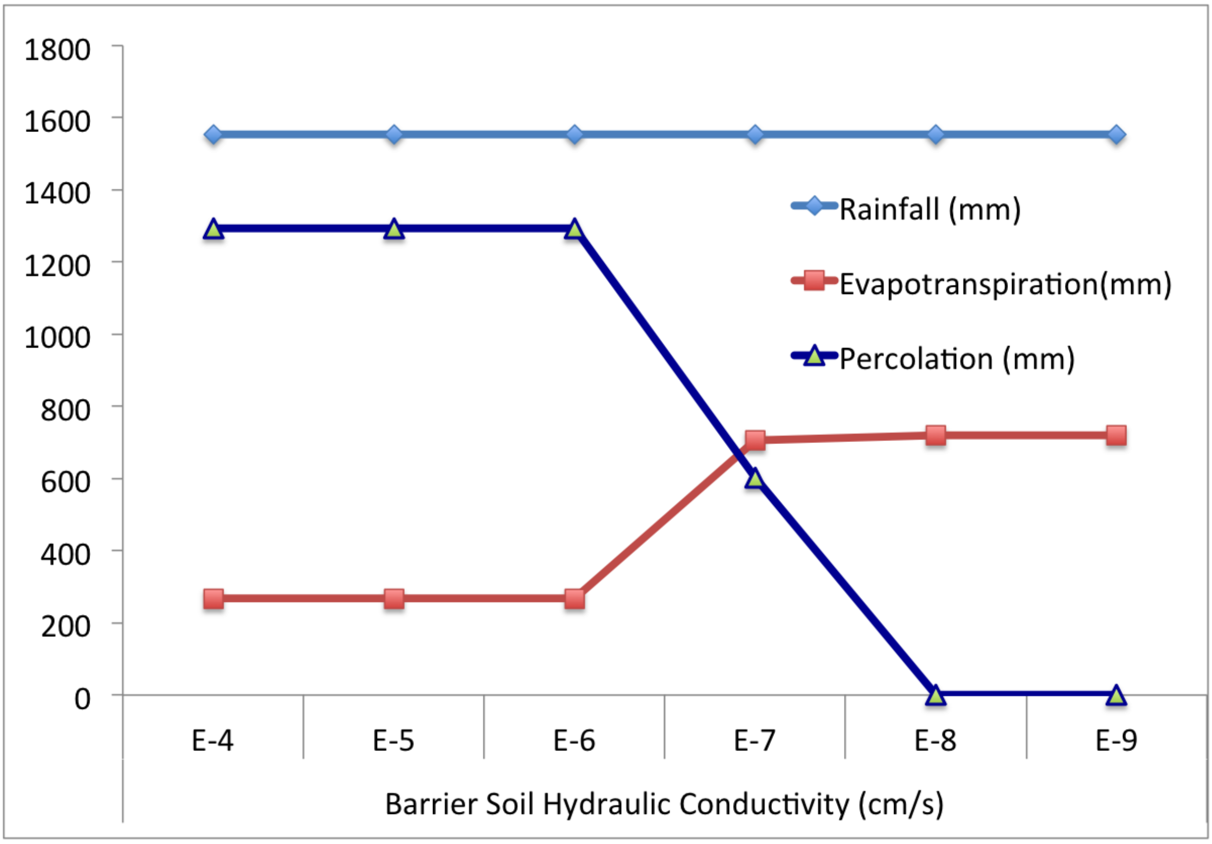

Figure 4.2: Average Yearly Percolation Values of Water Balance

The percolation rate is high in lysimeter, which is mainly due to small area of lysimeter. There seems to be more percolation than evapotranspiration as more infiltration occurred before there is any evapotranspiration. The lysimeter being a newly operated, and first of its kind in Nepal, the model was validated with the limited measured data. Its performance on a long-term basis is yet to be validated by simulating for much longer term measured data and with more variations of properties of soil and waste. But a wide application focusing on hydraulic properties of layer materials, rainfall response of the model in water balance was studied and predictions for future planning and evaluation of operation of landfills were assessed.

From the sensitivity analyses, it is seen that the depth of the various layers of the profile are not much sensitive for the leachate stream generation. The Field Capacity of the waste is a parameter of importance and has been modeled with respect to different hydraulic conductivities. This seems to be of significance as the desired field capacity could be achieved in the waste volume (which again depend upon the density/compaction) and will have a direct impact on the production of leachate. The waste composition and biodegradation (for release of water content) might have a direct effect on the production of leachate. The effect could be determined only relating it with field capacity, but the model has no such option to directly consider organic matter degradation and decomposition. This is taken as one of the limitation of the HELP model. The aim is to reduce the amount of leachate generation, for better performance and optimal design of landfill and leachate treatment system; and for remediation of possible contamination to the surface and ground water resources. The simulations results and sensitivity analyses have given a guideline for evaluation of operation and design of landfill by using this HELP model in developing countries like Nepal. It has shown that the hydraulic conductivity of barrier soil liner should be in the range of E^{-7} cm/s or lower so that leachate production can be controlled. This is an important parameter for design and operation of landfills. The hydraulic conductivity value recommended for Nepalese context is also clay soil within that range.

4.2 Extreme Rainfall Events and Response of Percolation

The average rainfall among the extreme rainfall events (higher rainfall events as indicated under section 3.8.3 above) during the year 2000 to 2006 is 107 mm/day and percolation (leachate generation) is about 5.8 mm/day (3.45-8.0 mm/m^2), which is only about 5.4 % of the average rainfall. The evapotranspiration is about 0.99-1.3 mm/m^2. On daily basis, the responses are varying depending on intensive rainfall for consecutive number of days. The response of rainfall as percolation is observed sometimes after few days, so the percentage of percolation may be even more than the rainfall amount on the same day. When aggregated in weeks, months or annual it is not necessarily agreeing with the percolation case as on daily basis.

In the higher rainfall, the results from the actual and model are not correspondingly similar. But the outputs of percolation from HELP model obtained during October to December are nearly similar to that of actual data. Thus it has been observed that, with extreme rainfall, it is not necessary that the model show the response. With such high rainfall events, however it is hypothetical, the percolation seems to be effected and possibly leachate mound over the layers will give a ponding effect and overland flow occurs. Other reason may be due to the field capacity of the layer materials, or draining capacity of the materials including waste, which after reaching saturation will generally tend to affect the transport of water downward. This is the limitation in simulation under specific circumstances such as seen in case of such extreme rainfall patterns. Thus it can be discussed that daily rates of percolation do not necessarily have impacts in the operation and design of landfills but the long term, i.e. monthly or annual rates do.

4.3 Results from Model with Variation of Waste Properties

Comparing the actual data and model outputs for percolation, the calibration was done from the data from model taking various values of hydraulic conductivity of waste as 0.001, 0.01 and 0.1 cm/s and changing of field capacity of waste as 0.2, 0.292 & 0.35 vol./vol. respectively provided fluctuating values of percolation with the actual data. The changes in hydraulic conductivity of waste have less change in the result of percolation, whereas changes in field capacity have some significant changes.

The evapotranspiration component of the water balance is not much changed with the change in rainfall pattern, as evapotranspiration depends upon the soil type, temperature, wind flow and the evaporative zone depth, which are kept constant for the simulations. This can be considered as one of the limitation of the HELP model. However, it can be concluded that these results have given a trend of leachate generation and variations with the rainfall pattern. Refer Table 3 and 4 of Appendix III.

Fig. 4.3 shows the yearly water balance and outcome of the simulation based on the yearly average data. It shows that the evapotranspiration (E_T) do not follow the rainfall and percolation trend. The run-off value is not shown as it is assumed that there is no runoff from the lysimeter. However, the factors, which can easily be controlled like landfill design criteria (layer data: hydraulic conductivity or slope) and operation processes have impact on leachate generation, which is in agreement with Hogland et al. (2005), Blakey (1989), Peyton (1988) and Schroeder (1994).

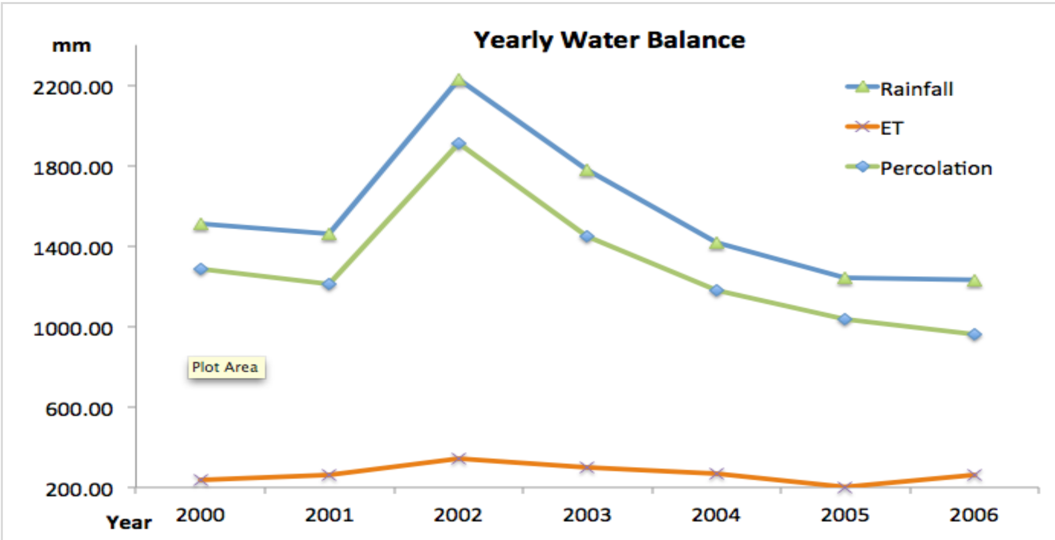

Figure 4.3: Yearly Water Balance over 2000-2006

The monthly averages of water balances were calculated as shown in Fig. 4.4. The percolation follows the rainfall pattern, whereas evapotranspiration (E_T) shows different trend. Solar radiation, a parameter dependent upon the temperature and sunshine duration hours, has an effect upon the evapotranspiration.

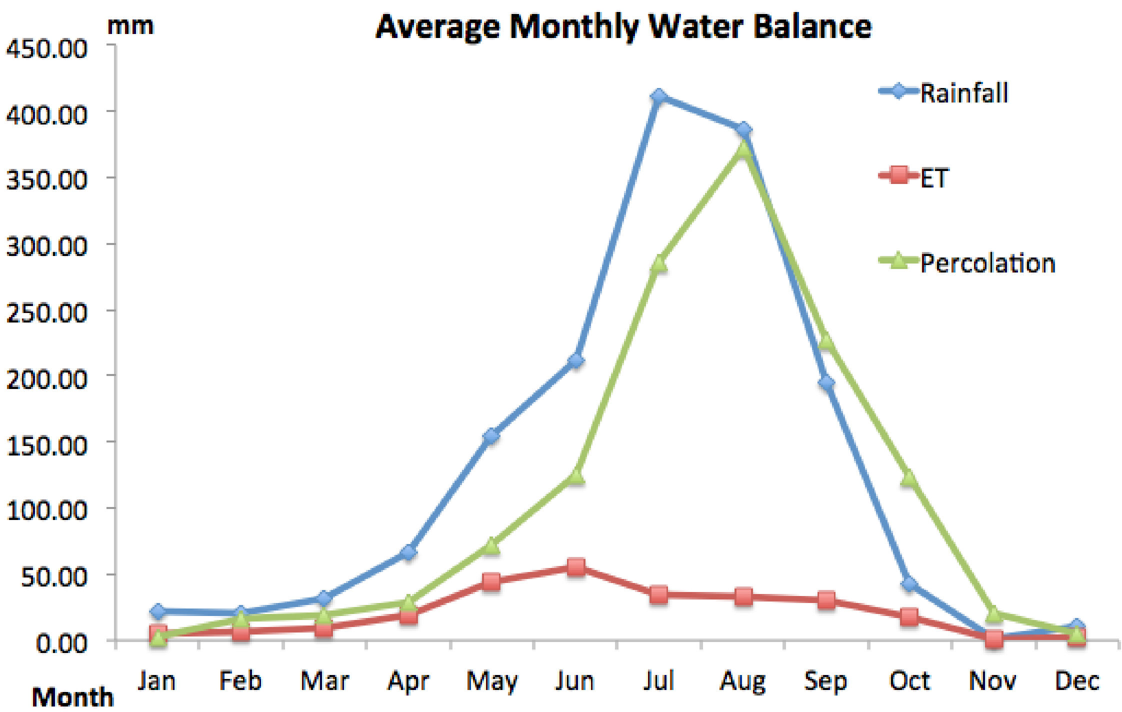

Figure 4.4: Monthly Average of Water Balance (2000-2006)

The solar radiation distribution in Nepalese context has shown that even during the wet season, the intensive solar radiation will have a strong effect on evapotranspiration, making E_T follow almost horizontal trend on average yearly basis. The evapotranspiration in this research was not high, may be due to the small area of lysimeter and higher portion has been percolated before evaporation could take place and there is a preferential flow through cracks in cover soil or wall effect. However, during the dry season the potential evapotranspiration is hardly applicable. The 7 yearly monthly cumulative water balance as shown in Fig. 4.5 also indicate that evapotranspiration is underestimated whereas percolation is following the trend of rainfall and is a dependent parameter. Table 5 and 6 of Appendix III shows the data.

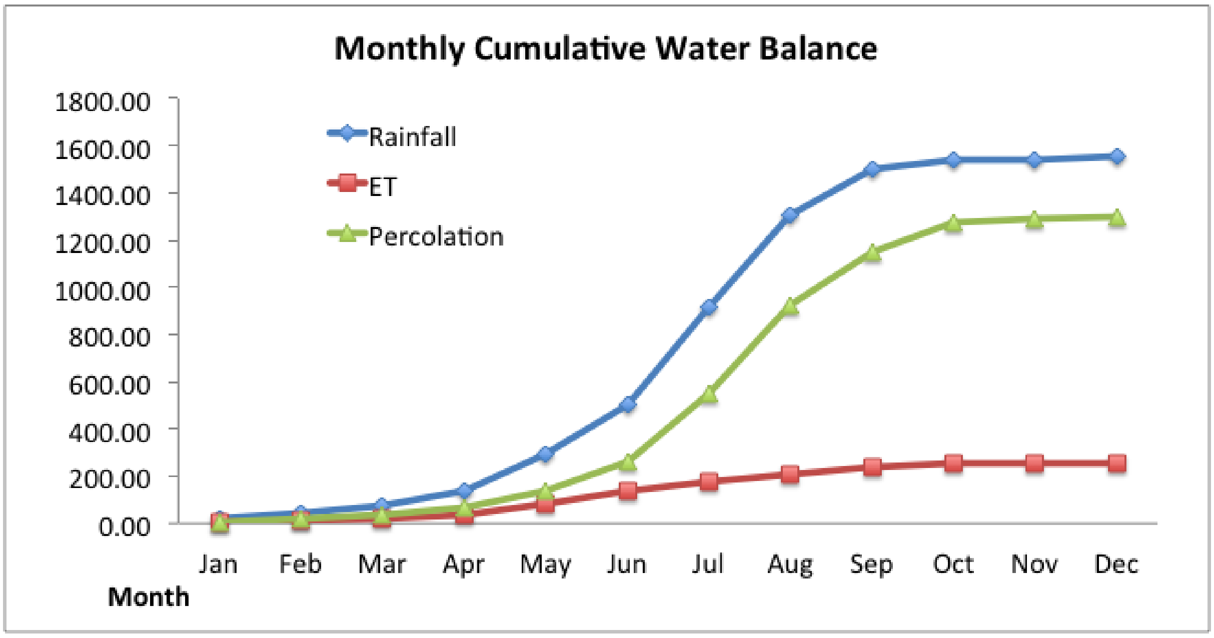

Figure 4.5: Monthly Cumulative Water Balance (2000-2006)

The evapotranspiration is not dependent on rainfall. There is an immediate response of percolation after rainfall. The input here is only rainfall and the moisture content of waste itself is negligible compared to rainfall, thus moisture content of waste is insignificant in this case. The annual data shows percolation of about 78-86% of rainfall amount, whereas evapotranspiration is about 15-21%. Similar research showed percolation of about 60% of annual rainfall (Visvanathan et al., 2002). The comparative daily cumulative water balance (Fig. 4.6) shows that percolation real (actual measured)) is higher than rainfall on cumulative basis. The response of rainfall as percolation is observed after few days only, so the percentage is even more than the rainfall amount on the same day at many occasions on daily basis. When aggregated in weeks, months or annual it is not the same case as daily basis.

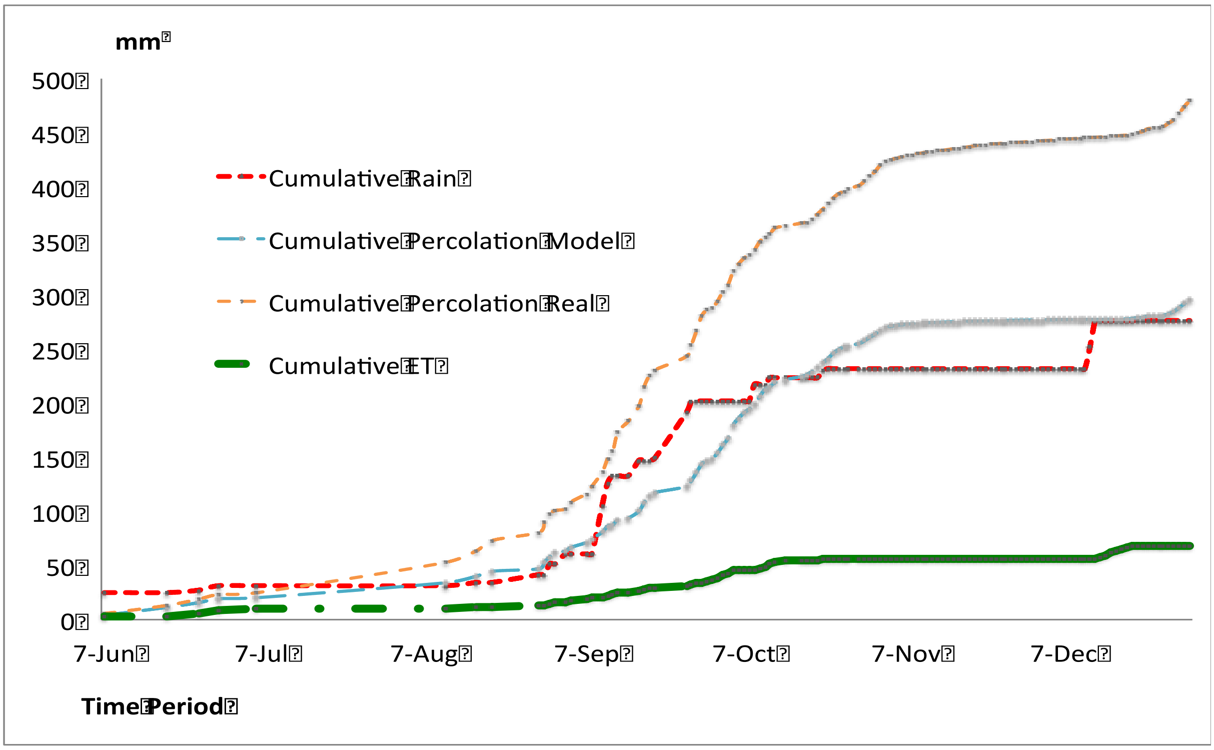

Figure 4.6: Comparative Cumulative Water Balance

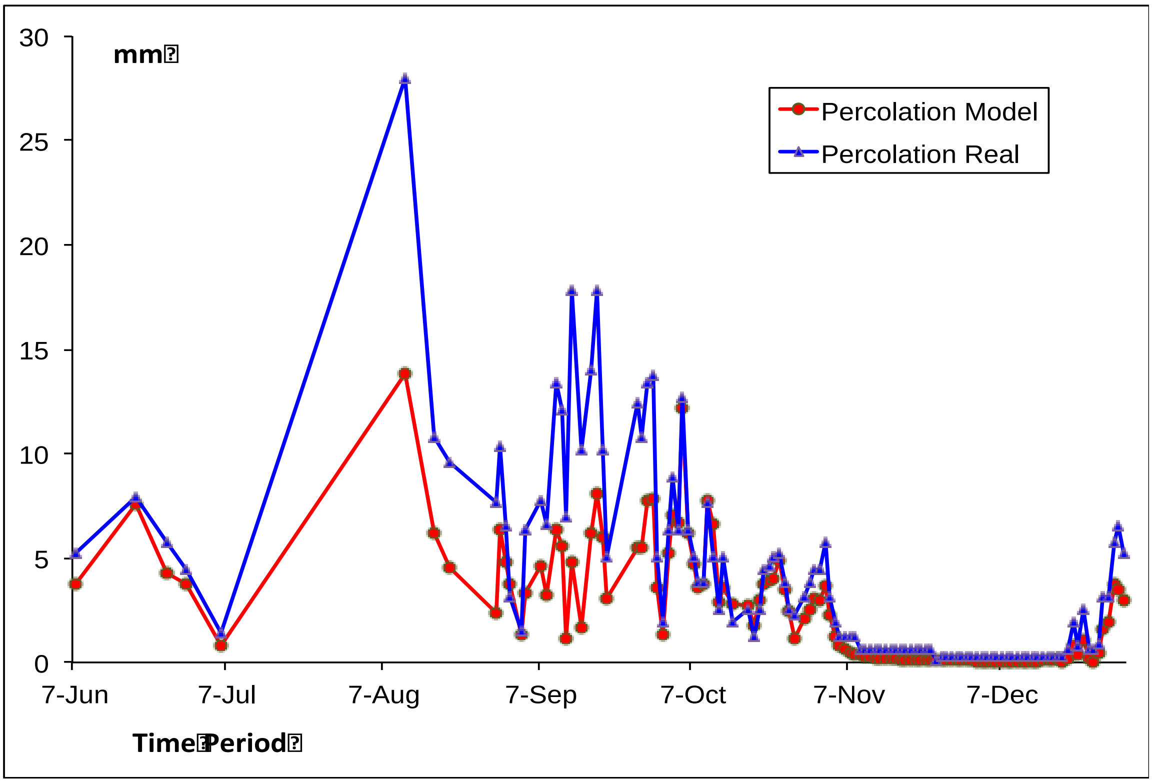

Figure 4.7: Comparison of Model and Actual Percolation

From data of leachate generation from lysimeter, the model has been calibrated with the local situation. A comparison of actual and model percolation and relation has been shown in Fig. 4.7 and Fig. 4.8. The trend of leachate generation (percolation) with the HELP model and actual data shows similar results from October to December season (Fig. 4.7 and 4.8), but from June to September, higher rate of actual percolation has been observed than HELP model predictions. This may be due to the higher value (in the range of E^{-5} cm/s) of hydraulic conductivity of barrier soil liner, which should be generally lower value (in the range of E^{-7} cm/s), though difficult to achieve naturally. The higher actual percolation may be due to the rainy season (June-September) when soil is wet at most of the time. The cracks developed in the cover soil when it is dry and preferential flow may be another reason as mentioned earlier. Fig. 2.2 in earlier chapter illustrates the preferential flow and also as pointed out by Nordtest Technical Report 473, 2000.

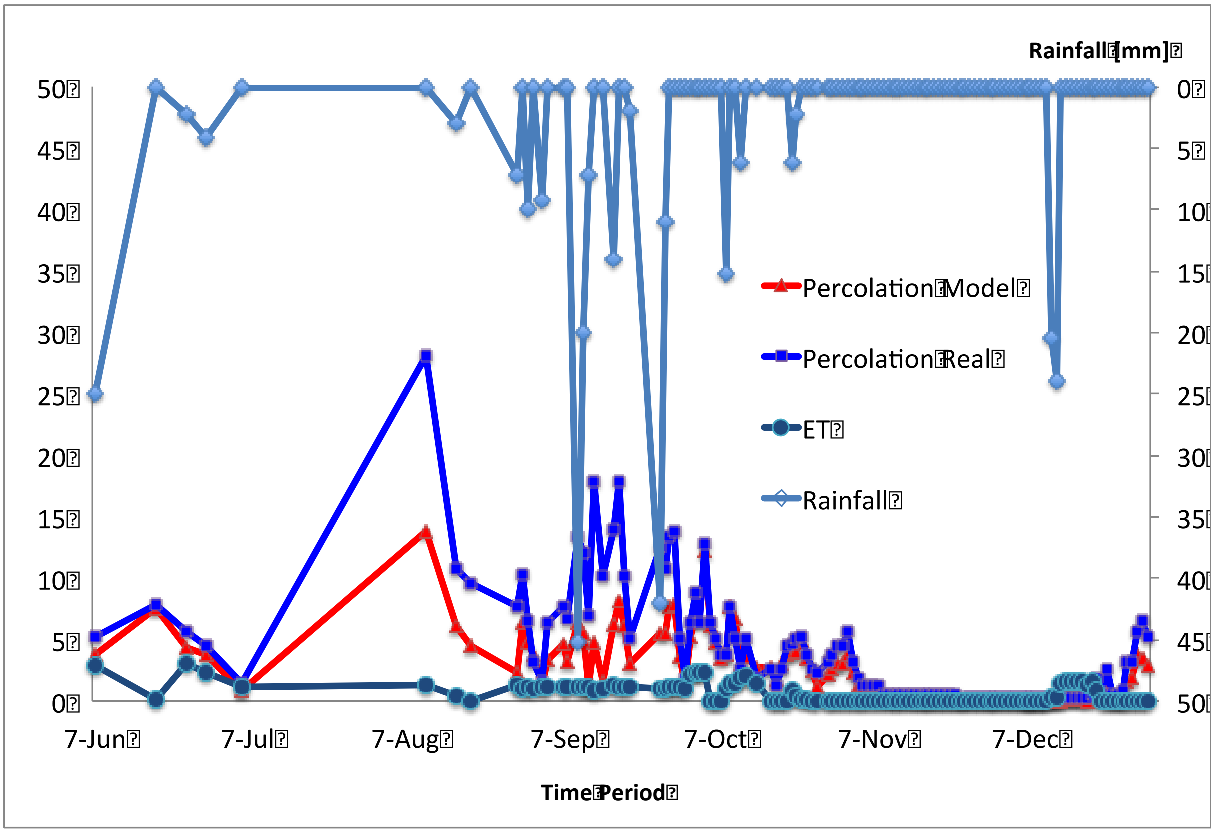

Figure 4.8: Relation of Rainfall, ET, Model and Actual Percolation

The evapotranspiration have high and low values on daily basis compared to average yearly horizontal trend as shown in Fig. 4.8. In winters, E_T values are also nil on certain days. The response of average percolation and evapotranspiration on yearly basis with change of hydraulic conductivity values of barrier soil liner is already shown in Fig. 4.2 above. With the change of order of HC of barrier soil from E^{-6} to E^{-7}cm/s, there is significant change in the results. With lesser values, there is no percolation and there is significant change in E_T value, showing that when vertical flow is restricted, evapotranspiration will increase. This provides an important design consideration of landfill, where hydraulic conductivity values of barrier soil liner is deciding parameter and should be in order of E^{-7} cm/s or lesser. When less or no percolation is observed, there will be a leachate mound in the layers above barrier soil liner, which needs to be collected from drainage layer and sent for leachate treatment. Another important parameter observed is field capacity of waste, which has been simulated as A, B and C mentioned earlier. The Filed Capacity (FC) value of 0.292 vol./vol. and hydraulic conductivity (HC) of 0.001 cm/s seems to best fit during regression analyses as shown in Table 4.5 and Fig. 4.9. The correlation, root mean square and standard deviation values agree with the above values for the waste. The fitting value is in agreement with the actual field capacity and hydraulic conductivity values of the waste used in the lysimeter in this research.

Table 4.5: Statistical Analyses of Actual and Model Percolation

FC of Waste = 0.292 vol./vol.			
Real Percolation for H.C	H.C=0.001	H.C=0.01	H.C=0.1
Correlation	0.8867	0.5504	0.5325
Root Mean Square	0.7862	0.3029	0.2835
Standard Deviation (mm)	2.75	3.72	3.96

As per Powrie & Beaven (1998), the hydraulic properties of waste will need to be used in the design of leachate collection and recirculation systems to achieve more rapid landfill stabilisation. However, the effects of landfill processes - such as the use of low hydraulic conductivity daily cover and barrier soil and modem landfill compaction techniques - that alter the bulk properties of the material must also be addressed. In addition, long term flowrates should be assessed on the basis of the hydraulic properties of aged or degraded wastes, however this is an area of continuing research.

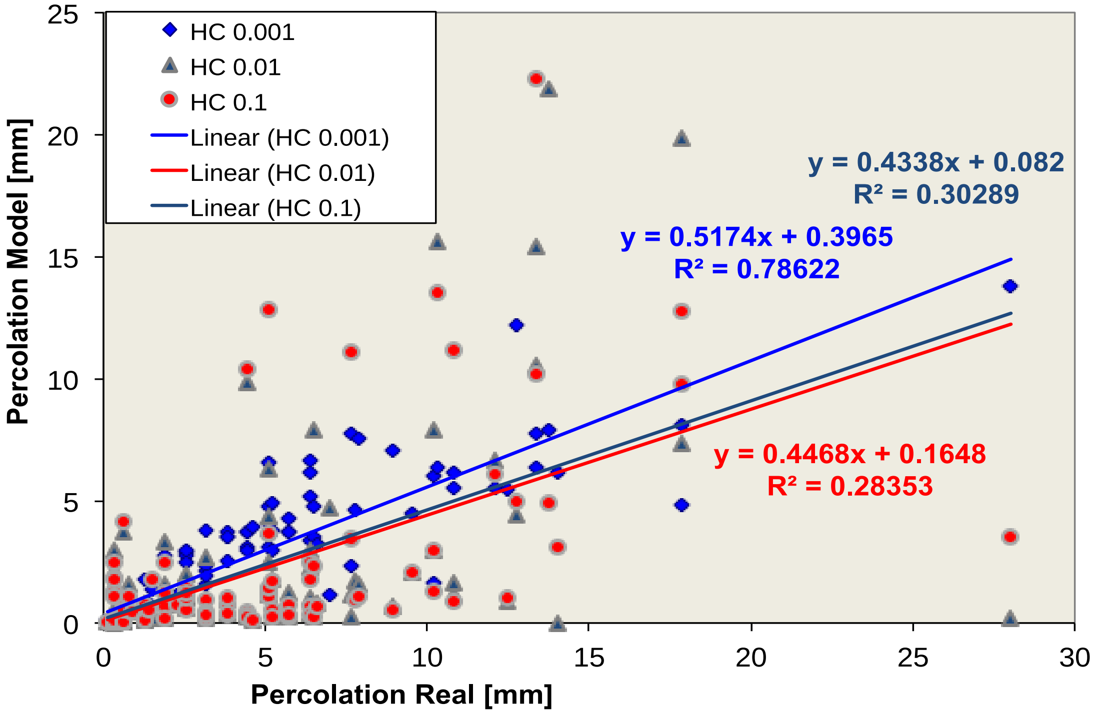

Figure 4.9: Regression of Model and Actual Percolation

Thus, with the results achieved in this research, we can conclude that Hydraulic Conductivity (HC) of barrier soil liner, Field Capacity (FC) and HC of the waste layer have significant effect on the percolation or leachate generation. The leachate generation can be controlled by variation of those parameters and the subsequently leachate treatment system can be designed accordingly. The annual leachate generation rate is more important factor than daily data for designing leachate treatment system as daily rates are low. The alternative landfill design and selection of layer materials and ultimately the operation of landfills in Nepalese context is predictable using the HELP model and comparing it with measured data as shown by this research. The findings are useful for the landfill operating agencies such as municipalities and private sector operators. However, use of this research in real landfills, laboratory scale lysimeters, installation of field scale lysimeters with more variations in layer properties, validation with long term measured data, qualitative evaluation and leachate treatment options are some of future scope of researches.

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The major conclusions of the study are as follows:

1. The annual percolation rate is high in lysimeter (78 to 86% of rainfall) due to small area of lysimeter. There is more percolation than evapotranspiration as more infiltration occurred before evapotranspiration. This is also due to cracks in cover soil and preferential flows & wall effect. But in real landfill, the situation might be different.
2. The daily average percolation rate is low as 5.8 mm (only 5.4% of daily average rainfall) when only the higher rainfall events are considered compared to the high annual values. The percolation response is observed only after few days of rainfall in this study instead of immediate response. This is an important consideration for landfill design. Thus, the design of landfill leachate treatment system should be done on annual leachate generation basis rather than daily data.
3. The runoff has been considered NIL in this research and model simulations, as it is a small-scale lysimeter. The runoff would also have been percolated in the small area of lysimeter even if it has been considered. This is one of the reasons that percolation is higher than evapotranspiration.
4. The HELP model has underestimated the evapotranspiration component of the water balance, as the evapotranspiration is dependent on solar radiation, vegetative growth, evaporative zone depth, wind speed, and relative humidity.
5. The leachate should be minimized and directed to leachate collection and treatment system rather than allowing percolation through barrier soil liner and to ground water or surface water bodies.
6. The landfill cover specification for Nepal is about 60 cm and capping of 30 cm. The top cover used for lysimeter is also 30 cm in this research. The depth of cover soil and other layers do not seem to have much impact on the quantity of leachate produced, however cracks developed in soil and preferential pathways are governing factors as discussed earlier.
7. The HELP model simulations results and sensitivity analyses have given a guideline for evaluation of operation and design of landfill in developing countries like Nepal. The major design considerations are the Field Capacity & hydraulic conductivity values of waste and hydraulic conductivity values of barrier soil liner for water

balance in terms of controlling leachate generation. The estimates of the cumulative leachate volume were strongly dependent on the variation of the above parameters.

8. The performance of HELP model could be further validated using long-term measured data by simulating with variations of other parameters of soil and waste.
9. The HELP model is found as a good tool for evaluation of design, planning and operation of landfills in developing countries like Nepal.

5.2 Applicability of Research Outcomes

This research has raised some issues regarding effect of hydraulic properties of layer materials on water balance and its applications towards proper design and operation of sanitary landfills and other influencing parameters to be investigated further.

1. The model application proved a valuable tool to determine strengths and weaknesses of design and operation of landfills in developing countries like Nepal. It has been found that hydraulic conductivities of the barrier soil and field capacity & hydraulic conductivities of waste have significant effect in water balance while designing and operating landfill. The hydraulic conductivity of cover soil and barrier soil and waste hydraulic properties can also change the operation of landfills with respect to water balance.
2. Another important consideration is the development of cracks in the cover soil. The hydraulic conductivity as determined in the laboratory scale could not be achieved at the field and possibly the actual leachate (percolation) might have been overestimated. During most dry period, there is a high possibility of development of these cracks. Cracks can also develop due to poor workmanship during construction or low compaction. These will aggravate the preferential flow from sidewalls. The model also does not take into account of such cracks and fissures, and if occurs in large scale, the model result might be much under estimated than the actual percolation. Thus, this is one of the important design parameter.
3. Leachate recirculation during operation may be one of the options for mitigating the problem by keeping the cover soil moistened and prevent it from cracking.
4. The functioning of leachate management and treatment system depends upon the parameters studied.

5.3 Recommendations and Scope of Future Research

1. The landfill operating agencies (municipalities and private operators) could use the findings of this research for alternative designs and operation of landfills.
2. Clay soil with low permeability ($1X10^{-7}$ cm/s) is a recommended liner specification in Nepal. However, flexible membrane liners such as polymeric sheeting can be also used. But for maintenance and cost purpose clay liners are found suitable based upon the findings.
3. The preferential flow from sidewalls of lysimeter can be prevented. Liquefied petrolatum can be injected into an annular gap between the soil and the lysimeter casing producing a watertight seal. Water and solute movement in the sealed lysimeter will therefore be confined within the soil monolith and no edge-flow occurs. Hydraulic conductivity and solute leaching rates are significantly lower in sealed lysimeters compared with unsealed ones (Cameron et al., 1990).
4. Various real landfills in the country need to be modeled for further validation of the HELP model and for water balance study and evaluation of landfill operation and design alternatives.
5. Different types of waste could be placed in separate lysimeters and HELP model simulations done to observe findings in future.
6. The field scale lysimeter and laboratory scale studies on water balance are suggested for further validation of the model, as all model parameters were not tested.
7. The recirculation of leachate could be piloted in a lysimeter to assess the impact of recirculation in real landfills.
8. The model does not take evaporation as a direct input for account of evapotranspiration. These parameters need to be looked into detail and should represent the local conditions to give better results from the model.
9. The study of influencing parameters like evaporative zone depth, SCS curve number are also other research areas.
10. Laboratory scale lysimeters, validation of HELP model with long term measured data, variation of other properties of layer materials in lysimeter and simulations and application in real landfills etc. are other research areas.
11. Study of leachate characteristics and leachate treatment options could be focused in future research.
12. Following methods (Tchobanoglous et al., 1993) of leachate treatment are discussed briefly.

- Leachate Recycling
- Leachate Evaporation
- Discharge to Municipal Treatment System

Various leachate treatment options could be used however a treatment system to cater for maximum leachate generation has to be designed based upon the result of rainfall response of the model. If leachate recycling and evaporation or direct disposal of leachate to a treatment facility is not possible, some form of pretreatment or complete treatment will be required. Because the characteristics of the collected leachate can vary so widely, a number of options have been used for the treatment of leachate. The treatment process or processes selected will depend to a large extent on the contaminant to be removed.

For the design of landfill and an appropriate treatment system, the characteristics of the leachate will be the most important aspect in terms of the pollution load to the environment. Moreover, the effluent standard of the specific country has to be complied before deciding on a suitable treatment method. In Nepal, Ministry of Science, Technology and Environment (MoSTE) is responsible for regulating such standards, so thorough study of leachate characteristics and its impacts on human as well as environment need to be done.

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APPENDICES

APPENDIX I: PHOTOGRAPHS

Photograph 1: Lysimeter Setup

Photograph 2: Leachate Collection Buckets

Photograph 3: Lysimeter Construction

Photograph 4: Lysimeter and Temperature Probe

Photograph 5: Waste Brought from Teku Transfer Station

Photograph 6: Placement of Leachate Collection Pipes

Photograph 7: Perforations in PVC Pipes

Photograph 8: Monitoring of Lysimeter

Photograph 9: Lysimeter Construction

Photograph 10: Drainage Layer and PVC Pipe Fixation

Photograph 11: Sieve Analyses of Aggregate Chips

Photograph 12: Leachate Collection Pipes

APPENDIX II: WEATHER DATA

Rainfall Data 2000-2006 mm

2000	January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	March	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	4.4	0.0	0.0	0.0
2000	April	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	2.0	0.0	2.0	0.0	12.2	15.4	0.0	18.4	2.5	14.0	0.0	0.0	0.0	0.0	0.0
2000	May	0.0	6.0	0.0	0.0	0.0	0.0	3.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	50.4	0.0	2.2	0.0	18.0	0.0	8.2	2.2	26.0	0.0	10.0	5.0	27.2	25.2	22.0	0.0
2000	June	62.2	0.0	0.0	0.0	0.0	8.4	14.0	18.4	0.0	0.0	0.0	2.0	0.0	0.0	0.0	2.2	0.0	10.0	22.0	2.2	3.2	12.2	32.4	10.2	10.2	6.0	3.2	0.0	0.0	0.0	0.0
2000	July	0.0	22.2	3.2	8.5	0.0	4.2	26.2	2.0	2.2	7.0	2.4	0.0	0.0	0.0	0.0	10.4	5.2	26.0	12.0	0.0	4.0	42.2	4.0	30.2	60.2	26.4	0.0	0.0	26.0	0.0	49.0
2000	August	30.2	67.2	16.0	0.0	0.0	0.0	16.2	64.0	7.0	34.0	6.0	0.0	18.2	7.2	20.2	0.0	2.0	0.0	0.0	0.0	28.0	8.4	0.0	10.2	30.0	0.0	0.0	3.0	6.2	36.0	20.0
2000	September	59.0	9.2	0.0	0.0	0.0	0.0	4.2	0.0	0.0	15.0	0.0	0.0	0.0	0.0	16.0	3.0	0.0	11.0	38.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0
2000	October	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2000	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0
2001	January	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0
2001	March	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	April	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	11.2	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
2001	May	51.0	0.0	0.0	10.5	0.0	0.0	14.0	0.0	0.0	3.0	23.4	0.0	0.0	0.0	13.4	0.0	0.0	19.0	0.0	0.0	13.0	0.0	0.0	0.0	9.0	8.0	12.0	0.0	2.0	0.0	0.0
2001	June	0.0	0.0	13.2	2.0	20.0	14.2	4.0	0.0	4.2	0.0	0.0	0.0	35.0	24.0	6.2	0.0	22.0	18.4	24.0	2.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	15.2	43.0	14.0	0.0
2001	July	0.0	0.0	2.4	31.0	5.0	0.0	14.2	0.0	2.2	0.0	0.0	2.0	0.0	0.0	34.2	50.2	10.0	13.0	35.0	26.0	0.0	22.2	1.0	2.0	0.0	22.2	2.0	2.0	49.0	40.0	19.0
2001	August	14.0	0.0	3.0	0.0	9.0	12.0	0.0	21.0	4.0	0.0	5.4	4.0	10.0	2.0	5.0	11.0	9.0	44.0	41.0	4.0	16.0	13.2	28.0	5.0	18.0	5.0	0.0	41.0	0.0	0.0	16.0
2001	September	2.0	13.0	4.2	0.0	16.0	13.0	0.0	11.2	5.0	2.0	0.0	15.0	8.5	3.0	0.0	16.0	10.0	3.0	0.0	0.0	0.0	0.0	0.0	55.0	8.0	0.0	0.0	0.0	0.0	6.0	0.0
2001	October	0.0	2.0	6.0	18.0	32.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2001	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	2.0	0.0	0.0
2002	February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	8.2	0.0	0.0	0.0	0.0	0.0
2002	March	0.0	0.0	11.0	1.2	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	0.0	0.0	14.0	13.2	0.0	24.0	0.0	4.0	0.0	0.0	0.0	5.0
2002	April	0.0	3.0	28.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.0	4.0	0.0	10.2	23.2	0.0	1.0	14.0	0.0
2002	May	0.0	0.0	0.0	39.2	0.0	2.0	42.0	0.0	0.0	0.0	3.0	0.0	0.0	42.0	0.0	8.0	0.0	14.0	30.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0	11.0	5.0	33.0	10.0	0.0
2002	June	0.0	2.3	16.0	0.0	3.0	0.0	2.4	0.0	0.0	24.0	10.2	4.2	4.2	34.2	16.2	5.0	0.0	0.0	0.0	8.0	12.5	0.0	3.8	18.0	24.0	0.0	0.0	0.0	0.0	6.0	0.0
2002	July	73.0	22.2	8.0	48.0	5.0	3.0	0.0	5.0	0.0	2.0	4.2	4.0	0.0	2.5	6.5	0.0	3.0	51.0	0.0	21.0	3.0	88.2	220.0	20.0	4.0	14.0	4.0	45.0	2.2	5.0	4.5
2002	August	0.0	0.0	1.3	24.0	9.0	50.0	80.0	18.0	0.0	67.0	32.0	28.0	26.0	0.0	0.0	16.0	70.0	0.0	0.0	11.0	49.0	43.0	5.0	1.2	0.0	32.0	0.0	0.0	7.0	0.0	0.0
2002	September	0.0	0.0	0.0	30.0	20.0	0.0	0.0	0.0	0.0	35.0	0.0	0.0	0.0	10.0	0.0	0.0	0.0	7.0	5.2	0.0	0.0	43.0	0.0	24.0	6.0	58.4	33.2	0.0	2.0	0.0	0.0
2002	October	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2002	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	January	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	5.2	0.0
2003	February	29.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.0	21.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0
2003	March	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.0	0.0	11.0	0.0	3.0	3.1	0.0
2003	April	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2	13.0	9.0	0.0	0.0	0.0	14.2	5.0	6.0	24.0	11.0	0.0
2003	May	0.0	3.0	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	0.0	6.2	0.0	0.0	0.0	0.0	6.0	0.0	14.2	0.0	7.0	1.2	0.0	0.0	1.0	0.0	0.0	0.0	0.0
2003	June	0.0	2.0	0.0	12.0	6.2	1.2	5.4	0.0	15.0	16.0	2.0	15.2	7.2	6.2	8.2	2.0	0.0	0.0	0.0	0.0	12.2	14.2	11.0	20.0	6.2	0.0	12.2	44.2	19.0	38.0	0.0
2003	July	52.2	4.0	3.0	20.0	11.0	4.0	9.0	22.0	56.0	12.2	0.0	17.2	34.0	10.0	15.2	0.0	54.0	35.2	2.0	55.0	0.0	3.0	0.0	9.0	0.0	24.0	9.0	0.0	1.0	9.2	71.0
2003	August	2.0	1.0	3.0	0.0	0.0	44.0	0.0	55.0	0.0	0.0	4.2	1.0	0.0	0.0	0.0	0.0	13.2	86.0	59.0	0.0	12.4	0.0	7.2	0.0	0.0	62.0	11.0	0.0	0.0	0.0	16.2
2003	September	50.2	7.5	14.2	0.0	9.2	20.0	0.0	2.2	0.0	0.0	0.0	3.3	44.0	0.0	0.0	0.0	0.0	10.0	0.0	0.0	29.2	2.0	11.0	20.0	2.2	0.0	0.0	0.0	0.0	12.0	0.0
2003	October	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2003	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	21.2	0.0	0.0
2004	January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	2.0	9.2	22.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	March	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	April	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	14.0	0.0	2.0	0.0	0.0	0.0	18.2	0.0	0.0
2004	May	13.0	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	11.0	0.0	34.0	26.0	5.0	2.0	5.2	2.0	13.0	3.2	0.0	0.0	6.0	0.0
2004	June	3.0	0.0	13.0	14.0	18.2	14.2	1.0	0.0	1.2	60.0	60.0	0.0	0.0	0.0	0.0	3.0	1.0	22.2	0.0	0.0	18.2	42.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	July	1.0	1.2	2.0	0.0	0.0	0.0	16.0	18.0	146.0	27.0	38.0	16.0	7.2	0.0	0.0	0.0	0.0	5.0	0.0	25.0	0.0	4.2	0.0	11.0	48.0	0.0	22.0	19.2	8.0	0.0	0.0
2004	August	0.0	0.0	0.0	38.0	5.2	0.0	0.0	3.2	0.0	0.0	1.0	2.2	0.0	15.0	0.0	18.2	22.0	0.0	2.2	13.0	2.0	0.0	0.0	0.0	0.0	26.0	0.0	0.0	71.0	0.0	7.0
2004	September	27.0	0.0	0.0	3.0	22.0	20.0	10.2	7.0	1.2	15.0	0.0	20.2	6.2	12.0	24.2	20.0	2.0	23.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	18.2	0.0	0.0
2004	October	1.2	7.0	0.0	0.0	2.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0
2004	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2004	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	14.2	0.0	0.0	6.2	7.0	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	0.0	2.0	0.0	0.0	0.0	7.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	March	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	22.2	0.0	0.0	5.0	5.2	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0
2005	April	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	20.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	4.0	0.0	0.0	14.2	0.0
2005	May	3.2	0.0	3.2	0.0	15.0	7.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	12.2	4.2	0.0	0.0	4.0	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	June	0.0	0.0	0.0	9.1	1.2	1.3	2.0	7.0	0.0	0.0	0.0	6.2	0.0	0.0	4.0	0.0	0.0	0.0	0.0	4.0	4.2	13.2	18.2	5.2	6.0	0.0	0.0	0.0	4.0	34.2	0.0
2005	July	0.0	2.2	4.2	2.0	0.0	0.0	0.0	0.0	3.0	62.0	0.0	2.0	9.2	51.0	23.0	0.0	11.0	22.2	0.0	14.0	2.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	2.0	0.0	17.2
2005	August	0.0	0.0	0.0	58.0	9.0	10.0	123.0	14.0	30.0	0.0	7.2	14.0	9.0	19.2	10.0	0.0	0.0	28.0	9.0	49.0	0.0	22.0	3.0	3.2	19.2	31.2	21.2	6.0	11.0	0.0	0.0
2005	September	0.0	0.0	0.0	0.0	2.0	20.0	0.0	1.2	14.0	14.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.2	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	October	0.0	0.0	0.0	0.0	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.2	41.0	46.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2005	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	January	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	February	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	March	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	3.2	0.0	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	April	0.0	0.0	0.0	0.0	0.0	0.0	16.2	17.2	2.0	0.0	9.2	0.0	0.0	0.0	0.0	0.0	0.0	41.0	4.0	0.0	0.0	0.0	26.0	0.0	0.0	0.0	0.0	0.0	3.0	0.0	0.0
2006	May	0.0	7.0	8.2	0.0	3.2	21.0	0.0	5.0	0.0	10.0	14.2	30.0	9.0	1.0	0.0	0.0	0.0	0.0	2.0	2.2	4.0	2.0	0.0	0.0	0.0	11.0	8.2	0.0	0.0	10.0	0.0
2006	June	0.0	21.0	0.0	8.0	5.2	25.0	22.0	6.2	34.2	0.0	15.0	0.0	0.0	0.0	0.0	9.0	0.0	0.0	0.0	0.0	20.2	0.0	18.2	2.2	5.2	5.2	14.0	4.2	6.0	4.0	0.0
2006	July	0.0	0.0	0.0	0.0	0.0	0.0	10.4	48.0	0.0	15.0	18.0	8.2	13.0	0.0	0.0	0.0	18.0	0.0	57.0	22.2	0.0	1.2	0.0	11.0	1.2	32.2	0.0	11.0	0.0	14.0	0.0
2006	August	0.0	30.0	28.0	0.0	0.0	2.0	2.2	0.0	6.0	0.0	0.0	0.0	0.0	5.0	0.0	3.0	2.2	0.0	0.0	10.2	12.2	0.0	0.0	2.0	15.2	15.0	26.0	7.2	0.0	10.0	0.0
2006	September	0.0	9.2	0.0	7.0	0.0	0.0	0.0	0.0	45.2	20.0	7.2	0.0	0.0	0.0	0.0	14.0	0.0	0.0	2.0	0.0	5.0	17.0	5.2	3.0	42.0	11.0	0.0	0.0	0.0	0.0	0.0
2006	October	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.2	0.0	0.0	6.2	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	2.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	November	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2006	December	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.5	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Source: Department of Hydrology and Metereology

Temperature 2000-2006 mm

2000	January	9.8	9.8	9.5	9.3	9.0	8.8	8.5	8.5	8.3	9.0	11.0	11.5	9.8	9.5	11.0	9.0	8.8	7.5	9.3	9.3	9.5	9.3	8.5	8.3	8.8	9.3	10.3	9.3	7.8	8.3	9.3
2000	February	10.0	10.0	11.5	9.0	11.0	8.5	10.0	10.5	8.5	8.8	8.8	10.5	10.8	11.5	10.3	11.3	10.0	9.5	8.3	8.5	9.8	9.8	10.0	11.0	11.5	11.0	9.0	7.8	10.0	0.0	0.0
2000	March	11.0	11.0	11.5	13.0	14.5	14.5	15.3	15.3	12.5	12.8	12.3	13.3	14.0	13.5	14.0	13.5	13.8	13.3	15.0	15.3	15.3	16.5	13.3	12.8	14.8	16.3	17.0	15.8	17.3	18.3	19.5
2000	April	20.5	21.0	20.8	19.3	20.8	19.3	20.0	19.8	21.0	20.8	18.5	18.5	19.0	18.5	18.0	18.0	18.0	18.0	18.8	18.3	18.3	18.5	20.0	16.5	15.8	17.8	18.3	20.0	21.0	20.0	0.0
2000	May	20.0	19.0	20.3	22.0	21.5	21.8	17.5	19.0	21.0	20.8	23.0	25.0	23.0	23.0	272.5	21.0	22.0	23.0	21.3	19.0	19.0	21.0	21.0	20.5	21.8	21.5	19.8	20.3	20.8	18.3	19.5
2000	June	20.8	22.3	19.5	20.8	21.5	22.5	21.8	24.5	24.3	22.3	22.5	18.2	19.3	22.3	23.3	23.5	23.0	24.0	23.5	22.8	22.8	23.0	22.0	21.8	22.8	21.5	21.3	18.0	21.0	22.0	0.0
2000	July	21.6	21.5	22.5	22.8	23.8	20.5	22.0	22.3	22.8	23.3	23.5	24.3	24.3	24.0	22.5	23.3	23.3	22.5	22.8	22.8	21.3	22.5	22.3	22.3	21.8	21.8	23.0	22.3	22.5	22.3	22.0
2000	August	22.0	23.0	24.3	24.3	25.0	24.8	24.8	22.5	23.3	23.3	22.0	23.0	24.3	24.0	24.3	21.0	24.0	25.0	22.8	23.3	21.3	21.5	22.5	23.5	22.0	23.8	23.0	22.0	22.5	22.3	22.8
2000	September	23.0	24.0	24.5	24.8	23.0	23.5	23.3	23.0	21.3	20.8	22.5	22.5	23.0	22.3	22.3	21.9	22.0	21.3	20.5	19.8	20.0	20.0	20.3	21.0	20.3	20.8	19.5	19.3	18.0	18.0	0.0
2000	October	18.3	20.0	20.0	21.0	21.5	20.8	20.8	20.3	19.3	19.3	19.3	19.3	19.0	18.3	18.0	18.8	18.3	17.8	16.3	16.8	17.0	17.5	17.5	17.0	17.5	17.3	15.3	17.0	16.8	16.0	15.3
2000	November	16.5	16.3	16.3	16.0	15.8	15.3	14.5	14.5	15.0	15.8	16.0	15.8	16.3	15.5	14.8	15.0	14.3	14.5	14.8	13.5	12.5	12.3	13.0	11.5	12.8	13.5	13.3	12.0	11.5	11.0	0.0
2000	December	8.5	9.0	9.0	9.5	9.5	8.8	9.0	9.0	10.8	9.5	9.0	8.5	10.0	10.5	10.8	9.8	11.0	11.0	11.0	10.5	10.8	11.0	11.3	11.5	11.3	11.0	9.5	9.8	9.0	9.0	9.0
2001	January	10.3	11.8	10.5	9.0	7.8	7.8	8.3	7.8	7.0	5.8	6.5	7.3	7.3	7.5	8.8	9.0	9.0	8.5	8.8	9.3	9.8	10.0	9.8	8.0	8.0	9.8	9.0	9.3	10.3	12.0	14.3
2001	February	15.8	16.8	10.8	10.3	10.5	10.3	9.5	10.0	10.0	12.0	11.8	12.0	12.0	11.5	12.5	15.0	13.8	13.5	13.5	13.3	10.5	11.3	13.3	12.3	13.3	12.5	12.3	13.5	0.0	0.0	0.0
2001	March	13.8	14.5	13.3	15.0	14.5	13.3	13.8	14.3	14.5	14.3	13.8	15.5	14.3	14.8	15.0	15.5	15.8	15.5	16.3	17.0	17.8	14.7	15.3	16.3	16.5	16.5	16.5	18.0	18.0	18.8	18.8
2001	April	15.5	17.3	17.0	18.5	19.0	20.3	19.5	20.0	20.0	21.3	21.5	21.3	20.3	17.8	15.5	17.5	17.8	15.5	17.0	18.5	19.0	18.5	19.8	21.0	20.8	20.0	20.3	21.0	22.8	19.1	0.0
2001	May	19.5	20.0	22.0	23.0	22.8	23.3	22.5	24.3	20.3	19.8	16.8	18.5	18.3	19.0	19.3	19.0	22.5	21.5	20.3	20.0	21.5	21.8	22.8	22.3	22.8	22.0	22.3	22.0	22.8	23.0	23.0
2001	June	17.3	18.3	18.3	16.0	16.8	17.5	17.8	16.8	17.3	17.8	19.0	19.3	18.8	18.0	18.3	18.3	18.8	17.3	18.0	18.5	19.3	19.5	19.5	18.8	18.8	18.5	19.5	18.8	18.8	19.3	0.0
2001	July	20.0	18.0	19.0	18.5	18.5	19.5	19.0	19.5	19.5	19.8	20.0	20.0	19.8	17.8	16.3	15.8	18.0	19.3	18.0	18.8	18.5	18.8	19.3	19.5	19.0	17.8	18.0	17.3	17.3	16.8	16.0
2001	August	17.5	17.3	19.8	19.3	18.3	17.0	17.5	18.3	18.0	19.0	18.5	19.0	17.3	18.5	18.5	18.3	18.3	18.5	18.5	18.8	17.8	16.5	16.5	17.3	18.3	18.3	17.8	17.5	17.5	18.0	17.5
2001	September	18.3	16.5	17.3	17.3	15.8	17.0	18.5	17.0	18.0	16.3	16.0	16.0	17.0	17.0	16.5	14.5	17.3	16.3	15.3	16.0	17.3	17.0	17.5	16.0	16.5	17.3	16.0	16.5	16.8	16.0	0.0
2001	October	14.5	13.8	15.8	14.0	14.8	15.5	16.3	16.3	17.0	16.0	16.3	14.5	15.3	13.3	13.0	13.5	14.8	12.3	12.3	12.3	13.0	14.8	13.5	12.5	12.3	11.8	12.3	12.3	12.0	13.5	12.3
2001	November	12.0	12.8	13.5	13.0	12.0	12.5	11.5	11.0	10.3	10.5	11.5	10.3	10.0	10.3	10.8	10.3	10.0	10.3	11.0	9.8	11.3	10.8	10.8	9.8	10.0	10.8	10.0	10.5	8.8	10.0	0.0
2001	December	10.0	9.3	10.8	11.0	10.3	10.0	9.0	9.5	9.0	8.8	10.0	10.3	10.0	9.5	10.0	9.5	9.0	9.8	10.3	10.3	9.3	10.0	10.5	9.8	9.3	9.3	9.0	9.0	9.3	8.8	7.8
2002	January	8.0	8.5	9.3	8.5	9.3	8.3	9.0	8.5	9.0	9.3	8.5	9.0	9.5	9.0	10.0	10.0	7.0	9.5	11.5	11.3	8.5	9.8	8.5	8.5	8.0	7.5	7.3	5.8	6.8	9.0	9.5
2002	February	8.8	9.8	10.0	9.3	9.8	10.8	12.5	11.5	12.5	12.5	11.3	11.0	11.8	10.8	11.5	12.3	13.0	12.3	12.8	13.3	13.5	12.5	13.3	14.5	10.3	11.0	10.5	11.8	0.0	0.0	0.0
2002	March	13.8	14.0	11.5	11.3	12.8	13.5	12.3	14.3	13.5	15.0	15.5	16.5	17.0	16.3	15.5	14.8	16.3	14.3	17.0	17.8	16.3	15.3	15.5	16.3	16.0	16.8	14.5	15.5	15.5	14.3	14.0
2002	April	16.8	14.8	12.8	15.5	16.3	17.5	18.5	18.0	18.0	17.0	15.5	13.8	16.3	17.0	17.5	19.0	20.5	19.5	21.5	20.5	20.3	16.0	17.0	17.0	19.0	17.5	15.5	18.0	17.3	16.5	0.0
2002	May	17.5	19.0	18.0	18.5	19.5	20.0	18.8	21.0	20.3	19.0	18.8	21.0	23.0	20.5	21.8	21.3	20.8	18.0	20.5	22.3	21.0	20.8	20.8	19.8	18.5	17.8	17.5	18.5	18.8	18.8	19.0
2002	June	21.0	20.8	21.5	22.0	20.5	20.5	20.0	23.3	23.3	21.5	21.0	22.0	22.0	22.3	22.0	21.3	22.0	22.8	22.5	22.5	21.8	22.3	23.5	23.3	23.5	23.3	23.0	22.5	23.5	21.5	0.0
2002	July	21.5	22.0	22.0	21.5	22.3	22.8	23.8	23.0	23.3	22.0	22.5	22.8	22.5	22.0	22.0	24.0	23.5	22.8	23.5	20.5	21.0	19.5	19.0	21.3	21.0	22.0	21.5	21.5	20.0	21.3	22.5
2002	August	22.0	23.0	22.5	23.0	23.0	22.8	22.8	23.0	23.0	21.8	21.8	21.0	22.3	22.3	22.5	22.3	22.0	22.5	22.0	20.5	20.6	19.8	20.5	21.8	20.8	21.4	22.5	22.5	22.5	21.5	21.5
2002	September	22.0	22.0	21.5	21.0	21.0	20.8	21.3	21.3	21.5	20.5	21.0	19.3	20.3	20.8	21.5	19.5	19.0	17.5	19.3	22.2	20.3	18.3	20.0	19.0	18.8	17.0	19.3	19.5	20.8	21.0	0.0
2002	October	21.3	20.8	19.8	19.8	20.0	19.5	19.8	17.5	17.3	17.8	18.0	17.8	17.8	16.3	17.8	17.8	17.5	15.5	16.0	17.8	16.5	16.5	16.8	16.0	15.5	15.3	14.8	15.3	14.5	15.3	15.3
2002	November	14.8	14.8	14.0	13.8	13.3	13.0	14.3	14.8	14.8	14.5	13.8	14.0	14.0	13.3	13.5	13.5	13.8	13.0	13.3	12.5	12.5	13.5	12.3	11.5	12.0	12.5	13.3	14.3	13.3	12.8	0.0
2002	December	12.3	11.8	11.8	12.8	12.0	12.5	11.5	11.3	11.8	10.8	11.0	11.5	10.8	10.8	10.8	9.8	9.8	9.5	9.8	9.5	9.0	8.3	9.5	9.0	8.3	8.8	8.3	8.0	7.5	6.8	6.0
2003	January	6.3	7.3	9.5	8.3	7.8	8.5	9.0	7.8	7.0	7.5	7.8	7.5	8.0	7.0	8.3	9.0	9.8	10.3	10.3	11.0	9.3	8.8	8.8	8.5	7.5	8.5	8.5	9.3	7.8	8.8	9.0
2003	February	9.0	9.0	8.8	9.3	9.0	10.0	10.0	11.5	9.8	10.3	11.0	10.0	9.5	8.3	8.5	11.0	12.5	13.0	8.5	9.8	9.8	10.5	12.3	12.3	12.0	11.5	10.5	13.0	0.0	0.0	0.0
2003	March	13.5	14.3	16.0	14.8	13.0	11.0	11.3	10.8	11.3	13.8	14.3	12.0	11.3	12.3	14.0	15.5	13.5	14.5	14.0	14.0	14.8	16.3	16.8	16.5	14.5	14.8	14.5	16.8	15.8	15.3	16.3
2003	April	16.0	16.8	17.3	17.5	17.5	17.5	18.3	18.3	18.8	19.0	18.8	18.5	20.5	20.0	18.3	19.8	19.8	19.8	21.0	19.8	19.0	18.3	19.0	20.5	20.8	17.8	18.5	18.5	17.3	15.0	0.0
2003	May	16.3	17.5	18.3	17.3	19.3	19.0	19.0	19.5	19.0	17.3	18.0	17.3	20.0	17.3	19.3	19.3	20.0	20.3	18.3	18.8	20.0	17.8	18.5	20.8	20.3	20.8	21.3	22.0	22.3	22.8	22.3
2003	June	21.8	22.5	22.8	19.0	20.0	19.3	20.0	20.8	21.3	22.5	21.3	21.3	21.8	20.5	20.5	19.8	21.3	22.3	23.0	20.5	21.8	23.0	21.0	19.8	22.8	22.8	21.0	20.5	22.0	22.5	0.0
2003	July	20.3	22.0	22.5	19.8	20.3	21.8	22.5	21.0	20.0	20.0	23.0	21.0	21.5	22.0	22.8	22.5	22.0	22.5	21.0	21.3	22.8	23.0	23.8	22.5	23.5	22.5	23.0	23.0	23.3	21.0	21.3
2003	August	22.8	21.3	22.0	23.8	23.3	22.3	23.8	23.0	23.0	23.0	22.5	23.0	23.5	23.0	23.5	22.5	21.3	20.5	19.3	19.5	22.3	23.3	22.8	21.8	21.3	22.0	22.0	22.5	22.3	22.0	21.5
2003	September	21.0	21.3	21.8	22.0	21.0	22.0	22.3	22.0	21.8	22.3	21.5	22.0	21.8	21.3	20.5	20.5	21.5	21.0	21.3	22.0	21.2	20.5	20.0	17.5	19.8	20.0	21.0	20.8	19.8	18.0	0.0
2003	October	20.0	20.3	20.5	20.3	18.3	18.3	18.5	18.8	17.8	20.0	18.5	18.5	18.3	18.0	18.5	19.0	18.8	18.3	17.8	17.0	17.0	16.0	15.3	15.8	16.3	15.8	18.0	18.0	16.5	17.0	17.3
2003	November	16.0	15.0	14.5	14.8	15.3	14.5	14.0	14.8	14.3	14.5	14.0	12.8	14.0	14.3	14.8	15.0	14.0	12.8	12.8	11.5	13.0	13.0	12.8	13.3	13.0	13.0	12.8	12.5	11.5	11.3	0.0
2003	December	11.3	11.3	12.0	11.8	10.5	10.3	10.3	10.5	10.3	10.5	10.3	11.0	11.0	10.5	10.0	9.3	9.5	10.0	10.0	9.0	9.3	9.5	9.5	9.3	8.0	8.0	8.3	4.0	5.3	6.3	6.8
2004	January	7.0	7.8	7.5	8.0	7.0	9.5	9.8	9.5	9.0	8.8	8.8	9.0	9.5	9.6	9.0	8.5	8.8	9.3	10.0	9.8	9.8	10.3	8.8	6.0	5.0	8.5	6.0	6.3	8.0	8.5	8.0
2004	February	9.0	8.0	7.8	8.5	8.0	7.5	7.5	8.5	9.8	10.5	10.5	11.0	11.5	12.5	9.8	10.3	13.3	12.0	11.3	11.8	11.5	13.3	13.0	13.8	14.5	14.3	15.3	15.0	15.3	0.0	0.0
2004	March	15.8	15.5	14.3	14.3	16.3	15.0	12.0	13.0	15.8	14.3	14.0	14.8	15.3	15.8	16.3	16.0	18.0	18.5	18.8	20.0	21.0	21.3	22.5	20.3	19.5	20.0	19.8	18.8	19.3	17.3	16.5
2004	April	17.0	16.3	16.0	18.5	19.0	20.3	18.0	16.5	17.8	19.0	20.5	20.8	19.8	21.5	21.0	20.8	20.8	20.0	18.0	20.0	20.5	20.5	19.3	16.5	16.0	18.5	19.5	16.0	16.8	18.8	0.0
2004	May	16.5	18.5	19.0	19.0	18.5	19.8	21.5	22.3	22.3	24.5	24.5	23.8	23.8	24.5	25.0	25.5	21.8	22.8	21.3	17.1	16.5	17.5	19.3	18.3	19.0	19.5	20.5	19.8	19.8	20.0	20.5
2004	June	19.0	20.8	20.8	20.5	20.2	20.5	20.8	21.3	20.5	21.0	21.3	21.5	22.0	22.5	22.8	22.3	22.0	22.5	22.0	22.3	22.8	22.0	22.5	21.5	23.0	22.8	23.0	23.3	22.8	21.8	0.0
2004	July	22.8	22.8	22.8	22.5	23.0	22.5	20.5	18.8	18.8	19.0	19.3	19.8	20.8	22.3	21.8	22.5	22.8	21.5	22.3	20.8	21.0	21.3	22.3	21.8	20.8	21.3	21.8	22.4	21.0	22.3	22.3
2004	August	21.8	21.3	22.8	23.3	22.8	23.5	22.3	21.8	23.5	22.5	23.3	22.5	23.0	23.5	23.0	22.5	22.5	22.5	21.8	21.5	22.5	23.0	23.3	22.8	23.0	22.5	22.3	22.0	21.8	22.0	22.5
2004	September	22.3	22.8	21.8	22.0	22.5	22.3	21.5	22.0	21.2	20.8	21.0	21.0	21.5	21.0	20.0	19.5	20.5	20.5	21.3	21.0	20.3	21.3	21.5	21.0	21.8	21.3	20.8	19.8	19.2	19.5	0.0
2004	October	19.5	20.0	19.5	18.8	19.5	19.8	20.0	20.0	19.3	19.8	19.8	16.3	15.8	16.3	14.8	15.0	16.0	16.8	17.0	17.3	16.5	16.5	15.5	15.0	14.8	14.8	15.0	13.8	13.3	13.0	12.5
2004	November	13.5	13.5	13.3	13.0	12.5	13.0	13.0	14.0	13.5	13.5	13.5	13.3	13.0	12.5	12.0	12.3	12.8	11.8	12.0	12.5	12.0	13.0	11.5	11.3	11.8	11.8	11.0	10.8	11.0	11.0	0.0
2004	December	10.5	10.3	10.3	12.3	11.0	10.0	11.3	11.5	11.3	11.0	12.5	12.0	11.8	11.0	10.5	11.0	11.5	11.3	11.5	10.8	11.3	8.8	9.8	9.0	8.0	9.8	4.8	7.5	8.5	8.3	9.8
2005	January	9.5	12.8	12.0	11.3	10.5	10.3	10.3	10.3	10.3	7.3	8.0	6.8	6.3	8.5	9.0	9.5	8.3	6.5	5.8	8.0	6.8	7.3	5.3	7.5	8.3	8.8	9.5	7.8	8.3	8.3	9.3
2005	February	9.0	9.3	9.0	8.3	10.3	8.8	10.3	10.3	10.8	11.8	11.8	13.8	13.3	13.0	11.0	11.8	11.5	11.5	12.8	12.5	13.3	13.5	11.5	12.3	14.0	14.3	13.8	14.5	0.0	0.0	0.0
2005	March	14.8	15.3	16.3	17.0	15.8	16.0	16.5	17.8	18.3	17.8	13.8	12.3	15.3	16.5	16.3	16.0	16.3	16.8	16.8	16.8	17.5	14.5	14.5	12.3	12.3	13.5	15.8	17.0	15.8	15.8	16.3
2005	April	16.8	17.0	17.0	16.0	16.8	17.5	17.5	18.5	19.5	18.5	18.5	19.0	19.0	18.8	19.5	20.5	20.8	20.8	20.3	20.3	20.3	19.5	20.0	20.3	20.3	20.3	17.5	17.5	17.5	12.5	0.0
2005	May	16.5	17.8	15.8	17.0	16.3	16.3	15.5	19.0	20.0	20.8	19.8	19.8	20.3	19.5	18.0	20.5	20.0	20.3	20.8	18.5	20.5	21.5	22.5	22.5	24.3	24.5	25.0	22.8	24.0	24.5	25.3
2005	June	25.3	24.5	23.5	20.5	20.3	21.3	19.8	22.0	22.8	22.8	24.0	24.5	24.0	24.3	25.5	25.5	25.8	26.3	25.3	20.8	22.0	21.0	20.3	21.5	22.8	21.5	23.8	23.8	22.8	23.3	0.0
2005	July	23.5	22.0	23.0	23.3	22.8	23.0	23.8	23.5	22.5	21.3	22.4	22.3	21.0	21.8	21.4	19.7	19.8	20.0	21.3	21.0	22.0	22.3	23.3	23.3	24.3	23.8	23.8	24.5	22.8	24.5	23.8
2005	August	24.0	24.3	23.3	23.5	22.5	20.8	19.5	21.8	23.3	22.5	22.3	21.7	23.0	22.5	23.0	22.8	22.0	21.5	22.1	21.5	21.5	21.8	20.8	21.8	20.0	20.8	21.0	21.5	21.8	22.0	22.0
2005	September	22.8	22.8	22.3	20.8	21.0	21.3	21.5	23.5	20.8	20.7	22.0	23.0	21.8	20.5	20.8	22.3	21.5	21.8	22.0	23.5	21.3	20.3	21.0	21.3	22.0	22.0	21.5	21.5	21.5	21.3	0.0
2005	October	20.8	21.0	20.8	19.8	19.5	20.0	19.0	17.8	19.2	18.0	17.5	19.3	18.0	16.8	16.8	16.8	16.0	16.5	16.8	14.8	15.5	17.3	17.3	16.0	16.5	16.5	15.0	16.8	16.0	14.0	15.0
2005	November	14.0	13.5	13.8	13.8	13.3	12.8	13.0	13.3	13.0	12.8	13.3	12.8	14.5	14.0	14.0	13.5	14.8	13.8	13.2	12.5	13.0	13.0	12.3	12.0	12.8	11.7	11.8	11.0	10.3	9.8	0.0
2005	December	12.3	12.0	10.8	11.8	9.5	11.5	11.0	10.5	10.5	10.0	9.0	9.0	9.0	9.5	10.3	10.0	10.0	9.5	9.5	9.0	9.8	10.8	8.8	9.8	9.5	9.0	9.5	8.5	8.5	8.0	9.0
2006	January	8.0	10.0	13.0	12.3	13.3	13.0	13.5	12.5	11.5	9.8	10.3	9.0	9.0	8.5	7.5	9.0	12.3	13.0	13.0	13.5	11.8	10.8	9.0	9.3	7.5	9.0	9.0	9.5	10.5	10.8	12.0
2006	February	12.8	12.0	13.0	12.8	12.3	12.3	13.3	13.3	13.3	14.3	13.0	12.8	13.8	13.3	14.0	14.8	14.5	14.5	15.3	17.3	16.5	17.0	17.0	17.3	18.0	18.0	17.5	16.0	0.0	0.0	0.0
2006	March	15.3	15.0	13.5	15.0	13.8	14.3	15.3	16.3	17.3	13.8	13.0	13.3	14.0	15.3	14.0	13.5	13.5	14.0	14.8	15.3	16.3	15.8	16.0	16.8	18.0	18.8	19.5	17.5	15.8	16.3	17.0
2006	April	17.8	17.8	17.8	18.0	18.3	17.5	17.5	17.3	18.0	19.8	17.8	18.8	19.8	19.5	20.3	21.0	21.0	11.5	11.8	15.0	15.5	16.3	16.5	17.8	17.5	17.3	19.0	21.3	21.0	21.0	0.0
2006	May	20.5	19.0	18.8	18.8	19.3	19.5	20.3	19.8	19.5	19.5	19.0	18.5	18.1	19.8	21.3	21.0	21.0	21.5	19.5	20.0	17.5	20.5	20.3	21.3	22.0	22.5	21.8	22.5	21.5	21.8	24.0
2006	June	22.0	20.8	21.5	21.3	22.8	21.5	21.8	22.8	22.5	21.5	21.8	23.5	22.3	21.8	21.3	21.0	21.8	22.5	22.8	22.8	22.0	22.0	22.5	22.0	22.5	22.3	22.3	22.8	22.3	23.0	0.0
2006	July	23.5	23.8	23.3	24.5	23.8	23.8	22.0	23.0	23.0	24.0	23.5	23.4	22.5	23.5	23.5	23.3	23.8	24.5	22.5	22.5	23.8	23.3	21.8	21.9	20.8	20.8	22.3	22.3	22.5	22.3	23.5
2006	August	24.0	22.5	21.8	23.3	23.3	22.0	22.0	22.5	23.5	21.5	23.8	23.8	23.8	23.3	23.8	23.5	22.8	23.8	23.5	23.5	23.3	24.0	23.0	22.5	22.0	20.8	21.0	21.5	22.0	21.8	22.5
2006	September	22.5	22.5	21.3	22.0	22.3	21.5	22.0	21.5	18.8	18.8	19.5	20.8	21.3	21.5	21.0	20.5	21.0	22.0	22.5	22.3	19.8	19.3	19.8	19.0	17.5	20.0	21.0	21.0	20.5	19.8	0.0
2006	October	19.8	20.5	21.0	21.5	19.5	18.0	18.8	19.3	19.3	19.0	19.0	18.3	18.0	17.8	17.5	17.0	17.5	17.5	16.5	17.3	12.0	13.5	13.3	14.3	14.8	16.0	15.5	13.8	14.0	14.8	14.8
2006	November	15.8	15.3	15.8	16.0	15.8	15.3	15.3	14.0	14.8	15.0	14.8	14.5	14.3	14.3	14.5	14.8	14.0	13.8	12.3	12.8	11.8	12.8	12.5	11.8	10.8	10.0	9.5	10.8	10.8	10.0	0.0
2006	December	11.5	9.5	10.0	11.5	11.0	11.8	11.0	11.3	11.0	10.3	8.5	8.0	7.8	9.3	10.0	11.5	10.8	10.0	11.0	10.8	11.3	11.3	10.0	10.3	10.3	11.3	9.5	9.0	9.5	8.8	10.5

Source: Department of Hydrology and Metereology

Solar Radiation Data (2000-2006)- MJ/m2/day

2000	January	62.17	84.84	122.90	139.76	165.03	11.60	42.99	64.62	80.91	7.09	17.73	120.34	47.46	47.21	3.83	56.97	166.84	87.46	19.59	50.06	56.61	157.18	7.47	30.56	70.08	78.66	32.60	22.82	149.45	140.19	165.00
2000	February	94.60	49.64	52.56	120.68	185.21	106.19	51.26	14.99	22.40	55.22	176.38	186.90	109.59	4.79	3.07	3.72	29.87	167.34	89.13	21.94	13.05	29.35	87.12	120.42	117.56	70.08	20.13	76.71	14.37		
2000	March	103.47	42.63	122.52	39.29	19.26	9.32	109.64	191.44	9.44	27.17	23.36	3.30	95.44	56.88	59.15	134.64	39.32	18.44	33.30	115.85	82.42	40.44	86.70	61.32	32.40	85.44	204.15	153.27	71.69	5.82	34.45
2000	April	4.53	77.74	123.20	86.25	10.13	4.34	67.43	50.93	168.99	9.84	3.97	46.76	16.06	49.04	190.89	69.04	102.32	4.60	46.75	98.44	166.16	85.36	24.38	95.18	16.77	115.84	172.10	146.79	95.78	20.88	
2000	May	52.56	26.95	23.88	116.03	150.25	99.30	76.32	45.14	115.27	97.63	68.26	54.17	20.61	38.94	35.13	39.07	161.08	133.42	80.10	53.42	94.23	110.67	62.40	125.74	48.19	73.65	27.61	113.75	135.53	175.68	125.47
2000	June	66.61	49.13	39.59	36.90	138.28	13.56	38.18	8.66	2.32	146.29	160.79	131.64	42.41	58.47	32.62	90.04	135.18	207.67	182.14	110.87	69.58	88.62	139.71	150.34	184.24	7.09	57.55	58.17	99.71	1.81	
2000	July	22.72	156.35	42.50	65.47	1.14	61.00	198.77	105.78	30.22	63.44	46.45	146.15	3.18	35.73	72.04	84.47	31.75	32.65	157.49	158.06	151.15	103.44	76.76	100.18	154.01	206.81	115.54	30.84	24.42	41.65	86.93
2000	August	150.29	186.37	130.87	13.86	15.43	1.92	48.07	204.83	109.74	66.92	41.08	89.50	139.76	178.79	170.31	108.14	21.55	65.75	5.76	85.11	38.33	131.62	64.67	54.69	80.31	114.46	204.99	4.51	51.34	58.92	0.67
2000	September	92.74	61.93	68.16	145.72	86.51	62.25	72.21	145.28	112.42	66.84	80.04	39.53	111.33	149.49	205.61	156.25	125.68	42.04	62.69	1.23	131.42	173.32	132.35	28.04	3.00	63.22	39.52	188.83	2.88	0.39	
2000	October	30.63	25.20	45.18	156.10	77.35	71.99	5.39	18.56	82.95	136.29	85.78	39.28	73.84	29.36	69.65	121.56	151.26	79.67	54.19	40.54	62.35	17.78	95.05	131.73	108.53	46.85	33.39	104.17	99.13	61.17	39.56
2000	November	24.83	33.81	47.62	45.12	170.45	148.98	81.34	47.43	91.33	102.75	67.63	129.10	51.08	55.96	23.35	113.49	130.38	160.74	111.25	53.94	50.40	32.63	68.19	187.80	8.69	42.46	6.10	4.86	115.36	157.14	39.56
2000	December	138.67	53.65	45.15	21.45	76.27	119.22	191.85	159.22	107.13	76.17	84.93	136.40	150.76	183.73	0.71	59.38	78.40	88.68	4.29	27.81	148.74	36.23	49.56	3.28	59.48	200.82	106.10	30.03	60.82	65.61	157.22
2001	January	28.02	192.55	79.97	15.27	15.74	42.40	97.36	33.52	28.32	49.08	59.37	78.12	3.12	51.13	67.08	39.78	46.49	44.39	34.67	29.76	48.87	52.14	46.06	49.52	73.21	70.43	41.23	74.25	80.07	40.79	55.03
2001	February	177.66	46.00	33.07	55.28	73.69	58.94	34.74	51.79	82.16	45.82	2.94	29.14	8.42	13.61	93.46	42.69	55.32	48.64	50.17	8.47	112.93	81.50	94.84	190.76	185.01	50.76	50.51	1.07			
2001	March	47.81	1.04	89.73	216.53	183.93	1.35	88.16	64.38	96.56	34.19	58.17	67.90	81.77	48.98	96.93	112.32	102.34	57.90	1.34	92.28	49.03	92.23	51.75	60.14	45.95	28.61	174.55	12.96	156.36	45.15	48.34
2001	April	33.41	73.90	87.64	33.69	36.80	36.01	35.97	15.25	47.76	56.55	29.73	55.62	94.41	55.72	204.25	97.27	68.80	30.06	121.81	92.57	34.74	9.25	9.50	56.84	61.52	100.21	97.19	96.13	34.47	45.94	
2001	May	60.17	96.64	65.78	57.74	206.49	150.03	8.44	211.82	93.02	7.97	64.54	33.45	9.74	186.32	54.48	174.88	172.41	116.75	76.18	2.41	77.93	1.33	64.48	74.25	29.21	2.40	57.97	3.03	155.99	12.79	151.83
2001	June	156.52	218.11	39.06	33.81	48.93	11.00	91.01	3.12	39.43	110.69	115.32	131.63	82.55	29.92	189.14	11.31	58.71	17.75	2.98	113.03	35.49	94.60	65.71	43.70	168.09	76.79	183.79	164.35	41.09	205.57	
2001	July	66.41	11.52	113.46	60.11	62.56	8.87	64.37	11.05	77.39	97.93	210.50	27.93	166.61	49.27	93.23	12.51	95.58	149.51	33.46	90.00	158.79	138.43	218.43	112.30	139.51	17.74	37.74	93.99	66.59	17.37	50.26
2001	August	73.00	62.74	160.13	183.19	217.60	161.12	107.53	57.73	109.43	5.58	97.95	64.94	67.21	32.47	55.07	83.34	46.57	41.86	84.83	148.89	62.62	92.56	41.83	77.66	75.86	32.94	149.31	55.71	162.72	61.62	94.90
2001	September	67.44	89.94	79.54	212.17	95.68	100.81	183.72	145.15	149.61	53.02	28.15	84.19	94.23	109.20	133.82	175.03	162.10	9.35	101.66	111.00	202.74	92.27	66.63	153.33	85.13	95.28	48.13	55.34	50.05	9.71	94.90
2001	October	76.53	197.43	40.18	89.86	48.29	9.14	9.34	44.85	56.12	52.27	39.95	1.33	5.62	46.79	90.82	34.20	5.29	1.06	8.33	58.17	34.30	48.65	87.34	34.94	58.59	92.99	102.11	99.39	96.64	9.23	57.90
2001	November	29.83	42.46	29.49	42.90	7.92	52.91	30.70	142.90	46.37	48.82	47.80	32.77	33.73	34.62	50.67	33.78	47.98	1.29	34.63	35.70	42.48	56.24	65.49	48.93	42.85	1.35	42.44	113.47	29.01	39.91	57.90
2001	December	64.68	205.86	2.40	174.91	173.30	27.55	17.75	18.11	57.59	74.32	113.25	2.30	133.90	135.20	60.50	3.12	48.53	33.53	42.50	47.86	47.02	29.86	52.21	51.14	28.56	91.70	75.00	140.46	57.21	11.47	59.10
2002	January	62.17	84.84	125.32	145.38	182.27	14.16	47.12	70.42	80.91	6.97	19.87	153.18	40.86	53.73	5.47	66.38	204.39	91.75	18.72	54.19	51.88	120.19	6.39	23.78	58.65	56.28	48.00	33.16	189.85	128.83	127.40
2002	February	78.21	58.44	85.97	144.47	179.48	101.29	55.24	26.05	38.44	56.60	158.85	139.29	76.72	4.10	5.00	6.26	42.54	206.18	78.44	44.81	35.21	40.96	97.34	128.54	170.78	54.76	12.30	51.80			
2002	March	9.85	103.43	45.71	86.19	46.29	44.55	60.24	118.55	141.84	7.68	33.78	34.74	2.59	76.63	59.04	60.53	140.62	87.43	43.38	58.74	164.98	117.22	51.07	62.94	30.85	55.28	108.70	139.15	169.65	124.73	43.60
2002	April	50.57	7.77	125.07	181.76	98.80	25.02	4.84	105.34	55.27	121.61	11.73	4.32	64.29	25.65	49.00	176.11	67.15	55.55	4.11	26.74	69.14	151.88	112.88	41.52	34.30	46.27	31.35	145.22	149.05	109.24	
2002	May	87.49	52.56	68.36	27.17	84.80	158.27	81.15	51.23	85.10	129.61	95.59	76.04	50.01	19.77	70.07	68.66	42.10	179.53	116.95	89.30	43.07	32.05	109.33	62.19	126.19	48.15	66.31	21.00	97.94	144.62	184.00
2002	June	128.31	27.71	11.14	15.17	84.20	202.61	15.95	40.83	9.35	2.43	134.80	187.58	169.78	74.24	62.25	9.76	93.55	135.18	192.97	159.52	100.70	44.53	100.07	140.81	142.83	196.97	6.37	40.78	53.87	86.66	
2002	July	1.73	21.41	157.46	41.34	65.64	1.10	68.73	200.04	105.25	26.33	53.83	52.85	148.92	3.46	37.01	72.04	84.37	37.51	42.23	181.07	145.12	140.73	98.29	75.51	99.35	164.44	184.50	106.99	59.66	23.54	41.03
2002	August	99.61	171.21	194.52	124.80	13.77	9.73	1.44	41.04	198.53	109.74	61.38	65.44	88.46	153.65	177.23	144.61	111.95	30.96	59.22	6.93	82.99	39.32	105.60	87.43	34.89	70.87	150.19	199.55	5.14	52.24	69.98
2002	September	0.68	104.95	64.61	66.38	142.90	39.53	36.65	31.85	146.75	133.70	71.77	76.64	47.21	74.78	139.82	204.41	158.77	111.79	28.70	15.17	1.14	112.97	164.60	118.59	31.87	3.65	98.47	53.44	191.61	2.10	
2002	October	0.44	50.58	14.90	35.82	183.19	86.01	113.14	10.22	42.95	82.95	116.06	75.23	32.62	62.81	13.96	104.48	172.45	201.66	92.84	52.33	30.67	51.42	16.55	85.32	112.16	69.64	39.93	29.88	75.87	74.20	64.02
2002	November	50.24	18.87	45.11	44.22	45.12	154.96	140.51	55.81	19.62	43.56	74.16	59.18	125.35	45.38	61.56	13.91	83.67	121.07	160.74	102.17	50.01	45.27	29.72	61.52	195.93	8.33	39.04	6.51	4.36	123.88	
2002	December	168.36	145.33	58.27	52.49	25.32	91.92	123.44	188.09	176.07	99.58	56.24	74.85	111.91	132.17	165.99	0.59	48.62	72.77	94.65	3.68	29.07	155.42	39.70	58.11	3.31	61.86	204.65	110.73	33.33	57.82	55.82
2003	January	69.50	102.78	139.61	142.71	186.64	11.92	45.82	80.53	86.10	7.84	20.71	151.33	42.82	48.10	4.53	62.74	172.21	84.60	17.77	35.46	37.45	121.89	6.56	27.96	67.49	81.18	42.21	38.50	159.99	162.73	151.18
2003	February	109.20	68.89	83.86	157.70	173.09	87.15	58.88	18.86	21.42	59.29	134.66	164.97	92.31	5.45	11.78	7.33	40.26	203.55	120.00	32.48	22.12	57.82	118.22	163.84	149.98	114.94	20.70	62.14			
2003	March	10.93	78.48	32.25	84.18	71.88	24.03	63.38	113.31	205.74	9.72	35.52	32.04	1.85	81.53	59.54	74.63	108.74	28.12	44.54	77.68	137.05	121.22	64.29	84.84	69.43	108.86	144.64	168.63	167.24	94.24	7.94
2003	April	58.87	4.53	92.80	137.85	97.11	8.42	1.09	51.08	52.37	191.11	10.76	4.62	54.15	20.43	29.45	156.64	68.11	36.37	4.60	14.72	92.30	112.14	101.97	33.46	96.50	44.54	101.14	154.08	208.40	120.43	
2003	May	109.64	46.92	37.39	22.68	69.47	89.14	59.78	33.45	75.37	76.40	95.03	75.49	50.88	21.14	54.19	18.75	24.85	152.83	114.71	83.78	16.24	95.31	106.54	38.12	98.06	27.81	6.96	3.54	46.14	122.17	179.24
2003	June	133.27	69.22	58.29	47.42	79.67	203.20	15.90	40.34	8.57	2.74	123.00	194.56	144.62	74.73	41.38	31.12	77.06	135.34	174.50	172.19	113.44	59.32	88.62	118.47	143.68	197.75	6.28	49.29	90.17	92.82	
2003	July	1.85	24.25	147.34	45.09	55.19	1.01	69.72	192.80	93.38	26.59	61.24	59.82	158.33	3.49	36.00	59.89	89.25	48.74	41.38	182.65	165.35	167.26	70.07	0.73	75.32	125.06	140.75	72.44	69.43	23.90	47.47
2003	August	100.30	158.34	199.16	143.43	13.35	6.66	1.24	48.07	191.09	121.05	72.68	74.39	49.85	133.13	136.96	155.41	109.21	30.20	66.61	7.03	97.83	41.53	112.17	51.96	55.82	71.52	135.95	203.27	4.99	52.37	69.87
2003	September	0.69	96.42	64.94	68.53	131.37	67.86	59.55	72.46	172.23	97.65	53.38	52.83	73.47	98.37	142.62	198.35	142.27	129.88	23.78	82.05	1.23	120.22	178.37	118.59	34.40	2.29	47.24	40.68	173.52	2.82	
2003	October	0.72	75.11	29.82	57.16	182.88	93.56	130.15	12.50	21.57	107.55	150.40	110.38	44.82	95.68	23.60	118.25	177.88	198.72	116.66	92.47	35.06	66.97	21.26	115.03	155.78	107.13	58.69	57.38	100.88	89.49	87.83
2003	November	57.76	23.56	32.43	53.84	49.24	172.20	153.58	81.34	30.24	77.79	84.16	62.34	109.21	41.92	49.18	19.62	103.33	113.46	152.91	99.29	46.84	61.31	38.67	65.41	174.54	8.20	39.04	5.76	4.36	121.19	
2003	December	186.53	162.11	66.26	60.29	30.02	94.39	138.39	208.08	169.00	116.33	54.10	74.85	113.16	135.43	195.25	0.69	45.75	86.41	87.72	3.76	26.15	134.28	30.63	45.89	2.80	62.21	190.47	101.99	34.11	58.79	62.49
2004	January	63.04	97.36	139.61	151.08	177.21	12.51	39.02	68.19	76.45	6.97	20.71	135.37	41.87	44.39	5.57	70.64	202.28	102.94	17.77	58.62	56.48	156.94	6.28	28.22	78.92	84.78	32.60	34.05	189.10	146.21	162.43
2004	February	70.25	31.67	52.56	128.26	177.95	120.00	74.15	16.51	25.22	66.78	129.23	139.29	100.37	6.46	13.96	5.17	35.23	175.84	109.18	38.40	61.26	78.78	142.30	180.01	146.57	108.15	32.29	44.35	8.42		
2004	March	70.57	32.77	95.68	46.29	33.59	70.70	158.30	163.33	8.52	48.13	47.82	4.65	98.00	66.48	74.33	145.50	82.02	70.55	75.59	168.91	125.71	55.48	48.27	22.97	47.42	87.43	207.82	122.82	106.30	35.10	79.13
2004	April	7.59	117.02	150.59	97.11	34.04	2.09	93.25	51.42	189.30	8.24	4.04	44.07	16.44	38.82	164.92	68.11	88.83	10.29	47.55	111.94	162.30	102.73	35.74	83.96	43.40	99.82	175.25	175.47	85.05	92.31	40.64
2004	May	40.64	6.97	13.08	75.38	121.83	42.97	7.39	12.77	62.67	86.22	52.97	36.04	7.39	18.82	24.55	43.88	205.38	171.61	95.20	49.71	80.14	95.47	60.01	129.51	48.02	68.04	27.10	125.21	141.22	184.53	138.98
2004	June	76.79	75.65	30.45	87.20	201.87	11.59	21.62	9.15	2.63	145.95	179.00	162.72	73.45	64.00	30.44	92.42	134.47	205.95	182.30	114.74	73.10	104.11	121.75	152.60	157.68	3.21	34.40	79.12	98.42	1.74	
2004	July	21.81	160.61	44.60	55.47	1.12	72.38	176.35	93.38	25.49	53.83	58.73	138.57	3.43	36.54	65.32	90.97	49.98	46.38	189.35	165.35	142.17	108.36	70.95	99.66	145.65	190.81	108.27	69.78	23.90	47.87	99.36
2004	August	166.34	198.71	128.56	12.37	15.35	1.79	45.33	200.81	127.90	72.37	76.76	89.20	153.62	161.65	155.41	114.22	34.81	79.17	7.46	90.03	38.51	94.66	38.67	33.91	77.89	141.36	202.93	5.04	51.34	66.87	0.68
2004	September	105.04	64.70	61.79	128.85	62.82	66.93	66.71	163.39	118.39	71.52	90.92	69.05	106.01	149.18	202.94	177.53	129.99	42.20	86.80	1.18	114.43	157.19	126.92	24.82	2.44	87.66	53.25	200.19	3.10	0.70	
2004	October	77.55	27.30	56.84	191.87	95.86	112.01	10.68	33.63	103.34	145.76	86.84	46.86	61.29	47.21	103.14	112.76	163.68	79.67	67.95	19.54	46.11	13.52	82.90	142.93	58.94	78.94	82.54	115.86	102.81	65.83	40.43
2004	November	13.93	18.88	35.50	35.70	154.96	118.30	66.33	28.27	48.81	76.82	54.73	108.01	40.00	48.11	22.87	123.69	132.92	161.79	118.78	62.18	60.34	39.04	78.44	192.89	9.09	44.47	5.52	3.53	108.93	163.63	
2004	December	140.07	51.41	43.09	19.81	69.26	118.08	183.95	148.46	109.39	76.03	88.18	110.63	152.79	196.41	0.63	51.76	64.82	85.71	4.31	26.56	144.99	41.07	44.91	2.84	54.29	181.79	105.33	28.60	42.32	65.42	133.21
2005	January	64.49	98.65	127.59	135.38	172.96	11.92	43.73	75.47	91.41	7.26	18.60	138.26	40.86	50.65	5.72	76.50	207.77	88.37	24.64	33.13	52.91	156.55	7.34	30.73	70.08	67.04	44.71	32.61	143.77	160.93	138.74
2005	February	110.16	56.40	68.63	166.19	177.95	108.58	76.34	26.50	26.13	55.22	121.48	134.72	85.86	4.10	14.20	6.78	40.01	206.18	76.79	66.32	66.48	86.88	89.24	128.54	111.42	58.79	15.10	44.35			
2005	March	12.02	75.22	38.64	142.01	31.80	14.17	79.29	99.83	129.52	11.38	51.60	43.41	1.85	59.70	54.51	69.28	145.41	77.95	44.54	44.95	164.36	82.42	63.18	37.20	71.70	74.21	114.72	139.15	179.51	46.30	36.75
2005	April	21.48	5.44	127.92	141.69	102.06	37.87	2.20	86.49	59.30	170.56	7.62	3.24	75.21	21.25	35.08	134.95	74.25	70.49	4.36	29.13	107.57	163.08	114.64	32.18	77.83	38.41	97.08	175.25	159.73	110.34	
2005	May	92.03	74.19	69.54	29.25	117.75	157.81	104.87	77.30	73.74	47.60	50.50	49.75	34.91	18.20	5.14	45.42	32.91	154.96	112.43	30.35	13.74	92.56	96.93	48.40	68.19	17.42	5.14	0.68	39.00	112.48	111.46
2005	June	59.34	29.22	47.86	13.19	86.68	201.25	15.94	7.85	4.58	0.74	108.73	192.39	159.49	74.64	61.76	9.76	68.74	84.66	169.22	153.43	115.37	68.11	88.62	139.71	145.16	168.26	7.04	58.08	87.19	72.96	
2005	July	1.87	24.46	160.61	43.75	63.33	1.30	60.95	206.00	110.53	28.71	62.62	59.82	133.26	3.37	36.17	60.84	76.61	43.08	46.29	184.61	140.03	167.34	99.44	73.84	101.04	168.10	151.97	110.94	70.60	26.86	47.06
2005	August	71.44	178.04	167.53	140.49	12.80	13.08	1.75	48.95	201.75	126.66	72.87	72.30	80.40	136.57	175.14	168.71	114.69	35.88	77.01	7.12	97.47	36.27	139.66	92.38	48.65	73.01	153.53	205.49	5.17	35.84	47.62
2005	September	0.46	101.84	62.45	63.85	144.06	89.10	70.49	54.00	88.37	107.99	61.18	66.15	72.58	93.71	130.66	203.86	149.27	130.10	23.02	64.96	1.22	125.14	183.76	93.98	17.97	2.29	91.66	42.85	175.50	2.72	
2005	October	0.60	52.99	26.06	56.95	190.23	94.04	109.67	10.38	45.63	90.73	143.23	87.87	37.25	47.98	25.33	55.02	110.46	163.68	122.70	99.54	74.02	59.19	13.52	82.90	152.98	84.99	29.11	41.68	115.86	79.58	76.51
2005	November	53.88	18.41	25.15	35.50	33.08	150.67	120.52	61.21	24.10	50.49	69.96	63.12	128.54	44.28	45.91	16.57	105.83	126.55	167.60	114.67	66.61	60.34	37.89	71.25	200.48	9.26	41.69	4.73	3.53	127.64	
2005	December	163.80	161.48	52.17	42.03	20.37	82.11	107.90	182.49	153.32	84.08	50.69	72.01	115.57	132.17	165.99	0.61	37.14	62.28	96.10	4.16	26.53	142.89	40.16	48.68	3.57	62.21	194.45	114.77	30.03	63.07	60.43
2006	January	59.40	87.13	125.32	137.63	168.33	12.22	38.17	56.67	71.36	7.15	19.49	144.80	42.82	35.86	6.12	77.54	191.11	88.36	16.77	30.71	31.65	121.89	6.08	30.73	64.56	73.84	29.22	32.61	171.07	163.73	138.52
2006	February	73.54	63.06	86.98	166.73	200.73	118.72	74.44	26.05	45.48	89.19	156.87	194.56	144.21	9.09	13.74	6.68	43.15	180.44	119.50	65.25	63.99	82.75	132.81	160.34	147.41	84.82	14.41	25.01			
2006	March	9.26	85.32	33.78	105.90	65.74	26.30	39.77	145.27	204.76	10.87	48.67	51.83	3.44	66.29	59.58	61.20	93.61	41.08	23.14	53.86	142.95	98.59	51.85	66.36	16.19	51.42	105.49	157.00	143.84	97.48	35.10
2006	April	68.34	7.27	88.56	152.25	78.29	37.76	4.26	64.40	60.29	124.12	6.05	4.69	30.63	7.84	33.31	130.49	76.31	107.46	9.83	27.55	55.32	169.74	80.46	38.19	49.25	46.31	81.25	148.33	124.55	74.68	
2006	May	107.79	35.14	24.12	18.79	105.22	154.02	109.68	76.17	85.41	139.85	97.60	84.27	69.29	9.45	70.71	71.16	29.13	187.37	177.79	103.90	53.93	83.84	111.76	63.81	128.95	45.97	69.99	23.80	123.23	147.23	158.42
2006	June	138.27	73.89	77.90	40.54	84.20	191.89	13.68	40.05	6.60	2.32	144.32	106.45	91.47	30.35	26.46	5.24	77.98	77.43	139.61	150.39	59.10	61.20	105.33	140.87	154.62	184.37	6.91	58.40	86.75	98.13	
2006	July	1.80	21.58	160.60	42.80	54.77	1.19	61.00	191.66	104.12	30.32	64.00	61.65	156.57	3.03	36.35	65.52	90.98	44.12	45.81	188.99	147.67	129.27	100.92	73.74	98.65	155.04	195.10	115.58	69.84	26.43	28.69
2006	August	89.15	174.65	198.21	135.05	12.58	15.54	1.93	42.65	204.83	129.75	57.66	72.44	63.23	152.62	176.33	158.83	58.72	17.77	66.61	7.34	93.13	36.81	145.98	77.70	49.83	68.35	130.74	207.84	5.09	52.08	69.66
2006	September	0.45	94.37	59.57	58.49	102.44	89.23	35.37	63.50	145.28	112.42	71.52	71.75	17.96	93.71	114.92	188.64	154.37	88.47	29.97	38.85	1.11	110.88	160.28	118.59	29.90	4.00	72.74	37.69	147.34	2.58	
2006	October	0.59	32.23	12.15	38.05	127.75	75.50	109.63	7.34	29.70	81.73	141.92	110.08	47.82	78.59	30.12	65.65	125.72	179.49	114.58	97.83	62.27	44.17	21.27	80.39	105.00	64.43	25.78	28.08	71.47	71.90	64.02
2006	November	48.21	17.48	25.15	35.50	33.08	150.67	120.52	61.21	24.10	50.49	69.96	63.12	128.54	44.28	56.83	16.57	99.32	126.55	167.60	114.67	66.61	60.34	37.89	71.25	200.48	9.26	41.69	4.73	3.53	127.64	
2006	December	163.63	165.95	64.63	67.29	12.19	58.37	106.49	185.37	127.35	72.75	59.24	83.79	127.24	122.13	162.62	0.55	35.18	58.24	88.68	3.80	27.55	153.19	36.62	38.58	2.16	52.45	173.90	105.33	27.00	38.26	56.04

Source: Department of Hydrology and Metereology

APPENDIX III: PERCOLATION DATA

Table 1: Percolation (Leachate) from HELP Model

A. Simulations	**Waste FC = 0.292**					
Cover soil HC	E-3	E-3	E-3	E-3	E-3	E-3
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	268	268	268	705	719	719
Ave. Percolation/yr	1293	1293	1293	603	0	0

Cover soil HC	E-4	E-4	E-4	E-4	E-4	E-4
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	275	275	275	704	719	719
Ave. Percolation/yr	1286	1286	1286	603	0	0

Cover soil HC	E-5	E-5	E-5	E-5	E-5	E-5
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	282	282	282	703	719	719
Ave. Percolation/yr	1279	1279	1279	603	0	0

B. Simulations	**Waste FC = 0.2**					
Cover soil HC	E-3	E-3	E-3	E-3	E-3	E-3
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	261	261	261	698	719	719
Ave. Percolation/yr	1290	1290	1290	601	0	0

Cover soil HC	E-4	E-4	E-4	E-4	E-4	E-4
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	268	268	268	698	719	719
Ave. Percolation/yr	1281	1281	1281	601	0	0

Cover soil HC	E-5	E-5	E-5	E-5	E-5	E-5
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	275	275	275	697	719	719
Ave. Percolation/yr	1272	1272	1272	601	0	0

C. Simulations	Waste FC = 0.35					
Cover soil HC	E-3	E-3	E-3	E-3	E-3	E-3
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	259	259	259	704	719	719
Ave. Percolation/yr	1298	1298	1298	603	0	0

Cover soil HC	E-4	E-4	E-4	E-4	E-4	E-4
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	268	268	268	704	719	719
Ave. Percolation/yr	1290	1290	1290	602	0	0

Cover soil HC	E-5	E-5	E-5	E-5	E-5	E-5
Barrier Soil HC	E-4	E-5	E-6	E-7	E-8	E-9
Ave. Rainfall/yr	1553	1553	1553	1553	1553	1553
Ave. Evapotranspiration/yr	274	274	274	703	719	719
Ave. Percolation/yr	1282	1282	1282	602	0	0

Table 2: Extreme Rainfall Events and Corresponding Water Balance: Actual Field Condition of Cover Soil E-4 cm/s, Barrier Soil E-5 cm/s and Field Capacity of Waste 0.292 vol./vol. and HC = 0.001 cm/s

Date	Max Rainfall (mm)	E_T (mm)	Percolation (mm)
2-Aug, 2000	67.2	1.38	7.154
25-Sep, 2001	55	1.09	4.11
23-Jul, 2002	220	1.2	4.247
19-Aug, 2003	86	1.05	8.036
9-Jul, 2004	146	1	5.353
8 August, 2005	123	0.99	3.498
20 July, 2006	57	1.13	7.568
Average	**107.74**	**1.12**	**5.71**

Table 3: Comparison of Percolation Value (REAL AND HELP MODEL)

Date	Rainfall (mm)	Percolation Real/0.785 m^2	Percolation Real (per m^2)	Model (per m^2)
7-Jun	25.00	4.10	5.22	3.77
19-Jun	0.00	6.20	7.90	7.54
25-Jun	2.20	4.50	5.73	4.32
29-Jun	4.20	3.50	4.46	3.74
6-Jul	0.00	1.10	1.40	0.81
11-Aug	0.00	22.00	28.03	13.81
17-Aug	3.00	8.50	10.83	6.15
20-Aug	0.00	7.50	9.55	4.51
29-Aug	7.20	6.00	7.64	2.33
30-Aug	0.00	8.10	10.32	6.40
31-Aug	10.00	5.10	6.50	4.78
1-Sep	0.00	2.50	3.18	3.79
3-Sep	9.20	1.20	1.53	1.34
4-Sep	0.00	5.00	6.37	3.36
7-Sep	0.00	6.10	7.77	4.60
8-Sep	0.00	5.20	6.62	3.22
10-Sep	45.20	10.50	13.38	6.35
11-Sep	20.00	9.50	12.10	5.57
12-Sep	7.20	5.50	7.01	1.17
13-Sep	0.00	14.00	17.83	4.84
15-Sep	0.00	8.00	10.19	1.65
17-Sep	14.00	11.00	14.01	6.20
18-Sep	0.00	14.00	17.83	8.09
19-Sep	0.00	8.00	10.19	6.05
20-Sep	2.00	4.00	5.10	3.08
26-Sep	42.00	9.80	12.48	5.46
27-Sep	11.00	8.50	10.83	5.52
28-Sep	0.00	10.50	13.38	7.76
29-Sep	0.00	10.80	13.76	7.87
30-Sep	0.00	4.00	5.10	3.56
1-Oct	0.00	1.50	1.91	1.31
2-Oct	0.00	5.00	6.37	5.23
3-Oct	0.00	7.00	8.92	7.06
4-Oct	0.00	5.00	6.37	6.68
5-Oct	0.00	10.00	12.74	12.20
6-Oct	0.00	5.00	6.37	6.16
7-Oct	0.00	4.00	5.10	4.76
8-Oct	0.00	3.00	3.82	3.55

9-Oct	15.20	3.00	3.82	3.75
10-Oct	0.00	6.00	7.64	7.75
11-Oct	0.00	4.00	5.10	6.61
12-Oct	6.20	2.00	2.55	2.90
13-Oct	0.00	4.00	5.10	3.56
15-Oct	0.00	1.50	1.91	2.77
18-Oct	0.00	2.00	2.55	2.75
19-Oct	0.00	1.00	1.27	1.77
20-Oct	0.00	2.00	2.55	2.99
21-Oct	0.00	3.50	4.46	3.74
22-Oct	6.20	3.60	4.59	3.91
23-Oct	2.20	4.00	5.10	4.06
24-Oct	0.00	4.10	5.22	4.89
25-Oct	0.00	3.00	3.82	3.53
26-Oct	0.00	2.00	2.55	2.45
27-Oct	0.00	1.80	2.29	1.15
29-Oct	0.00	2.50	3.18	2.13
30-Oct	0.00	3.00	3.82	2.56
31-Oct	0.00	3.50	4.46	3.10
1-Nov	0.00	3.50	4.46	2.98
2-Nov	0.00	4.50	5.73	3.71
3-Nov	0.00	2.50	3.18	2.32
4-Nov	0.00	1.50	1.91	1.24
5-Nov	0.00	1.00	1.27	0.83
6-Nov	0.00	1.00	1.27	0.62
7-Nov	0.00	1.00	1.27	0.49
8-Nov	0.00	1.00	1.27	0.41
9-Nov	0.00	0.50	0.64	0.34
10-Nov	0.00	0.50	0.64	0.30
11-Nov	0.00	0.50	0.64	0.26
12-Nov	0.00	0.50	0.64	0.23
13-Nov	0.00	0.50	0.64	0.21
14-Nov	0.00	0.50	0.64	0.19
15-Nov	0.00	0.50	0.64	0.17
16-Nov	0.00	0.50	0.64	0.16
17-Nov	0.00	0.50	0.64	0.15
18-Nov	0.00	0.50	0.64	0.14
19-Nov	0.00	0.50	0.64	0.13
20-Nov	0.00	0.50	0.64	0.12
21-Nov	0.00	0.50	0.64	0.11
22-Nov	0.00	0.50	0.64	0.11
23-Nov	0.00	0.50	0.64	0.10
24-Nov	0.00	0.10	0.13	0.10
25-Nov	0.00	0.25	0.32	0.09

26-Nov	0.00	0.25	0.32	0.09
27-Nov	0.00	0.25	0.32	0.08
28-Nov	0.00	0.25	0.32	0.08
29-Nov	0.00	0.25	0.32	0.08
30-Nov	0.00	0.25	0.32	0.07
1-Dec	0.00	0.25	0.32	0.07
2-Dec	0.00	0.25	0.32	0.07
3-Dec	0.00	0.25	0.32	0.07
4-Dec	0.00	0.25	0.32	0.06
5-Dec	0.00	0.25	0.32	0.06
6-Dec	0.00	0.25	0.32	0.06
7-Dec	0.00	0.25	0.32	0.06
8-Dec	0.00	0.25	0.32	0.05
9-Dec	0.00	0.25	0.32	0.05
10-Dec	0.00	0.25	0.32	0.05
11-Dec	0.00	0.25	0.32	0.05
12-Dec	20.50	0.25	0.32	0.05
13-Dec	24.00	0.25	0.32	0.03
14-Dec	0.00	0.25	0.32	0.00
15-Dec	0.00	0.25	0.32	0.09
16-Dec	0.00	0.25	0.32	0.07
17-Dec	0.00	0.25	0.32	0.11
18-Dec	0.00	0.25	0.32	0.20
19-Dec	0.00	0.25	0.32	0.02
20-Dec	0.00	0.50	0.64	0.23
21-Dec	0.00	1.50	1.91	0.84
22-Dec	0.00	0.60	0.76	0.36
23-Dec	0.00	2.00	2.55	1.10
24-Dec	0.00	0.50	0.64	0.19
25-Dec	0.00	0.50	0.64	0.00
26-Dec	0.00	0.70	0.89	0.47
27-Dec	0.00	2.50	3.18	1.56
28-Dec	0.00	2.50	3.18	1.95
29-Dec	0.00	4.50	5.73	3.72
30-Dec	0.00	5.10	6.50	3.52
31-Dec	0.00	4.10	5.22	2.96

Table 4: Simulations of Model with respect to Field Capacity and Sat. Hydraulic Conductivity of Waste

Date	FC of Waste (vol./vol.)	0.292	0.2	0.35
	Hydraulic Conductivity of Waste (cm/s)	0.001		
	Rainfall (mm)	Percolation (mm)	Percolation (mm)	Percolation (mm)
7-Jun	25.00	3.771	3.217	0.6929
19-Jun	0.00	7.541	7.829	2.348
25-Jun	2.20	4.318	5.049	1.565
29-Jun	4.20	3.741	2.86	1.067
6-Jul	0.00	0.8101	2.289	0.8621
11-Aug	0.00	13.81	10.72	1.653
17-Aug	3.00	6.152	5.96	1.488
20-Aug	0.00	4.514	6.093	2.083
29-Aug	7.20	2.329	2.686	1.261
30-Aug	0.00	6.397	6.026	2.038
31-Aug	10.00	4.782	4.651	2.458
1-Sep	0.00	3.79	3.553	18.37
2-Sep	9.20	1.344	1.356	1.076
3-Sep	0.00	3.362	3.875	2.326
4-Sep	0.00	4.603	4.444	2.54
5-Sep	0.00	3.222	4.247	1.028
6-Sep	45.20	6.347	4.908	5.253
7-Sep	20.00	5.569	6.328	5.985
8-Sep	7.20	1.169	1.868	13.22
9-Sep	0.00	4.842	4.773	2.078
10-Sep	0.00	1.651	1.213	21.2
11-Sep	14.00	6.198	8.422	1.173
12-Sep	0.00	8.089	8.419	5.487
13-Sep	0.00	6.051	6.009	6.475
14-Sep	2.00	3.077	3.09	6.494
15-Sep	42.00	5.458	5.495	1.769
16-Sep	11.00	5.521	5.562	1.489
17-Sep	0.00	7.757	7.761	1.351
18-Sep	0.00	7.872	7.465	0.5491
19-Sep	0.00	3.562	2.994	16.4
20-Sep	0.00	1.306	0.7268	15.97
21-Sep	0.00	5.225	7.054	3.526
22-Sep	0.00	7.062	7.859	1.517
23-Sep	0.00	6.682	5.966	0.9552
24-Sep	0.00	12.2	8.071	0.5369

25-Sep	0.00	6.163	6.845	4.765
26-Sep	0.00	4.755	5.352	2.941
27-Sep	0.00	3.551	5.06	1.406
28-Sep	15.20	3.754	4.673	0.7737
29-Sep	0.00	7.753	5.014	0.6253
30-Sep	0.00	6.614	8.141	3.338
1-Oct	6.20	2.895	3.012	3.446
2-Oct	0.00	3.562	4.628	2.267
3-Oct	0.00	2.774	2.292	0
4-Oct	0.00	2.753	3.304	1.868
5-Oct	0.00	1.769	2.957	1.09
6-Oct	0.00	2.985	2.892	0.7597
7-Oct	0.00	3.74	2.948	0.5783
8-Oct	6.20	3.914	2.99	0.2436
9-Oct	2.20	4.056	2.663	0.7654
10-Oct	0.00	4.886	3.905	2.296
11-Oct	0.00	3.526	2.555	1.404
12-Oct	0.00	2.449	3.084	1.03
13-Oct	0.00	1.145	2.929	0.7293
14-Oct	0.00	2.131	2.428	0.4518
15-Oct	0.00	2.555	2.34	0.3771
16-Oct	0.00	3.101	2.306	0.3226
17-Oct	0.00	2.984	2.297	0.2812
18-Oct	0.00	3.709	2.294	0.2487
19-Oct	0.00	2.318	2.287	0.2226
20-Oct	0.00	1.235	2.274	0.2011
21-Oct	0.00	0.8306	2.254	0.1832
22-Oct	0.00	0.6199	2.226	0.1681
23-Oct	0.00	0.4913	2.193	0.1551
24-Oct	0.00	0.405	2.155	0.1439
25-Oct	0.00	0.3432	2.115	0.1341
26-Oct	0.00	0.297	2.072	0.1255
27-Oct	0.00	0.2612	2.028	0.1178
28-Oct	0.00	0.2327	1.984	0.111
29-Oct	0.00	0.2095	1.939	0.1049
30-Oct	0.00	0.1902	1.895	9.94E-02
31-Oct	0.00	0.174	1.851	9.43E-02
1-Nov	0.00	0.1602	1.809	8.98E-02
2-Nov	0.00	0.1483	1.767	8.56E-02
3-Nov	0.00	0.138	1.726	8.18E-02
4-Nov	0.00	0.1289	1.686	7.83E-02
5-Nov	0.00	0.1209	1.648	7.50E-02
6-Nov	0.00	0.1137	1.611	7.20E-02
7-Nov	0.00	0.1073	1.574	6.93E-02
8-Nov	0.00	0.1016	1.539	6.67E-02

9-Nov	0.00	9.64E-02	1.506	6.43E-02
10-Nov	0.00	9.16E-02	1.473	6.20E-02
11-Nov	0.00	8.73E-02	1.441	5.99E-02
12-Nov	0.00	8.33E-02	1.411	5.79E-02
13-Nov	0.00	7.97E-02	1.381	5.60E-02
14-Nov	0.00	7.64E-02	1.353	5.43E-02
15-Nov	0.00	7.33E-02	1.325	5.26E-02
16-Nov	0.00	7.04E-02	1.299	5.10E-02
17-Nov	0.00	6.77E-02	1.273	4.96E-02
18-Nov	0.00	6.52E-02	1.248	4.82E-02
19-Nov	0.00	6.29E-02	1.224	4.68E-02
20-Nov	0.00	6.07E-02	1.201	4.56E-02
21-Nov	0.00	5.87E-02	1.178	4.44E-02
22-Nov	0.00	5.68E-02	1.156	4.32E-02
23-Nov	0.00	5.50E-02	1.135	4.21E-02
24-Nov	0.00	5.33E-02	1.115	4.11E-02
25-Nov	0.00	5.17E-02	1.095	4.01E-02
26-Nov	0.00	5.02E-02	1.076	3.91E-02
27-Nov	20.50	4.87E-02	1.043	7.92E-02
28-Nov	24.00	2.51E-02	1.026	0.1496
29-Nov	0.00	0	0.9827	7.08E-02
30-Nov	0.00	9.32E-02	1.053	1.259
1-Dec	0.00	7.00E-02	1.124	0.8519
2-Dec	0.00	0.1132	1.024	2.1
3-Dec	0.00	0.1978	1.17	1.8
4-Dec	0.00	1.65E-02	1.037	0.5869
5-Dec	0.00	0.2256	1.094	2.773
6-Dec	0.00	0.8441	0.9216	3.721
7-Dec	0.00	0.3574	1.03	3.034
8-Dec	0.00	1.097	1.04	1.725
9-Dec	0.00	0.1878	1.031	0.8731
10-Dec	0.00	0	0.9828	0.6564
11-Dec	0.00	0.4702	0.8838	0.5233
12-Dec	0.00	1.562	0.779	0.4334
13-Dec	0.00	1.949	0.6823	0.3689
14-Dec	0.00	3.724	0.5968	0.3204
15-Dec	0.00	3.52	0.5221	0.2826
16-Dec	0.00	2.958	0.457	0.2525
17-Dec	25.00	3.771	3.217	0.6929
18-Dec	0.00	7.541	7.829	2.348
19-Dec	2.20	4.318	5.049	1.565
20-Dec	4.20	3.741	2.86	1.067
21-Dec	0.00	0.8101	2.289	0.8621
22-Dec	0.00	13.81	10.72	1.653
23-Dec	3.00	6.152	5.96	1.488

24-Dec	0.00	4.514	6.093	2.083
25-Dec	7.20	2.329	2.686	1.261
26-Dec	0.00	6.397	6.026	2.038
27-Dec	10.00	4.782	4.651	2.458
28-Dec	0.00	3.79	3.553	18.37
29-Dec	9.20	1.344	1.356	1.076
30-Dec	0.00	3.362	3.875	2.326
31-Dec	0.00	4.603	4.444	2.54

	FC of Waste (vol./vol.)	**0.292**	**0.2**	**0.35**
	Hydraulic Conductivity of Waste (cm/s)	**0.01**		
Date	**Rainfall (mm)**	**Percolation (mm)**	**Percolation (mm)**	**Percolation (mm)**
7-Jun	25.00	0.5125	3.99	0.5123
19-Jun	0.00	1.579	7.703	1.07
25-Jun	2.20	1.261	4.051	0.726
29-Jun	4.20	9.833	4.11	10.43
6-Jul	0.00	0.6321	2.841	0.5471
11-Aug	0.00	0.1959	10.1	3.555
17-Aug	3.00	1.165	6.058	0.8948
20-Aug	0.00	2.078	3.695	2.074
29-Aug	7.20	1.188	3.366	11.12
30-Aug	0.00	15.62	5.922	13.54
31-Aug	10.00	7.872	4.269	2.351
1-Sep	0.00	2.712	2.628	0.9844
2-Sep	9.20	0.2157	2.702	1.79
3-Sep	0.00	2.987	5.663	1.769
4-Sep	0.00	1.724	4.951	0.9759
5-Sep	0.00	0.8142	3.705	0.7077
6-Sep	45.20	15.39	3.677	10.23
7-Sep	20.00	6.674	5.581	6.101
8-Sep	7.20	4.675	1.968	22.07
9-Sep	0.00	19.85	4.504	12.78
10-Sep	0.00	2.999	1.969	1.315
11-Sep	14.00	0	9.959	3.115
12-Sep	0.00	7.328	6.532	9.814
13-Sep	0.00	7.907	6.985	2.946
14-Sep	2.00	2.492	2.481	12.87
15-Sep	42.00	0.9157	5.555	0.9908
16-Sep	11.00	1.637	5.683	11.17
17-Sep	0.00	10.57	8.957	22.31

18-Sep	0.00	21.9	4.895	4.913
19-Sep	0.00	4.367	0.3525	1.397
20-Sep	0.00	1.608	5.908	0.7065
21-Sep	0.00	0.9921	8.58	0.7097
22-Sep	0.00	0.7092	8.058	0.5479
23-Sep	0.00	0.4221	7.17	0.3406
24-Sep	0.00	4.446	7.498	5.005
25-Sep	0.00	2.295	3.998	2.515
26-Sep	0.00	1.571	4.217	1.08
27-Sep	0.00	0.9871	4.084	0.7641
28-Sep	15.20	0.5747	3.931	0.3146
29-Sep	0.00	0.2609	4.144	3.453
30-Sep	0.00	6.33	6.039	3.683
1-Oct	6.20	2.026	3.486	1.451
2-Oct	0.00	1.197	3.406	1.112
3-Oct	0.00	1.189	2.6	1.229
4-Oct	0.00	1.138	2.85	1.034
5-Oct	0.00	0.784	2.389	0.7315
6-Oct	0.00	0.5927	2.332	0.5612
7-Oct	0.00	0.4736	2.459	0.4527
8-Oct	6.20	0.1047	2.687	0.1005
9-Oct	2.20	1.448	2.4	1.413
10-Oct	0.00	1.774	4.034	1.747
11-Oct	0.00	1.015	2.223	1.006
12-Oct	0.00	1.012	2.562	1.006
13-Oct	0.00	0.7198	2.419	0.7166
14-Oct	0.00	0.4479	1.969	0.4466
15-Oct	0.00	0.3744	1.916	0.3734
16-Oct	0.00	0.3206	1.918	0.3199
17-Oct	0.00	0.2796	1.938	0.2791
18-Oct	0.00	0.2474	1.955	0.247
19-Oct	0.00	0.2215	1.961	0.2212
20-Oct	0.00	0.2003	1.953	0.2
21-Oct	0.00	0.1825	1.935	0.1822
22-Oct	0.00	0.1675	1.907	0.1673
23-Oct	0.00	0.1546	1.873	0.1544
24-Oct	0.00	0.1434	1.834	0.1433
25-Oct	0.00	0.1337	1.792	0.1336
26-Oct	0.00	0.1251	1.749	0.125
27-Oct	0.00	0.1175	1.705	0.1174
28-Oct	0.00	0.1107	1.662	0.1106
29-Oct	0.00	0.1046	1.618	0.1045
30-Oct	0.00	9.91E-02	1.576	9.90E-02
31-Oct	0.00	9.41E-02	1.535	9.41E-02
1-Nov	0.00	8.96E-02	1.494	8.95E-02

2-Nov	0.00	8.54E-02	1.455	8.54E-02
3-Nov	0.00	8.16E-02	1.418	8.16E-02
4-Nov	0.00	7.81E-02	1.382	7.81E-02
5-Nov	0.00	7.49E-02	1.347	7.49E-02
6-Nov	0.00	7.19E-02	1.313	7.19E-02
7-Nov	0.00	6.91E-02	1.28	6.91E-02
8-Nov	0.00	6.66E-02	1.249	6.65E-02
9-Nov	0.00	6.41E-02	1.219	6.41E-02
10-Nov	0.00	6.19E-02	1.19	6.19E-02
11-Nov	0.00	5.98E-02	1.163	5.98E-02
12-Nov	0.00	5.78E-02	1.136	5.78E-02
13-Nov	0.00	5.59E-02	1.11	5.59E-02
14-Nov	0.00	5.42E-02	1.086	5.42E-02
15-Nov	0.00	5.25E-02	1.062	5.25E-02
16-Nov	0.00	5.10E-02	1.039	5.10E-02
17-Nov	0.00	4.95E-02	1.052	4.95E-02
18-Nov	0.00	4.81E-02	1.223	4.81E-02
19-Nov	0.00	4.68E-02	0.8964	4.67E-02
20-Nov	0.00	4.55E-02	0.8851	4.55E-02
21-Nov	0.00	4.43E-02	0.8931	4.43E-02
22-Nov	0.00	4.32E-02	0.9048	4.31E-02
23-Nov	0.00	4.21E-02	0.9136	4.21E-02
24-Nov	0.00	4.10E-02	0.9175	4.10E-02
25-Nov	0.00	4.00E-02	0.9163	4.00E-02
26-Nov	0.00	3.91E-02	0.911	3.91E-02
27-Nov	20.50	0.1176	0.8212	0.1176
28-Nov	24.00	0.1467	0.7072	0.1467
29-Nov	0.00	0	1.111	1.272
30-Nov	0.00	1.59	1.051	1.09
1-Dec	0.00	0.5395	1.049	1.88
2-Dec	0.00	2.993	0.9477	1.8
3-Dec	0.00	1.409	1.001	1.065
4-Dec	0.00	2.167	0.9786	2.495
5-Dec	0.00	3.768	0.8734	4.117
6-Dec	0.00	3.316	0.6929	2.484
7-Dec	0.00	1.561	0.7204	1.085
8-Dec	0.00	1.008	0.7091	1.218
9-Dec	0.00	0.737	0.6808	0.695
10-Dec	0.00	0.577	0.6758	0.5513
11-Dec	0.00	0.4719	0.7001	0.4548
12-Dec	0.00	0.3978	0.6547	0.3857
13-Dec	0.00	0.3429	0.5845	0.334
14-Dec	0.00	0.3007	0.5105	0.2939
15-Dec	0.00	0.2673	0.4391	0.2619
16-Dec	0.00	0.2402	0.3717	0.2359

17-Dec	25.00	0.5125	3.99	0.5123
18-Dec	0.00	1.579	7.703	1.07
19-Dec	2.20	1.261	4.051	0.726
20-Dec	4.20	9.833	4.11	10.43
21-Dec	0.00	0.6321	2.841	0.5471
22-Dec	0.00	0.1959	10.1	3.555
23-Dec	3.00	1.165	6.058	0.8948
24-Dec	0.00	2.078	3.695	2.074
25-Dec	7.20	1.188	3.366	11.12
26-Dec	0.00	15.62	5.922	13.54
27-Dec	10.00	7.872	4.269	2.351
28-Dec	0.00	2.712	2.628	0.9844
29-Dec	9.20	0.2157	2.702	1.79
30-Dec	0.00	2.987	5.663	1.769
31-Dec	0.00	1.724	4.951	0.9759

	FC of Waste (vol./vol.)	**0.292**	**0.2**	**0.35**
	Hydraulic Conductivity of Waste (cm/s)	**0.1**		
Date	**Rainfall (mm)**	**Percolation (mm)**	**Percolation (mm)**	**Percolation (mm)**
7-Jun	25.00	0.5123	4.336	0.5123
19-Jun	0.00	1.07	6.639	1.07
25-Jun	2.20	0.726	2.586	0.726
29-Jun	4.20	10.43	1.217	10.43
6-Jul	0.00	0.5471	4.016	0.5471
11-Aug	0.00	3.555	8.779	3.555
17-Aug	3.00	0.8948	4.497	0.8948
20-Aug	0.00	2.074	4.517	2.074
29-Aug	7.20	11.12	4.481	11.12
30-Aug	0.00	13.54	4.844	13.54
31-Aug	10.00	2.351	3.429	2.351
1-Sep	0.00	0.9844	1.012	0.9844
2-Sep	9.20	1.79	7.036	1.79
3-Sep	0.00	1.769	5.795	1.769
4-Sep	0.00	0.9759	3.356	0.9759
5-Sep	0.00	0.7077	2.986	0.7077
6-Sep	45.20	10.23	3.915	10.23
7-Sep	20.00	6.101	4.864	6.101
8-Sep	7.20	22.07	3.074	22.07
9-Sep	0.00	12.78	3.798	12.78
10-Sep	0.00	1.315	14.21	1.315

11-Sep	14.00	3.115	11.75	3.115
12-Sep	0.00	9.814	7.308	9.814
13-Sep	0.00	2.946	4.822	2.946
14-Sep	2.00	12.87	3.469	12.87
15-Sep	42.00	0.9908	5.622	0.9908
16-Sep	11.00	11.17	6.392	11.17
17-Sep	0.00	22.31	6.975	22.31
18-Sep	0.00	4.913	2.642	4.913
19-Sep	0.00	1.397	3.138	1.397
20-Sep	0.00	0.7065	9.663	0.7065
21-Sep	0.00	0.7097	8.343	0.7097
22-Sep	0.00	0.5479	7.899	0.5479
23-Sep	0.00	0.3406	6.915	0.3406
24-Sep	0.00	5.005	6.942	5.005
25-Sep	0.00	2.515	3.945	2.515
26-Sep	0.00	1.08	2.231	1.08
27-Sep	0.00	0.7641	2.273	0.7641
28-Sep	15.20	0.3146	1.811	0.3146
29-Sep	0.00	3.453	3.852	3.453
30-Sep	0.00	3.683	5.226	3.683
1-Oct	6.20	1.451	2.999	1.451
2-Oct	0.00	1.112	1.91	1.112
3-Oct	0.00	1.229	1.39	1.229
4-Oct	0.00	1.034	2.357	1.034
5-Oct	0.00	0.7315	1.375	0.7315
6-Oct	0.00	0.5612	1.333	0.5612
7-Oct	0.00	0.4527	2.597	0.4527
8-Oct	6.20	0.1005	3.042	0.1005
9-Oct	2.20	1.413	3.154	1.413
10-Oct	0.00	1.747	3.189	1.747
11-Oct	0.00	1.006	2.975	1.006
12-Oct	0.00	1.006	1.971	1.006
13-Oct	0.00	0.7166	1.645	0.7166
14-Oct	0.00	0.4466	0.8465	0.4466
15-Oct	0.00	0.3734	1.517	0.3734
16-Oct	0.00	0.3199	1.927	0.3199
17-Oct	0.00	0.2791	2.048	0.2791
18-Oct	0.00	0.247	1.795	0.247
19-Oct	0.00	0.2212	2.483	0.2212
20-Oct	0.00	0.2	2.594	0.2
21-Oct	0.00	0.1822	2.099	0.1822
22-Oct	0.00	0.1673	1.168	0.1673
23-Oct	0.00	0.1544	0.7984	0.1544
24-Oct	0.00	0.1433	0.6012	0.1433
25-Oct	0.00	0.1336	0.4791	0.1336

26-Oct	0.00	0.125	0.3965	0.125
27-Oct	0.00	0.1174	0.337	0.1174
28-Oct	0.00	0.1106	0.2922	0.1106
29-Oct	0.00	0.1045	0.2574	0.1045
30-Oct	0.00	9.90E-02	0.2296	9.90E-02
31-Oct	0.00	9.41E-02	0.207	9.41E-02
1-Nov	0.00	8.95E-02	0.1881	8.95E-02
2-Nov	0.00	8.54E-02	0.1723	8.54E-02
3-Nov	0.00	8.16E-02	0.1587	8.16E-02
4-Nov	0.00	7.81E-02	0.147	7.81E-02
5-Nov	0.00	7.49E-02	0.1368	7.49E-02
6-Nov	0.00	7.19E-02	0.1279	7.19E-02
7-Nov	0.00	6.91E-02	0.12	6.91E-02
8-Nov	0.00	6.65E-02	0.1129	6.65E-02
9-Nov	0.00	6.41E-02	0.1066	6.41E-02
10-Nov	0.00	6.19E-02	0.1009	6.19E-02
11-Nov	0.00	5.98E-02	9.58E-02	5.98E-02
12-Nov	0.00	5.78E-02	9.11E-02	5.78E-02
13-Nov	0.00	5.59E-02	8.68E-02	5.59E-02
14-Nov	0.00	5.42E-02	8.29E-02	5.42E-02
15-Nov	0.00	5.25E-02	7.93E-02	5.25E-02
16-Nov	0.00	5.10E-02	7.60E-02	5.10E-02
17-Nov	0.00	4.95E-02	7.29E-02	4.95E-02
18-Nov	0.00	4.81E-02	7.01E-02	4.81E-02
19-Nov	0.00	4.67E-02	6.74E-02	4.67E-02
20-Nov	0.00	4.55E-02	6.49E-02	4.55E-02
21-Nov	0.00	4.43E-02	6.26E-02	4.43E-02
22-Nov	0.00	4.31E-02	6.05E-02	4.31E-02
23-Nov	0.00	4.21E-02	5.85E-02	4.21E-02
24-Nov	0.00	4.10E-02	5.66E-02	4.10E-02
25-Nov	0.00	4.00E-02	5.48E-02	4.00E-02
26-Nov	0.00	3.91E-02	5.31E-02	3.91E-02
27-Nov	20.50	0.1176	5.15E-02	0.1176
28-Nov	24.00	0.1467	3.02E-02	0.1467
29-Nov	0.00	1.272	1.36E-02	1.272
30-Nov	0.00	1.09	8.85E-02	1.09
1-Dec	0.00	1.88	2.19E-02	1.88
2-Dec	0.00	1.8	7.43E-02	1.8
3-Dec	0.00	1.065	0	1.065
4-Dec	0.00	2.495	7.19E-02	2.495
5-Dec	0.00	4.117	0.1096	4.117
6-Dec	0.00	2.484	0.1425	2.484
7-Dec	0.00	1.085	5.42E-02	1.085
8-Dec	0.00	1.218	0.1609	1.218
9-Dec	0.00	0.695	0.2606	0.695

10-Dec	0.00	0.5513	0	0.5513
11-Dec	0.00	0.4548	0	0.4548
12-Dec	0.00	0.3857	0.1424	0.3857
13-Dec	0.00	0.334	1.47	0.334
14-Dec	0.00	0.2939	2.168	0.2939
15-Dec	0.00	0.2619	2.264	0.2619
16-Dec	0.00	0.2359	2.19	0.2359
17-Dec	25.00	0.5123	4.336	0.5123
18-Dec	0.00	1.07	6.639	1.07
19-Dec	2.20	0.726	2.586	0.726
20-Dec	4.20	10.43	1.217	10.43
21-Dec	0.00	0.5471	4.016	0.5471
22-Dec	0.00	3.555	8.779	3.555
23-Dec	3.00	0.8948	4.497	0.8948
24-Dec	0.00	2.074	4.517	2.074
25-Dec	7.20	11.12	4.481	11.12
26-Dec	0.00	13.54	4.844	13.54
27-Dec	10.00	2.351	3.429	2.351
28-Dec	0.00	0.9844	1.012	0.9844
29-Dec	9.20	1.79	7.036	1.79
30-Dec	0.00	1.769	5.795	1.769
31-Dec	0.00	0.9759	3.356	0.9759

Table 5: Average Annual Rainfall, E_T and Percolation

Year	Rain	Runoff	E_T	Leak or Percolation
2000	1508.60	0.00	238.52	1288.58
2001	1462.40	0.00	260.12	1213.02
2002	2228.00	0.00	343.87	1911.99
2003	1778.80	0.00	300.03	1449.06
2004	1417.80	0.00	269.64	1177.84
2005	1242.40	0.00	202.30	1033.74
2006	1232.30	0.00	263.29	960.49
Average Annual Rainfall	**1552.90**	**0.00**	**268.25**	**1290.67**

Table 6: Average Monthly Rainfall, E_T and Percolation

Average (2000-2006)			
Months	**Rainfall (mm)**	**Evapotranspiration (mm)**	**Percolation (mm)**
January	21.31	4.99	2.69
February	20.87	6.54	16.28
March	31.10	8.89	18.57
April	66.89	18.49	28.32
May	154.07	44.17	71.56
June	211.89	55.56	125.40
July	411.20	34.70	285.50
August	386.46	33.60	372.26
September	195.50	30.41	226.62
October	42.46	17.22	123.31
November	1.03	0.22	20.28
December	10.13	1.86	4.38
Total	**1552.91**	**256.65**	**1295.17**