INFILTRATION CHARACTERISTICS OF TROPICAL SOILS AT UTP CAMPUS

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Infiltration Characteristics of Tropical Soils at University Technology PETRONAS Campus

by

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CERTIFICATION OF APPROVAL

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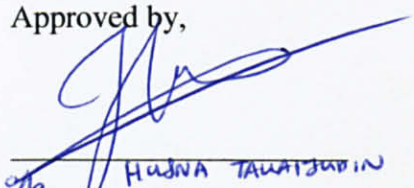

(AP Rezaur R.B)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

MOHD FARHAN B MOHD PATANI

ABSTRACT

This study is chosen by the author is to examine the relationship between rainfall amount and settlement in University Technology Petronas (UTP), Tronoh, Perak. The settlement had occurred near student residential college, Blok K which caused a small hole on the road. The incident is said that caused by the heavy rainfall. This study is done to propose an investigation to find out the effect of rainfall to the ground settlement in UTP. This is study also to suggest the method to proceed with the investigation. From the result of this study at the end of this project, hopefully it will be useful to others in solving settlement problem and come out with other solution in order to avoid ground settlement in future. The result shows that the significant variation of soil infiltration exists in the area of studied. Larger range and the lower sill indicates that the soil infiltration are spatially dependent over long distance (large range) and the variability is low (indicates by low sill). Land disturbance and land topographic conditions contribute to the variability of soil infiltration.

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LIST OF ABBREVIATIONS

GS+ Software	Gamma Design Software, Plainwell, MI, USA
UTP	University Technology Petronas

CHAPTER 1

INTRODUCTION

1.1 Background of study

Soil is a natural body consisting of layers (soil horizons) of mineral constituents of variable thicknesses, which differ from the parent materials in their morphological, physical, chemical, and mineralogical characteristics. It is composed of particles of broken rock that have been altered by chemical and environmental processes that include weathering and erosion. Soil differs from its parent rock due to interactions between the lithosphere, hydrosphere, atmosphere, and the biosphere. It is a mixture of mineral and organic constituents that are in solid, gaseous and aqueous states. Soil particles pack loosely, forming a soil structure filled with pore spaces. These pores contain soil solution (liquid) and air (gas). Accordingly, soils are often treated as a three state system. Most soils have a density between 1 and 2 g/cm^3. Soil is also known as earth: it is the substance from which our planet takes its name. Little of the soil composition of planet Earth is older than Tertiary and most no older than Pleistocene. In engineering, soil is referred to as regolith, or loose rock material (Wikipedia,2009).

Soil hydraulic (infiltration) characteristic vary spatially and temporally from a field scale to a large regional scale and are influenced by both intrinsic (e.g: soil formation process, composition of parent rocks, soil organisms) and extrinsic factors (e.g: regional climate, vegetations, soil management practices, fertilization and etc.). Spatial variability

causes difficulty in representing a soil with a deterministic or precisely defined set of characteristic and precludes characterization of soil hydrological response. One of the major issues in distributed parameter hydrological modeling is how to estimate attributes of spatially varying soil nutrients (Wikipedia,2009).

1.2 Problem Statement

Few pollutants ever disappear from the urban landscape. They are merely transferred from one medium to another: from air to land, from land to surface water, or from soil to groundwater. This last interaction is of great interest when it comes to the infiltration of urban storm water (Robert Pit, 2009).

Infiltration is used as a technique to treat both the quality and quantity of urban runoff. It diverts runoff back into the ground in an attempt to replicate the normal hydrological cycle, whereby most rainfall infiltrates into the soil. Infiltrating runoff, rather than rainfall, can create some risks, particularly since runoff is likely to have picked up pollutants along the way (Robert Pit, 2009).

1.3 Significant of Project

This proposed project will allow understanding and characterization of small scale spatial variability nature of infiltration characteristics of tropical soil at University Technology Petronas (UTP) campus area. Besides, it can evaluate the effect of land use that affect on the variability of infiltration characteristic in the study area. The significant of this project is it is important in land management practices are the result of the variability of soil infiltration are due to topographic features and land disturbances.

1.4 Objectives

The objectives of this study are:

i. To characterize spatial structure of infiltration characteristic of soil under tropical climate in terms of semivariogram parameters
ii. To map the variation in soil hydraulic characteristic in the study area
iii. To evaluate the effect of land use changes on the variability of infiltration characteristics

1.5 Scope of Study

The scope of study is to determine the inconsistency of infiltration characteristic of soil hydraulic properties inside UTP campus area. The double-ring infiltrometer test is often used for measuring infiltration rates, and has been described by ASTM D3385. These references contain standard guidelines for conducting double-ring infiltration tests; however, in practice a wide variety of testing methodologies are used. The statistics and geo-statistic characterization of the data was performed and the Kriging method is used for mapping the contour mapping of the ensample area as the result of the spatial variability of the infiltration.

1.6 Relevancy of the project

This study will identify the geo-statistic analysis in campus area which could reveal the spatial variability nature of soil infiltration and causes in the variability. From the 50 samples taken, the spatial variability in campus area can be determined. The samples are

taken from different area which is undisturbed and disturbed area. Disturbed area is the area where there are buildings and parking area while undisturbed area is the forest area. This will give the variability in infiltration in the area.

1.7 Feasibility of the project within the scope and time frame

There are 50 samples is taken from campus area. This will make sure that the data is feasible and not too many untested area and time wasting occurred. By taking 50 samples, the inconsistencies in the result between each geo-grid sample can be avoided. Actually, the more samples taken from UTP campus area, it will provide more accurate samples but due to limited time that the author have, 50 samples is a time consuming, as 1 point required 4 hours for the site work to be done, and in a week it is only 5 days, so in a week it can finished only 3 to 4 samples.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

Infiltration is the process by which water on the ground surface enters the soil. Infiltration rate (IR) in soil science is a measure of the rate at which soil is able to absorb rainfall or irrigation. It is measured in inches per hour or millimeters per hour. The rate decreases as the soil becomes saturated. If the precipitation rate exceeds the infiltration rate, runoff will usually occur unless there is some physical barrier. It is related to the saturated hydraulic conductivity of the near-surface soil. The rate of infiltration can be measured using an infiltrometer (Wikipedia,2009).

Infiltration is governed by two forces: gravity and capillary action. While smaller pores offer greater resistance to gravity, very small pores pull water through capillary action in addition to and even against the force of gravity (Wikipedia,2009).

The rate of infiltration is affected by soil characteristics including ease of entry, storage capacity, and transmission rate through the soil. The soil texture and structure, vegetation types and cover, water content of the soil, soil temperature, and rainfall intensity all play a role in controlling infiltration rate and capacity. For example, coarse-grained sandy soils have large spaces between each grain and allow water to infiltrate

quickly. Vegetation creates more porous soils by both protecting the soil from pounding rainfall, which can close natural gaps between soil particles, and loosening soil through root action. This is why forested areas have the highest infiltration rates of any vegetative types (Wikipedia, 2009).

The top layer of leaf litter that is not decomposed protects the soil from the pounding action of rain, without this the soil can become far less permeable. In chaparrals vegetated areas, the hydrophobic oils in the succulent leaves can be spread over the soil surface with fire, creating large areas of hydrophobic soil. Other conditions that can lower infiltration rates or block them include dry plant litter that resists re-wetting, or frost. If soil is saturated at the time of an intense freezing period, the soil can become a concrete frost on which almost no infiltration would occur. Over an entire watershed, there are likely to be gaps in the concrete frost or hydrophobic soil where water can infiltrate. Once water has infiltrated the soil it remains in the soil, percolates down to the ground water table, or becomes part of the subsurface runoff process (Wikipedia, 2009).

The process of infiltration can continue only if there is room available for additional water at the soil surface. The available volume for additional water in the soil depends on the porosity of the soil and the rate at which previously infiltrated water can move away from the surface through the soil. The maximum rate that water can enter a soil in a given condition is the infiltration capacity. If the arrival of the water at the soil surface is less than the infiltration capacity, all of the water will infiltrate. If rainfall intensity at the soil surface occurs at a rate that exceeds the infiltration capacity, pounding begins and is followed by runoff over the ground surface, once depression storage is filled. This runoff is called Horton overland flow. The entire hydrologic system of a watershed is sometimes analyzed using hydrology transport models, mathematical models that consider infiltration, runoff and channel flow to predict river flow rates and stream water quality (Wikipedia,2009).

2.1 Kriging Method

Kriging is a group of geostatistical techniques to interpolate the value of a random field (e.g., the elevation, z, of the landscape as a function of the geographic location) at an unobserved location from observations of its value at nearby locations(Wikipedia,2009).

In kriging, the weight is based not only on the distance between the measured points and the prediction location, but also on the overall spatial arrangement among the measured points and their values. To use the spatial arrangement in the weights, the spatial autocorrelation must be quantified. Thus in the Ordinary Kriging, the weight, λ_i, depends on a fitted model to be measured points, the distance to the prediction location, and the spatial relationships among the measured values around the prediction location.

To make the prediction with kriging, two tasks are necessary which are to uncover the dependency rules and to make the predictions. In order to realize these two tasks, Kriging goes through a two-step process which are variograms and covariance function are created to estimate the statistical dependence called spatial autocorrelation model and the prediction of unknown values are made. It is because of these two distinct tasks that it has been said that Kriging uses the data twice. The first time is to estimate the spatial autocorrelation of the data and the second time to make the predictions.

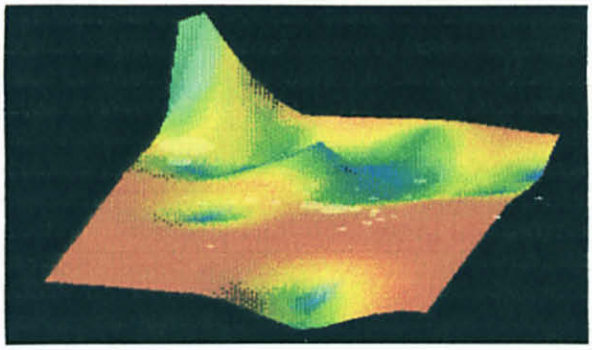

Figure 1: Kriging interpolation in random field

From the geological point of view, the practice of kriging is based on assuming continued mineralization between measured values. Assuming prior knowledge encapsulates how minerals co-occur as a function of space. Then, given an ordered set of measured grades, interpolation by kriging predicts mineral concentrations at unobserved points.

2.2 Statistical Analysis

Statistics is the science of making effective use of numerical data relating to groups of individuals or experiments. It deals with all aspects of this, including not only the collection, analysis and interpretation of such data, but also the planning of the collection of data, in terms of the design of surveys and experiments (Best Joel, 2001). Statistics is considered by some to be a mathematical science pertaining to the collection, analysis, interpretation or explanation, and presentation of data, while others consider it to be a branch of mathematics concerned with collecting and interpreting data. Because of its empirical roots and its focus on applications, statistics is usually considered to be a distinct mathematical science rather than a branch of mathematics.

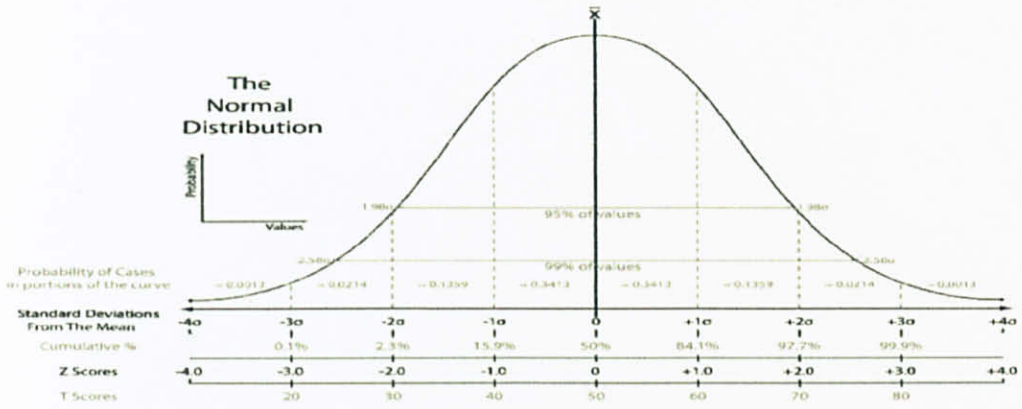

Figure 2: Normal Distribution graph for normal statistic

Statisticians improve the quality of data with the design of experiments and survey sampling. Statistics also provides tools for prediction and forecasting using data and statistical models. Statistics is applicable to a wide variety of academic disciplines, including natural and social sciences, government, and business.

Statistical methods can be used to summarize or describe a collection of data; this is called descriptive statistics. This is useful in research, when communicating the results of experiments. In addition, patterns in the data may be modeled in a way that accounts for randomness and uncertainty in the observations, and are then used to draw inferences about the process or population being studied; this is called inferential statistics. Inference is a vital element of scientific advance, since it provides a prediction (based in data) for where a theory logically leads. To further prove the guiding theory, these predictions are tested as well, as part of the scientific method. If the inference holds true, then the descriptive statistics of the new data increase the soundness of that hypothesis. Descriptive statistics and inferential statistics (a.k.a., predictive statistics) together comprise applied statistics (Tijms Henk,2009).

From statistical analysis, the general statistical parameter in calculated includes the maximum, minimum, mean, median, standard deviation and also coefficient of variation. Mean can be defines as the average of a numerical set which is found by dividing the sum of a set of numbers by the number of members in the group. Median can be defined as the value of a numerical set that equally divides the number of values that is larger and smaller. For example, in a set containing nine numbers, the median would be the fifth number. Standard deviation can be defined as a number representing the degree of variation within a numerical set.

2.2 Geo-statistical analysis

Geostatistics is a branch of applied statistics developed by George Matheron of the Centre de Morophologie Mathematicque in Fontainebleau, France. The original purpose of geostatistics centered on estimating changes in ore grade within a mine. However, the principles have been applied to a variety of areas in geology and other scientific disciplines. A unique aspect of geostatistics is the use of regionalized variables which are variables that fall between random variables and completely deterministic variables.

Regionalized variables describe phenomena with geographical distribution (e.g. elevation of ground surface).The phenomenon exhibit spatial continuity; however, it is not always possible to sample every location. Therefore, unknown values must be estimated from data taken at specific locations that can be sampled. The size, shape, orientation, and spatial arrangement of the sample locations are termed the support and influence the capability to predict the unknown samples. If any of these characteristics change, then the unknown values will change. The sampling and estimating of

regionalized variables are done so that a pattern of variation in the phenomenon under investigation can be mapped such as a contour map for a geographical region.

2.3 Semivariance

Semivariance is a measure of the degree of spatial dependence between samples. The magnitude of the semivariance between points depends on the distance between the points. A smaller distance yields a smaller semivariance and a larger distance results in a larger semivariance. The plot of the semivariances as a function of distance from a point is referred to as a semivariogram. The semivariance increases as the distance increases until at a certain distance away from a point the semivariance will equal the variance around the average value, and will therefore no longer increase, causing a flat region to occur on the semivariogram called a sill. From the point of interest to the distance where the flat region begins is termed the range or span of the regionalized variable. Within this range, locations are related to each other, and all known samples contained in this region, also referred to as the neighborhood, must be considered when estimating the unknown point of interest (Danny Dorsel & Timothy LaBreache,2004).

The center of the neighborhood is usually the unknown value. In order to determine this value, all known values within the neighborhood are assigned weights using the semivariogram. These weights and known values are then used to calculate the unknown value. Problems with this method arise when the regionalized variable is not stationary, but changes its average value from location to location. Defining a neighborhood and assigning weights becomes impossible. Therefore, the regionalized variable is divided into two parts, the residual and the drift. The drift is the weighted average of points within the neighborhood around the unknown value. The residual is

the difference between the regionalized variable and the drift (Danny Dorsel & Timothy LaBreche,2004).

This residual then becomes a regionalized variable in itself which is stationary, and thereby, allowing a semivariogram to be made. However, once again the problem of not being able to define a neighborhood arises. Therefore, an arbitrary neighborhood is chosen from which a drift can be calculated. The calculation includes the points within the assumed neighborhood and a corresponding coefficient for each point which will be explained in more detail in the kriging section. The only variable left in the calculation is the semivariance; however, no semivariograms exist from which to obtain the semivariances. Therefore, a reasonable semivariogram is assumed and compared to the resultant residual semivariogram. If the two are the same, then the assumptions made about the neighborhood and semivariogram are correct, and the unknown value can be determined. If they differ, then another semivariogram must be used as an assumption until they are the same (Danny Dorsel & Timothy LaBreache,2004).

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In studying the spatial structure of infiltration, soil hydraulic characteristic (infiltration) within UTP campus area will be examined. There are three steps involved which include:

1. Preparation of the geo-grid for sampling of at least 50 different points. Determine the coordinates of the location the soil sample will taken by GPS.
2. Conducting the Double-ring Infiltrometer Test to determine the infiltration value for different soil sample which is taken from the different locations in UTP campus area.
3. Digitizing Software use to digitize the boundary map of the study area. Computer analysis of the soil infiltration data to examine the spatial variability of the infiltration, to quantity the spatial correlation in the data in terms of the semivariogram parameters, and to prepare spatial distribution maps of the infiltration by using the statistical and geo-statistical method from the GS+ and Surfer software. Use Kriging method for interpolation of the untested area.

3.2 GPS (Global Positioning System)

GPS device as shown in below figure has been installed in 2 locations. This will act as the reference point to determine the other longitude and latitude points. In setting the device, the procedure below:

1. Switch on the device by press the 'on' button
2. Prepare the device (wait for a while)
3. Set the device to show the longitude and latitude of the current location.
4. Place the device onto the desire location and leave it for 2 to 3 minutes.
5. After that, read the reading shown in the device and record the measurement.
6. Press the 'off' button to switch off the device.

Figure 3 : Reference Point

3.3 Mapping

The study area was conducted in the University Technology of Petronas (UTP) campus area as shown in the figure above, located in Tronoh. The study area is in the west part of Perak. The soil is under tropical climate. It lies on latitude 4° 23.01' 30'' N and 100° 58' 41'' E. It is about 19 kilometers from Batu Gajah town. The campus is divided into two regions which is undisturbed area where all the tree and forest are still remaining. The other region is disturbed area which consists of academic block, administration blocks, hostel and all the infrastructures.

3.4 Geo-grid sampling location

The geo-grid sampling method was used for this study on the premise that grid-sampling reduces the possibility of uneven samples. First, take the map of UTP from google earth. The map consists of all the building, road and pavement, trees, contours and also boundaries of UTP. Then the campus area from the map is divided by a number of regular geo-grids by using the Photoshop software. There will be two reference points that taken by GPS as the reference to make the geo-grid as shown in above map. One of the reference point lies on latitude 4° 23' 0'' N and 100° 58' 10'' which is near the Chancellor hall which is Block I (black grid) while the point near the block 13 lies on latitude 4° 22' 52'' and 100° 57' 51''. The location for each soil sample collection points will be marked based on the intersection of grid lines. 50 points will be chosen from the generated campus map for soil sample testing.

Soil sample will were collected at each-grid node. The sampling location which fell on paved area or on building or where the sampling location was inaccessible was omitted. If sample location fell at the corner of the building, the samples were collected from the adjacent ground.

During field sampling, the grid nodes were located by the GPS (Global Positioning System). Fifty soil samples were collected around the UTP campus. For infiltration, it will be tested on site. Each point will take 2 hours for the experiment.

Infiltration procedure

This procedure is taken from ASTM D3385. This double ring method is a simple method to determine infiltration rate of a fluid into soil on the tested surface.

1. Driving infiltration ring
    i. Place driving cap on outer ring. Place plywood on the driving cap
    ii. Drive the ring into the ground using evenly distributed blows until a depth of 4"-6" is reached
    iii. Ensure the ring is level
    iv. Using the above steps, center inner ring within outer ring and drive to a depth 2"-4"
    v. Secure the level float valves in the clamps of the appropriate space. The nipples on the valves should point up.

2. Tamping Disturbed Soil

   i. Tamp soil (using tamp provided or foot) in order to restore soil to original firmness

   ii. If the soil has been excessively disturbed, re-drive rings in a new area

   iii. If the firmness is adequate, no tamping is required

3. Driving The Mounting All-Thread

   i. Using sledge, drive driving rod into the ground up to the level mark. Ensure that the end of the driving rod sticking up out of the ground is the deformed end.

   ii. Remove the driving rod and place the mounting all thread into the hole. Using a wood block and sledge, drive the all-thread 2"-3" into the ground.

   iii. Ensure the mounting all-thread is level. Tamp soil around the all-thread

4. Securing Graduated Cylinder Assembly and Tubing

   i. Screw the graduated cylinder assembly onto the mounting all-thread until secure.

   ii. Turn assembly until valves at bottom of assembly face the driven rings

   iii. Connect one tube to nipple at the end of the valves at the bottom of the smaller graduated cylinder.

   iv. Connect other end of tube to nipple at the top of the level valve in the smaller ring. Make sure to pass the tube through one hole in the side wall of the outer ring and the hole in the side wall of the inner ring.

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   ii. Remove the driving rod and place the mounting all thread into the hole. Using a wood block and sledge, drive the all-thread 2"-3" into the ground.

   iii. Ensure the mounting all-thread is level. Tamp soil around the all-thread

4. Securing Graduated Cylinder Assembly and Tubing

   i. Screw the graduated cylinder assembly onto the mounting all-thread until secure.

   ii. Turn assembly until valves at bottom of assembly face the driven rings

   iii. Connect one tube to nipple at the end of the valves at the bottom of the smaller graduated cylinder.

   iv. Connect other end of tube to nipple at the top of the level valve in the smaller ring. Make sure to pass the tube through one hole in the side wall of the outer ring and the hole in the side wall of the inner ring.

v. Follow step iii and iv, for other tube, connecting it to larger graduated cylinder and the flow valve in the annular space.

5. Maintaining Liquid Level

i. Close both valves at the bottom of the graduated cylinders before adding any water.

ii. Fill both cylinder with water

iii. Open the flow valves until the tubes have started to discharge in the rings.

iv. Close valves

v. Fill both cylinders to the zero level. Record this on the data sheet

vi. Place splash guards in the spaces and fill with water until the floating level stop rising. If the floats are not even, raise the lower float by adjusting the PVC and clamp. Refill the space with lower float until it stops again. Repeat until floats are level

vii. Open valves and start timer

The procedure above is the standard procedure for the Double-ring Infiltration Test. Since in Geotechnical Lab in UTP did not have full equipment for the test, the author has used double-ring infiltrometer which has been fabricated by other student a few years back. Below is the procedure that has been used by the author to run the experiment.

1. Clear the tested area from any vegetation and dig a hole about 25 cm into the ground.
2. Tamp the area to restore it to the original firmness.
3. Place the double-ring infiltrometer at the tested area.

4. Make sure that the infiltrometer and the soil do not have any gap
5. If there are any gap, use rubber mallet to knock the infiltrometer until the gap is no longer exist
6. Fill the double ring infiltrometer with water
7. Take the measurement for every 15 minutes for two hours
8. Record the data

3.5 Statistical Analysis

Statistical analysis was used for this project to analyze results of infiltration rate measurements on soil infiltration characteristics. The analysis involves the process of collecting and analyzing data and after that summarizing the data into a numerical form. All of the data for all 50 soil samples location will shows the variation in each different point as the soil infiltration characteristics of each point are different with another which making it difficult to identify the parameters. The maximum, minimum, mean, standard deviation and coefficient of variation for all 50 samples data were calculated.

3.6 Geo-statistical Analysis

3.6.1 Analysis using the Semivariogram Modeling

The relationship between all of the 50 soil sample locations was modeled to indicate the variability of the measurement with distance of separation which known as Semivariogram Modeling. Geostatistical analysis which included examining spatial variability nature of the soil infiltration by determining the semivariogram parameter. Semivariogram parameters called sill, nugget and range establishing best fitted

semivariogram models for the soil infiltration, and computing maps of the distribution of infiltration over the studied area using Kriging method.

The semivariogram parameters for this study were computed by using the GS+ software (Gamma Design Software, Plainwell, MI, USA) and Surfer software. Semi variance is a measurement of the degree of spatial dependence between samples. The semivariance data was estimated for the infiltration data.

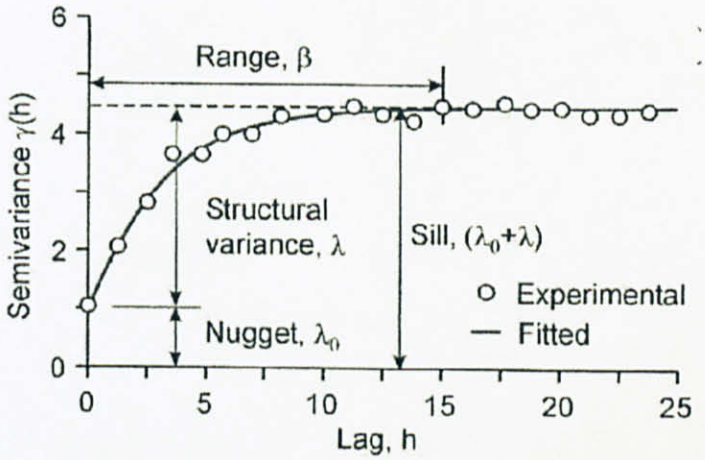

Figure 4: Schematic diagram of a semivariogram and its parameters

The magnitude of the semi variance between points depends on the distance between the points. A smaller distance gives a smaller semi variances and a larger distance gives a larger semi variances. **Figure 4** illustrates an experimental and fitted semivariogram with parameters. The Semivariance rises with the increasing lag then levels off. The lag at which the plateau is achieved is called the 'range' β, and the Semivariance value of the plateau is called the 'sill' (**Figure 4**). Points within the range are considered to be spatially dependent while outside the range is considered independent. The discontinuity is the 'nugget'. It represents all unaccounted spatial

variability at distance smaller than the smallest lag while the semivariogram models the structural spatial dependence (Goovaert, 1997) .

Therefore the 'nugget-to-sill' ratio gives a measure of the spatial dependence of infiltration data. The smaller the ratio, the stronger is the spatial dependence. Five different models (Figure 4) were examined to fit the semivariance data. These include the spherical, exponential, linear, linear-to-sill and Gaussian model. The optimal models were determined by examining the fit of the model to the semivariogram as judged by the coefficient of determination (r^2) and RSS (residual sums of squares) (Wikipedia, 2009).

3.6.2 Analysis using the Kriging Analysis

Kriging is mathematically closely related to regression analysis. Both theories derive a best linear unbiased estimator, based on assumptions on covariances, make use of Gauss-Markov theorem to prove independence of the estimate and error, and make use of very similar formulae. They are nevertheless useful in different frameworks: kriging is made for interpolation of a single realisation of a random field, while regression models are based on multiple observations of a multivariate dataset (Wikipedia,2009).

In the statistical community the same technique is also known as Gaussian process regression, Kolmogorov Wiener prediction, or best linear unbiased prediction. The kriging interpolation may also be seen as a spline in a reproducing kernel Hilbert

space, with reproducing kernel given by the covariance function.[11] The difference with the classical kriging approach is provided by the interpretation: while the spline is motivated by a minimum norm interpolation based on a Hilbert space structure, kriging is motivated by an expected squared prediction error based on a stochastic model (Wikipedia,2009).

Kriging with polynomial trend surfaces is mathematically identical to generalized least squares polynomial curve fitting. Kriging can also be understood as a form of Bayesian inference. Kriging starts with a prior distribution over functions. This prior takes the form of a Gaussian process: N samples from a function will be normally distributed, where the covariance between any two samples is the covariance function (or kernel) of the Gaussian process evaluated at the spatial location of two points. A set of values is then observed, each value associated with a spatial location. Now, a new value can be predicted at any new spatial location, by combining the Gaussian prior with a Gaussian likelihood function for each of the observed values. The resulting posterior distribution is also Gaussian, with a mean and covariance that can be simply computed from the observed values, their variance, and the kernel matrix derived from the prior (Wikipedia,2009).

Kriging interpolation is used for mapping soil properties in the analysis and interpolation of spatial variation of soil. The soil contour maps will show the variability at the boundaries between different soil types which can provide valuable categorical information for interpreting variation in soil properties. Kriging is most appropriate when it know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology (Google,*analyst using kriging in 3D analysis,*2005)

By using Kriging analysis, the spatial distribution of infiltration rate were determined at the untested location. The maps of spatial distribution of soil infiltration in conjunction with the site map allow examining the closeness of association between variation in soil infiltration and topographic condition.

3.7 Tools and Equipment

3.7.1 Software tools

1. CorelDraw9 Software
2. GS+ Software
3. Surfer Software
4. Digitizing Software
5. Microsoft Excel 2007

3.7.2 Hardware tools

1. Scope and Trowel
2. Hoe
3. Double Ring Infiltrometer
4. GPS instrument
5. Rubber mallet

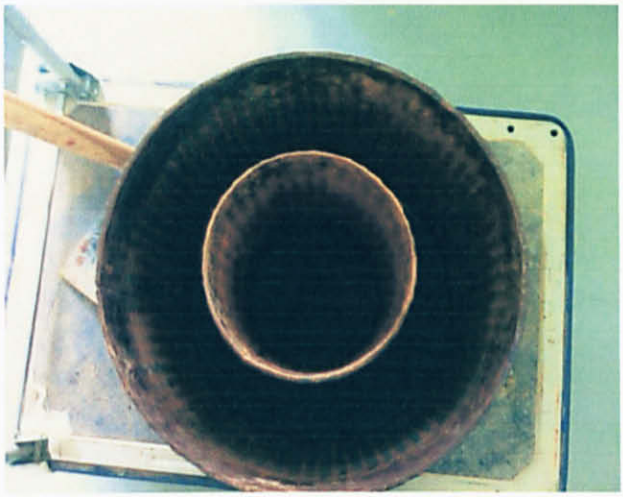

Figure 5 : Double Ring infiltrometer

3.8 Gantt Chart and Milestone of Project

Gantt chart and milestone for the project is attached in the attachment behind (refer Appendix A1 and A2).

CHAPTER 4

RESULT AND DISCUSSION

4.1 Geo-grid Sampling Location

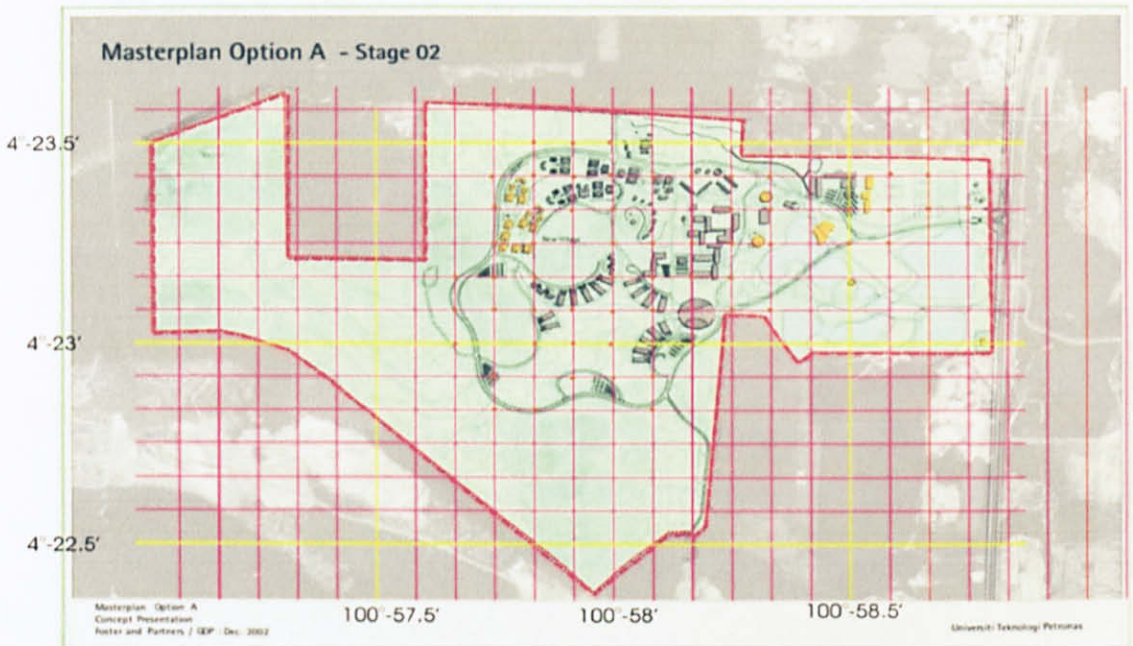

Figure 6: Gridline for UTP Master Map

Global Positioning System was used to determine the coordinates (Latitude and Longitude) of two selected control point. Then these two points were plotted into the UTP map and the geo-grid was designed on the map (**Figure 3**). Software called Coral draw 9 was used to sketch the geo-grid sampling location. After that, the geo-grid location was determined by choosing the intersection of the gridlines. The location of two references point which is near Block I and Block 13 shown in the **Table 1** below.

Table 1: GPS reading of control point

Point	Latitude (N)	Longitude (E)
Block I	4^{o} 23' N	100^{o} 58' 10'' E
Block 13	4^{o} 22' 52'' N	100^{o} 57' 51'' E

Both points were used as the control point in order to generate UTP campus map design the geo-grid sampling location and all the longitude and latitude for other point were determined by interpolation method. **Figure 7** below shows the 50 samples point that's been taken as the authors samples. It is also shown the gridlines of the UTP map.

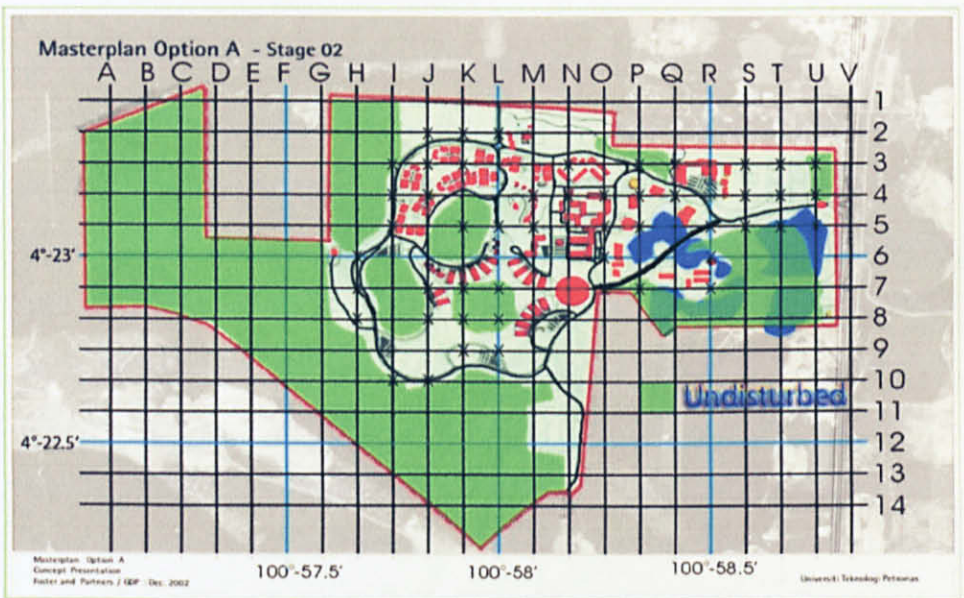

Figure 7 : Geo-grid sampling location

4.2 Statistical analysis

In the **Table 2** below is showing the summary of the soil infiltration obtained for all the 50 samples. Its include all the statistical value which contain mean, median, maximum, minimum, standard deviation (SD), and the coefficient of the variation (CV) for the tested 50 samples from UTP campus area.

Table 2: Statitical data for 50 samples

No of Samples	50
Total	6.83
Average	0.14
Standard Deviation	0.06
Minimum	0.07
Maximum	0.47
Median	0.12
Coefficient of Variation	0.43

Mean is the average of a numerical set. It is found by dividing the sum of a set of numbers by the number of members in the group. Median is the value of a numerical set that equally divides the number of values that is larger and smaller. For example, in a set containing eleven numbers, the median would be the sixth number. Standard deviation is the number representing the degree of variation within a numerical set. Coefficient of variation is the normalized measure of dispersion of a probability of distribution. The maximum is the maximum value for the infiltration rate and the minimum is the minimum value for the infiltration rate of the 50 samples tested.

4.3 Geo-statistical Analysis

From the result, the best semivariogram model parameter chosen is spherical model. Range or A_0, is the distance over which spatial dependence is apparent for the infiltration data. The separation distance at which point in the model domain are no longer spatially correlated is called effective range. Propotion of Spatial Structure or also known as C/(Co + C) or also known as nugget-to-sill ratio provides a measurement of the proportion of sample variance (Co + C) that is explained by spatially structured variance C. The strength of the data depends on the value of the nugget-to-sill ratio. The strength will increase if the nugget-to-sill ratio increases.

r^2 or regression coefficient indicates how well the model fits the variogram data. The higher the r^2 value, the better the model fit the data. Residual Sums of Squares provides an exact measure of how well the model fits the variogram data. The lower RSS value, the better model fits. A lower RSS value indicates that the model is fit with the data.

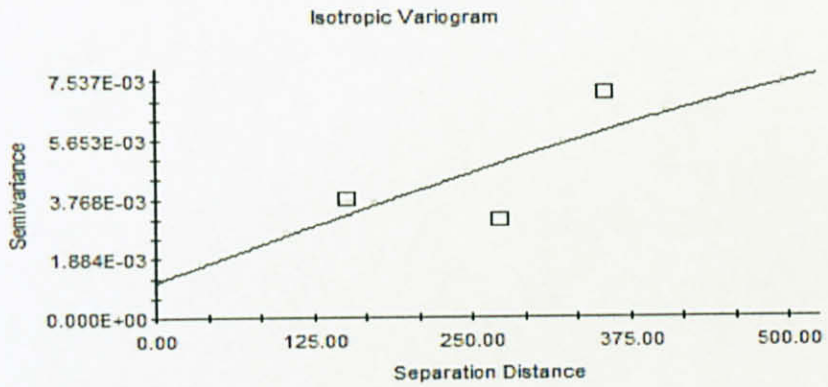

Figure 8 : Empirical semivariogram and best-fitted semivariogram of soil infiltration

From the result, the sill is a measure of the variability in the data. Sill for the infiltration data is 0.00947 which is considered low. This sill data must be must be

consistent with the normal CV from the normal statistical analysis. From the statistical analysis, the CV value is 0.43 which is considered low. So the variability of the infiltration for the tested area is low.

Nugget-to-sill data will indicate the spatial dependency of the data. If the ratio is less than 25%, it is considered to have a strong dependency. The moderate spatial dependency is 25%-75% and above of 75% is considered weak dependency (Goderya et al., 1996).

$$\frac{0.001120}{0.009470} \times 100\% = 12.67\%$$

Since the nugget-to-sill is below 25% which is 12.7%, so the infiltration data is considered strong spatial dependences. The nugget is measure of all unaccounted spatial variability at distance smaller than smallest lag (160m) while the structural variance accounts for variation due to spatial autocorrelations. The large range and the lower sill indicates that the soil infiltration are spatially dependent over long distance (large range) and the variability is low (indicates by low sill).

4.4 Mapping of the Infiltration Distribution

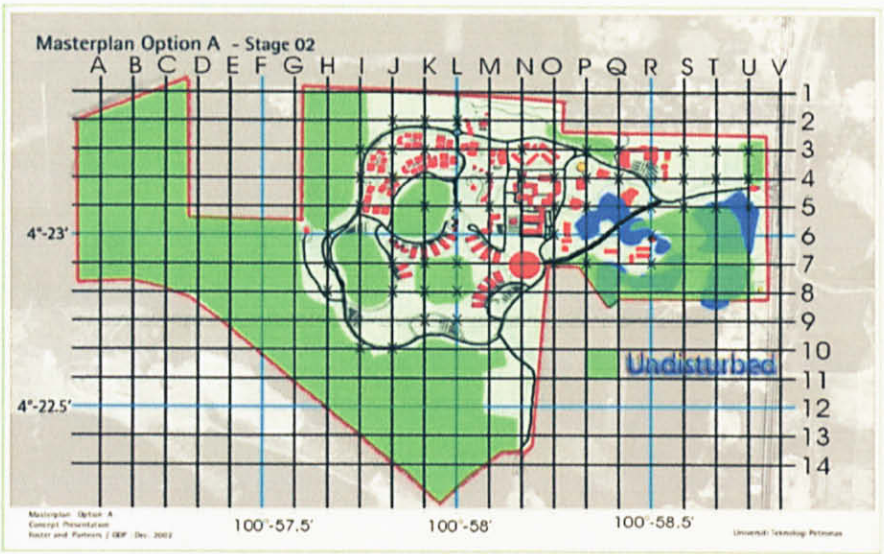

Figure 9 : The digitize map of the boundary and sampling location

The mapping of the infiltration data distribution in UTP campus area was done to see the spatial distribution. The data for longitude and latitude were taken as minutes North or minutes South which were taken from GPS. The result for mapping can be seen in **Figure 9** above.

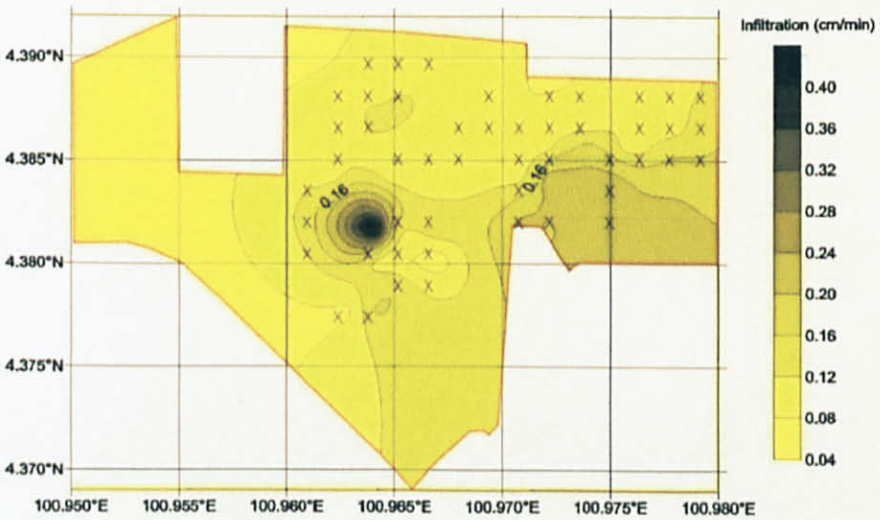

Figure 10 : The overlay of contour map of infiltration with the UTP Boundary map

Figure 10 is showing the overlay contour map of infiltration with the UTP boundary. This indicates the testes area which the author has used for this project.

4.5 Kriging Spatial Soil Infiltration

The spatial distribution of soil infiltration rate for ensamples location in the studied area was obtained from interpolation between samples location by the methods of Kriging.this method is based on Semivariogram of the soil infiltration rate at the tested area.

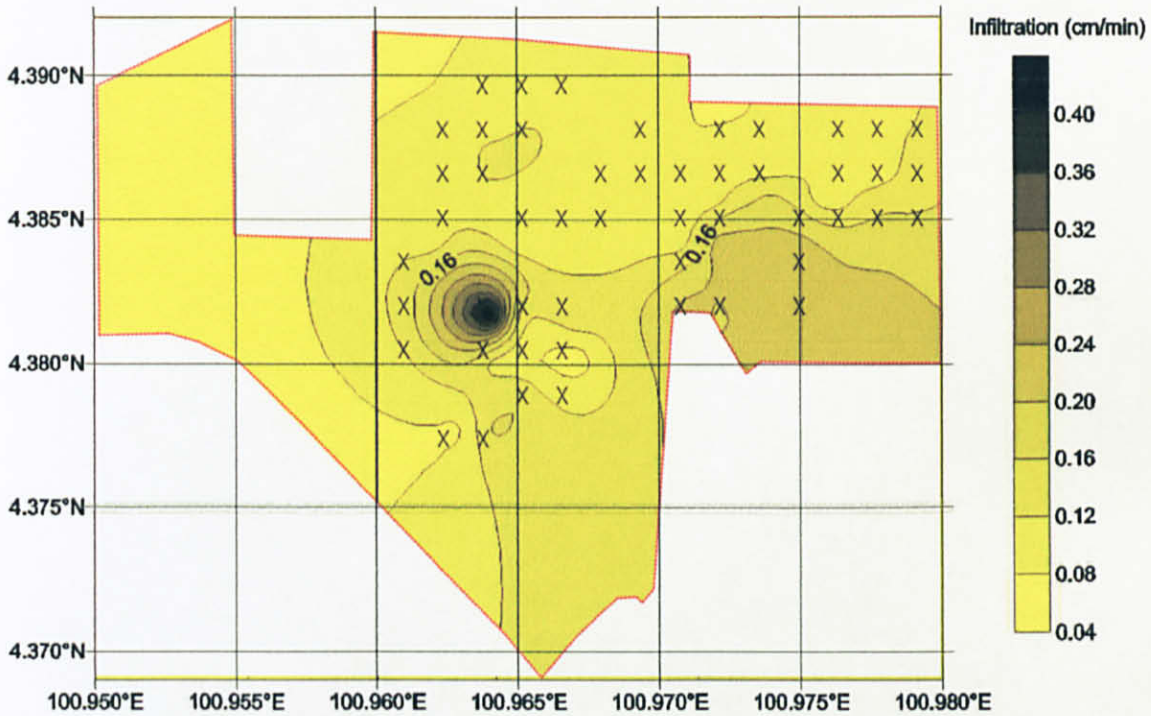

Figure 11 : Spatial distribution of soil infiltration in UTP area

Figure 11 above illustrates the spatial distribution of soil infiltration over the study area. From this figure, it shows that higher soil infiltration rate appears to be associated with lake and lower infiltration rate appear to be associated with the forest

and near building area. Thus, it is reasonable to infer that the spatial variability is induced partly by these topographic features present in the study area.

4.6 Variation of soil properties on land use conditions

Statistical and geostatistical characterization of the soil infiltration provide very strong evidence to the existence of the influence from intrinsic or extrinsic factors on the spatial variability of soil infiltration. Thus, the effect of land use changes was examined. To examine this, the study area is divided by 2 zones which is disturbed and undisturbed area (**Figure 12**).

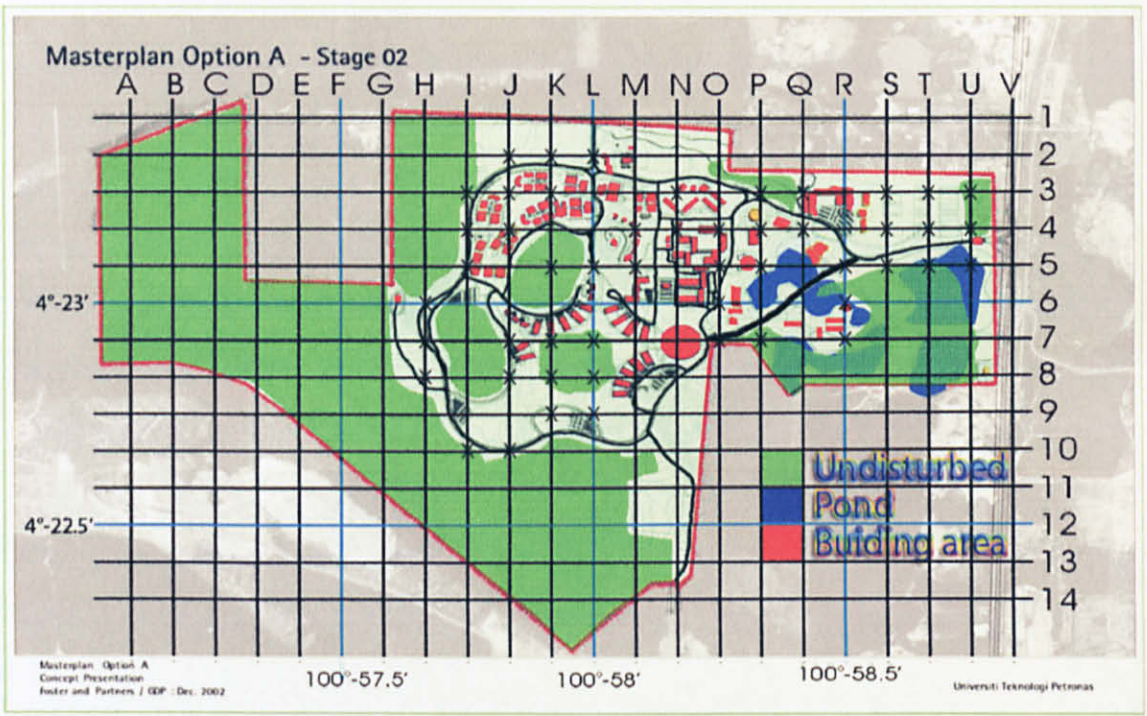

Figure 12: Disturbed and undisturbed area in UTP campus area

Disturbed area is the area which is having forest clearance, building and parking area. Undisturbed area is the area where the soil is still original where there is no activity

which is disturbing the area such as forest area. These 2 places were compared in the **Figure 12** above.

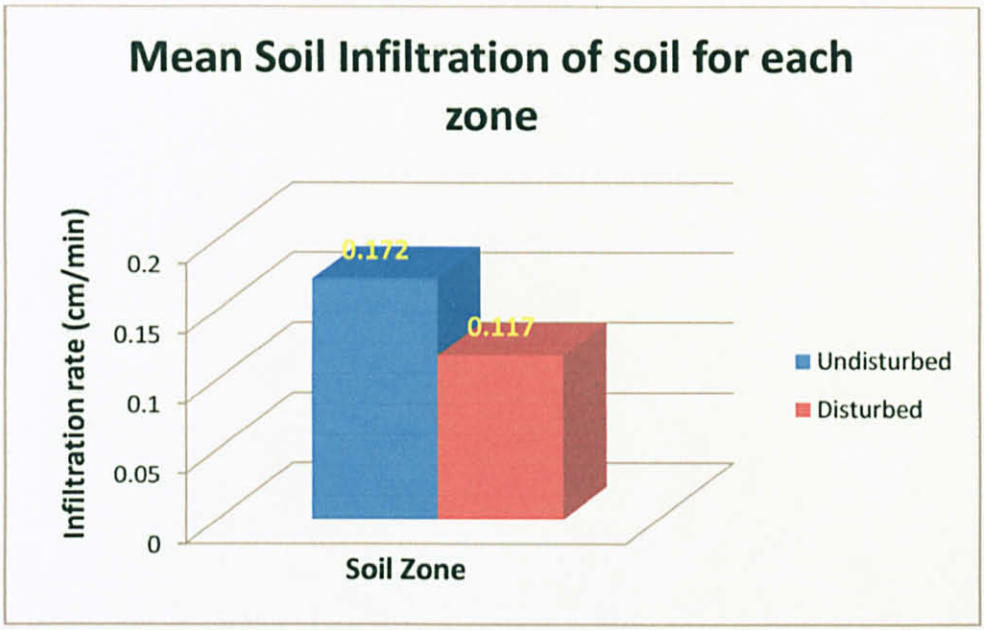

Figure 13 : The effect of land use in infiltration rate

From the chart above in **Figure 13**, it is clearly shows that the undisturbed area has the higher mean of infiltration rate than disturbed area. The lower infiltration rate at the disturbed area may be affected by compaction process due to construction of the building or human activities. The undisturbed area has the higher mean of infiltration rate due to higher pores in the soil because there is no compaction likes disturbed area. The higher in organic content in the undisturbed area which will increase the infiltration rate due to higher pores in the soil. It also shows that the variability appears due to the consequence of the land use conditions.

CHAPTER 5

COST OF THE PROJECT AND ECONOMICAL VALUE

5.1 Cost of the project

For this project, it has been done in University Technology PETRONAS. So the cost for this project is negligible since everything can be taken from Civil Department Laboratory. All of the tools for this project have been borrowed from the laboratory. The soil sample only taken from UTP campus area which was free and water from the project also can be taken from any water source. For this project, the author had used tap water.

5.2 Economics Value

The economics value for this project is this experiment can be done at any place. Since the cost for this project is negligible or very low cost, this experiment can be done at any site and it would not burden any client. it is important to do this experiment at any site where we can know the infiltration rate of the soil at sites.

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

From the experiment and observations done by the author, the author can conclude that the soil properties are varying spatially and both are influenced by the intrinsic and extrinsic factors. The spatial variability causes difficulty in representing a soil with a deterministic or precisely defined set of characteristics and precludes characterization of soil hydrological response. Therefore the spatial variability of soil properties should be monitored and quantified.

The result shows that the significant variation of soil infiltration exists in the area of studied. Larger range and the lower sill indicates that the soil infiltration are spatially dependent over long distance (large range) and the variability is low (indicates by low sill). Land disturbance and land topographic conditions contribute to the variability of soil infiltration.

This study will find out and characterize spatial structure of infiltration characteristics of soil under tropical climate in terms of semivariogram parameters. The characterization of the spatial variability and scale dependence of infiltration characteristics is performed by using geo statistical approaches.

The geo-statistic application in conjunction with the normal statistic analysis in evaluate the spatial variability of soil infiltration revealed that certain aspects that not captured by normal statistic. By using geo-statistic, it can indicate distance of where the correlated data occurred, the variability of the data and also the degree of the spatial dependency.

Besides, it also can allows mapping of the spatial distribution and the normal statistics will helped in identifying causes of the variability in the soil infiltration. Others, even the semivariogram shows the consistent result, however the relatively low r^2 (0.473) show poor fit to data. This is because in the fact that the number of the sample is not enough for that extend of area studied [Rezaur R.B,2004].

Author suggests to have more closely spaced sampling data taken in order to make it relative to the area studied. For next time, more samples are taken and also the study is expanded and continues for a lot of other applications in geotechnical studies, not only focusing in the farming practices.

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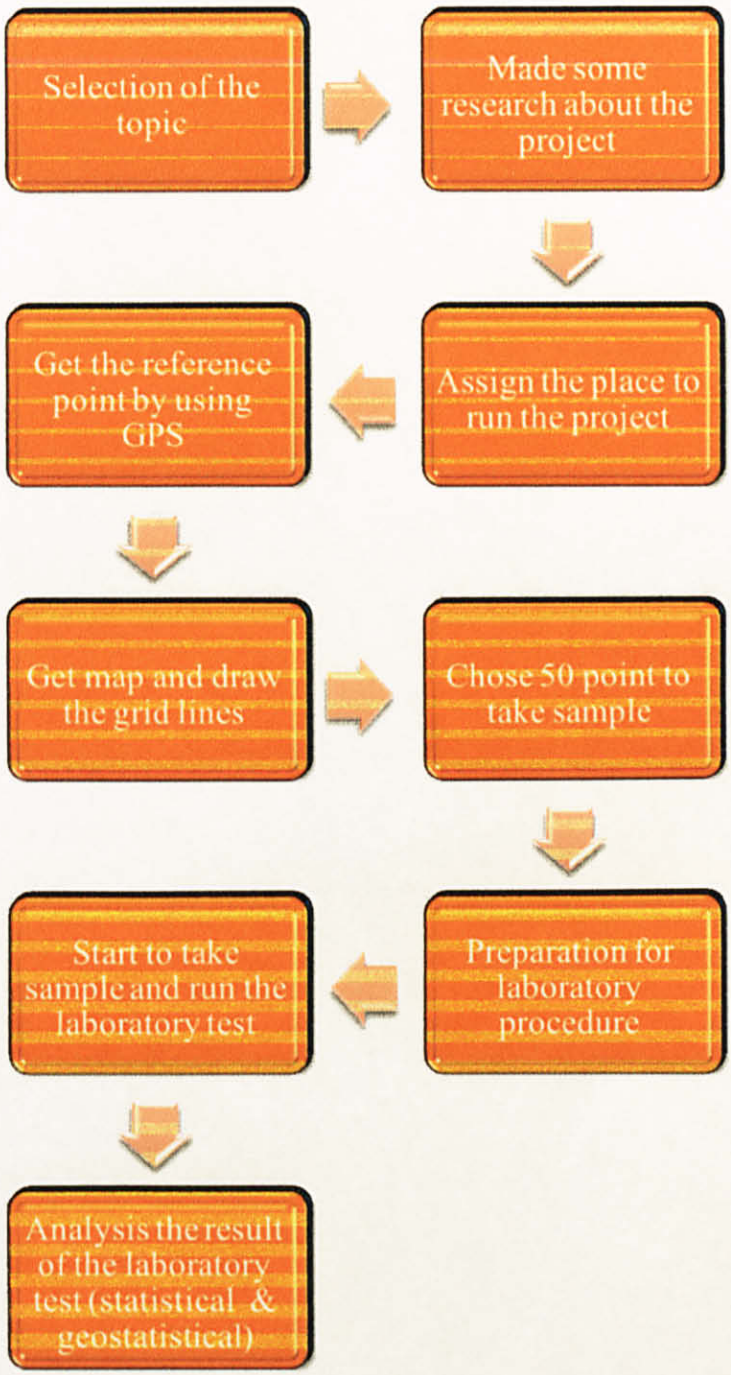
ASTM D3385 - 09 Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometer

Appendices

Project Flow Diagram



Latitude	Longitude	Sample no	Time(min)								Infiltration rate(cm/min)								Average Infiltration Rate
			15	30	45	60	75	90	105	120	15	30	45	60	75	90	105	120	
100° 57' 50''	4° 22' 55''	1	10,5	18,5	25,4	30,15	30,85	31,2	31,5	31,9	0,7	0,616667	0,564444	0,5025	0,411333	0,346667	0,3	0,26583333	0,463430556
100° 57' 50''	4° 22' 50''	2	3,5	5,2	7,3	7,5	7,55	7,6	7,6	7,65	0,233333	0,173333	0,162222	0,125	0,100667	0,084444	0,072381	0,06375	0,126891369
100° 57' 45''	4° 23' 10''	3	2,95	5,1	6,8	7,3	7,85	8,05	8,15	8,25	0,196667	0,17	0,151111	0,121667	0,104667	0,089444	0,077619	0,06875	0,122490575
100° 57' 45''	4° 23' 15''	4	2,3	4	4,8	5,25	5,8	6,3	6,4	6,45	0,153333	0,133333	0,106667	0,0875	0,077333	0,07	0,060952	0,05375	0,092858631
100° 57' 50''	4° 23' 20''	5	2,15	3,9	4,6	5,4	6	6,2	6,25	6,35	0,143333	0,13	0,102222	0,09	0,08	0,068889	0,059524	0,05291667	0,090860615
100° 57' 55'	4° 23' 20''	6	2,2	4,85	6,2	7,65	8,2	8,85	9,15	9,2	0,146667	0,161667	0,137778	0,1275	0,109333	0,098333	0,087143	0,07666667	0,118135913
100° 58' 00''	4° 23' 20''	7	2,65	4,8	6,2	7,15	7,65	7,95	8,1	8,25	0,176667	0,16	0,137778	0,119167	0,102	0,088333	0,077143	0,06875	0,116229663
100° 57' 50''	4° 23' 15''	8	3,35	6,1	8,2	8,95	9,3	9,65	9,8	9,9	0,223333	0,203333	0,182222	0,149167	0,124	0,107222	0,093333	0,0825	0,145638889
100° 57' 45''	4° 23' 05''	9	2	3,85	4,8	5,65	6,1	6,4	6,65	6,7	0,133333	0,128333	0,106667	0,094167	0,081333	0,071111	0,063333	0,05583333	0,091763889
100° 57' 40''	4° 23' 00''	10	2,95	5,3	7,2	8,5	9,2	9,5	9,75	9,9	0,196667	0,176667	0,16	0,141667	0,122667	0,105556	0,092857	0,0825	0,134822421
100° 57' 40''	4° 22' 55''	11	3,4	5,9	7,3	8,15	8,9	9,25	9,45	9,7	0,226667	0,196667	0,162222	0,135833	0,118667	0,102778	0,09	0,08083333	0,139208333
100° 57' 40''	4° 22' 50''	12	2,7	4,9	6,2	7,1	7,65	7,9	8,1	8,15	0,18	0,163333	0,137778	0,118333	0,102	0,087778	0,077143	0,06791667	0,116785218
100° 57' 45''	4° 22' 40''	13	1,9	3,15	3,8	4,3	4,55	4,7	4,85	4,95	0,126667	0,105	0,084444	0,071667	0,060667	0,052222	0,04619	0,04125	0,073513393
100° 57' 50''	4° 22' 40''	14	3,5	6,75	9,2	10,15	10,65	11	11,15	11,2	0,233333	0,225	0,204444	0,169167	0,142	0,122222	0,10619	0,09333333	0,16196131
100° 57' 55''	4° 22' 45''	15	3,65	7	8,5	9,6	10,15	10,8	10,95	11,1	0,243333	0,233333	0,188889	0,16	0,135333	0,12	0,104286	0,0925	0,159709325
100° 58' 00''	4° 22' 45''	16	2,15	3,9	5,2	6,2	6,8	7,5	7,65	7,8	0,143333	0,13	0,115556	0,103333	0,090667	0,083333	0,072857	0,065	0,100509921
100° 57' 55''	4° 22' 50''	17	2,25	2,85	3,5	4,3	4,8	5	5,3	5,45	0,15	0,095	0,077778	0,071667	0,064	0,055556	0,050476	0,04541667	0,076236607
100° 58' 00''	4° 22' 50''	18	1,5	2,2	2,6	3	3,2	3,35	3,5	3,6	0,1	0,073333	0,057778	0,05	0,042667	0,037222	0,033333	0,03	0,053041667
100° 57' 55''	4° 22' 55''	19	3,55	6,1	7,8	8,65	9,35	9,6	9,8	10	0,236667	0,203333	0,173333	0,144167	0,124667	0,106667	0,093333	0,08333333	0,1456875
100° 58' 00''	4° 22' 55''	20	3,85	6,8	8,9	9,65	10,3	10,55	10,75	10,9	0,256667	0,226667	0,197778	0,160833	0,137333	0,117222	0,102381	0,09083333	0,161214286
100° 58' 35''	4° 23' 15''	21	3,1	5,35	6,5	7,4	8,2	8,65	8,9	9,15	0,206667	0,178333	0,144444	0,123333	0,109333	0,096111	0,084762	0,07625	0,127404266
100° 58' 40''	4° 23' 15''	22	2,15	3,5	4,3	4,95	5,4	5,8	6	6,1	0,143333	0,116667	0,095556	0,0825	0,072	0,064444	0,057143	0,05083333	0,085309524
100° 58' 40''	4° 23' 10''	23	3,6	6,1	7,95	8,5	9,3	9,7	9,95	10,1	0,24	0,203333	0,176667	0,141667	0,124	0,107778	0,094762	0,08416667	0,146546627
100° 58' 35''	4° 23' 10''	24	2,25	3,8	4,6	5,3	5,85	6,1	6,4	6,55	0,15	0,126667	0,102222	0,088333	0,078	0,067778	0,060952	0,05458333	0,091066964
100° 58' 45''	4° 23' 10''	25	3,55	6,2	7,85	8,6	9,1	9,55	9,8	10	0,236667	0,206667	0,174444	0,143333	0,121333	0,106111	0,093333	0,08333333	0,145652778
100° 58' 45''	4° 23' 15''	26	3,5	6,1	7,8	8,7	9,4	9,6	9,95	10,2	0,233333	0,203333	0,173333	0,145	0,125333	0,106667	0,094762	0,085	0,145845238
100° 58' 40''	4° 23' 05''	27	4,8	8,35	10,1	10,9	11,5	11,8	12,2	12,45	0,32	0,278333	0,224444	0,181667	0,153333	0,131111	0,11619	0,10375	0,188603671
100° 58' 45''	4° 23' 05''	28	4,55	8,1	9,8	10,65	11,2	11,7	12	12,2	0,303333	0,27	0,217778	0,1775	0,149333	0,13	0,114286	0,10166667	0,182987103
100° 58' 30''	4° 23' 05''	29	5,1	8,9	11,1	12,7	13,55	14,15	14,6	14,9	0,34	0,296667	0,246667	0,211667	0,180667	0,157222	0,139048	0,12416667	0,212012897
100° 58' 35''	4° 23' 05''	30	4,9	8,75	10,4	10,8	11,45	11,7	12,1	12,3	0,326667	0,291667	0,231111	0,18	0,152667	0,13	0,115238	0,1025	0,191231151
100° 58' 20''	4° 23' 15''	31	2,2	3,7	4,65	5,1	5,5	5,85	6,1	6,35	0,146667	0,123333	0,103333	0,085	0,073333	0,065	0,058095	0,05291667	0,088459821
100° 58' 25''	4° 22' 15''	32	2,25	3,8	4,7	5,25	5,6	5,9	6,25	6,4	0,15	0,126667	0,104444	0,0875	0,074667	0,065556	0,059524	0,05333333	0,09021131
100° 58' 20''	4° 23' 10''	33	2,85	4,5	5,3	6	6,55	6,9	7,2	7,4	0,19	0,15	0,117778	0,1	0,087333	0,076667	0,068571	0,06166667	0,106501984
100° 58' 15''	4° 23' 10''	34	2,1	3,6	4,5	5,1	5,45	5,7	6,05	6,25	0,14	0,12	0,1	0,085	0,072667	0,063333	0,057619	0,05208333	0,086337798
100° 58' 20''	4° 23' 05''	35	5,35	9,3	11,25	12,8	13,7	14,4	14,9	15,2	0,356667	0,31	0,25	0,213333	0,182667	0,16	0,141905	0,12666667	0,217654762
100° 58' 25''	4° 23' 10''	36	4	7,45	9,75	10,2	11,1	11,6	11,9	12,1	0,266667	0,248333	0,216667	0,17	0,148	0,128889	0,113333	0,10083333	0,174090278
100° 58' 15''	4° 23' 05''	37	2,6	4,3	5	5,7	6,35	6,7	7,1	7,35	0,173333	0,143333	0,111111	0,095	0,084667	0,074444	0,067619	0,06125	0,101344742
100° 58' 15''	4° 23' 00''	38	4,25	7,7	9,5	10,7	11,3	11,6	12	12,2	0,283333	0,256667	0,211111	0,178333	0,150667	0,128889	0,114286	0,10166667	0,178119048
100° 58' 25''	4° 22' 15''	39	2,25	3,7	4,55	5	5,8	6,3	6,65	6,8	0,15	0,123333	0,101111	0,083333	0,077333	0,07	0,063333	0,05666667	0,090638889
100° 58' 25''	4° 23' 10''	40	2,4	3,9	4,8	5,2	6	6,45	6,7	7,1	0,16	0,13	0,106667	0,086667	0,08	0,071667	0,06381	0,05916667	0,094747024
100° 58' 20''	4° 23' 10''	41	2,45	4,15	5,2	5,8	6,35	6,7	7	7,25	0,163333	0,138333	0,115556	0,096667	0,084667	0,074444	0,066667	0,06041667	0,100010417
100° 58' 20''	4° 23' 05''	42	2,2	3,65	4,3	4,85	5,4	5,9	6,25	6,4	0,146667	0,121667	0,095556	0,080833	0,072	0,065556	0,059524	0,05333333	0,086891865
100° 58' 00''	4° 22' 45''	43	3,3	5,5	6,7	7,2	7,9	8,2	8,6	8,85	0,22	0,183333	0,148889	0,12	0,105333	0,091111	0,081905	0,07375	0,128040179
100° 58' 05''	4° 23' 10''	44	2,25	3,8	4,5	5,35	5,9	6,2	6,45	6,6	0,15	0,126667	0,1	0,089167	0,078667	0,068889	0,061429	0,055	0,091227183
100° 57' 55''	4° 23' 05''	45	2,05	3,4	4,15	4,7	5,2	5,45	5,7	5,85	0,136667	0,113333	0,092222	0,078333	0,069333	0,060556	0,054286	0,04875	0,08168502
100° 58' 00''	4° 23' 05''	46	2,1	3,5	4,3	4,9	5,45	5,7	5,9	6,1	0,14	0,116667	0,095556	0,081667	0,072667	0,063333	0,05619	0,05083333	0,084614087
100° 58' 20''	4° 22' 55''	47	4,95	8,2	10,5	11,65	12,3	12,65	12,9	13,1	0,33	0,273333	0,233333	0,194167	0,164	0,140556	0,122857	0,10916667	0,195926587
100° 58' 15''	4° 22' 55''	48	5,6	9,55	11,8	12,9	13,6	14,1	14,5	14,85	0,373333	0,318333	0,262222	0,215	0,181333	0,156667	0,138095	0,12375	0,221091766
100° 58' 30''	4° 23' 00''	49	5	8,9	10,6	11,8	12,5	13,1	13,5	13,7	0,333333	0,296667	0,235556	0,196667	0,166667	0,145556	0,128571	0,11416667	0,202147817
100° 58' 30''	4° 22' 55''	50	5,15	9,3	11	11,9	12,75	13,3	13,6	13,85	0,343333	0,31	0,244444	0,198333	0,17	0,147778	0,129524	0,11541667	0,207353671

Gantt Chart

Suggested Milestone for the First Semester of Final Year Project

No.	Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Selection of Project Topic																
2	Preliminary Research work																
3	Submission of Premilinary																
4	Seminar (optional)																
5	Project Work																
6	Submission of Progress report																
7	Submission of Interim Report Final Draft																
8	Oral Presentation																

progress

suggested milestone

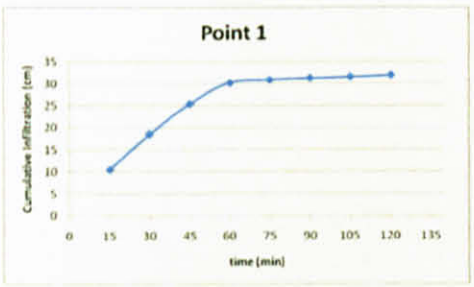
Suggested Milestone for the Second Semester of Final Year Project

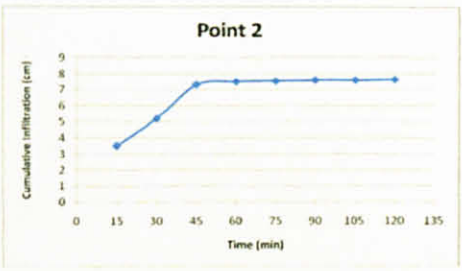
No.	Detail/Week	1	2	3	4	5	6	7	Mid-semester break	8	9	10	11	12	13	14
1	Project work continue -soil sampling -laboratory analysis															
2	Submission of progress report 1															
3	Project work continue - statistical and geostatistic analysis															
4	Preparing poster and oral presentation, dissertation report															
5	Poster Exhibition															
6	Submission Of Dissertation (soft bound)															
7	Oral Presentation															
8	Submission Of Dissertation (hard bound)															

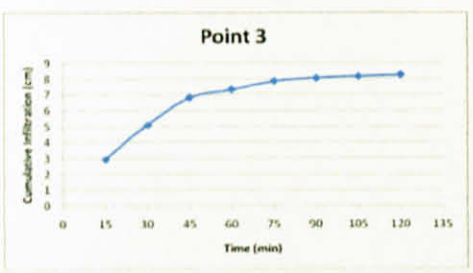
Suggested milestone

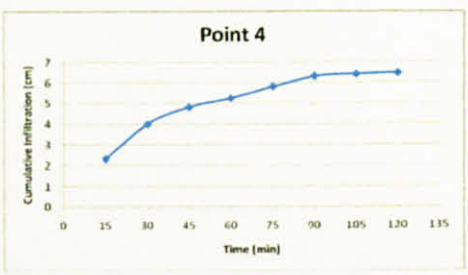
Progress

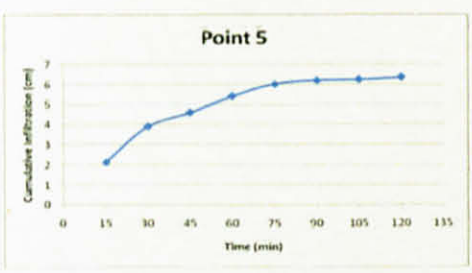
Graph of Cumulative Infiltration (cm) Vs Time (min)

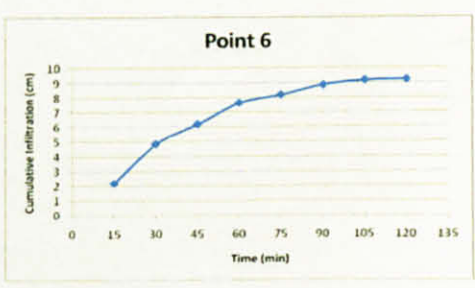

Point 1
Cumulative Infiltration (cm)
0 5 10 15 20 25 30 35
0 15 30 45 60 75 90 105 120 135
time (min)

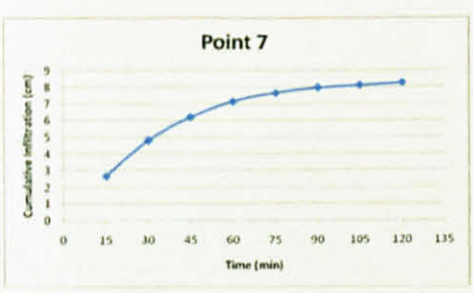

Point 2
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9
0 15 30 45 60 75 90 105 120 135
Time (min)

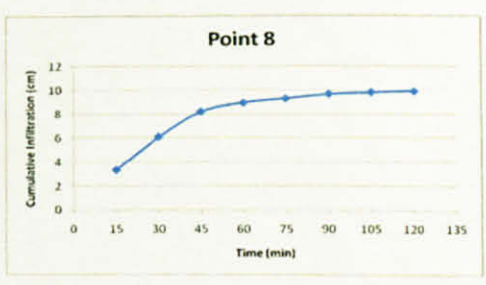

Point 3
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9
0 15 30 45 60 75 90 105 120 135
Time (min)

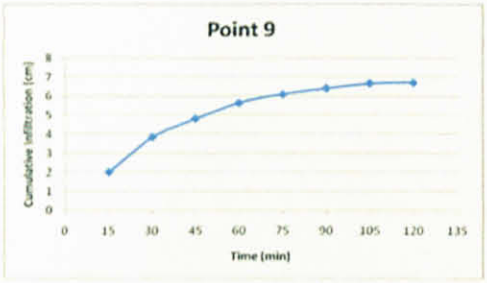

Point 4
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

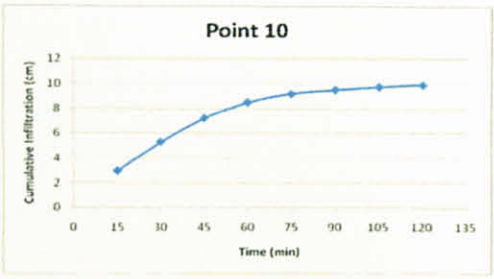

Point 5
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

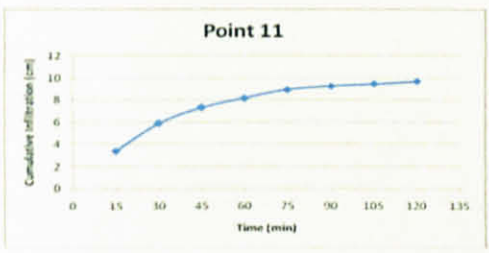

Point 6
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9 10
0 15 30 45 60 75 90 105 120 135
Time (min)

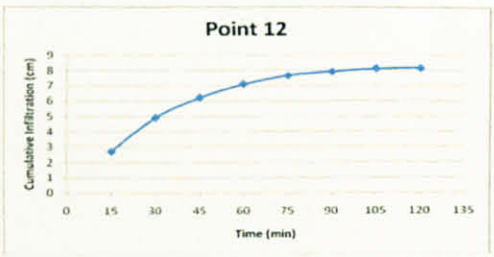

Point 7
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9
0 15 30 45 60 75 90 105 120 135
Time (min)

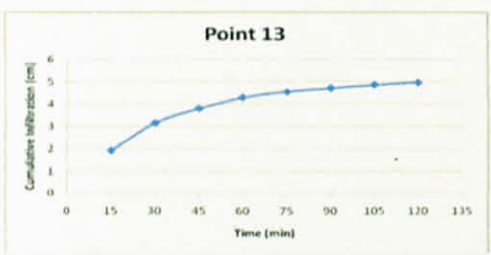

Point 8
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

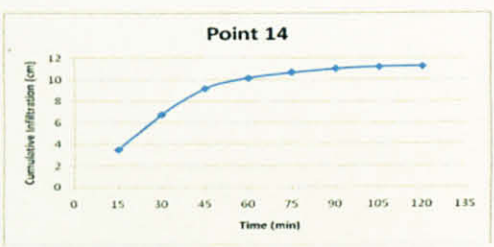

Point 9
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8
0 15 30 45 60 75 90 105 120 135
Time (min)

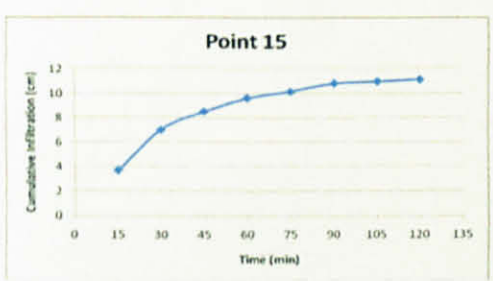

Point 10
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

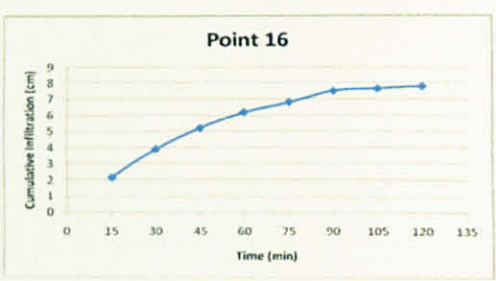

Point 11
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

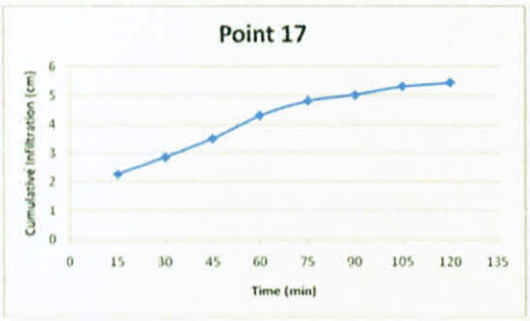

Point 12
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9
0 15 30 45 60 75 90 105 120 135
Time (min)

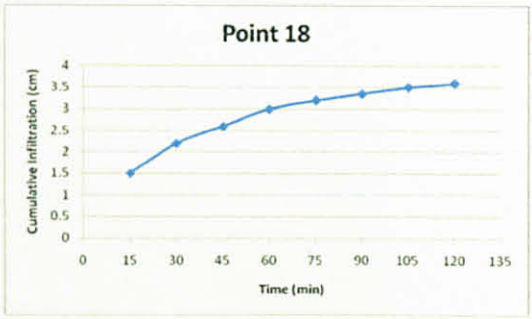

Point 13
Cumulative Infiltration (cm)
0 1 2 3 4 5 6
0 15 30 45 60 75 90 105 120 135
Time (min)

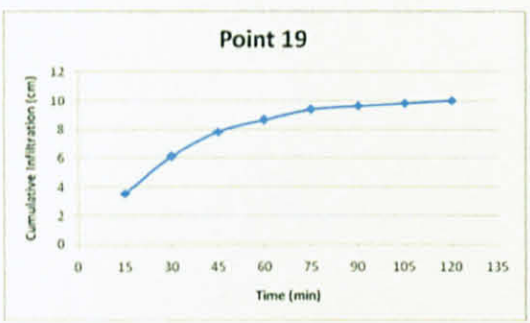

Point 14
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

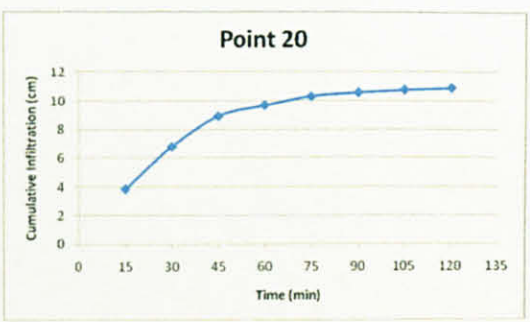

Point 15
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

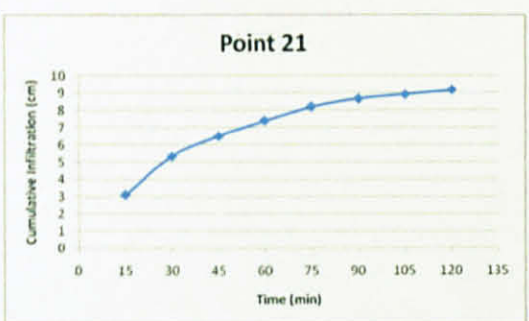

Point 16
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9
0 15 30 45 60 75 90 105 120 135
Time (min)

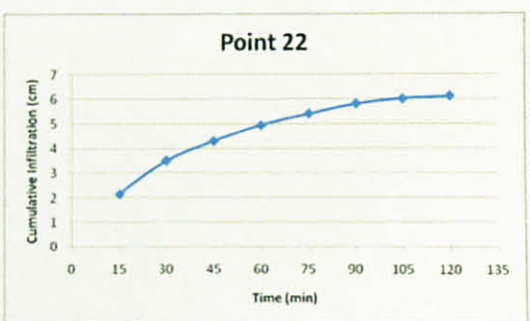

Point 17
Cumulative Infiltration (cm)
0
1
2
3
4
5
6
0 15 30 45 60 75 90 105 120 135
Time (min)

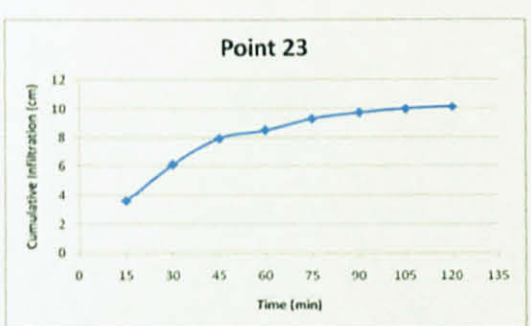

Point 18
Cumulative Infiltration (cm)
0
0.5
1
1.5
2
2.5
3
3.5
4
0 15 30 45 60 75 90 105 120 135
Time (min)

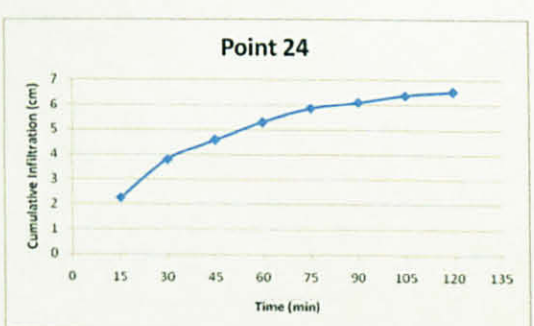

Point 19
Cumulative Infiltration (cm)
0
2
4
6
8
10
12
0 15 30 45 60 75 90 105 120 135
Time (min)

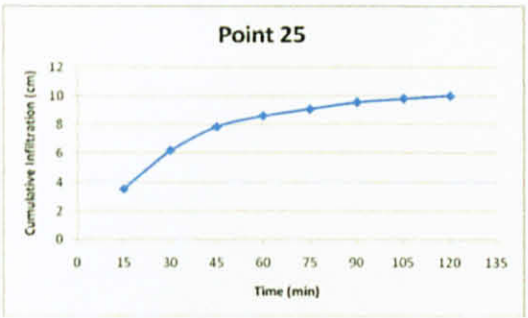

Point 20
Cumulative Infiltration (cm)
0
2
4
6
8
10
12
0 15 30 45 60 75 90 105 120 135
Time (min)

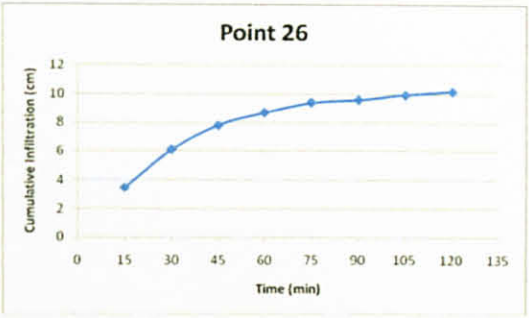

Point 21
Cumulative Infiltration (cm)
0
1
2
3
4
5
6
7
8
9
10
0 15 30 45 60 75 90 105 120 135
Time (min)

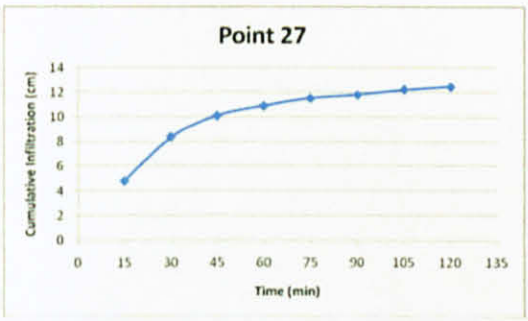

Point 22
Cumulative Infiltration (cm)
0
1
2
3
4
5
6
7
0 15 30 45 60 75 90 105 120 135
Time (min)

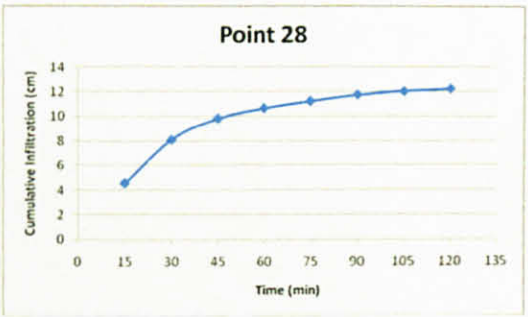

Point 23
Cumulative Infiltration (cm)
0
2
4
6
8
10
12
0 15 30 45 60 75 90 105 120 135
Time (min)

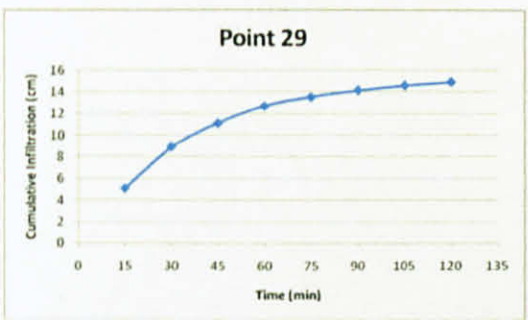

Point 24
Cumulative Infiltration (cm)
0
1
2
3
4
5
6
7
0 15 30 45 60 75 90 105 120 135
Time (min)

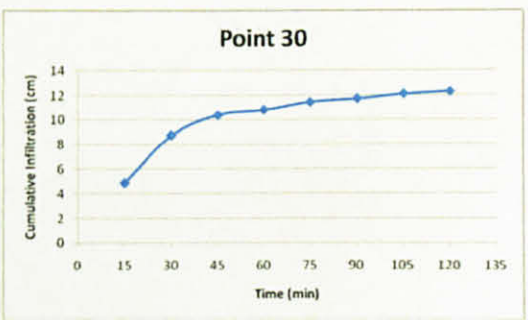

Point 25
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

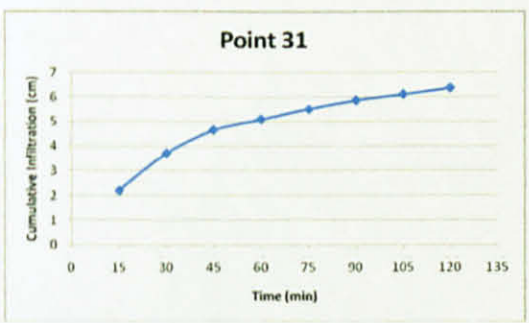

Point 26
Cumulative Infiltration (cm)
0 2 4 6 8 10 12
0 15 30 45 60 75 90 105 120 135
Time (min)

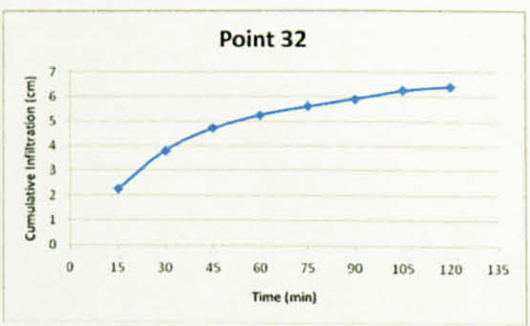

Point 27
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14
0 15 30 45 60 75 90 105 120 135
Time (min)

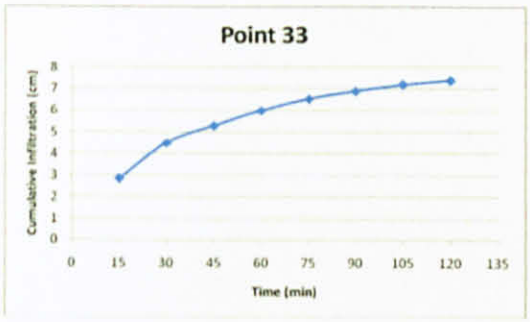

Point 28
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14
0 15 30 45 60 75 90 105 120 135
Time (min)

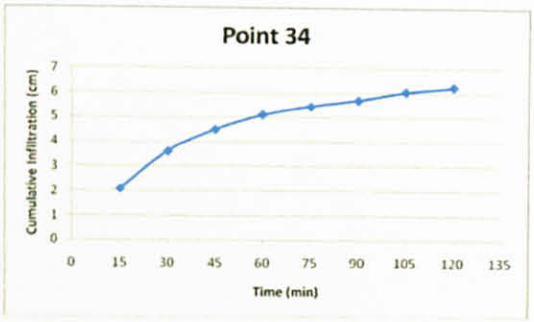

Point 29
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14 16
0 15 30 45 60 75 90 105 120 135
Time (min)

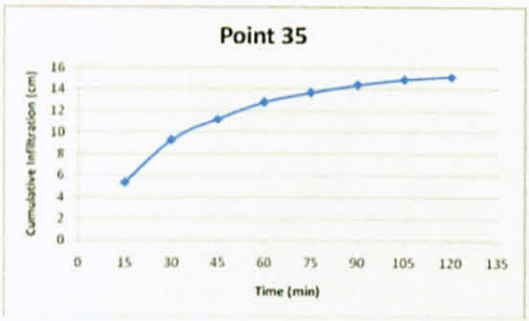

Point 30
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14
0 15 30 45 60 75 90 105 120 135
Time (min)

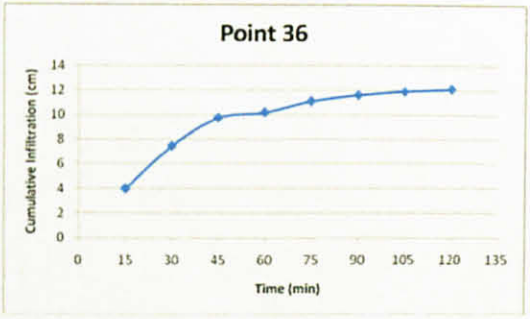

Point 31
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

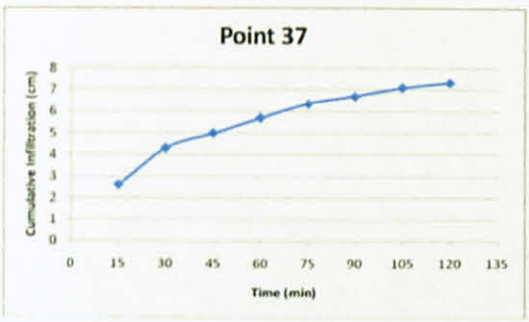

Point 32
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

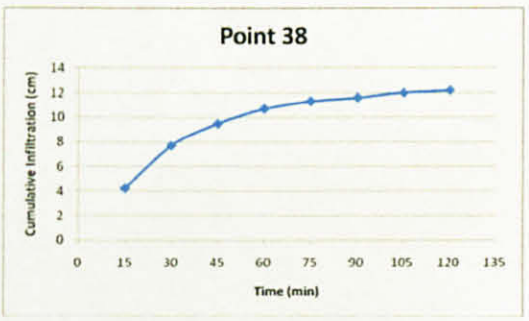

Point 33
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8
0 15 30 45 60 75 90 105 120 135
Time (min)

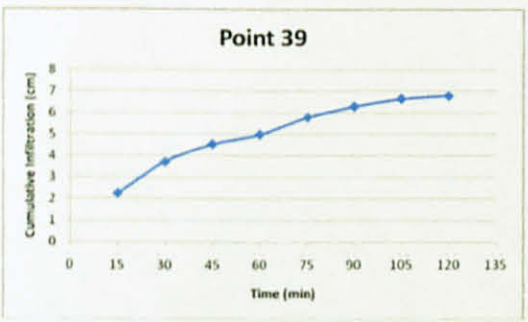

Point 34
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

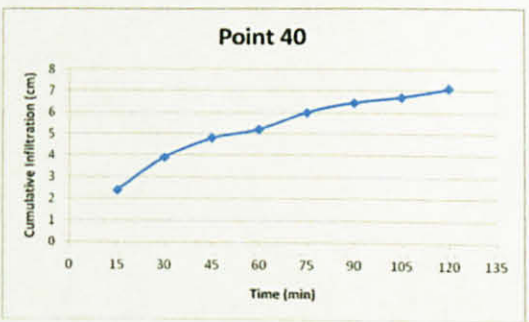

Point 35
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14 16
0 15 30 45 60 75 90 105 120 135
Time (min)

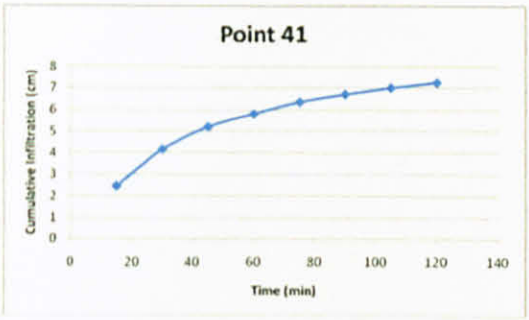

Point 36
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14
0 15 30 45 60 75 90 105 120 135
Time (min)

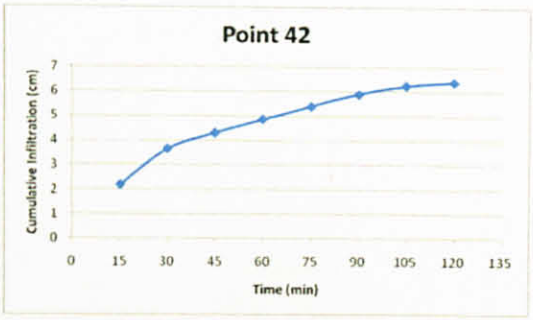

Point 37
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8
0 15 30 45 60 75 90 105 120 135
Time (min)

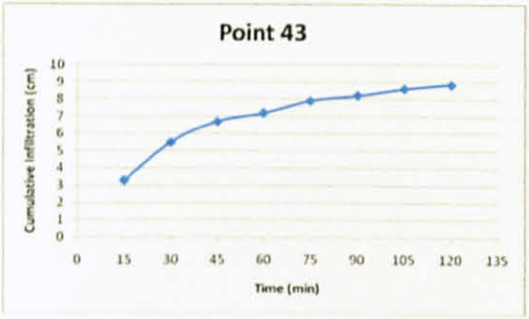

Point 38
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14
0 15 30 45 60 75 90 105 120 135
Time (min)

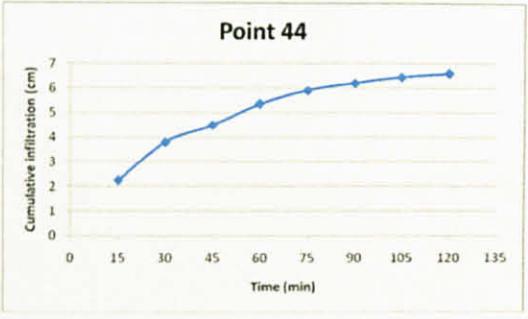

Point 39
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8
0 15 30 45 60 75 90 105 120 135
Time (min)

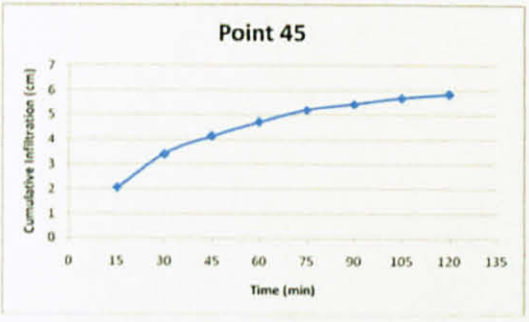

Point 40
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8
0 15 30 45 60 75 90 105 120 135
Time (min)

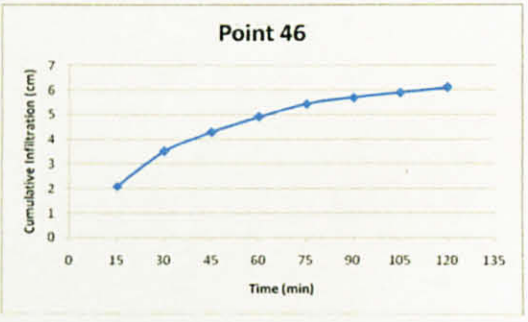

Point 41
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8
0 20 40 60 80 100 120 140
Time (min)

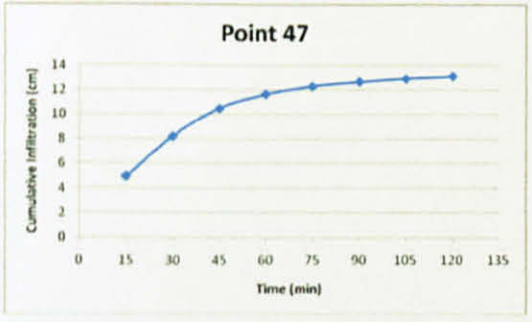

Point 42
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

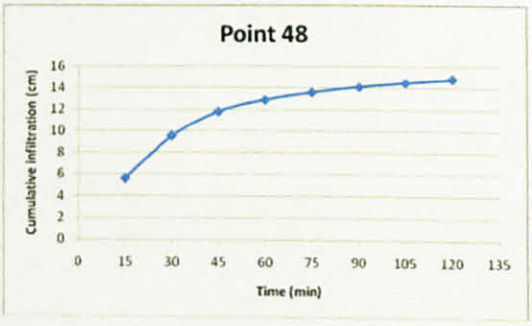

Point 43
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7 8 9 10
0 15 30 45 60 75 90 105 120 135
Time (min)

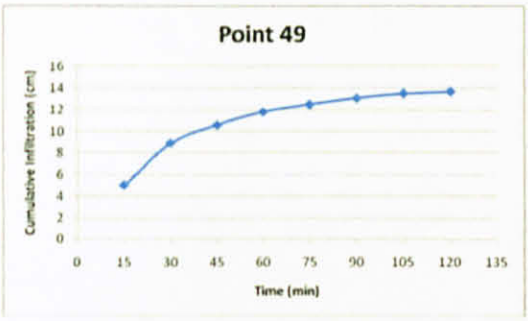

Point 44
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)

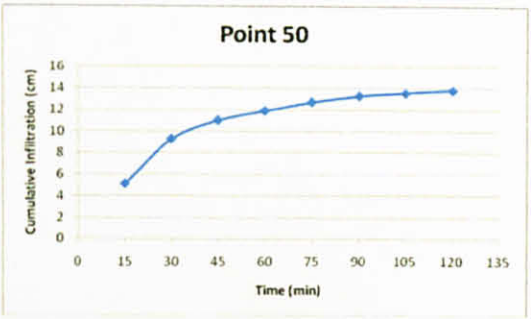

Point 45
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)


Point 46
Cumulative Infiltration (cm)
0 1 2 3 4 5 6 7
0 15 30 45 60 75 90 105 120 135
Time (min)


Point 47
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14
0 15 30 45 60 75 90 105 120 135
Time (min)


Point 48
Cumulative Infiltration (cm)
0 2 4 6 8 10 12 14 16
0 15 30 45 60 75 90 105 120 135
Time (min)

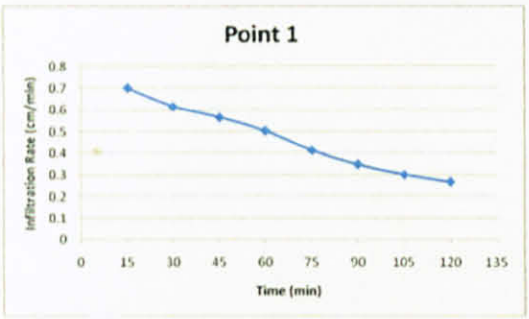

Point 49
Cumulative Infiltration (cm)
16
14
12
10
8
6
4
2
0
0
15
30
45
60
75
90
105
120
135
Time (min)

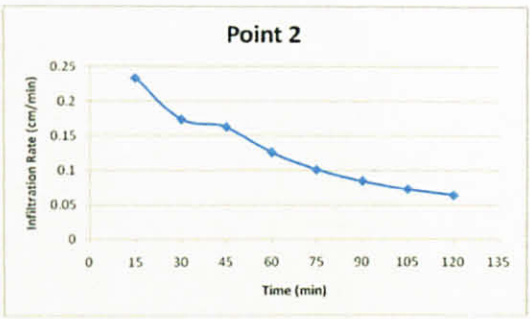

Point 50
Cumulative Infiltration (cm)
16
14
12
10
8
6
4
2
0
0
15
30
45
60
75
90
105
120
135
Time (min)

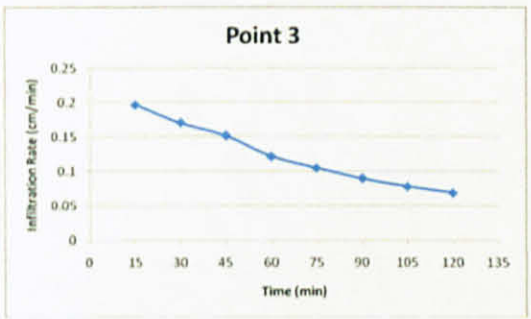
Graph of

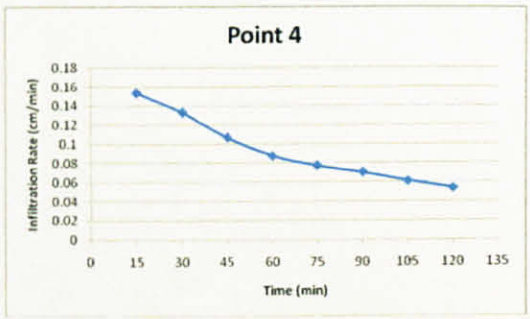
Infiltration Rate (cm/min)

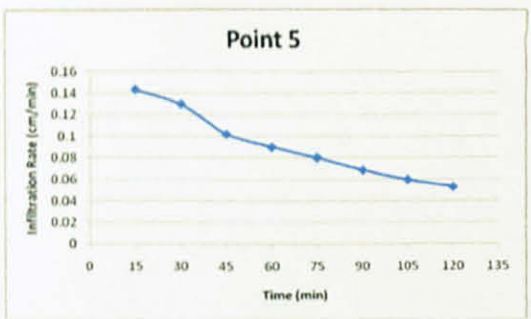
Vs Time (min)

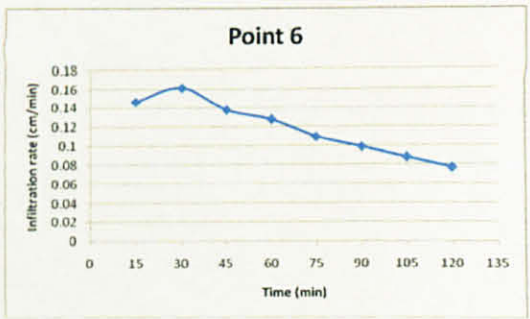

Point 1
Infiltration Rate (cm/min)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 15 30 45 60 75 90 105 120 135
Time (min)

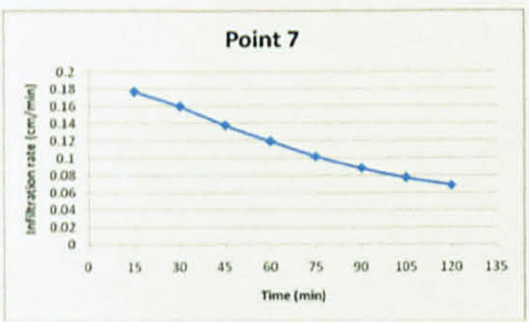

Point 2
Infiltration Rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 15 30 45 60 75 90 105 120 135
Time (min)

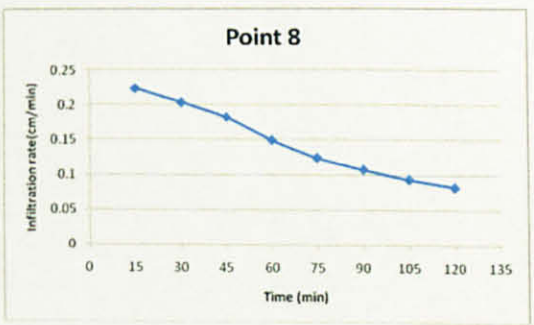

Point 3
Infiltration Rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 15 30 45 60 75 90 105 120 135
Time (min)

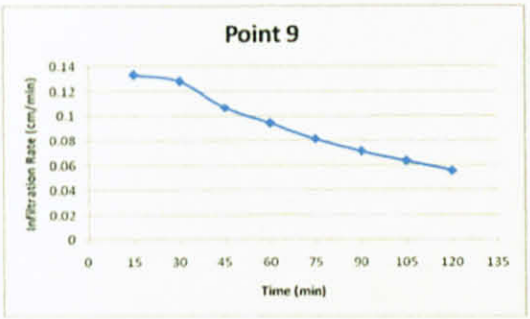

Point 4
Infiltration Rate (cm/min)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 15 30 45 60 75 90 105 120 135
Time (min)

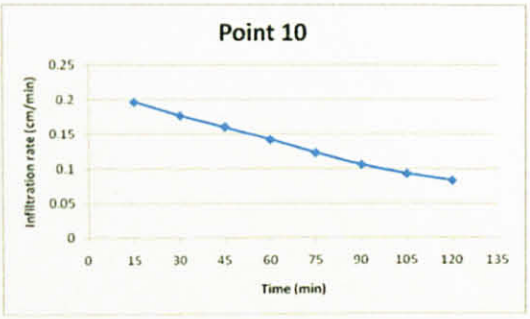

Point 5
Infiltration Rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 15 30 45 60 75 90 105 120 135
Time (min)

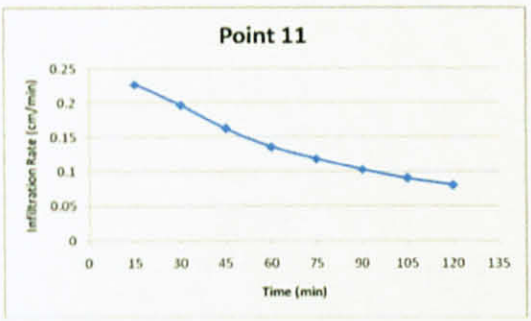

Point 6
Infiltration rate (cm/min)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 15 30 45 60 75 90 105 120 135
Time (min)

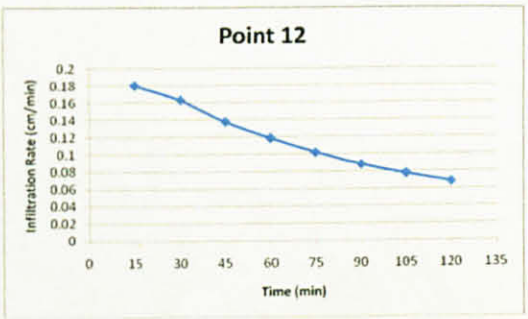

Point 7
Infiltration rate (cm/min)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 15 30 45 60 75 90 105 120 135
Time (min)

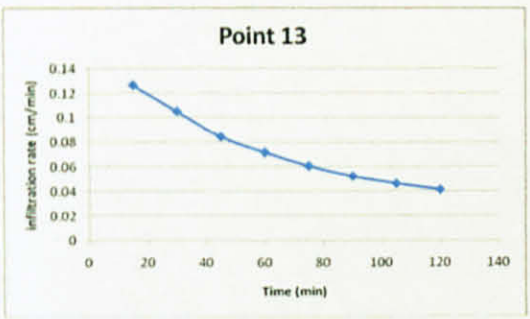

Point 8
Infiltration rate(cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 15 30 45 60 75 90 105 120 135
Time (min)

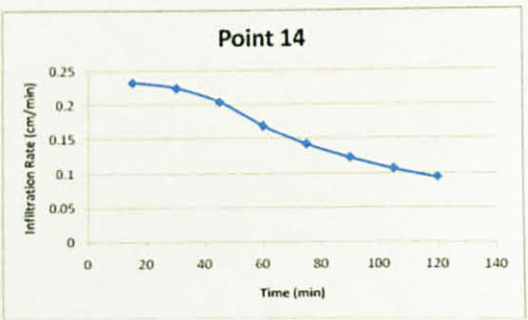

Point 9
Infiltration Rate (cm/min)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 15 30 45 60 75 90 105 120 135
Time (min)

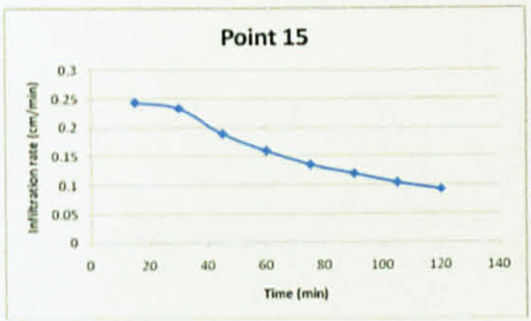

Point 10
Infiltration rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 15 30 45 60 75 90 105 120 135
Time (min)

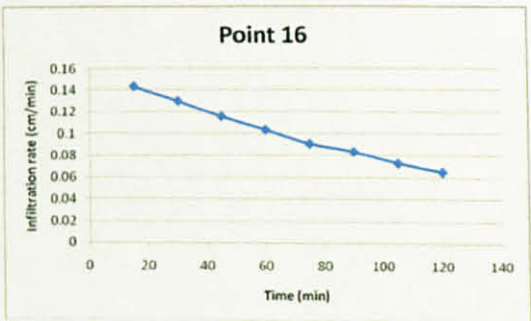

Point 11
Infiltration Rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 15 30 45 60 75 90 105 120 135
Time (min)

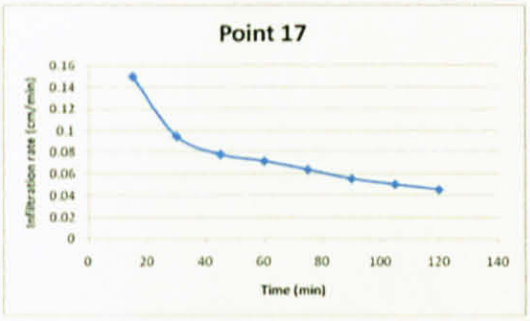

Point 12
Infiltration Rate (cm/min)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 15 30 45 60 75 90 105 120 135
Time (min)

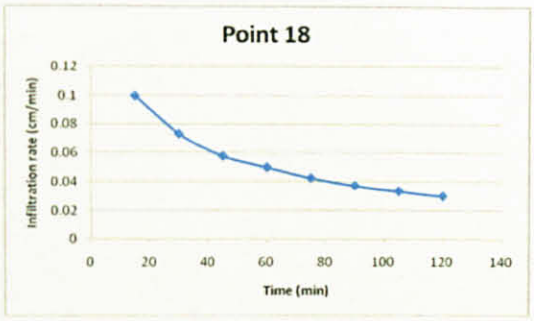

Point 13
Infiltration rate (cm/min)
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

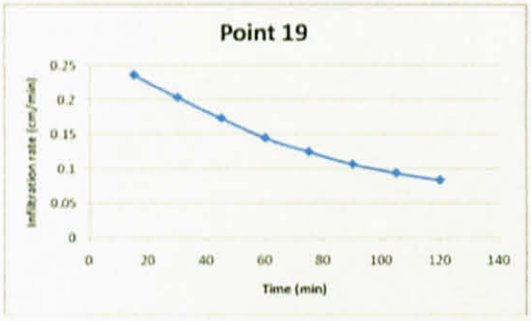

Point 14
Infiltration Rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

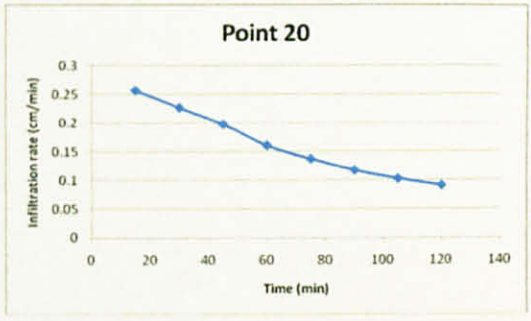

Point 15
Infiltration rate (cm/min)
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

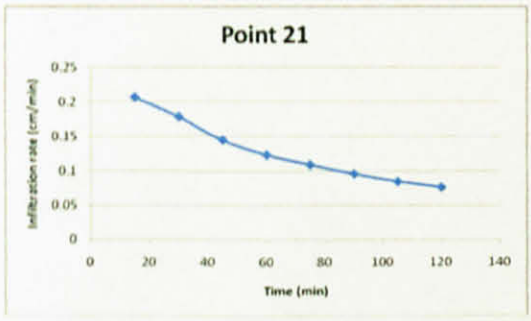

Point 16
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

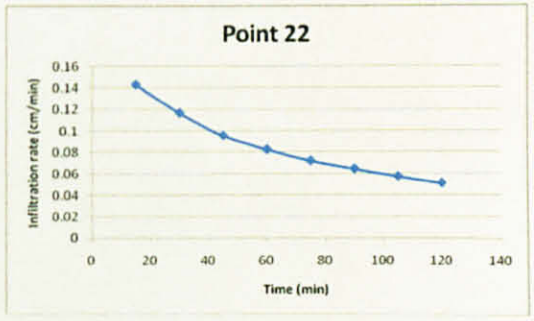

Point 17
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

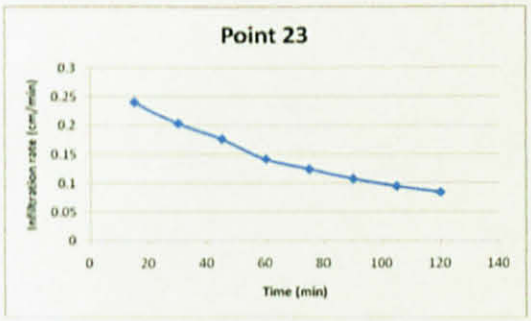

Point 18
Infiltration rate (cm/min)
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

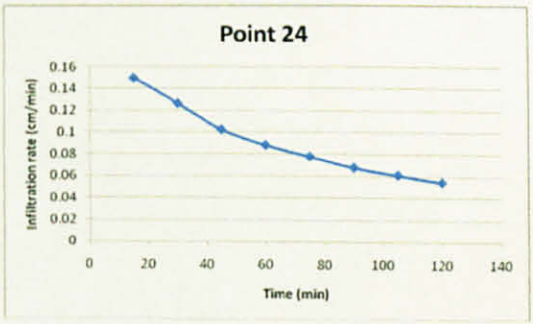

Point 19
Infiltration rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

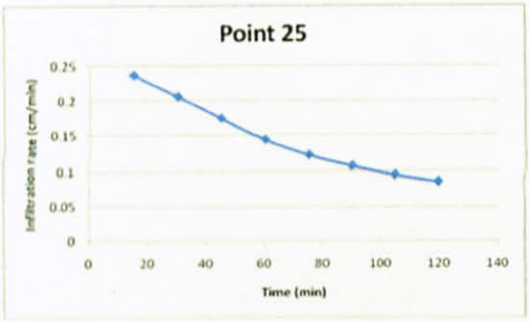

Point 20
Infiltration rate (cm/min)
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

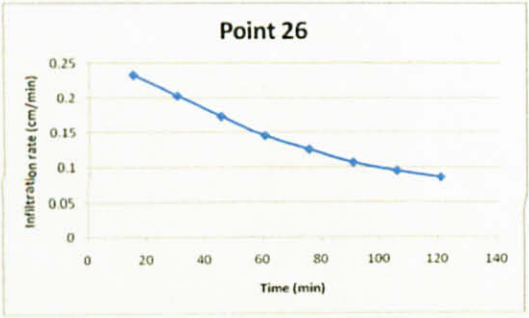

Point 21
Infiltration rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

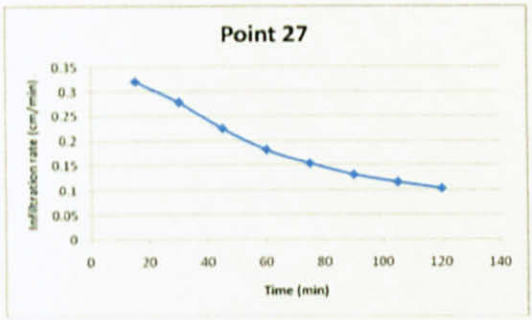

Point 22
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

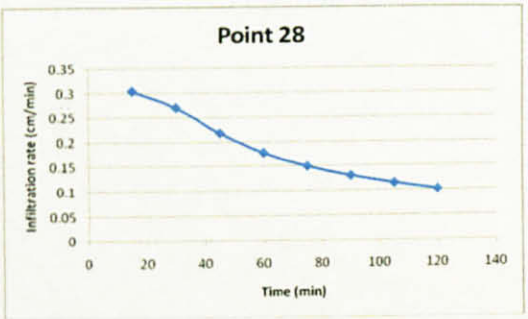

Point 23
Infiltration rate (cm/min)
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

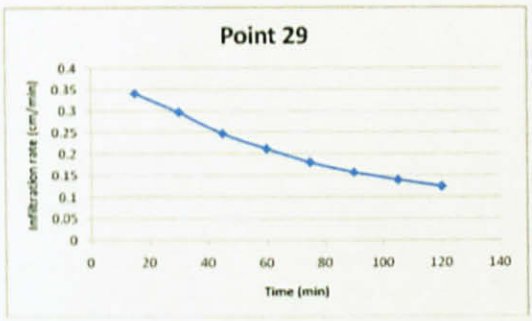

Point 24
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

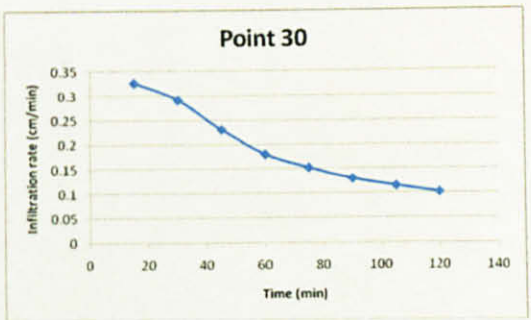

Point 25
Infiltration rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

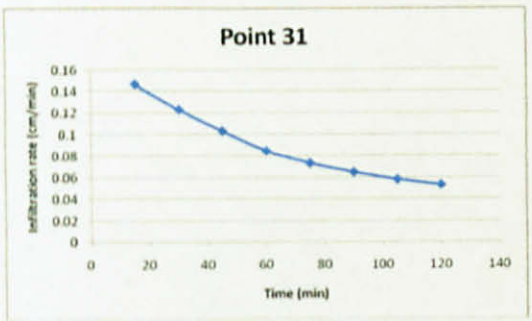

Point 26
Infiltration rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

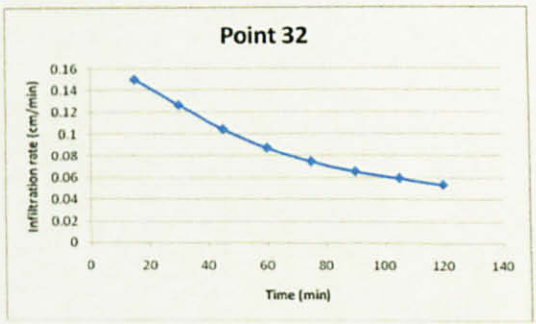

Point 27
Infiltration rate (cm/min)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

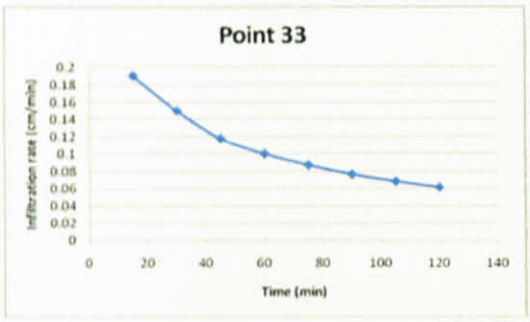

Point 28
Infiltration rate (cm/min)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

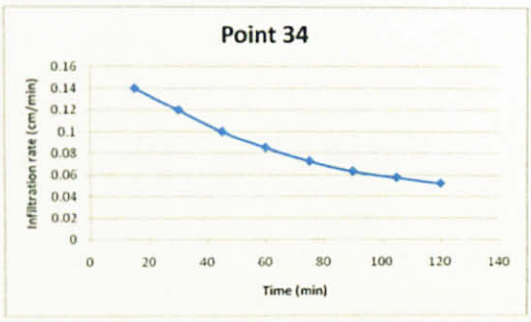

Point 29
Infiltration rate (cm/min)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

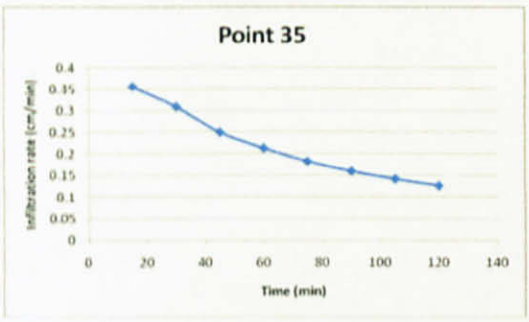

Point 30
Infiltration rate (cm/min)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

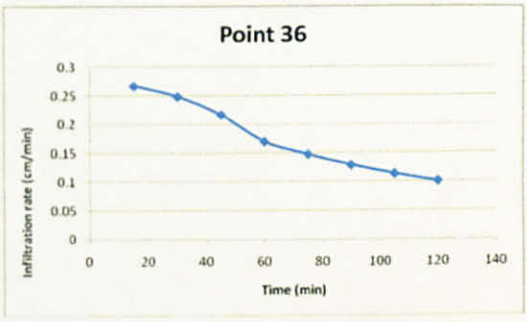

Point 31
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

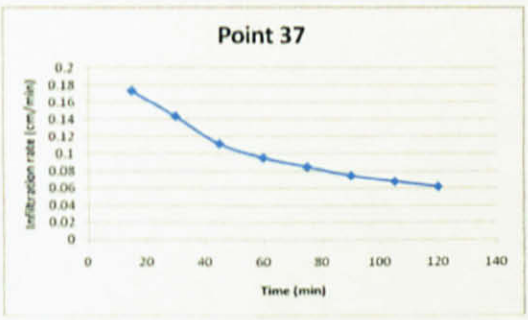

Point 32
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

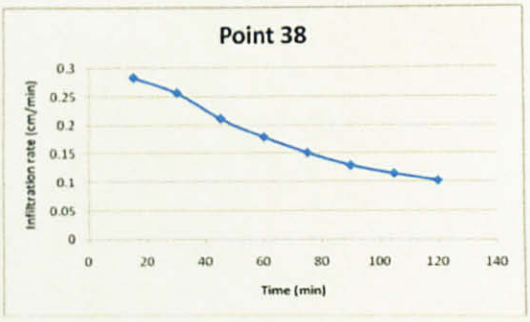

Point 33
Infiltration rate (cm/min)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

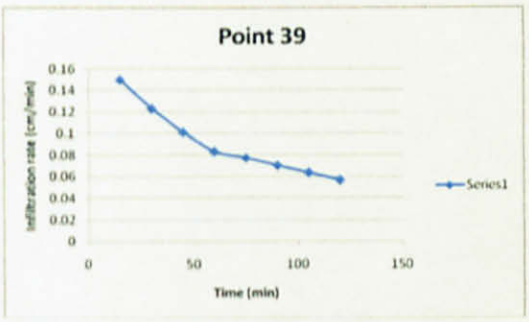

Point 34
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

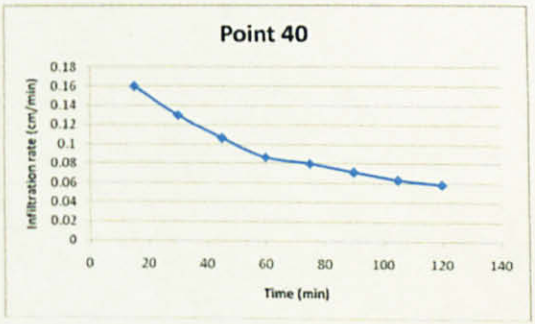

Point 35
Infiltration rate (cm/min)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

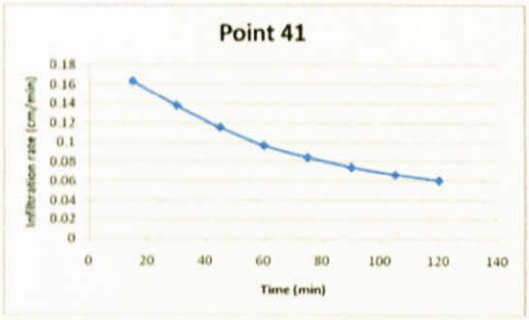

Point 36
Infiltration rate (cm/min)
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

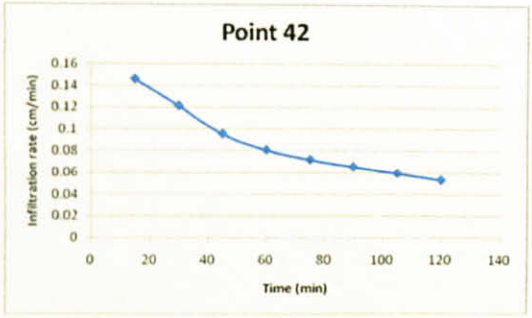

Point 37
Infiltration rate (cm/min)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

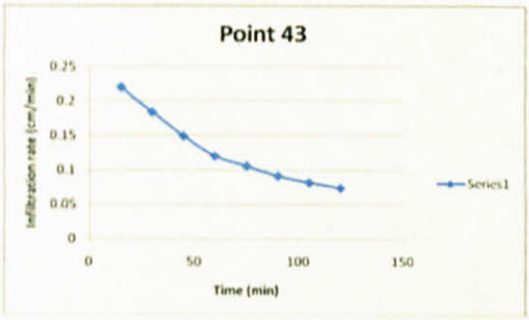

Point 38
Infiltration rate (cm/min)
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)

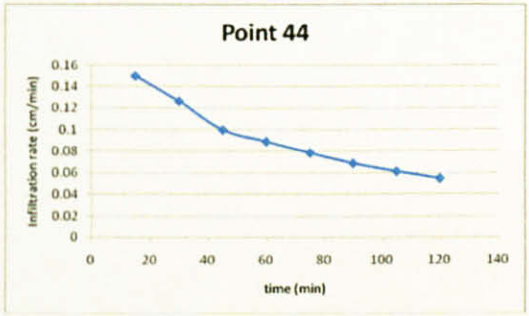

Point 39
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 50 100 150
Time (min)
Series1

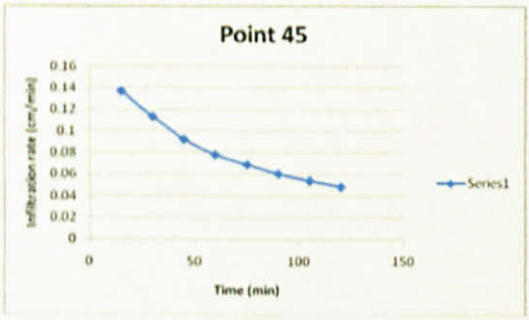

Point 40
Infiltration rate (cm/min)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

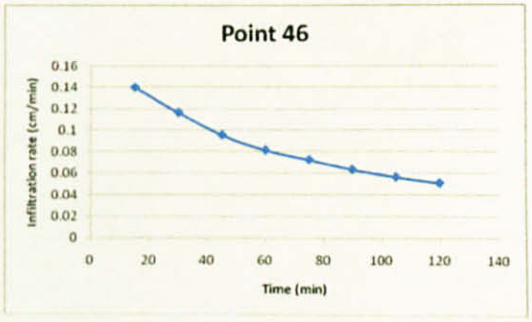

Point 41
Infiltration rate (cm/min)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

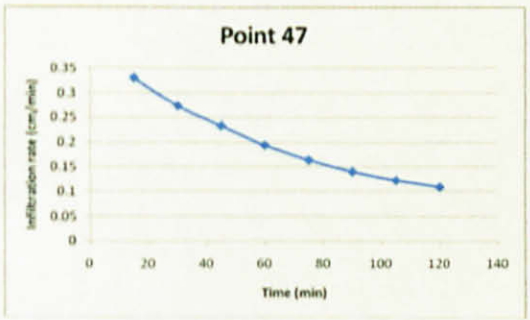

Point 42
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)

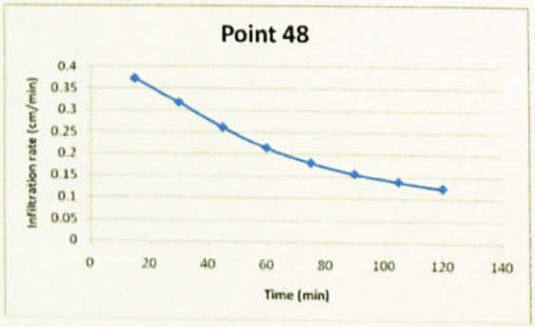

Point 43
Infiltration rate (cm/min)
0.25
0.2
0.15
0.1
0.05
0
0 50 100 150
Time (min)
Series1

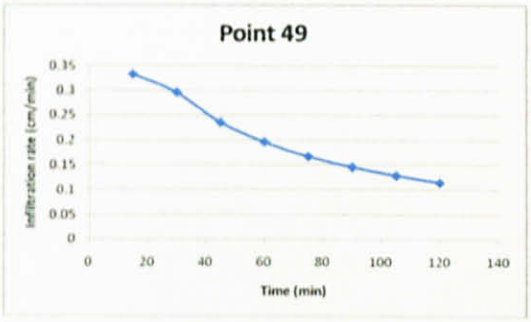

Point 44
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
time (min)


Point 45
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 50 100 150
Time (min)
Series1


Point 46
Infiltration rate (cm/min)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0 20 40 60 80 100 120 140
Time (min)


Point 47
Infiltration rate (cm/min)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)


Point 48
Infiltration rate (cm/min)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0 20 40 60 80 100 120 140
Time (min)


Point 49
Infiltration rate (cm/min)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
140
Time (min)

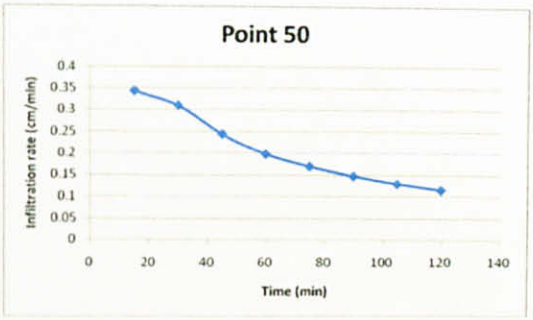

Point 50
Infiltration rate (cm/min)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
140
Time (min)

Figure 1: GPS (Global Positioning System)

Figure 2: At a Reference Point

Figure 3 : The author while setting the GPS

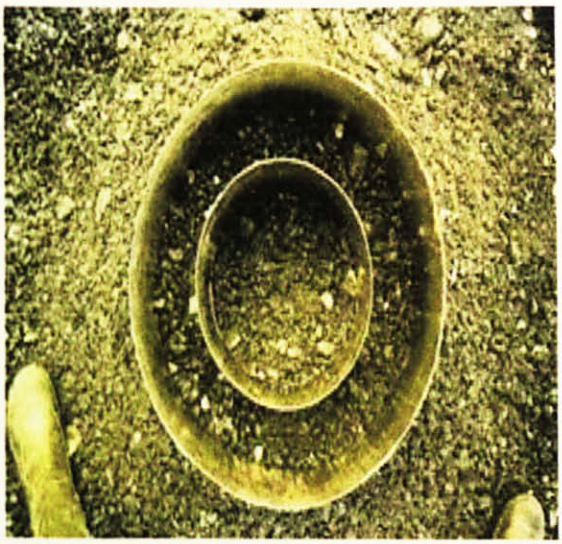


Figure 4: Double Ring Infiltrometer