

**SOIL INFILTRATION VARIABILITY MAPPING: KUALA LUMPUR**

**By**

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This dissertation is submitted to

**UNIVERSITI SAINS MALAYSIA**

as partial fulfillment of requirements for the degree of

**BACHELOR of ENGINEERING (CIVIL ENGINEERING)**

**School of Civil Engineering  
Universiti Science Malaysia**

**March 2006**

## **ABSTRAK**

Kerajaan telah telah membangunkan Manual Saliran Mesra Alam (MSMA) untuk jurutera-jurutera rekabentuk sejak tahun 1990-an. MSMA memperkenalkan kaedah baru dalam menangani masalah air larian dengan mengawal air larian di peringkat awal. Keputusannya boleh mengawal kualiti dan kuantiti air secara efektif. Kaedah penyusupan ialah cara yang boleh merealisasikan objektif MSMA. Projek ini memaparkan variasi kadar penyusupan di Kuala Lumpur. Kajian ini dijalankan dengan berpandukan 55 buah laporan kajian tanah tanpa menjalankan eksperimen dijalankan di tapak. Borehole dan ujian makmal yang dicatatkan dalam laporan dirujuk untuk menklasifikasikan jenis tanah di tapak. Setelah itu, kadar penyusupan ditentukan berpandu kepada jadual kajian oleh USDA. Peta penyusupan dibangunkan dengan bantuan program SURFER. Dalam keputusan yang diperolehi, beberapa tapak kajian dijangka sangat sesuai untuk dijadikan tapak untuk mengaplikasikan kaedah penyusupan. Tempat-tempat ini ialah National Theatre, Hospital Kuala Lumpur, Brickfield HQ, DBKL club, Jalan Bukit Bintang, Cheras Batu 2 ½. Satu kajian statistic dijalankan dengan program GS+ untuk menentukan variasi data yang digunakan. Dalam kajian ini, nilai-nilai penyusupan yang direkod tidak menunjukkan nilai sebenar di tapak kerana keputusan adalah berpandu kepada jadual yang dibangunkan oleh USDA (US department of Agriculture).

## **ABSTRACT**

The government has developed new guidelines to designer of stormwater management since 1990's. The Malaysian Stormwater Management Manual (MSMA) introduced new method in controlling rainfall runoff by source control. The result is a controlled runoff considering both quantity and quality. Infiltration is an important tool in visualizing the objectives of MSMA. This study addresses the spatial variability of infiltration rates in the area of Kuala Lumpur. The study is base on site investigation reports on 55 locations, which means this is an off-site study. Borehole log and laboratory results provide data in soil type decision making. The steady state infiltration rate is base on USDA study recommendations. Contour maps is then prepared by using SURFER surface mapping programme. The infiltration variability map shows a few possible potential infiltration practicing area, namely National Theatre, Hospital Kuala Lumpur, Bricksfield HQ, DBKL club, Jalan Bukit Bintang, Cheras Batu 2 ½. A geostatistical analysis was performed to investigate spatial autocorrelation of infiltration data using GS+ software. This study do not provide exact value of infiltration contour. It is a result of study references and recommendation value.

## ACKNOWLEDGEMENTS

I would like to express my heartfelt gratitude to Associate Professor Dr. Nor Azazi Zakaria for spending precious time in guiding me throughout the process of completing my research. I would also thank Associate Professor Dr. Aminuddin Ab. Ghani as my second supervisor, who has shown utmost professionalism. Special thanks to all staffs of River Engineering & Urban Drainage Research Center (REDAC), especially En. Mohd Fazly Yusof as my facilitator.

Sincere thanks to Dr. Redzaur, who has given me help in this project. Not to forget, I would thank Goh Kim Meng, my dear friend who had been giving me guidance on the application of SURFER programme.

Special dedication to my family and my darling for giving me support. I feel grateful for all the encouragement and understanding during the process. All efforts will always be remembered and cherished.

*Chan Shen Sam*

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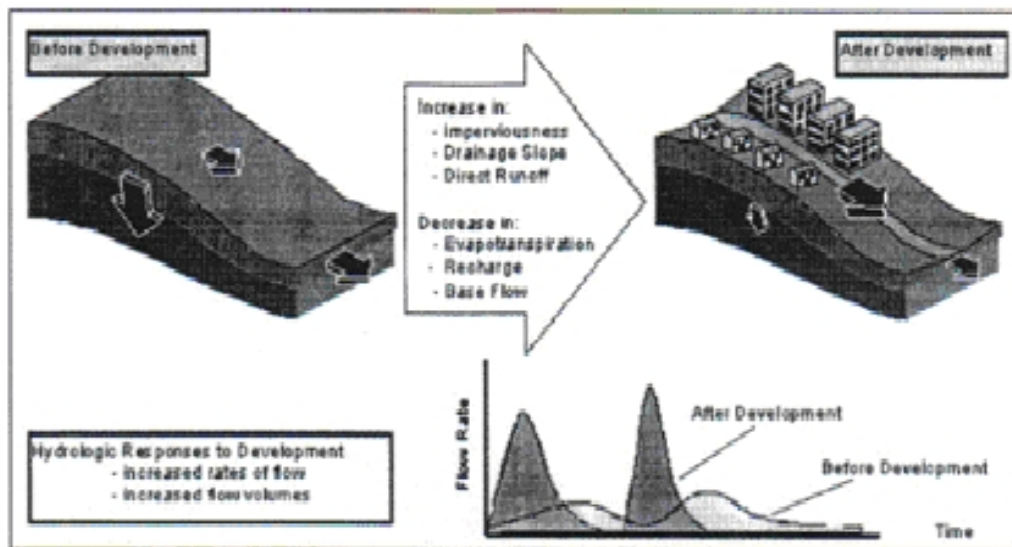
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# 1.0 INTRODUCTION

## 1.1 BACKGROUND

Rapid development in our country has caused much changes to soil engineering properties. In this case of study, soil infiltration rate is pointed out. Undeveloped land has very little surface runoff, most of the rainfall soaks into the topsoil or evapotranspirates or migrates slowly through the soil mantle, as interflow to the stream, lakes or estuary (Roesner. et., 2001). As a result, rainfall effects are averaged out over a long period of time (Figure 1.1).



**Figure 1.1: Impacts of Urbanization on Hydrology**  
(Roesner et al., 2001)

While developments keep going on, more lands are covered with impervious surface (e.g. roads, sidewalks, buildings). Most of the rainfall will become surface runoff. This will change the hydrological cycle. The after development runoff peak will change dramatically, which can reach more than twice the value of pre-

development runoff. The Department of Irrigation and Drainage (DID) has introduced a new manual since January 2001. The control at source, as been mentioned in MSMA is used to try to restore balance by retention or detention methods, such as balancing chambers, dry ponds, wet ponds and infiltration into soil.

Sustainable stormwater management requires that designer address not just peak rates but the increased volume of runoff, and that the attempt to mimic the natural hydrologic balance that existed before development. Design approaches and infiltration methods are the most effective means to do this, but require a change in approach to site development. (Michele C. Adams et. Al., 2001)

For a successful control at source design, soil should be permeable and unsaturated (CIRIA, 1996). It is thus at the very first stage to develop a infiltration map for the designated area for the purpose of selecting the best locations for infiltration based source control design.

## **1.2 OBJECTIVES OF STUDY**

1. To generate geotechnical and hydrological data for the study area.
2. Classification of soil types base on selected data.
3. Produce an infiltration map for the area of Kuala Lumpur.
4. To discuss the reliability and accuracy of this method.

## **1.3 STUDY AREA**

The study area is within the area of Kuala Lumpur (K.L.). Kuala Lumpur is situated midway along the west coast of Peninsular Malaysia, at the confluence of the Klang and Gombak rivers. It is approximately 35 km from the coast and sits at

the centre of the Peninsula's extensive and modern transportation network. Most of the areas of K.L. are developed, especially at the city center, (KLCC) and Sentul. Apart from recreational parks, golf clubs and lakes or ponds, surface impermeability can reach 90% in these area. It is therefore of great importance to study the subsoil of these area so that if any runoff control need to be set up, a better decision can be made.

Position of Site:	Latitude	-3°8' N
	Longitude	-101°42' E
Area :	243.65 km <sup>2</sup>	
Population :	City	- 1.48 million (2004)
	Metropolitan	- 4.20 million (2004)



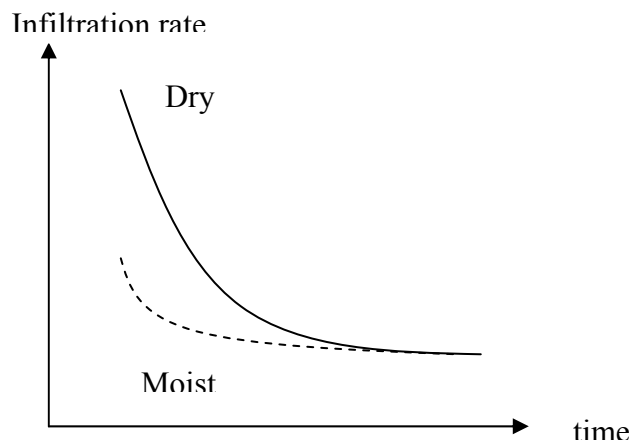
**Figure 1.2: Location of the study area (Kuala Lumpur)**

## 2.0 LITERATURE REVIEW

### 2.1 INFILTRATION

Infiltration is a natural process which water seeps through the soil. Water is able to infiltrate soil particles because soil particles contain certain amounts of voids. Infiltration plays an important role in the runoff process by affecting the timing, distribution and magnitude of the runoff. Infiltration also contributes to natural groundwater recharge. (Dr. Rezaur, 2004).

The infiltration rate is the velocity or speed at which water enters into the soil. Is is usually measured in inches/hour or mm/hour. 5 mm/hour infiltration rate means in an hour, water will reach until 5 mm below ground level. Figure 2.1 shows the ideal infiltration rate for dry and moist soil. Infiltration is measured in 2 stage, initial infiltration rate and final infiltration rate. Initial infiltration rate for moist soil is lower compare to dry soil because water fills part of voids in the soil particles, hence water is not easily seep through. At a stage, infiltration rate will be the same when the initial dry soil become as saturated as the moist soil.



**Figure 2.1: Ideal infiltration curves**

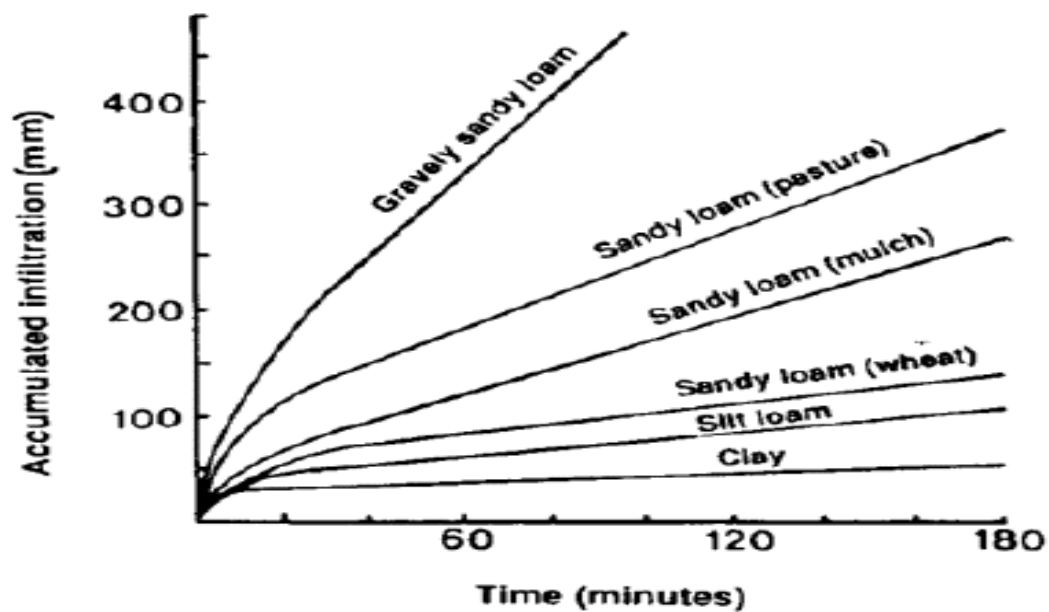
## **2.2 FACTORS AFFECTING INFILTRATION**

The important factors affecting infiltration process is:

### **2.2.1 Characteristic of soil**

The type of soil, soil texture and soil structure are the important characteristics that influence infiltration rate. (Morgan and Rickson, 1986). The soil texture is an important factor in determining the water holding characteristics of the soil and therefore the infiltration capacity of a soil layer. As the diameters of the soil particles increase, the pore spaces increases in size, which increases the capacity of the soil to pass and store infiltrating water through the soil profile. (Mc. Cuen, 1998)

A soil with good under-drainage would have a higher infiltration capacity. Compaction had dramatic effects on infiltration rates through sandy soils, while compaction was generally just as important as soil moisture at sites with predominately clay rich soils. Moisture levels had little effect on infiltration rates at sandy sites. (Robert Pitt, et. Al., 2000). Land use has a significant effect on infiltration capacity. For example, a forest soil rich in organic matter will have a much higher value of infiltration capacity under identical conditions than the same soil in an urban area where it is subjected to compaction.



**Figure 2.2: Infiltration curves for a variety of soil textures**  
(Source: McLaren and Cameron, 1990)

**Table 2.1 : Soil infiltration rates and Water Storage Capacities**

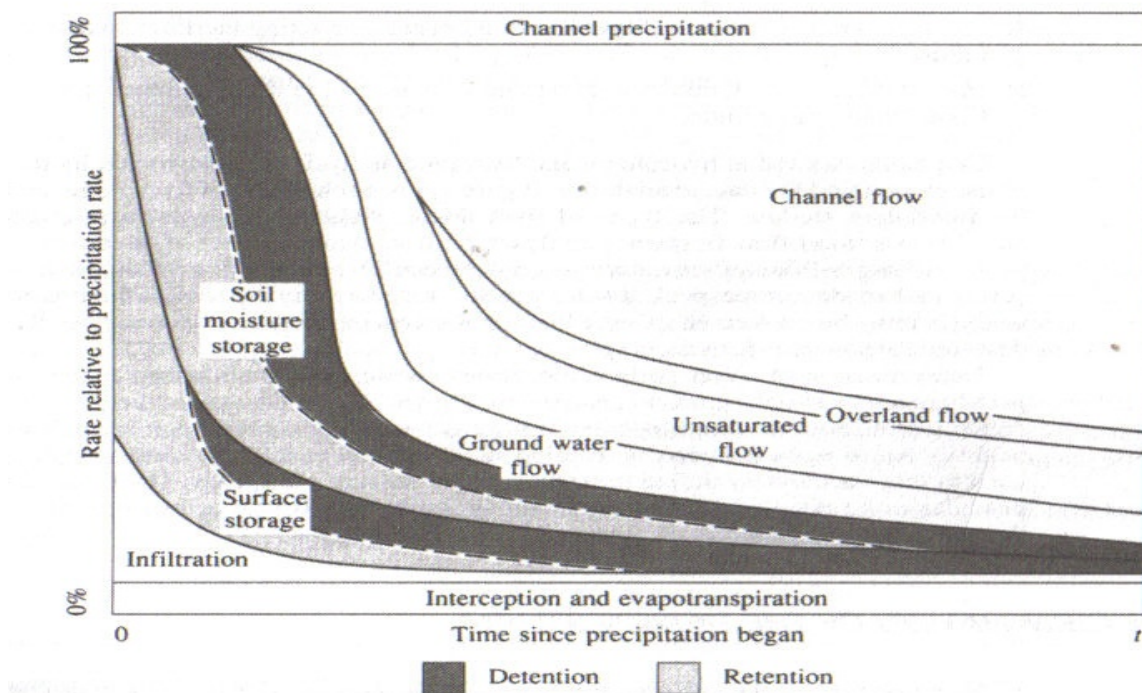
(Source: Maryland standards and Specification for Stormwater Management  
Infiltration Practices, 1984)

Soil Group	Infiltration rate (mm/hour)	Water Storage Capacity (in. of water)
Sand, open-structured	210	0.35
Loamy sand	61	0.31
Sandy loam	26	0.25
Loam	13	0.19
Silty loam	7	
Sandy clay loam	4	
Clay loam	2	
Silty clay loam	1.5	
Sandy Clay	1.2	
Silty Clay	1.0	
Clay	0.5	



### 2.2.2 Soil surface condition

At the soil surface, the impact of raindrops causes the fines in the soils to displace and this in turn can clog the pore space in the surface. This is an important factor affecting infiltration capacity. A surface covered with grass and other vegetation also greatly influence the value of infiltration. Infiltration rate is influenced by top soil. Infiltration rate take place most rapidly when the water is first applied to the soil. But when the top soil becomes saturated, the swelling of the clay is caused and hence, the infiltration becomes constant (Donen and Wescot, 1988)



**Figure 2.3 : Disposal of precipitation during a storm**

(Resource : Chow, et al., 1988)

### 2.2.3 Fluid characteristic

Water infiltrating into the soil will have many impurities, both in solution and in suspension. The turbidity of water, especially elements such as clay and colloidal content block the fine pores and reduce its infiltration capacity. Dissolved salt in rainwater can affect soil structure and in turn affect infiltration rate. Temperature is also a factor influencing infiltration because the viscosity of infiltrating fluid depends on temperature.

## 2.3 INFILTRATION ANALYSIS

There are 3 widely used and accepted infiltration equations (Green-Ampt, Horton and SCS). (Larry W. Mays, 2004). However, in this study, Horton's Equation will be used as the analytical tool for infiltration. One of the oldest and most widely used infiltration equations was developed by Robert Elmer Horton (1939). This equation was used in this study to compare the measured equation parameters with published literature values. The equation is as follows:

$$i(t) = i_f + (i_0 - i_f)e^{-\gamma t} \quad (2.1)$$

$$I(t) = i_f t + \frac{1}{\gamma}(i_0 - i_f)(1 - e^{-\gamma t}) \quad (2.2)$$

where  $i_0$  and  $i_f$  are the presumed initial and final infiltration rates, and  $\gamma$  is an empirical constant. It is readily seen that  $I(t)$  is non-zero as  $t$  approaches infinity Parlange and Haverkamp (1989), in their comparison study of various empirical

infiltration equations, found the performance of Horton's equation to be inferior to that of Kostiakov's equation.

In a more simplified manner:-

$$f = f_c + (f_o - f_c) e^{-kt} \quad (2.3)$$

where:

$f$  = infiltration capacity (in/hr),

$f_o$  = initial infiltration capacity (in/hr),

$f_c$  = final infiltration capacity (in/hr),

$k$  = empirical constant ( $hr^{-1}$ )

This equation assumes that the rainfall intensity is greater than the infiltration capacity at all times and that the infiltration rate decreases with time (Bedient and Huber 1992). The capacity of the soil decreases as the time of the storm increases because the pores in the soil become saturated with water and do not allow water to continuously infiltrate through the surface (Bedient and Huber 1992). The Horton equation's major drawback is that it does not consider storage availability in the soil after varying amounts of infiltration have occurred, but only considers infiltration as a function of time (Akan 1993).

It is recommended that  $f_c$ ,  $f_o$ , and  $k$  all be obtained through field data, but they are rarely measured locally. More commonly, they are determined through calibration of relatively complex stormwater drainage models, or by using values published in the literature. The use of published values in place of reliable field data is the cause of much concern by many (Akan 1993). The following lists include commonly used Horton infiltration parameter values

**Table 2.2 : Commonly used Horton infiltration parameter values****(Source: Akan 1993)**

Soil Type		f <sub>o</sub> (in/hr)
Dry sandy soils with little to no vegetation		5
Dry loam soils with little to no vegetation		3
Dry clay soils with little to no vegetation		1
Dry sandy soils with dense vegetation		10
Dry loam soils with dense vegetation		6
Dry clay soils with dense vegetation		2
Moist sandy soils with little to no vegetation		1.7
Moist loam soils with little to no vegetation		1
Moist clay soils with little to no vegetation		0.3
Moist sandy soils with dense vegetation		3.3
Moist loam soils with dense vegetation		2
Moist clay soils with dense vegetation		0.7
Soil Type	f <sub>c</sub> mm/hr (in/hr)	k (1/min)
Clay loam, silty clay loams	0–1.3 (0–0.05)	0.069
Sandy clay loam	1.3–3.8 (0.05–0.15)	0.069
Silt loam, loam	3.8–7.6 (0.15–0.30)	0.069
Sand, loamy sand, sandy loams	7.6–11.4 (0.30–0.45)	0.069

The  $k$  values (Table 2.4) are not divided into categories, with only a single value used for all conditions (Akan 1993). The units of the  $k$  value are listed as 1/min instead of 1/hr because the time steps commonly used in urban hydrology are measured in minutes, while the infiltration rates are commonly measured in units of inches per

hour. These values will be compared to the measured values obtained during this study by calibrating the Horton equation.

**Table 2.3 : Permeability Indication Ratio**

**Resource : Mc Cuen, 1998**

<b>Ratio (<math>F_0/F_c</math>)</b>	<b>Permeability Capacity</b>
>5	High Permeability
3-5	Moderate Permeability
<3	Low Permeability

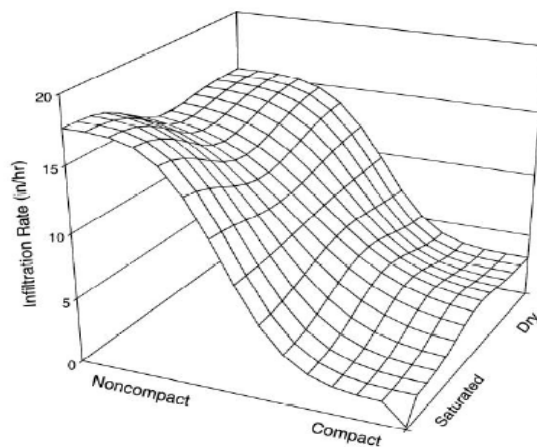
#### **2.4 SAMPLE CASE STUDY: FIELD RESEARCH at SINDH AGRICULTURE UNIVERSITY TANDOJAM, PAKISTAN**

The field research was conducted at Sindh Agriculture University Tandojam, Pakistan. The treatments were soil compactions (uncompacted, 5 and 10 times compacted soil) and their effect on water infiltration rate in silt loam soils. It was observed that infiltration rate was higher during initial irrigation application, but, gradually reduced and became constant when the soil was saturated. The bulk density of uncompacted, 5 and 10 times compacted soils was recorded as 1.13 to 1.20, 1.19 to 1.29 and 1.19 to 1.32 g/cc, respectively at 0 to 90 cm soil profile. The infiltration rate was higher (17.10 mm/hr) in the uncompacted soil compared to those 5 and 10 times compacted soils (13.89 and 9.78 mm/hr.) respectively. The increased infiltration rate in the uncompacted soil was mainly due to soil porous medium having low bulk density values.

**Table 2.4 : Compacted silt loam soil: field research at Sindh Agriculture University  
Tandojam, Pakistan**

**(Resource: Asian journal of Plant Sciences, volume 1 no 1 3-4, 2002)**

Nature of soil	Test No.	Infiltration Rate (mm/hr)	Average
Uncompacted soil	1	17.84	17.10
	2	16.42	
	3	17.05	
5 times compacted soil	1	13.89	13.89
	2	13.42	
	3	14.36	
10 times compacted soil	1	9.78	9.78
	2	10.42	
	3	9.15	



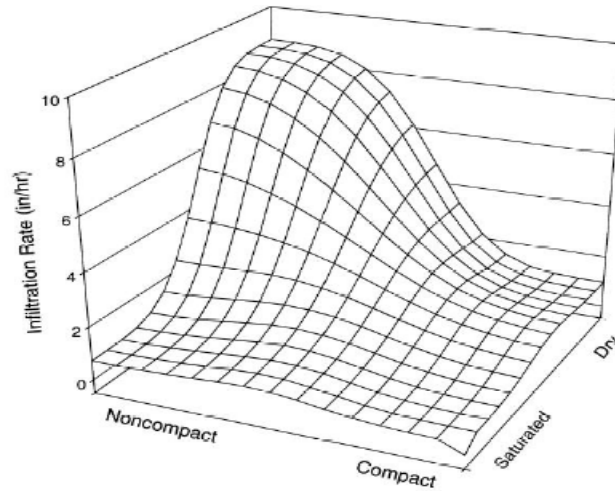
**Figure 2.4 : Three dimensional plot of infiltration rates for sandy soils**

**(Resource: Asian journal of Plant Sciences, volume 1 no 1 3-4, 2002)**

**Table 2.5 : Observed and published Horton equation parameter values for sandy soils**  
**(Resource: Asian journal of Plant Sciences, volume 1 no 1 3-4, 2002)**

	$f_0$ mm/hr (in/hr)		$f_0$ mm/hr (in/hr)		$k$ (1/min)	
	mean	range	mean	range	mean	Range
Observed noncompacted-sandy soils	990 (39)	110-3710 (4.2-146)	380 (15)	10-640 (0.4-25)	9.6	1.0-33
Observed compacted-sandy soils	380 (15)	3-2200 (0.1-86)	46 (1.8)	3-240 (0.1-9.5)	11	1.8-37
Published values		43-250 (1.7-10)		7.6-11 (0.30-0.45)		0.069

Figure 2.5 and Table 2.8 shows the observed infiltration rates and the fitted Horton equation parameter values for compacted-sandy soils. The observed rates are significantly less than for the above non-compacted sandy soils. The effect of compaction on sandy soils is very large, reducing the infiltration rates by between 5 and 10 times. Some initial rates were very large, but the rates decreased quickly with time. After 20 to 30 minutes, they are all within about 0 to 500 mm/hr (0 to 20 in/hr), with most of the 39 observations less than 125 mm/hr (5 in/hr).



**Figure 2.5 : Three dimensional plot of infiltration rates for clayey soils**

**(Resource: Asian journal of Plant Sciences, volume 1 no 1 3-4, 2002)**

**Table 2.6 : Observed and published Horton equation parameter values for clayey soils**

**(Resource: Asian journal of Plant Sciences, volume 1 no 1 3-4, 2002)**

	$f_0$		$f_s$		$k$ (1/min)	
	mean	range	mean	range	mean	range
Observed dry-noncompacted-clayey soils	460 (18)	64-1500 (2.5-58)	170 (5.6)	3-610 (0.1-24)	8.8	-6.2-19
Published values for dry-clayey soils		30-50 1-2		0-1 0-0.05	0.069	
Observed for all other clayey soils (compacted and dry, plus all saturated conditions)	86 (3.4)	0-1200 (0-48)	10 (0.4)	-15-170 (-0.6-6.7)	5.6	0-46
Published values for saturated-clayey soils		8-18 (0.3-0.7)		0-1 (0-0.05)	0.069	

Figure 2.6 is a similar plot for dry-non-compacted-clayey soils which was the highest infiltration rate by category for clayey soils. No significant change in infiltration rates were seen as a function of time, with all test average values within the range of 8 to 500 mm/hr (0.3 to 20 in/hr) and a mean rate of about 230 mm/hr (9 in/hr) for all 18 tests. Figure 3-6 shows the observed test results for the other clayey soils (dry and compact, and all saturated conditions).



These rates were the lowest observed. Some initial values of the saturated non-compacted-clayey soils were greater than later values, although most of the 60 sets of test data indicated infiltration rates were within a relatively narrow range of less than 125 mm/hr (5 in/hr). Table 2.9 shows the observed Horton equation parameters as compared to published values. The mean clayey-soil rates of infiltration were all greater than the published values, although the compacted and saturated clays were much closer to the published values than the observed rates of dry clayey soil.

These analyses show that compaction had the greatest effect on infiltration rates in sandy soils, with little detrimental effects associated with soil moisture. Compaction and moisture affected clayey soils. Compaction had about the same effect as moisture on clayey soils, with saturated-compacted-clayey soils having the least effective infiltration

The observed infiltration rates differed greatly from the published values. Typically, published values reflected moisture effects to the Horton infiltration equation and the equation coefficients, while the observations indicated very small effects associated with moisture for sandy soils, and very large effects associated with compaction. The constant-final-infiltration rates were larger than typically assumed, with infiltration rates for non-compacted, sandy soils of about 350 mm/hr (14 in/hr), ranging from about 125 to 635 mm/hr (5 to 25 in/hr) during the tests. The comparable published rates were less than 25 mm/hr (1 in/hr). The infiltration rates leveled-off to the constant-final values after about 30 to 45 min.

## **3.0 METHODOLOGY**

### **3.1 ESTABLISHING INFILTRATION DATA LOCATIONS**

This study is conducted on the area of Kuala Lumpur. The area covering 240 km<sup>2</sup>. A GPS map from the National Mapping Malaysia (NMM) is utilized for the identification of borehole log testing point. To do this, every borehole report location is studied and match with the exact points on the map. Every identified test point is recorded for later analysis.

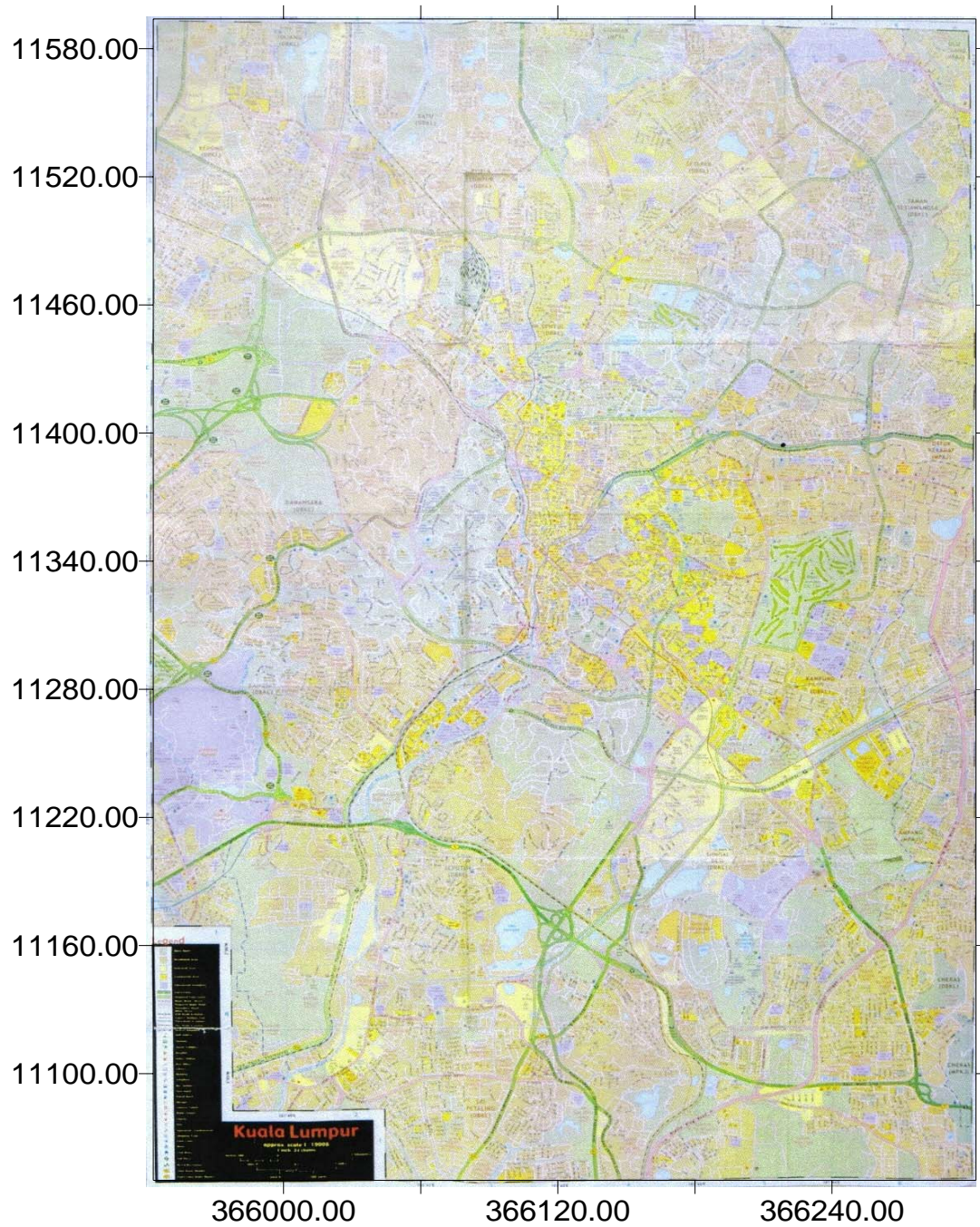
### **3.2 BASE MAP**

A detailed Kuala Lumpur map is used as a base map (Figure 3.1). Map is scanned into computer, scaling are created using SURFER. Study area is compounded by border points 101°39'03"E, 101°45'03"E, 3°04'10"N and 3°13'14"N.

### **3.3 SOIL DATA ANALYSIS**

From Dewan Bandaraya Kuala Lumpur (DBKL), 110 soil investigation reports are analyzed. For the fulfillment of data analysis, all reports should have the following data required.

- (i) location of testing
- (ii) borehole testing
- (iii) laboratory testing – sieve analysis



**Figure 3.1 : Kuala Lumpur base map**

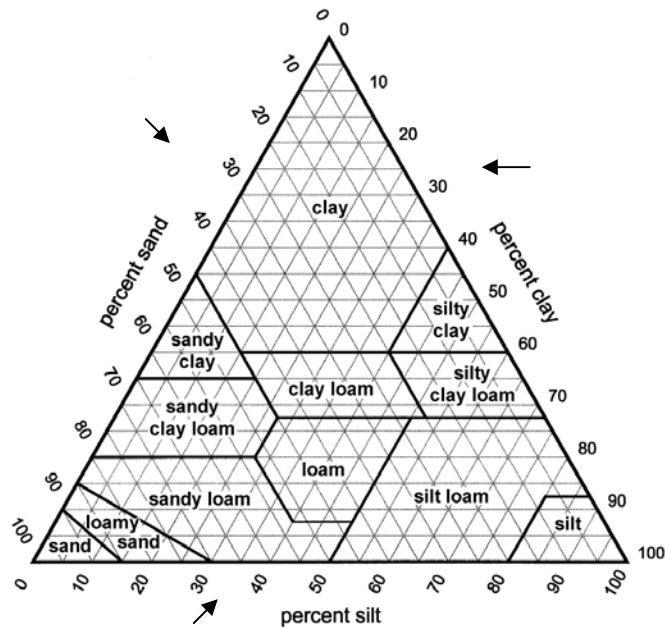
### **3.3.1 SOIL CLASSIFICATION**

In this study, the U.S. Department of Agriculture (USDA) Textural Triangle (Figure 3.2) is used to classified soil type, base on laboratory testing data (sieve analysis). Soil types are classified from the percentages of sand, silt, and clay. Percentage of each type of soil particles is acquired from the laboratory test in soil investigation report. Using the USDA soil textural triangle, read each soil type following the assigned arrow to identified soil type. For infiltration purpose, only the first 5 m soil type is analyzed.

### **3.3.2 BOREHOLE LOG**

Borehole log shows clear soil strata in a rough sketch after on-site investigation. Every borehole log is examine to illustrate a basic soil layer for surface soil layer, as only the first 5 m layer is considered. The dominant soil in the top 5 m layer will be considered as the soil type selected. The most ideal borehole log will then be selected. The soil profile is verified with the USDA textural triangle as shown in Figure 3.2. It is likely that visual description of borehole report differ from laboratory test result. As laboratory test result is more reliable, priority selection will be base on laboratory result. However, few reports do not execute laboratory test. In such case, soil type is classified by visual description.

Another important data from the borehole log report is the final water table. It is not analyzed in this study but this parameter provides important design requirement for future planning.



**Figure 3.2 : USDA Soils Textural Triangle**

### 3.4 MAP DEVELOPMENT

In creating a map, a surface mapping system is needed. In this study, SURFER 6.04 is utilized as a mapping tool. This software is created by Golden Software. 3 important parameters are neatly arranged, as shown in the result:-

- (i) latitude
- (ii) longitude
- (iii) infiltration rate

All results are firstly recorded in excel spreadsheet. Data in excel spreadsheet is later post to SURFER worksheet for further analysis.

### 3.4.1 SURFER 6.0

SURFER is a powerful tool for surface mapping, along with a few supporting software programmes, it provides detailed mapping with statistical analysis. Supporting tools like CorelDraw and GS+ helps SURFER to create a more informative map. The following steps explain how a infiltration-contour map is created.

#### 3.4.1.1 CREATING DATA FILE

- With your Excel worksheet open, start Surfer
- Use the *File ... Worksheet* menu item to open a Surfer worksheet
- Switch to Excel
- Highlight an entire column of data (click on the letter at the top of the worksheet).

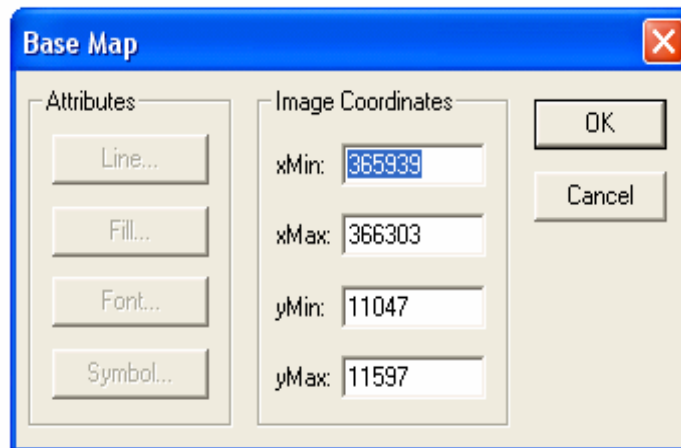
Copy the column (use either the *Edit ... Copy* menu or Ctrl+c)

- Switch to the Surfer worksheet
- Paste the column into the worksheet (use the *Edit ... Paste* menu or Ctrl+v)
- Repeat the above sequence until you have all three columns transferred.
- Save the Surfer worksheet using the *File ... Save As* command (save location must be remembered)
- Exit Excel
- Switch to the Surfer plot window using the *Window ...* menu

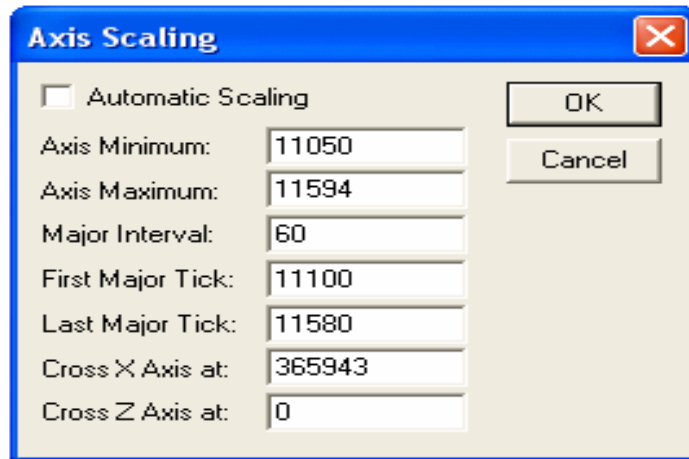
### 3.4.1.2 SCALING BASE MAP

The scaling of base map should be identical to the contour map which will be overlayed. Reference point of the base map must be identified. Latitude and Longitude is later adjusted using the scaling windows.

- Open SURFER plot windows
- Load base map
- Double-click base map
- Key in base map image border points in the base map border point windows (Figure 3.3)
- Press OK and base map with scale will be generated. Double-click the left axis and enter scaling window
- Key in desired scale and a scaled base map is produced as in Figure 3.1
- Save file



**Figure 3.3 : Base map border point window**



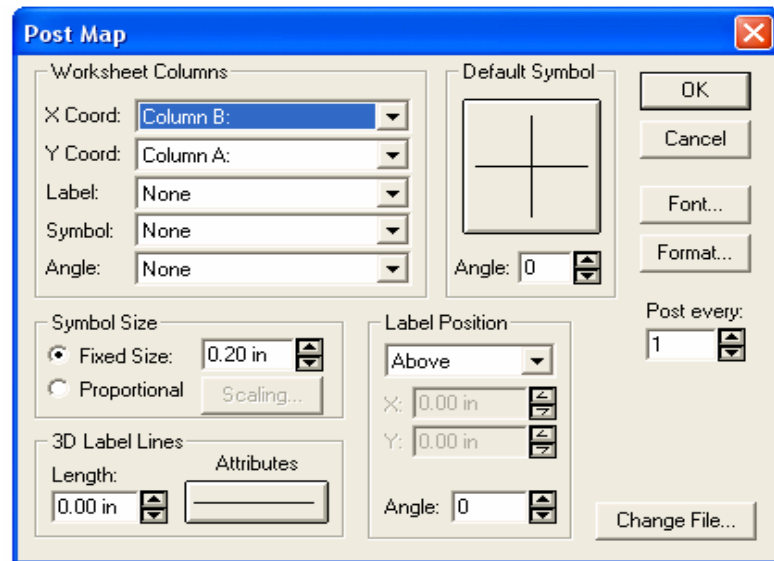
**Figure 3.4: Scaling window**

### **3.4.1.3 CREATE A MAP OF POINTS**

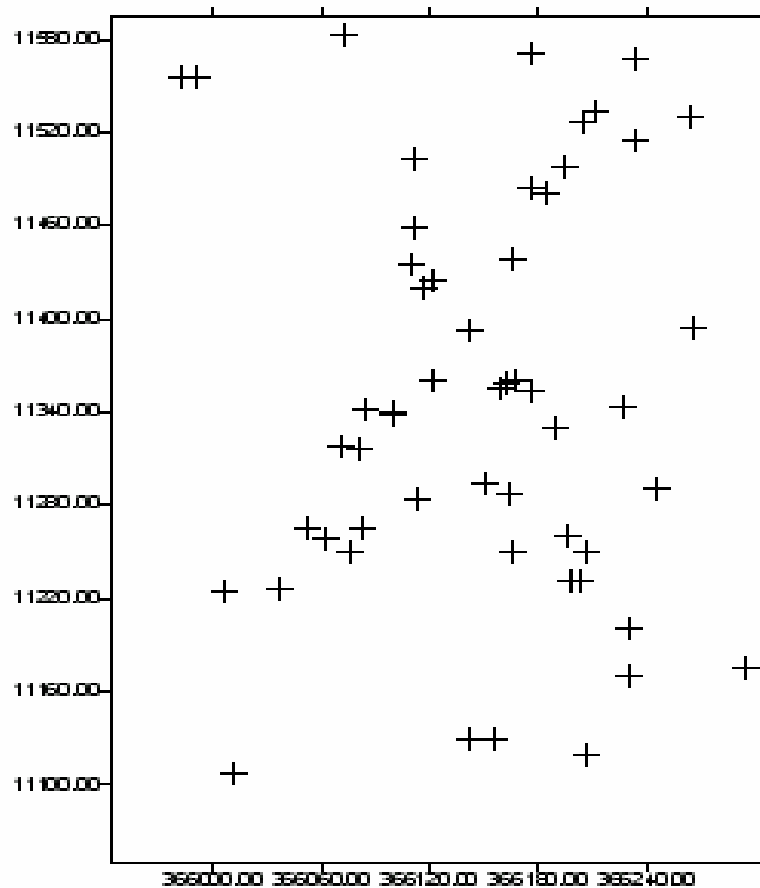
There are two parts to this step. You need to create a map of points with point numbers, and then overlay a second map that has elevations.

- At this point you should be in a Surfer plot window
- Choose the *Map ... Post* menu item
- You will not get a File Open dialog box. Find and open the data file you created in Step 1
- You will now get the Post Map dialog box (Figure 3.5)
- Select the correct columns for the E (or x), and N (or y) columns (the list boxes will contain the column names you used in the Surfer worksheet in step 1)
- Customize points in the box.
- Press OK and map points will be shown (Figure 3.6)
- Scale the map as in Step 2
- Save file





**Figure 3.5 : Post map dialog Box**



**Figure 3.6 : Map points**

#### **3.4.1.4 GRIDDING OR CONTOURING**

- Enter Grid in the SURFER plot menu. Click data
- Choose a data file to be contoured
- Specify any parameters in the Contour Map dialog box and click OK. A contour map is created in .grd file format

#### **3.4.1.5 OVERLAY MAPS**

Base map can be overlaid with map points or map contour. In this study, Infiltration contour is overlaid on base map to show the best location for infiltration practices. Map points is also lay on base map to show the reliability of the infiltration contour. Maps can be overlaid using Map and Arrange in the SURFER plot menu. Map results are shown in Chapter 4.

### **3.5 GS+**

The database is a 55 points testing locations. Data was brought into GS+ data worksheet. Semivariance Analysis was performed to produce a variogram model of auto correlation. GS+ provides analysis and interpolation of spatially auto correlated data. The semivariogram captures spatial dependence between samples by plotting semivariance against separation distance. Close samples tend to be more similar than distance samples (spatial auto correlation). Five different semivariance model were examined. The best model will be chosen. Chapter 4 shows analysis results of data.