

**EVALUATION OF DESIGN CRITERIA FOR INFLOW &  
INFILTRATION OF MEDIUM SCALE SEWERAGE CATCHMENT  
SYSTEM**

**(PENILAIAN KRITERIA REKABENTUK BAGI ALIRAN MASUK &  
PENYUSUPAN SISTEM PEMBENTUNGAN BERSKALA SEDERHANA)**

**NORHAN ABD RAHMAN  
NORALIANI ALIAS  
SITI SALHAWATI MOHD SALLEH  
MOHD KAMARUL HUDA SAMION**

**RESEARCH VOTE NO: 74281**

**Jabatan Hidraul & Hidrologi  
Fakulti Kejuruteraan Awam  
Universiti Teknologi Malaysia**

## ABSTRACT

Infiltration rate has long been important aspect considered in the design of sewerage systems. The study is about assessment of the extent of extraneous water that infiltrates into sewer pipes in the sewerage system and the appropriateness of the design criteria, under local conditions. The study is divided into two parts, flow characteristics measurement and infiltration measurement. Flow characteristics measurement includes collecting data using flowmeter at a pre-determined manhole and analyzing the data to find hourly flow characteristics, flow per capita contribution and the peak flow factor. Infiltration measurement is carried out at an abandoned sewer line (MH74-MH74a) in Taman Sri Pulai for a year, at active sewer line in Taman Universiti and at Hydraulic & Hydrology Laboratory, Faculty of Civil Engineering, UTM. The data collected is converted into graph form before analysis. Rainfall data has been collected to identify its influence on the infiltration rate. The results from both flow characteristics measurement and infiltration measurement are compared with design infiltration rate as mentioned in MS1228:1991, which is 50 liter/day/km/mm-dia as well as with previous studies on inflow and infiltration carried out in Taman Sri Pulai and Taman Universiti. The results showed that the flow per capita contribution and the peak flow factor in Taman Sri Pulai and Taman Universiti are lower than recommended in MS1228:1991 and that wet periods contribute more infiltration compared to dry periods. Infiltration rate will increase with the increase in rainfall volume.

## ABSTRAK

Kadar penyusupan telah lama merupakan aspek penting yang diambil kira dalam rekabentuk sistem pembetulan. Kajian ini adalah berkenaan dengan penilaian tahap penyusupan air dari luar ke dalam paip pembetung dalam sistem pembetulan dan kesesuaian kriteria rekabentuk di bawah keadaan tempatan. Kajian ini dibahagi kepada dua bahagian, pengukuran ciri aliran dan ukuran penyusupan. Pengukuran ciri aliran termasuk mengumpul data menggunakan 'flowmeter' di lurang yang telah ditetapkan dan menganalisa data tersebut untuk mencari ciri aliran per jam, aliran per kapita dan faktor aliran puncak. Ukuran penyusupan dijalankan di satu bahagian paip pembetung yang dibaikan (MH74-MH74a) di Taman Sri Pulai selama setahun, di paip pembetung yang aktif di Taman Universiti dan di Makmal Hidraulik & Hidrologi, Fakulti Kej. Awam, UTM. Semua data yang dikumpul ditukar ke dalam bentuk graf sebelum dianalisis. Data hujan telah dikumpul untuk mengenalpasti pengaruhnya ke atas kadar penyusupan. Keputusan daripada kedua-dua pengukuran ciri aliran dan ukuran penyusupan dibanding dengan kadar penyusupan rekabentuk yang dinyatakan dalam MS1228:1991, iaitu sebanyak 50 liter/hari/km/mm-dia dan juga dengan kajian-kajian lepas tentang aliran masuk dan penyusupan yang dijalankan di Taman Sri Pulai dan Taman Universiti. Keputusan menunjukkan aliran per kapita dan faktor aliran puncak di Taman Sri Pulai dan Taman Universiti adalah lebih rendah daripada yang disyorkan dalam MS1228:1991 dan musim hujan menyumbangkan lebih penyusupan berbanding dengan musim kering. Kadar penyusupan akan meningkat dengan peningkatan dalam isipadu hujan.

## CONTENTS

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	ABSTRACT (English)	v
	ABSTRAK (Bahasa Melayu)	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF PHOTOS	xiii
	LIST OF APPENDICES	xiv
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Objectives Of Study	2
	1.4 Scope Of Work	2
	1.5 Importance Of The Study	3
<b>2</b>	<b>LITERATURE REVIEW</b>	<b>4</b>
	2.1 History	4
	2.2 Types Of Sewerage System	5
	2.3 Transportation Of Wastewater	6
	2.4 Definition Of Sewer Terms	6
	2.5 Flow Design And Loading In Sewerage Systems	7
	2.6 Factors Contributing To Inflow And Infiltration In Sewerage Systems	9
	2.6.1 Sewer Pipes And Pipe Appurtenances	9
	2.6.2 Infiltration Through Soil And Soil Properties	9
	2.6.2.1 Type Of Soil (Hydraulic Conductivity)	10
	2.6.2.2 Moisture Content	11
	2.6.2.3 Permeability	11
	2.6.2.4 Porosity	12
	2.6.2.5 Surface Cover	12
	2.6.2.6 Water Table	12
	2.6.2.7 Rain	13
	2.6.3 Population Increase	13
	2.6.4 Passage Of Time	13
	2.7 Effects Of Inflow And Infiltration	14

<b>3</b>	<b>METHODOLOGY</b>	15
	3.1 Introduction	15
	3.2 Preliminary Works	15
	3.2.1 Information Gathering	15
	3.2.2 Site Visits	16
	3.3 Site Work	16
	3.3.1 Population Equivalent (PE) Determination	16
	3.3.2 Flow Characteristics Measurement	16
	3.3.3 Infiltration Measurement	17
	3.3.3.1 Field Model	18
	3.3.3.2 Laboratory Model	20
	3.3.3.3 Leakage Test	21
	3.3.3.4 Infiltration Test	22
	3.3.3.5 Inflow & Infiltration	23
	3.3.4 Rainfall Measurement	24
<b>4</b>	<b>RESULTS &amp; ANALYSIS</b>	25
	4.1 Introduction	25
	4.2 Population Equivalent Determination	25
	4.3 Flow Characteristics Measurement	25
	4.4 Infiltration Measurement - Taman Universiti Sewerage	30
	4.5 Infiltration Measurement - Field Model	30
<b>5</b>	<b>ANALYSIS AND DISCUSSION</b>	36
	5.1 Flow Characteristics Study	36
	5.1.1 Calibration Of ISCO Area – Velocity Flow Meter	36
	5.1.2 Flow Characteristics Measurement	38
	5.1.3 Flow Per Capita Contribution	40
	5.1.4 Peak Flow Factor	41
	5.2 Infiltration Study	43
	5.2.1 Infiltration Study - Taman Universiti Sewerage	43
	5.2.1.1 Infiltration Analysis	45
	5.2.2 Infiltration Study - Laboratory Model	48
	5.2.2.1 Leakage Test	48
	5.2.2.2 Infiltration Test	48
	5.2.3 Infiltration Study – Field Model	50
	5.2.3.1 Infiltration Measurement	50

<b>6</b>	<b>CONCLUSION AND RECOMMENDATIONS</b>	52
	6.1 Conclusion	52
	6.2 Recommendations	53
	<b>REFERENCES</b>	55
	<b>APPENDICES</b>	57

## LIST OF TABLES

<b>TABLE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
2.1	Equivalent Population, PE (MS1228:1991)	8
2.2	Soil Classification According to Coefficients of Permeability (Adapted from Terzaghi <i>et al.</i> , 1996)	12
3.1	Abandoned Sewer Section Characteristics (MH74-MH74a), Taman Sri Pulai	18
3.2	Characteristics of Laboratory Model	20
5.1	Calibration of Sensor Number 1 with Area Velocity Flow Meter	37
5.2	Calibration of Sensor Number 2 with Area Velocity Flow Meter	38
5.3	Calibration of Area Velocity Flow Meter at very Low Water Level	38
5.4	Result Summaries	39
5.5	Result Summary for the Laboratory Leakage Test	48
5.6	Result Summary for the Laboratory Infiltration Test	49

## LIST OF FIGURES

<b>FIGURE NO.</b>	<b>TITLE</b>	<b>PAGE</b>
3.1	Abandoned Manhole (MH74a)	18
3.2	Water Pump	19
3.3	Laboratory Physical Model	20
3.4	Top and Side Views of the Laboratory Model	21
3.5	Rainfall Pumping into the Laboratory Model for Infiltration Test	22
3.6	Flow Meter	23
3.7	ISCO Rain Gauge	24
3.8	Download Rainfall Data	24
4.1	Hourly Flow Rate Graph (30.6.2005 to 3.7.2005)	26
4.2	Hourly Flow Rate Graph (6.8.2005 to 9.8.2005)	26
4.3	Hourly Flow Rate Graph (27.8.2005 to 31.8.2005)	27
4.4	Hourly Flow Rate Graph (6.9.2005 to 10.9.2005)	27
4.5	Hourly Flow Rate Graph (17.1.2006 to 20.1.2006)	28
4.6	Hourly Flow Rate Graph (22.9.2005 to 27.9.2005)	28
4.7	Hourly Flow Rate Graph (1.10.2005 to 6.10.2005)	29
4.8	Hourly Flow Rate Graph (9.12.2005 to 12.12.2005)	29
4.9	Hourly Flow Rate Graph (30.12.2005 to 2.1.2006)	30
4.10	2 Manholes Measurements Flow Rate Graph (13.6.2006 to 20.6.2006)	31
4.11	2 Manholes Measurements Flow Rate Graph (17.5.2006 to 24.5.2006)	32
4.12	2 Manholes Measurements Flow Rate Graph (11.10.2006 to 18.10.2006)	33
4.13	2 Manholes Measurements Flow Rate Graph (18.12.2006 to 25.12.2006)	34
4.14	1-year Rainfall vs. Infiltration Rate Graph for Field Model (MH74-MH74a)	35
5.1	The Design Peak Flow Factor Compared with the Actual Peak Flow Factor from this Study	43
5.2	Infiltration against Rainfall Graph (13.6.2006 to 20.6.2006)	45
5.3	Infiltration against Rainfall Graph (17.5.2006 to 24.5.2006)	46
5.4	Infiltration against Rainfall Graph (11.10.2006 to 18.10.2006)	46
5.5	Infiltration against Rainfall Graph (18.12.2006 to 25.12.2006)	47
5.6	Infiltration Rate Corresponding to Leakage Rate vs. Rainfall Duration	49



**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Location of Abandoned Sewer (MH74-MH74a) at Taman Sri Pulai	57
B	1 Year Data from Abandoned Sewer Line (10 <sup>th</sup> February 2005 to 10 <sup>th</sup> February 2006)	58

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

A sewerage system is one of the most critical considerations in the sanitary element of any residential, commercial, institutional or industrial construction projects where the final structures will be used by humans for their various activities. This research is currently focused on sewerage system for residential areas and is a joint effort between Indah Water Konsortium (IWK) and Universiti Teknologi Malaysia (UTM).

A sewerage system is a pipe system that carries household and commercial sewage as well as industrial wastewater toward treatment facilities (Imhoff, 1989). The source can be residential, commercial or industrial area whereas the treatment facilities include activated sludge, oxidation ponds, aerated lagoons, trickling filters and rotating biological contactors.

Sewerage system is very important. It does for people the dirty work of daily waste disposal, which if not managed properly will result in pollution and contamination of various aspects of our surrounding and ultimately result in adverse effects on human beings, since as stated in Commoner's Law, "*Everything is connected to everything else*". That is why it is so important to make sure that the sewerage systems that exist are functioning well.

The effectiveness of a sewerage system is influenced to a large extent by infiltration. That is why sewerage system designers cannot look only at the sewage produced from the expected sources like houses, they must also take into serious consideration the effect infiltration has on the sewerage system they are designing, especially in tropical countries where it rains a lot since infiltration becomes critical when it rains. Common sewerage system designs do indeed include an allowance for infiltration but different geographical areas may not experience the same amount of infiltration as estimated by current common practices in sewerage system design. In Malaysia, sewerage systems are designed according to Malaysian Standard Code of Practice MS1228:1991 but in actual fact, MS1228:1991 itself is based on

BS8005:1987 and BS6297:1982 which are in fact conditioned for four season climate and may not be suited to tropical conditions. That is why this research was implemented.

## **1.2 Problem Statement**

Any sewerage system will initially be designed for a specific amount of sewage only based on the population equivalent (PE) at that time. The design will also include some allowance for infiltration to occur and in Malaysia's case; the maximum infiltration rate which the sewerage system may be designed for is 50 litres/mm-diameter/km-length/day as stated in MS1228:1991. The design will be adequate if infiltration does not exceed the amount stated but that is usually not the case in tropical climate areas. Kek (1999), Onn (2000), Teh (2001), Cheah (2002), Ho (2002) and Ngoi (2003) have all shown in their study that the amount of infiltration occurring in Malaysia way exceeds the maximum infiltration rate of 50 litres/mm-diameter/km-length/day as stated in MS1228:1991. When the infiltration rate exceeds the amount it is designed for, it will overburden the sewerage system and cause all sorts of negative effects which will be discussed further in the literature review. In view of all the negative effects, a research is desperately needed to study the situation as well as the suitability of the current design criteria for inflow and infiltration in sewerage systems situated in tropical climates.

## **1.3 Objectives Of Study**

- i) To study the effect of rainfall on inflow and infiltration patterns in sewerage systems
- ii) To determine the optimum design criterion for tropical climate in sewerage systems
- iii) To verify the infiltration rate in the sewerage system of Taman Sri Pulai and Taman Universiti

## **1.4 Scope Of Work**

- i) Infiltration rate measurement in abandoned sewer line (MH74a-MH74) as a physical field model at Taman Sri Pulai, Skudai, Johor.
- ii) Infiltration rate measurement using physical laboratory model at Hydraulic and Hidrology Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia, Skudai, Johor.

- iii) Inflow pattern measurement using 1 flowmeter and sensor in manhole (MH11) at Taman Sri Pulai with PE of 1705.
- iv) Inflow pattern measurement using 1 flowmeter and sensor in manhole (MH299 & MH1154) at Taman Universiti with PE of 3456 and 9905.
- v) Infiltration measurement using 2 flowmeters and sensors in manholes (MH299-MH306 & MH154-MH154a) at Taman Universiti.
- vi) Rain intensity measurement using rain gauge at all sites

## **1.5 Importance Of The Study**

Inflow and infiltration is a critical parameter of sewerage system design that can seriously impair sewerage systems as well as the sewage treatment facilities if not properly studied and implemented.

This research will increase our understanding on the factors causing inflow and infiltration as well as the effects of inflow and infiltration in sewerage systems. Among the knowledge to be acquired includes the effectiveness of the current standard design used in tropical climate areas. Since the Malaysian Standard on sewerage system design is based on foreign design, it may not be very suitable to tropical conditions even though it can still be used. Besides that, the rate of inflow and infiltration in sewerage systems as well as the ways to overcome them can also be known.

## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 History

Methods of waste disposal date from ancient times. In his work, Viessman (1985) mentioned that the earliest archeological records of wastewater disposal and central water supply date back to Nippur of Sumeria, about 5000 years back. Wastes from the palaces and the city's residential areas were transported by an elaborate drainage system. The separate drainage system to collect sewage and rain water individually was first found at the city of Knossos, Greece back around 2000 B.C as written by Mays (2001).

The earliest water treatment knowledge available is in Sanskrit writings which date back to about 2000 B.C. The writing describes the process of purifying dirty water using 4 steps in succession; boiling in copper vessels, exposure to sunlight, filtering through charcoal and finally cooling in an earthen vessel. The earliest equipment for clarifying water known was found pictured in Egypt around 1500-1300 B.C.

In the year 1627, Sir Francis Bacon wrote on experiments involving water purification through filtration, boiling, distillation and clarification by coagulation, citing that clarifying water improves health.

In the year 1685, Luc Antonio Porzio published the first known illustrated description of sand filters, which was focused on conserving the health of soldiers in camps during the Austro-Turkish War. In the 18<sup>th</sup> and 19<sup>th</sup> centuries, many experiments on sewerage design were conducted in Russia, Germany, France and England. Viessman (1985) mentioned that Henry Darcy became the first person to apply the laws of hydraulics to filter design and that present day rapid-sand filters were evolved from filters developed in the United States in 1890 which also introduced coagulants for better efficiency.

White (1970) wrote that it was during the Industrial Revolution that the importance of water sanitation systems in towns and urban areas became obvious. Insufficient water supply for waste removal was found in developed urban areas. Water was taken from wherever it can be found; from shallow wells, polluted streams and even leaky water mains which were pressurized for a short period of time every day. Pollution of water supplies results from accumulations of waste matter. A high death rate from dysentery, typhoid, cholera and other types of water-borne diseases was rampant, especially in densely populated areas. Stenis (2004) stated that 'as urbanization increased, it was no longer possible to employ the natural recycling possible in an agricultural community.'

In view of the poverty and early death resulting from failure of prompt waste matter removal as well as inadequate supply of clean water, Edwin Chadwick proposed a solution which was immediately sanctioned and became the norm in practice up till this day. His proposal was 'Each dwelling is supplied internally with clean water, continuously under pressure, and the water used conveys waste matter through a system of pipes at velocity high enough to prevent silting.' Deposition of solid matter in pipes could be avoided, as shown by John Roe, by using circular cross-section pipes with sufficient gradients provided.

## **2.2 Types Of Sewerage System**

Wastewater is carried from its source to treatment facility pipe systems that are generally classified according to the type of wastewater flowing through them. If the system carries both domestic and storm-water sewage, it is called a combined system, and these usually serve the older sections of urban areas. As the cities expanded and began to provide treatment of sewage, sanitary sewage was separated from storm sewage by a separate pipe network, called the separate system. This arrangement is more efficient because it excludes the voluminous storm sewage from the treatment plant. It permits flexibility in the operation of the plant and prevents pollution caused by combined sewer overflow, which occurs when the sewer is not big enough to transport both household sewage and storm water. Certain types of sewers, such as inverted siphons and pipes from pumping stations, flow under pressure, and are thus called force mains.

As this research is conducted in Malaysia, it should be made known that the type of sewerage system adopted in Malaysia is the separate system, with the sanitary sewer network flowing to treatment facilities while the storm sewer network flows to streams, rivers or the sea.

## **2.3 Transportation Of Wastewater**

Households are usually connected to the sewer mains by clay, cast-iron, or polyvinyl chloride (PVC) pipes 8 to 10 centimetres in diameter. Larger-diameter sewer mains can be located along the centerline of a street or alley about 1.8 m or more below the surface. The smaller pipes are usually made of clay, concrete, or asbestos cement, and the large pipes are generally of unlined or lined reinforced-concrete construction. Unlike the water-supply system, wastewater flows through sewer pipes by gravity rather than by pressure. The pipe must be sloped to permit the wastewater to flow at a velocity of at least 0.8 metre per second (MS1228:1991), because at lower velocities the solid material tends to settle in the pipe. Storm-water mains are similar to sanitary sewers except that they have a much larger diameter.

In some places, urban sewer mains discharge into interceptor sewers, which can then join to form a trunk line that discharges into the wastewater-treatment plant. Interceptors and trunk lines, generally made of brick or reinforced concrete, are sometimes large enough for a truck to pass through them.

## **2.4 Definition Of Sewer Terms**

For the convenience of the reader, many of the terms that the reader will regularly come across in this dissertation are listed here together with their meaning as taken from Hammer & Hammer (2004) and American Society of Civil Engineers (1982).

- a) Infiltration – groundwater entering sewers and building connections through defective joints and broken or cracked pipe and manholes.
- b) Inflow – water discharged into sewer pipes or service connections from such sources as foundation drains, roof leaders, cellar and yard area drains, cooling water from air conditioners, and other clean-water discharges from commercial and industrial establishments.
- c) Wastewater – the spent or used water of a community or industry which contains dissolved and suspended matter.
- d) Sanitary Sewer – a sewer that carries liquid and waterborne wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground, storm, and surface waters that are not admitted intentionally.
- e) Combined Sewer – a sewer intended to receive both wastewater and storm or surface water.
- f) Lateral Sewer – a sewer that discharges into a branch or other sewer and has no other common sewer tributary to it.
- g) Main Sewer – the principal sewer to which branch sewers and submains are tributary.

- h) Trunk Sewer – a sewer that receives many tributary branches and serves a large territory.
- i) Intercepting Sewer – a sewer that receives dry-weather flow from a number of transverse sewers or outlets and frequently additional predetermined quantities of storm water from a combined system and conducts such waters to a point for treatment or disposal.
- j) Separate Sewer – a sewer intended to receive only wastewater or storm water or surface water.
- k) Storm Sewer – a sewer that carries storm water and surface water, street wash and other wash waters, or drainage, but excludes domestic wastewater and industrial wastes.
- l) Population Equivalent – the number of persons required to contribute an equivalent quantity of wastewater related to the quantity of flow and strength of Biochemical Oxygen Demand, commonly expressed in terms of BOD<sub>5</sub>.

## 2.5 Flow Design And Loading In Sewerage Systems

This study is undertaken in Malaysia so the code of practice used is the Malaysian Standard Code of Practice. For the design of sewerage systems, MS1228:1991 is used and all the information in this section will be based on MS1228:1991. The various stages of design up to construction of sewer projects require an understanding of the objectives of each stage of the project and of the responsibilities as well as the interest of each and every one of the parties involved in it.

Generally, the sewerage systems should be designed adequately for their respective target areas that they will be servicing while putting in mind the possibility of increasing parts of the systems' capacity when the need arises due to future expansion of the areas serviced. The average daily design flow is based on the assumption that a person generates 225 litres of wastewater per day. This can be multiplied by the Population Equivalent (PE) for the said premise to get the average design daily flow. The PE can be referred to Table 2.1.

In the design of sewerage systems, the peak hourly flow is required and the Peak Flow Factor for hourly flow is obtained from the equation as follows:

$$\text{Peak Flow Factor} = 4.7 \times p^{-0.11} \quad (2.1)$$

Where:

$p$  = estimated PE, in thousand



Infiltration will inevitably happen in sewerage systems for very rare, if any, is there workmanship so excellent that there are no defects at all after the installation of the sewerage system.

Therefore, as guidance, all sewerage systems shall take into account a maximum infiltration rate of 50 litres/day/kilometre-length/millimetre-diameter in their design. Hammer & Hammer (2004) proposed in their written work an even smaller value, 46 litres/day/kilometre-length/millimetre-diameter. Thus can be seen that in actual fact, infiltration is something unwanted but tolerated only because there is no way to completely rid it from the system.

**Table 2.1:** Equivalent Population, PE (MS1228:1991)

No.	Type of Premise/Establishment	Population Equivalent (recommended)
1	Residential	5 per unit
2	Commercial (includes entertainment/recreational centres, restaurants, cafeteria, theatres)	3 per 100m gross area
3	Schools/Education Institutions: <ul style="list-style-type: none"> <li>• Day schools/institutions</li> <li>• Fully residential</li> <li>• Partial residential</li> </ul>	0.2 per student 1 per student 0.2 per student for non-residential & 1 per student for residential student
4	Hospitals	4 per bed
5	Hotels (with dining & laundry facilities)	4 per room
6	Factories (excluding process wastes)	0.3 per staff
7	Market (wet type)	3 per stall
8	Petrol kiosks/Service stations	18 per service bay
9	Bus terminal	4 per bus bay

## **2.6 Factors Contributing To Inflow & Infiltration In Sewerage Systems**

### **2.6.1 Sewer Pipes And Pipe Appurtenances**

Much of the infiltration that occurs in sewerage systems is the result of faulty joints, cracked pipes and manholes as well as joints which are too rigid and not watertight enough. All this happens due to a myriad of reasons, both during and after construction of the sewerage system.

During construction, poor supervision of work by the site supervisor as well as poor workmanship of the workers may result in faulty joints, cracking of pipes from rough handling, sub-standard fittings and also poor concreting. Besides that, defective material used to construct the sewerage system contributes to infiltration too for they wear out quickly which leads to cracks, fissures and holes where infiltration occurs.

On the other hand, after construction, differential settlement of the soil beneath the sewer pipes will dislocate the joints of the pipes and create openings for water to seep through. Other than that, unforeseen chemical reactions between the sewer pipes and the inflow contents may damage the insides on the pipes, which may lead to pipe weakening and ultimately cracks and fissures through which infiltration will occur.

### **2.6.2 Infiltration Through Soil And Soil Properties**

Infiltration is the biggest component of rainfall that does not go back to the atmosphere through the hydrologic cycle. It is the process where water from the surface of the earth infiltrates into the soil. Different soil will have different infiltration capacity, stated in mm/hour. It all depends on the soil parameters as well as rain.

To get the rate of infiltration in any particular soil, an infiltrometer is used, with the most convenient one being the double-ring infiltrometer. The infiltration rate can be obtained using two methods; the Horton Equation and the  $\phi$ -Index Method.

The Horton Equation is as follows:

$$f = f_c + (f_0 - f_c) e^{-kt} \quad (2.2)$$

Where:

f	= Infiltration rate (length/time)
f <sub>0</sub>	= Initial infiltration rate
f <sub>c</sub>	= Constant infiltration rate a.k.a. limiting rate
k	= Recession/Decay constant (time <sup>-1</sup> )
t	= Time

The infiltration through soil starts at rate  $f_0$  and will decrease exponentially until a constant rate,  $f_c$ . This is with the assumption that the soil surface is saturated all the time.

The  $\phi$ -Index Method is a way to obtain the average rain intensity rate where the volume of surface runoff is taken as the same as effective rainfall. This method is very simplified and is more suited to analyzing storm runoff from large catchment areas but can still be used in this case.

There are many factors which influence infiltration through soil and most of them are affiliated with the soil property itself.

### 2.6.2.1 Type Of Soil (Hydraulic Conductivity)

Water can move through soil as saturated flow, unsaturated flow, or vapor flow. Saturated flow takes place when the soil pores are completely filled with water. Unsaturated flow occurs when the larger pores in the soil are filled with air, leaving only the smaller pores to hold and transmit water. Vapor flow occurs as vapor pressure differences develop in relatively dry soils. Vapor migrates from an area of high vapor pressure to an area of low vapor pressure.

Flow through an unsaturated soil is more complicated than flow through continuously saturated pore spaces. Macropores are filled with air, leaving only finer pores to accommodate water movement. The movement of water in saturated soils is dictated by gravity whereas in unsaturated soils, it is dictated by matric potential. The matric potential gradient is the difference in the matric potential of the moist soil areas, and nearby drier areas into which the water is moving. Moist areas are considered having high matric potential while dry areas have low matric potential.

Hydraulic conductivity is a soil property that describes the ease with which the soil pores permit water, not vapor, movement. It depends on the type of soil, porosity, and the configuration of the soil pores. It is the most important transport property of soil and is a non-linear function of the volumetric water content. Different types of soil will have different hydraulic conductivity, which is stated in the form of  $i$ , length/time. The higher the hydraulic conductivity, the lower will be the surface runoff.

Hydraulic conductivity is an important soil property when determining the potential for infiltration through soil. Soils with high hydraulic conductivities and large pore spaces are likely candidates for heavy infiltration. The hydraulic conductivity in a saturated soil can be measured by injecting a non-reactive tracer like bromide in a monitoring well and measuring the time it takes for the tracer to reach a downgradient monitoring well.

#### **2.6.2.2 Moisture Content**

When moisture content is high or the soil is almost saturated, maximum hydraulic conductivity is achieved very quickly. So when that happens, it will lower surface runoff. When surface runoff is slow, the water tends to seep into the earth and thus add to the infiltration through the soil.

#### **2.6.2.3 Permeability**

According to Liu & Evett (2005), permeability refers to the movement of water within soil. The actual movement of water is through voids, which are small, interconnected and irregular conduits. Since water uses voids to move, soils with large voids like sands can usually be considered more permeable than soils such as clays, which have smaller voids. Also, permeability increases in tandem with the increase of void ratio in the soil. Permeability will influence the amount of infiltration through soil because it is related to water movement in soil. The permeability of any type of soil is stated in the form of coefficient of permeability,  $k$ , which is usually in metre/second. Table 2.2 shows the degree of permeability for soils according to the value of  $k$ .

**Table 2.2:** Soil Classification According to Coefficients of Permeability  
(Adapted from Terzaghi *et al.*, 1996)

Degree of Permeability	Value of $k$ (metre/second)
High	Over 0.001
Medium	0.001 to 0.00001
Low	0.00001 to 0.0000001
Very Low	0.0000001 to 0.000000001
Practically Impermeable	Less than 0.000000001

#### 2.6.2.4 Porosity

Porosity of the soil is high when there are a lot of air pockets or pores between the soil particles. Soil with high porosity, like sand, will induce higher rate of infiltration through the soil because there is a lot of empty space for the water to flow in.

#### 2.6.2.5 Surface Cover

Surface cover means the things available on the soil surface of that area. If the surface cover consists of vegetation like grass, then the infiltration rate through the soil will be high because vegetation will slow down surface runoff, making it so that it will take a longer time for the surface runoff to flow away. The longer the time surface runoff stays on the soil, the higher the chance that it will seep through the earth.

#### 2.6.2.6 Water Table

When groundwater table is far below the surface of the earth, infiltration from the earth surface will be high because the soil is not saturated but when water table is high, at the same level or higher than the sewer pipes, then the infiltration rate into the sewer pipes will increase since the water table surrounds wholly or partially the sewer pipes, giving ample opportunity for the water to seep through any cracks, holes or fissures in the pipes.

### **2.6.2.7 Rain**

The effect of rain on inflow and infiltration depends on the intensity, the duration and the volume of the rain. As the intensity increase, infiltration through the soil decreases because most of the rain will be washed away as surface runoff. A large part will not be able to percolate through the soil and vice versa. For duration, it is the opposite. A longer duration will give higher infiltration rate because the surface runoff is less and there is more time for it to seep into the soil. The same goes for volume. The higher the volume, of course the more infiltration can happen. In tropical countries, the weather is divided into wet season and dry season. During the wet season, there is a lot of rain and thunderstorms so infiltration will increase in those periods of time.

### **2.6.3 Population Increase**

The population of this world is ever-increasing and even the sewerage systems of this world are not spared the effect of this. Even though the sewerage system is designed for the population equivalent at the end of its service period, when the number of users using the sewerage system exceeds that value, it will overburden the sewerage system because the system does not have the capacity to support the additional sewage. If there is prolonged overburden of the sewerage system, it will likely cause cracks and other adverse effects, which will lead to infiltration. In severe cases, failure of the whole sewerage system will result.

### **2.6.4 Passage Of Time**

As time goes by, a sewerage system will deteriorate due to wear and tear as it performs the daily task of wastewater disposal. So it can be safely said that all the sewerage systems will deteriorate with time and with the deterioration comes the unwanted inflow and infiltration in increasing proportions.

## **2.7 Effects Of Inflow And Infiltration**

In many existing sanitary sewers infiltration is a major cause of hydraulic overloading of both the collection system and treatment plant. To handle this excess flow it may become necessary to construct relief sewers and expand existing treatment facilities. So, clean water infiltration into sanitary sewers should be avoided whenever possible. The following is a number of adverse effects that excessive inflow and infiltration will have on the sewerage systems.

- 1) Surcharging of sewer lines with back-up of sanitary wastewaters into house basements
- 2) Reducing the capacity of the sewer for conveying the waste flows for which it was designed
- 3) Higher pumping costs
- 4) Treatment plant hydraulic overloads, thus the bypass and overflow of untreated sewage into receiving waters
- 5) Flooding of street and road areas
- 6) Cave-ins and structural failures in sewers and pavements resulting from soil washing into the sewer
- 7) Higher maintenance costs resulting from soil deposits in sewers, additional root penetration into leaky joints, etc
- 8) Entrance of spores of bacterial and other organisms through the infiltration water

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1 Introduction**

Methodology is the statement of how the proposed research will be done. In this research, it will involve conducting different types of measurement to get different values that will ultimately be used in the endeavour to reach the objectives of this research. In this methodology chapter, the techniques to obtain the different data like rainfall intensity and flow from site will be stated and shown.

#### **3.2 Preliminary Works**

The term preliminary in this situation means the initial works that the author had to do before moving to the real data collection at site. This includes information gathering on the topic of inflow and infiltration, past dissertation reviews, self-study on similar and related topics in order to learn more. Site visits are also conducted to assess the situation and the best way to go about collecting data.

##### **3.2.1 Information Gathering**

A wide array of journals, books and articles has to be read in order to obtain information on the topic of inflow and infiltration. Sources mostly come from abroad since this topic is relatively new in Malaysia and very few local studies have been conducted.



### **3.2.3 Site Visits**

Site visits have been conducted to Taman Sri Pulai (MH74-MH74a & MH11-MH13a) and Taman Universiti (MH299-MH306 & MH154-MH154a) with the help of location maps obtained from the relevant authorities before any work can proceed at those sites. A special trip to Shah Alam has also been conducted on the 21<sup>st</sup> and 22<sup>nd</sup> of January 2006, specifically to visit our future site, Taman with a PE of 18000. Site visits are necessary because we can know the actual location of the site of work and the ground conditions first hand.

### **3.3 Site Work**

After the preliminary work is done and all is prepared, the site work can begin. In this study there are 3 sites namely Taman Sri Pulai, Taman Universiti and Shah Alam. The work in Taman Sri Pulai encompasses flow characteristics study and pure infiltration study while the work in Taman Universiti includes flow characteristics study and inflow & infiltration study. In Shah Alam, the work will be inflow and infiltration measurement. For all these sites, the PE is different and the rainfall intensity is constantly measured.

#### **3.3.1 Population Equivalent (PE) Determination**

The PE for the section of the sewerage pipe where the study is implemented can usually be obtained from either the developer or the sewerage service provider. In order to check the accuracy of the PE obtained as well as any increase or decrease from the initial PE value, a recount of PE is scheduled for each of the different site.

#### **3.3.2 Flow Characteristics Measurement**

The measurement for flow characteristics of a section of sewerage pipe systems is done using 1 flowmeter complete with sensor. In this study, the flowmeter used is the 4250 Area-Velocity Flow Meter, and it will automatically record the flow, velocity and water height at preset intervals, which in this case is 5 minutes. Once a measurement is complete regardless of the duration, the data from the flowmeter will be downloaded into a computer which has the Flowlink4 software. This software enables the plotting of graphs for the 3 parameters downloaded as well as transfer of data to other software's for the user's convenience.

From the flow measurements, we can get Q maximum hourly, Q minimum hourly and Q average with Q being the flow. From Q average, we can get the per capita flow by using the following equation:

**Flow per capita**

$$\begin{aligned}
 &= \frac{\text{Average daily flow (m}^3\text{/day)}}{\text{Total population equivalent (PE)}} && (3.1) \\
 &= \text{m}^3\text{/day/person}
 \end{aligned}$$

Examination of wastewater flow characteristics can also be done through a data that are obtained from the field experiment. The information that related to design sewerage systems are as following:

a. **Peak flow factor** =  $4.7 \times p^{-0.11}$  (3.2)

b. **Average domestic flow** = Flow per capita  $\times$  PE (3.3)  
 = m<sup>3</sup>/day

c. **Peak domestic flow**  
 = **Peak flow factor**  $\times$  **Average domestic flow** (3.4)  
 =  $4.7 \times p^{-0.11} \times$  Flow per capita  $\times$  PE  
 = m<sup>3</sup>/day

The ‘p’ value is an estimated PE in thousands (in section 3.6, MS 1228:1991). The average flow per capita used by Malaysian Standard is 0.225 m<sup>3</sup>/day/person (in section 3.2, MS 1228:1991).

Following is the formulae used in obtaining infiltration rate for measuring wastewater flow at 2 manholes:

**Infiltration rate (for 2 manholes flow measurement)**

$$\begin{aligned}
 &= \frac{[\text{Downstream flow (Q}_{out}) - \text{Upstream flow (Q}_{in})]}{[\text{Pipe length} \times \text{Pipe diameter}]} && (3.5) \\
 &= \text{l/day /km/mm-diameter}
 \end{aligned}$$

**3.3.3 Infiltration Measurement**

As mentioned in Section 2.4, infiltration is additional unwanted extraneous water in sewerage systems. In this study, the infiltration measurement is divided into 2 parts, pure infiltration measurement and inflow plus infiltration measurement.

### 3.3.3.1 Field Model

An abandoned downstream manhole (MH74a) was located in Taman Sri Pulai and on 15<sup>th</sup> February 2005 according to Mok (2005), cementing work was performed on the manhole so that no inflow will flow through it. Any water that is found in the manhole after that can safely be said to contain no inflow and thus be classified as infiltration.

**Table 3.1:** Abandoned Sewer Section Characteristics (MH74-MH74a), Taman Sri Pulai

Length	48 metres
Diametre	225 milimetres
Pipe Material	Vitrified Clay Pipe (VCP)



**Figure 3.1:** Abandoned Manhole (MH74a)



**Figure 3.2: Water Pump**

The pure infiltration measurement was started in February 2005 and will be taken daily at 6pm for the duration of 1 year until February 2006. Photo 3.1 shows the manhole 74a and Photo 3.2 shows the automatic pump that is sometimes used to pump out water from the manhole for measuring. The steps taken during the daily measurement work are as follows:

- 1) The manhole (MH74a) is opened using manhole openers.
- 2) The amount of water inside, which will be taken as pure infiltration, is taken out either manually using a pail or by means of a pump and measured with a 20-litres bucket.
- 3) The total infiltration for that day will be  $\text{Number of buckets} \times 20 \text{ litres}$ .
- 4) The value is noted and transferred to the computer file where all the data from the abandoned manhole is stored.
- 5) Analysis of the data is done periodically and when the 1-year duration is up.

### 3.3.3.2 Laboratory Model

A section of the sewer pipe representing actual sewer system having a length of 10 meters was set up in the laboratory of Hydrology and Hydraulics, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai Campus. The diameter of the pipe is 0.225 meters and it is a Vitrified Clay Pipe (VCP). It is laid with a slope of 1:250.

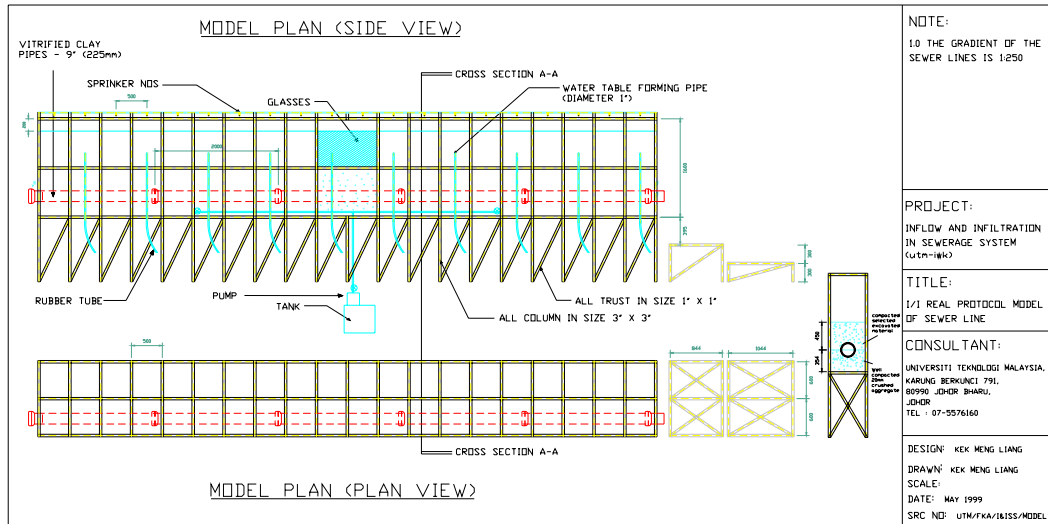
**Table 3.2:** Characteristics of Laboratory Model

Model Location	Hydraulics & Hydrology Laboratory, UTM, Skudai Campus
Model Name	I/I Real Protocol Model of Sewer Line
Pipe Material	Vitrified Clay Pipe (VCP)
Number of Sewers	Five
Pipe Length	10 m
Pipe Diameter	0.225 m
Slope of Pipe	1:250
Soil Type	Sand

Infiltration is studied by subjecting the model to two types of tests, leakage test and infiltration test under both saturated and unsaturated conditions.



**Figure 3.3:** Laboratory Physical Model



**Figure 3.4:** Top and Side Views of the Laboratory Model

### 3.3.3.3 Leakage Test

Leakage is defined as the loss of water in a pipe over a 30 minute period. This was determined by adding water from a measuring vessel at 10 minute intervals and recording the quantity of water required to maintain the original level. According to MS 1228:1991 the amount of leakage should not exceed 1 liter per hour per linear meter per meter of nominal internal diameter of the sewer. The leakage rate for the VCP pipe in the model has also been determined as an indicator to infiltration rate and follows the procedure as described in section 4.4.2, MS 1228:1991 and is given below:

#### Test Procedure for Leakage Test:

1. Fit an expanding plug, suitably strutted to resist the full hydrostatic head, at the lower end of the pipe and in any branches if necessary. The pipes may need strutting to prevent movement.
2. Fit a similar plug and strutting at the higher end but with access for the hose and standpipe.
3. Fill the system with water ensuring that there are no pockets of trapped air.
4. Fill the stand pipe of requisite level.
5. Leave for at least two hours to enable the pipe to become saturated, topping as necessary.
6. After the absorption period, measure the loss of water from the system by noting the amount of water needed to maintain the level in the stand pipe over a further period of 30 minutes, the stand pipe being topped up at regular intervals of 5 minutes.

### 3.3.3.4 Infiltration Test

During the infiltration test, the water was pumped into the model as rainfall at a constant rate of  $0.00039\text{m}^3/\text{s}$  for durations ranging from half an hour to five hours and the water that infiltrated into the model under saturated and unsaturated conditions was collected and measured to determine the infiltration rate. For saturated conditions the tabs at the bottom of the model for drainage were closed where as they were kept open for the unsaturated conditions.



**Figure 3.5:** Rainfall Pumping into the Laboratory Model for Infiltration Test

### 3.3.3.5 Inflow & Infiltration



**Figure 3.6:** Flow Meter

Inflow and infiltration is measured in sewerage systems that are in use. This measurement utilizes 2 flow meters complete with sensors, as shown in Photo 3.3. The steps taken for this measurement are as follows:

- 1) A suitable section of the sewerage system in between 2 manholes with the desired PE and no turbulence or lateral flow is determined from location map.
- 2) A site visit is conducted before the duration of the study is decided on.
- 3) Once the duration is confirmed, one flow meter with sensor will be placed in the upstream manhole and another flow meter with sensor will be placed in the downstream manhole.
- 4) The flow meters will automatically record the flow through the sensors every 5 minutes.
- 5) When the duration is up, the flow meters and sensors will be taken out and cleaned before the data is downloaded into a computer equipped with the software Flowlink4 to analyze the data.

Let's say  $Q_1$  is the flow in the upstream manhole and  $Q_2$  is the flow in the downstream manhole.

If  $Q_1 < Q_2$ , inflow & infiltration occurs.

If  $Q_1 > Q_2$ , leakage occurs.

If  $Q_1 = Q_2$ , no infiltration or leakage occurred

For flow characteristics study, the result obtained from one manhole is sufficient for analysis.



### 3.3.4 Rainfall Measurement

Rainfall can influence infiltration greatly. That is why rainfall measurement is of utmost importance in this research. For this study, there are 2 types of rain gauge available. One is the automated ISCO rain gauge, which is battery operated. The other is a tipping-bucket rain gauge as shown in Photo 3.4, which utilizes the flow meter to record its data since it has no recorder of its own. The rain gauges are put wherever any study takes place so that the effect of rainfall on the study can also be analyzed. The rainfall data downloading process is shown in Photo 3.5.



**Figure 3.7:** ISCO Rain Gauge



**Figure 3.8:** Download Rainfall Data

## **CHAPTER 4**

### **RESULTS AND ANALYSIS**

#### **4.1 Introduction**

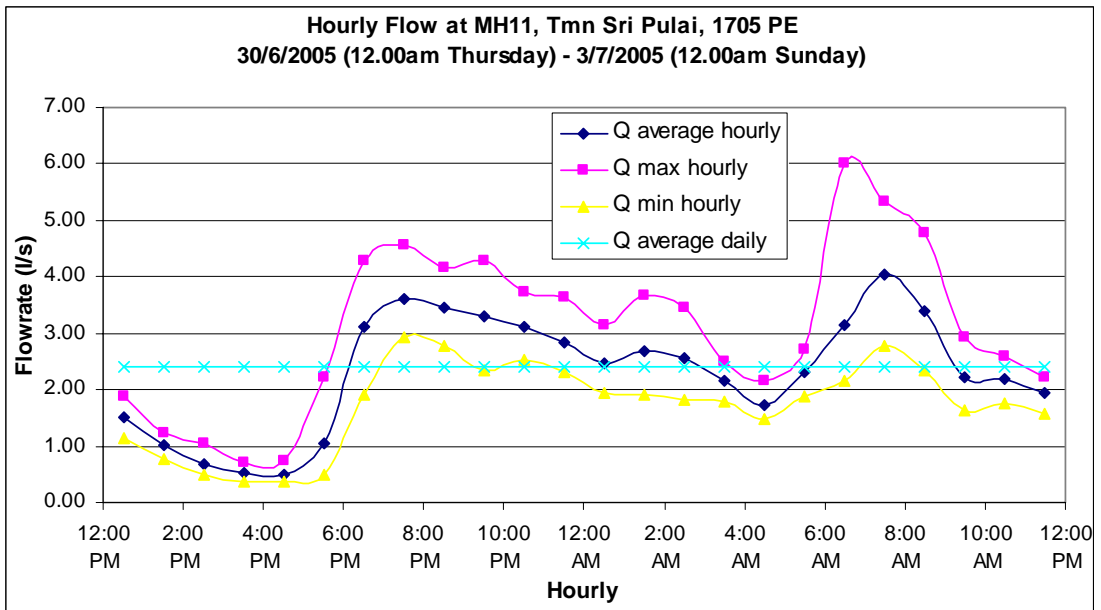
In this dissertation, the writer will concentrate on the results and analysis of Taman Sri Pulai and Taman Universiti, which consists of the abandoned sewer line (MH74-MH74a) and the live sewer line of MH11, MH299, MH306, MH154, MH154a with PE of 1705, 3456 and 9905.

#### **4.2 Population Equivalent Determination**

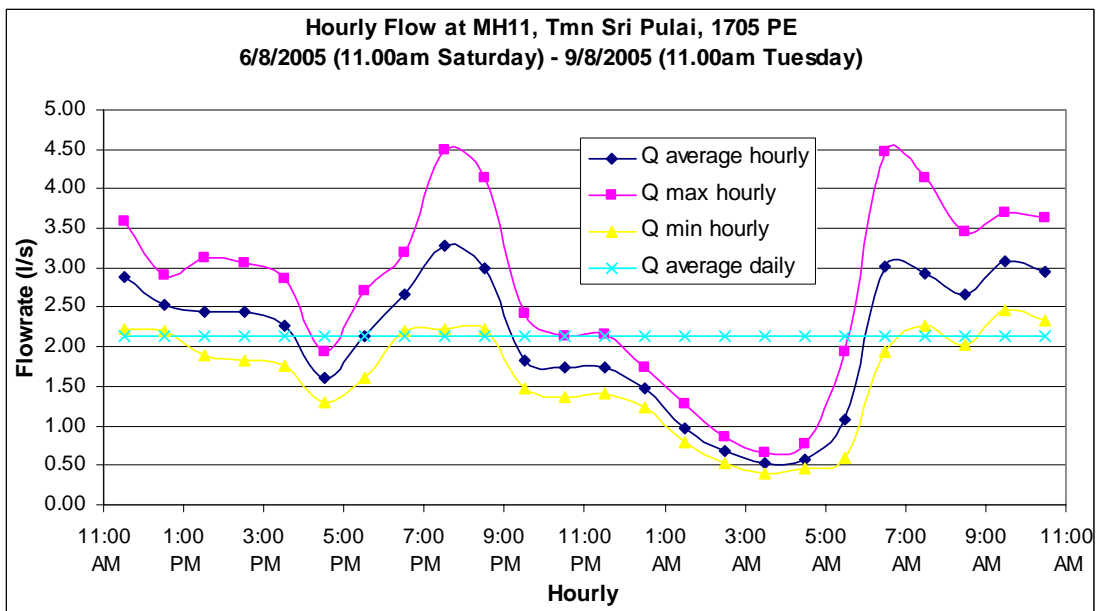
In actual fact, the population equivalent at any given time should be determined because that is the number of persons producing the flow in the sewerage system at that moment. Unfortunately, that will require a huge amount of coordination as well as people to do it, which we are incapable of doing at the moment because our group is currently too small. The population equivalent can only be counted based on MS1228:1991 using layout maps of the respective study areas. This has been done and the population equivalent for MH11 in Taman Sri Pulai is 1705, MH299 – MH306 in Taman Universiti is 3456 and MH154 – MH154a also in Taman Universiti is 9905.

#### **4.3 Flow Characteristics Measurement**

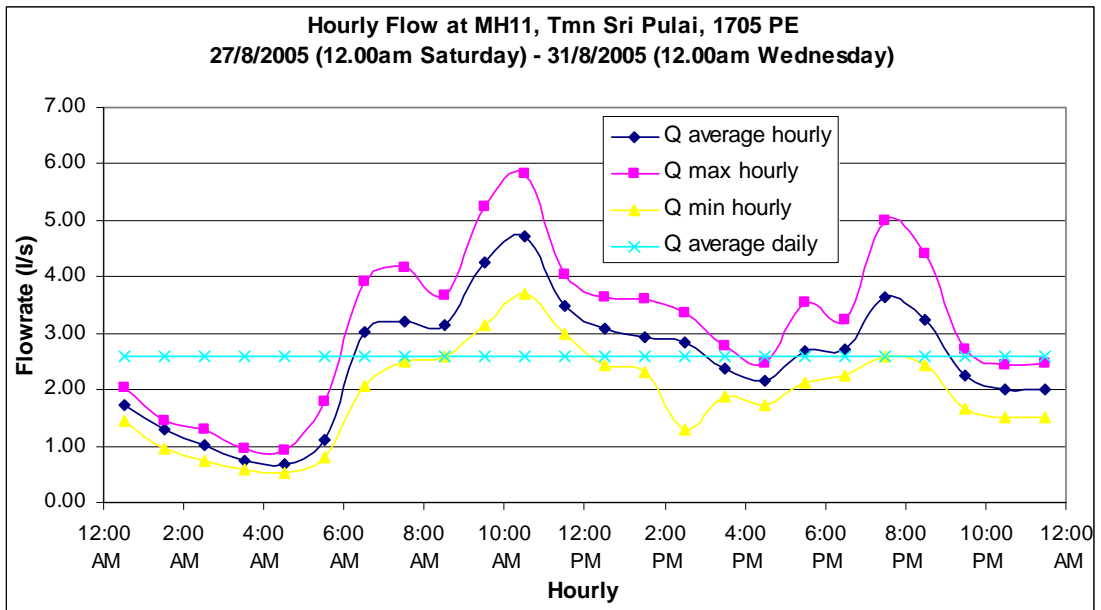
For flow characteristics measurement at Taman Sri Pulai and Taman Universiti, a total of 9 measurements with varying duration have been done using 1 flow meter installed inside MH11, MH229, MH154 and 9 sets of data were obtained. The following are the graphs showing hourly maximum flow (Q peak), hourly minimum flow (Q minimum) and hourly average flow (Q average) summarized from the raw data obtained for each of the 9 sets (refer figure 4.1 to figure 4.9).



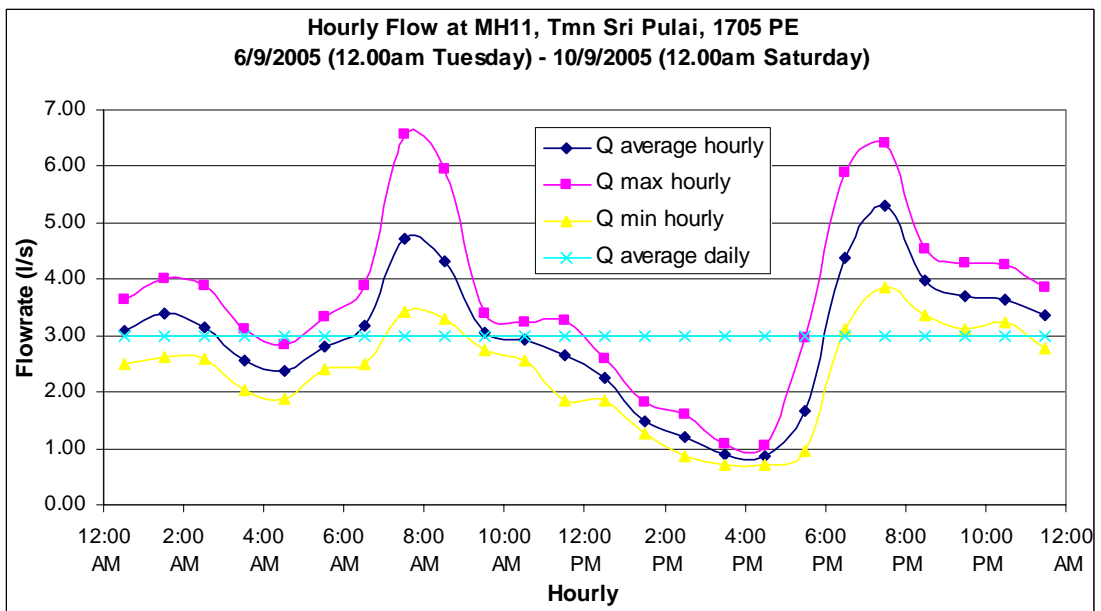
**Figure 4.1:** Hourly Flow Rate Graph (30.6.2005 to 3.7.2005)



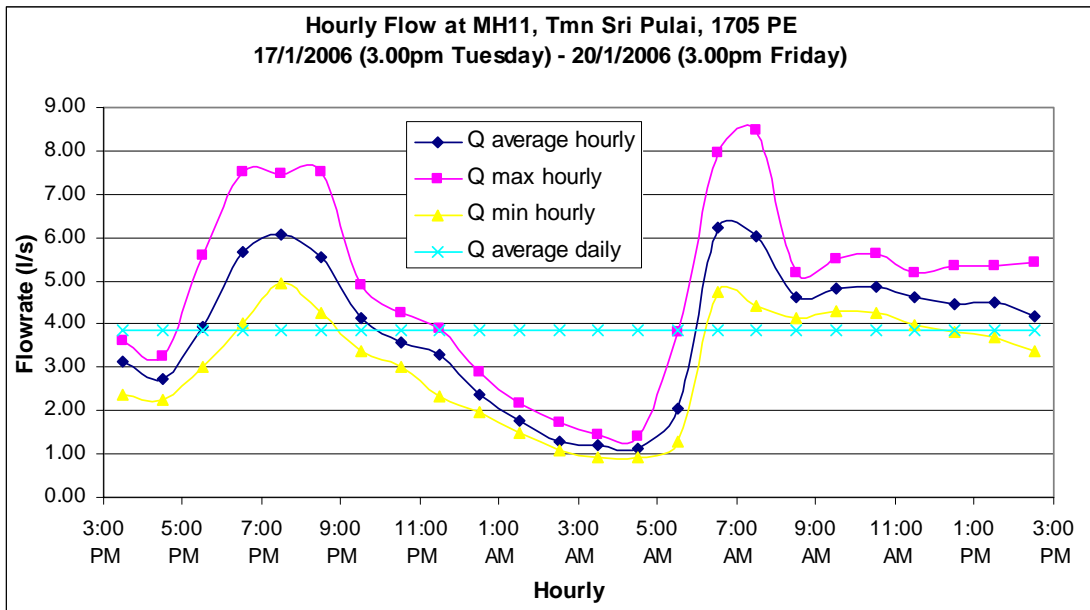
**Figure 4.2:** Hourly Flow Rate Graph (6.8.2005 to 9.8.2005)



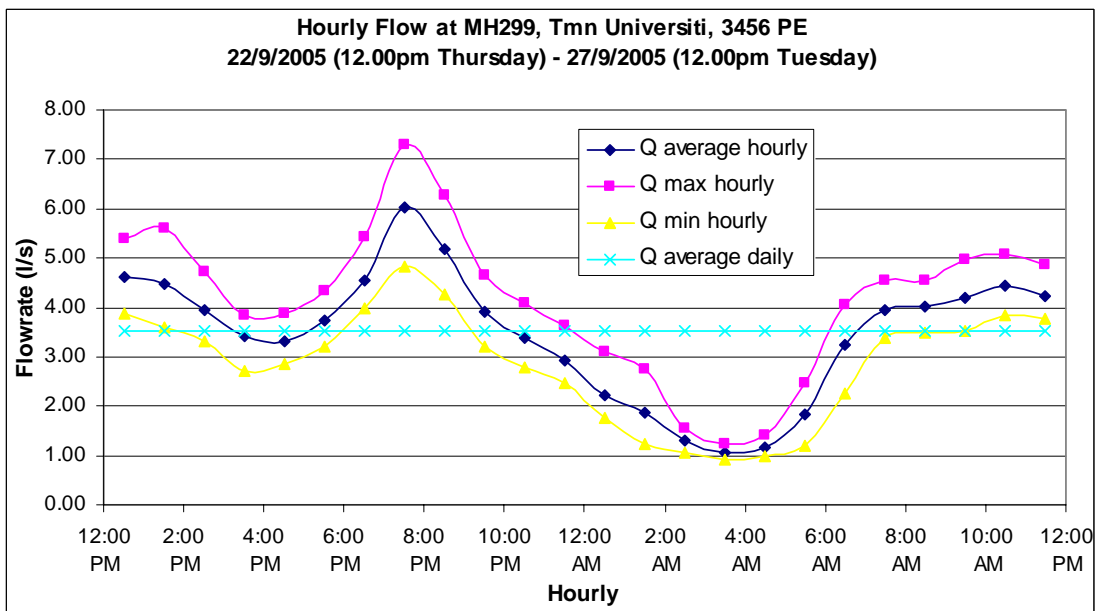
**Figure 4.3:** Hourly Flow Graph (27.8.2005 to 31.8.2005)



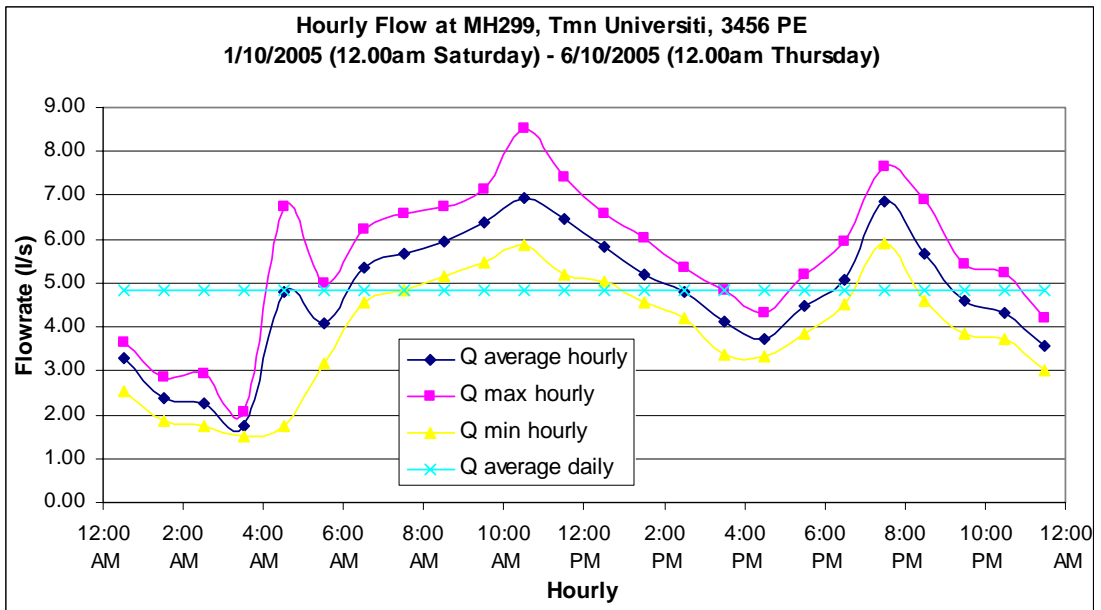
**Figure 4.4:** Hourly Flow Graph (6.9.2005 to 10.9.2005)



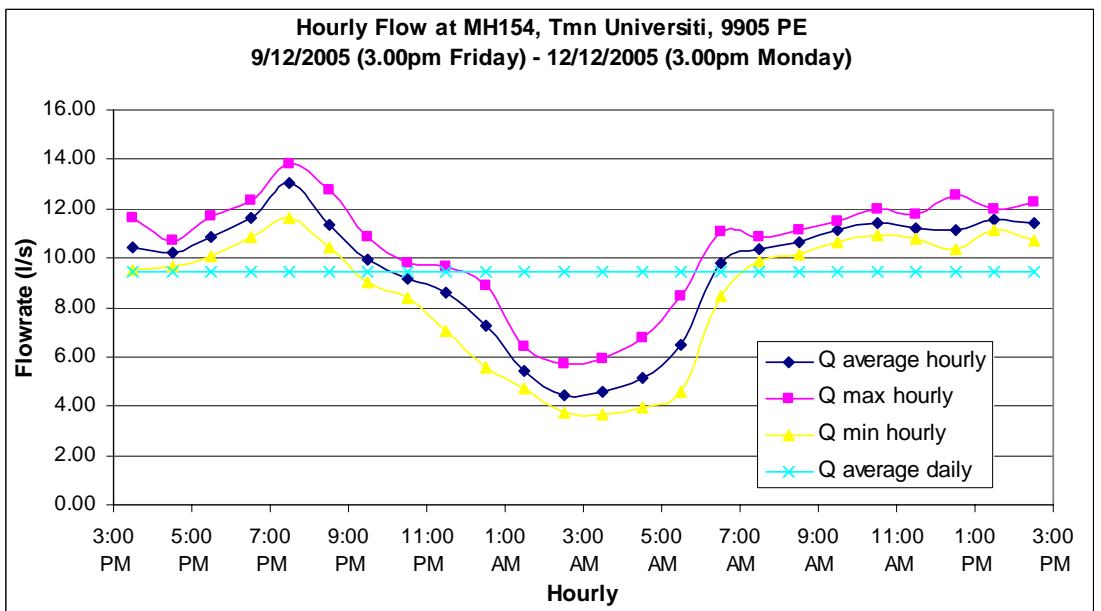
**Figure 4.5:** Hourly Flow Graph (17.1.2006 to 20.1.2006)



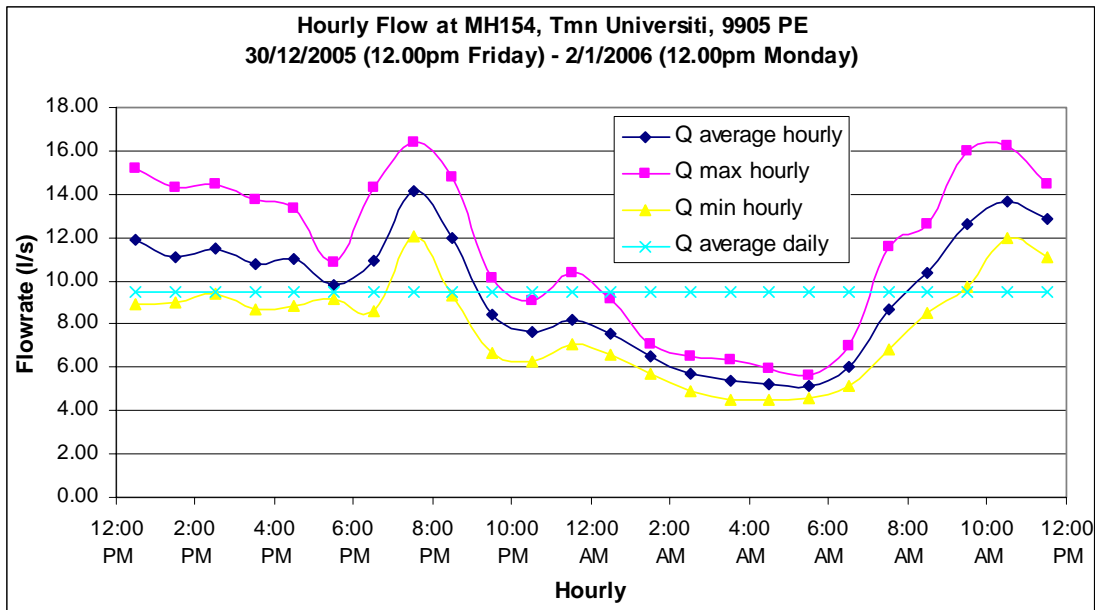
**Figure 4.6:** Hourly Flow Graph (22.9.2005 to 27.9.2005)



**Figure 4.7:** Hourly Flow Graph (1.10.2005 to 6.10.2005)



**Figure 4.8:** Hourly Flow Graph (9.12.2005 to 12.12.2005)



**Figure 4.9:** Hourly Flow Graph (30.12.2005 to 2.1.2006)

#### 4.4 Infiltration Measurement - Taman Universiti Sewerage

Similar flow measurements like in Section 4.3 were also conducted in Taman Universiti. A total of 4 measurements with 7 days duration have been done using 2 flow meter installed inside MH229 – MH306 and MH154 – MH154. The following are the 4 sets of graphs showing the flow rate in the selected manhole with rainfall measurement for those days (refer figure 4.10 to figure 4.13). The results analysis for the measurement will be discussed in Chapter 5.

#### 4.5 Infiltration Measurement - Field Model

Water infiltrating into the abandoned sewer line of MH74-MH74a has been measured everyday for a period of 1 year starting from 10<sup>th</sup> February 2005 and ending on 10<sup>th</sup> February 2006. The result is plotted together with the daily rainfall data (refer figure 4.14). The results analysis for the measurement will be discussed in Chapter 5.

MH299-MH306, Tmn Universiti, 3456 PE  
13/6/2006 (12.00am Tuesday) - 20/6/2006 (12.00am Tuesday)

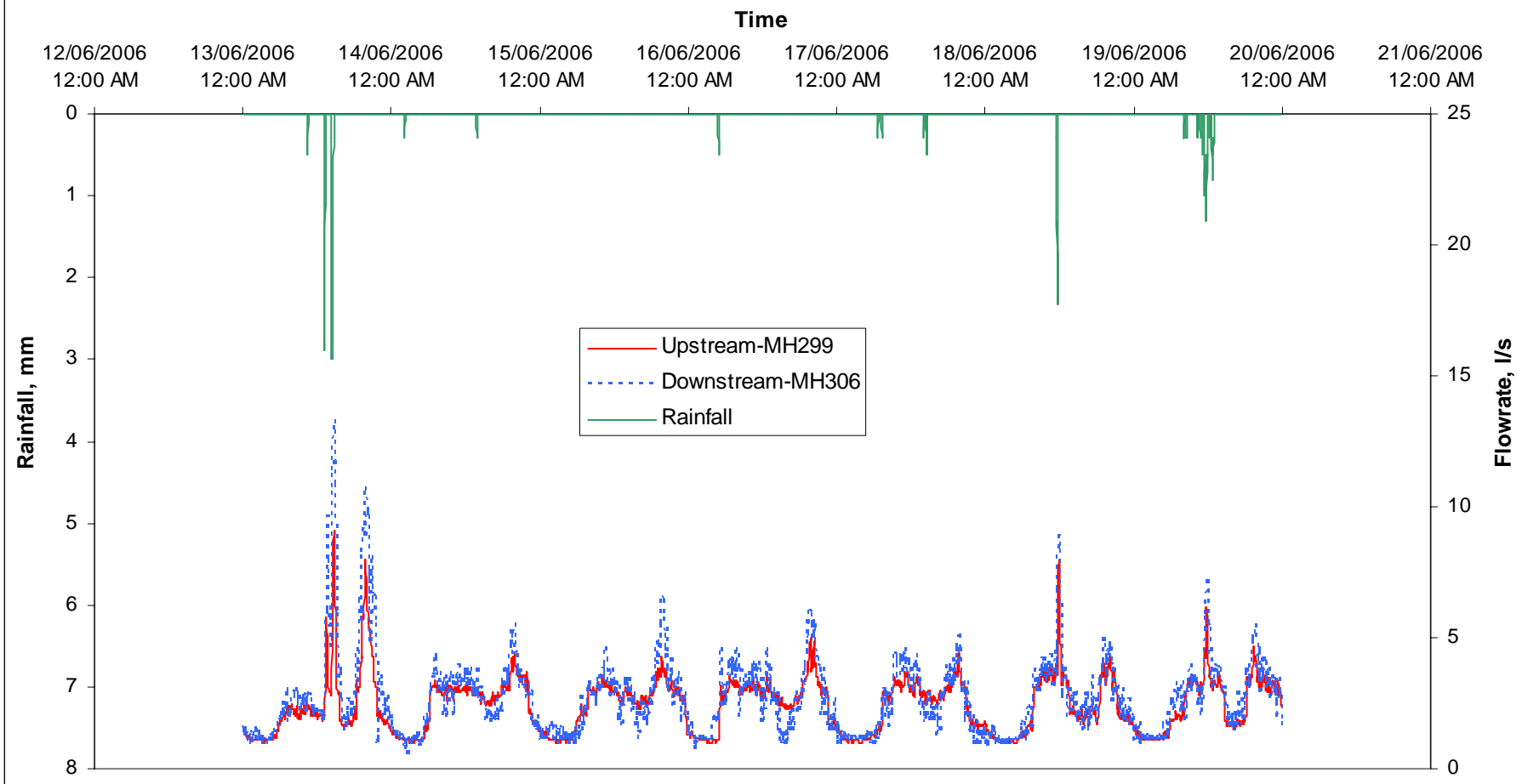


Figure 4.10: 2 Manholes Measurements Flow Rate Graph (13.6.2006 to 20.6.2006)



MH154-MH154a, Tmn Universiti, 9905 PE  
17/5/2006 (12.00pm Wednesday) - 24/5/2006 (12.00pm Wednesday)

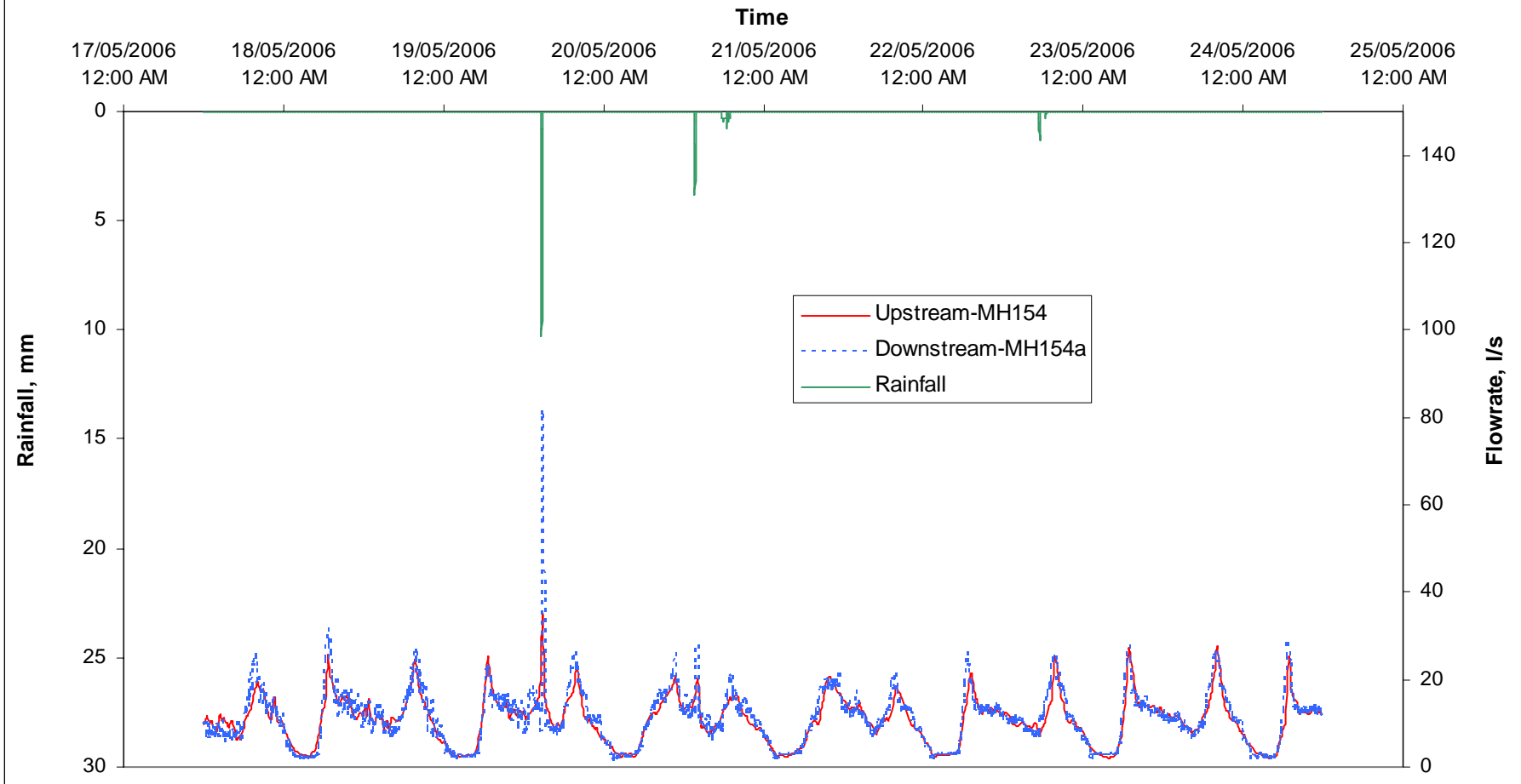
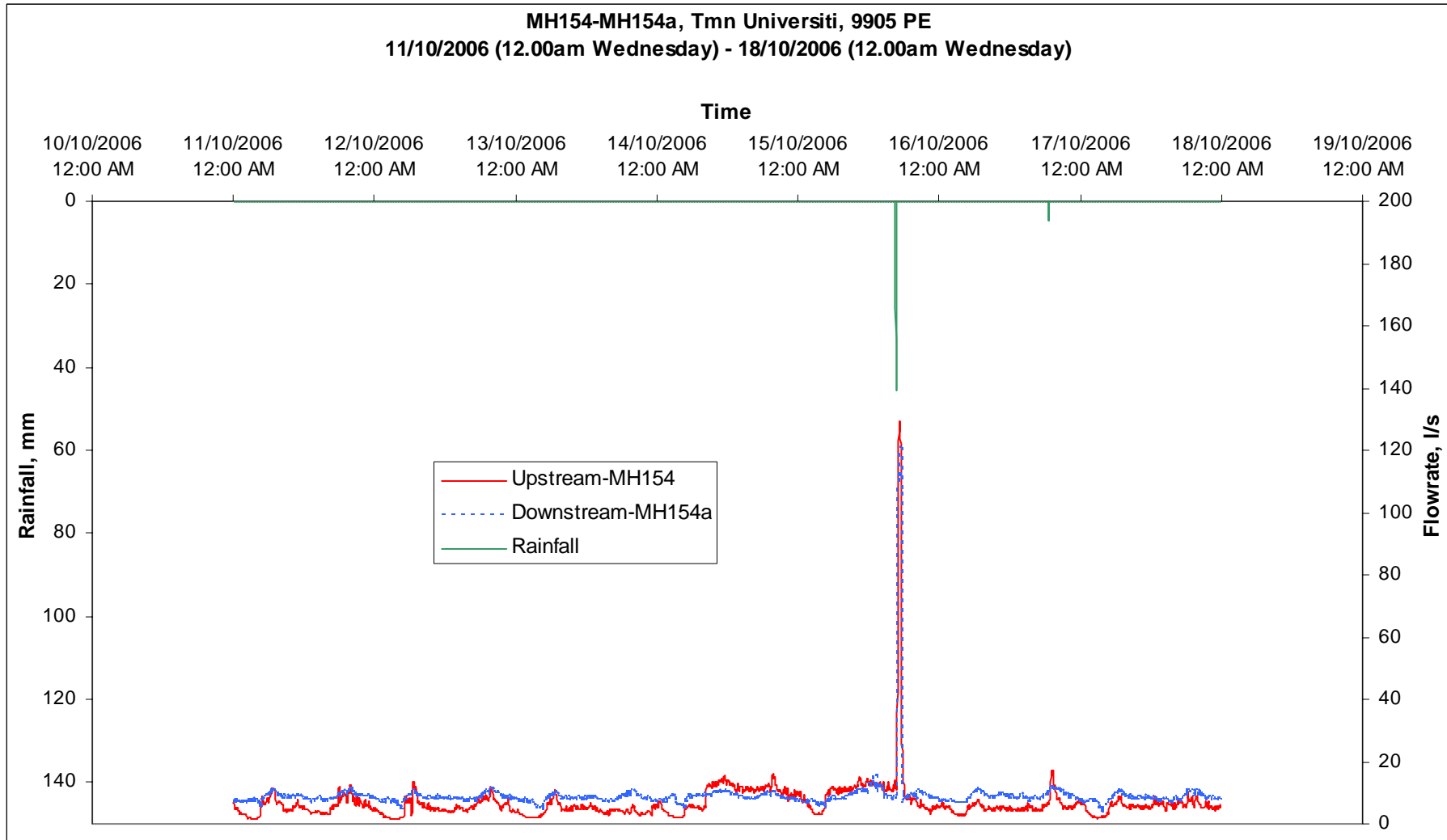
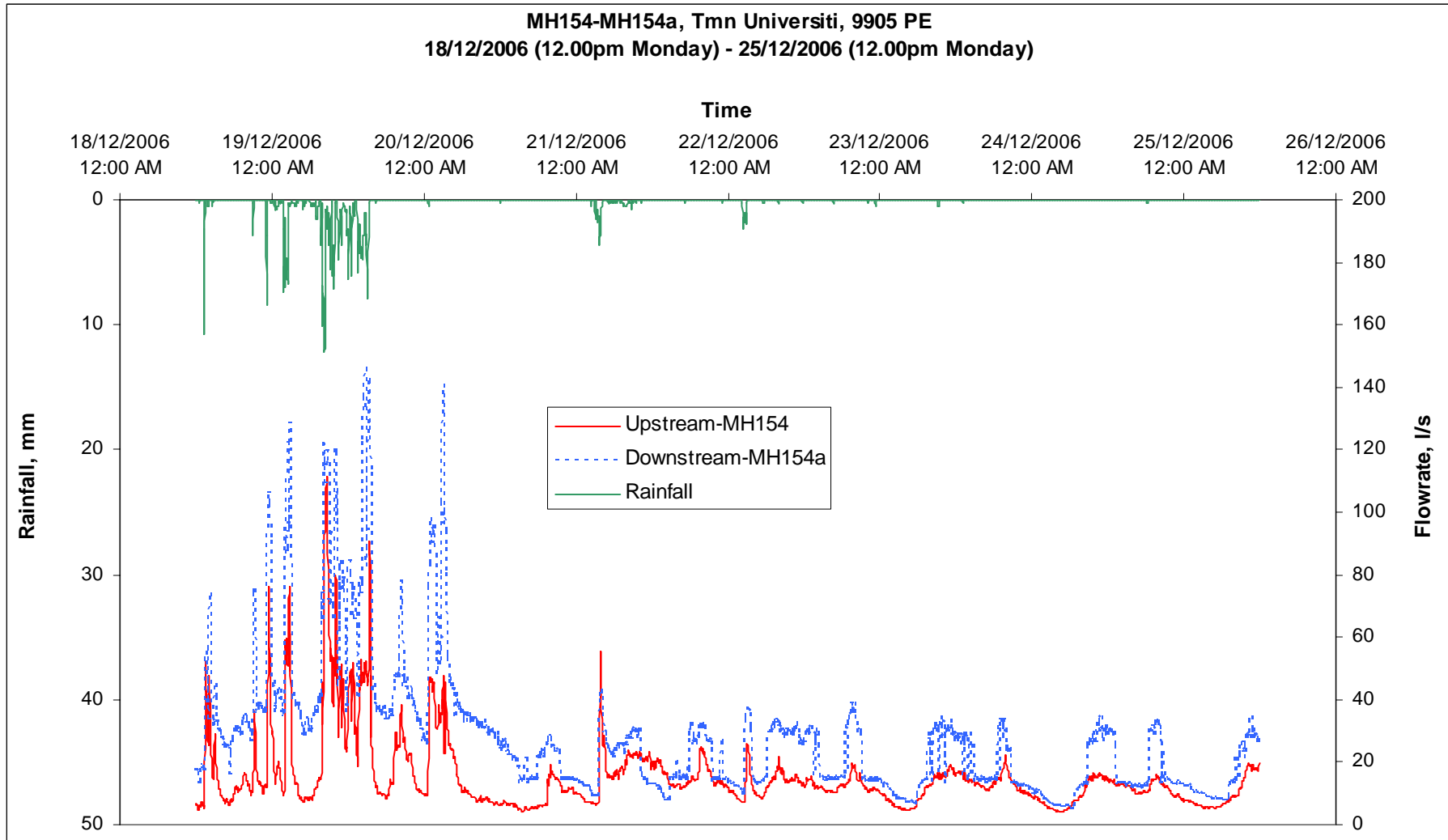


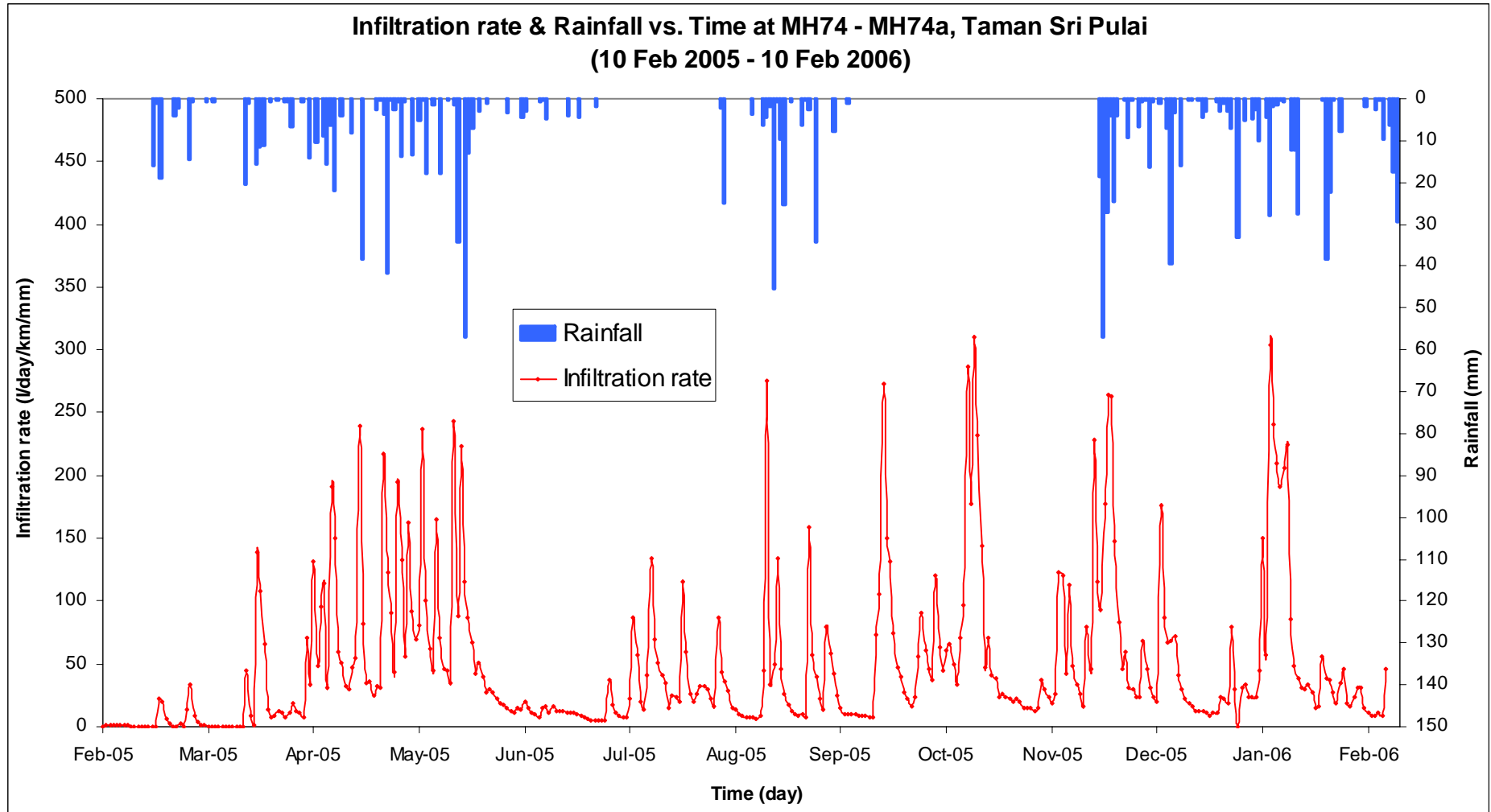
Figure 4.11: 2 Manholes Measurements Flow Rate Graph (17.5.2006 to 24.5.2006)



**Figure 4.12: 2 Manholes Measurements Flow Rate Graph (11.10.2006 to 18.10.2006)**



**Figure 4.13: 2 Manholes Measurements Flow Rate Graph (18.12.2006 to 25.12.2006)**



**Figure 4.14:** 1-year Rainfall vs. Infiltration Rate Graph for Field Model (MH74-MH74a)

## **CHAPTER 5**

### **ANALYSIS AND DISCUSSION**

#### **5.1 Flow Characteristics Study**

The study for the determination of flow characteristics is conducted in two residential areas of Skudai, Johor Bahru in the running sewer lines having different population equivalents. The first study is conducted on manhole MH11, Taman Sri Pulai residential area, Skudai, Johor. This line caters to a population equivalent of 1705. The second study is conducted on the manhole MH299 and MH154, Taman Universiti residential area, Skudai, Johor. This line caters to a population equivalent of 3456 and 9905. The flow meter is calibrated first in the Laboratory of Hydraulics & Hydrology, FKA, UTM, Skudai, Johor just to make sure that the equipment is working properly with minimum chances of error. The detail of the flow meter calibration is given in article 5.1.1. The details of the flow characteristics found during study on the two lines are discussed below:

##### **5.1.1 Calibration of ISCO Area - Velocity Flow Meter**

The calibration of the ISCO Area Velocity Flow Meter model 4250 is done in the laboratory of Hydraulics & Hydrology, Universiti Teknologi Malaysia. Two different sensors are used to measure the flow in the channel, velocity in the channel and depth of water level in the channel. The calibration is done on the Laminar/Turbulence Flow Apparatus by Plint & Partners, UK. The procedure for the determination of percent error, for different depths of flow, in the flow meter is described below:

1. Put the sensor in the channel and open the valve to start the flow of water in the channel after switching on the power supply.
2. Measure the initial depth in the channel as well as the width of the channel and input the same in the flow meter.
3. Find the differential head from the differential manometer attached with the apparatus.

4. With the help of this differential head find the flow in litres/second in the channel using the Manning's graph.
5. Using the depth of flow and the width of channel to find the area of flow in the channel to find the velocity of flow in the channel.
6. Note the depth, velocity and flow through the area velocity flow meter and compare the results with the actual values found manually.
7. Hence the percentage error for the values.
8. Repeat the steps from step 3 to 7 by increasing the flow in the channel slowly.

After going through all the results the details of which are given in Tables 5.1 to Table 5.3, it is found that:

1. The Flow Meter is unable to detect the velocity of flow and discharge in the channel if the depth of water decreases below 29 mm. Where as the depth is found by the sensor.
2. The minimum error for sensor 1 is found as 6.56% at the depth of 65mm.
3. The maximum error for sensor 1 is found as 31.35% at the depth of 35 mm.
4. The minimum error for sensor 2 is found as 1.12% at the depth of 86mm.
5. The maximum error for sensor 2 is found as 20.45% at the depth of 50 mm.
6. On the average the percent error for sensor 1 is 15.06 %.
7. On the average the percent error for sensor 2 is 13.03 %.

**Table 5.1:** Calibration of Sensor Number 1 with Area Velocity Flow Meter

No	Height, (mm) (Actual)	Height, (mm) f/meter	velocity, (m/s) (actual)	velocity, (m/s) f/meter	q, (l/s) (actual)	q, (l/s) f/meter	% Error
1	22.00	20.10	0.14	0.00	2.50	0.00	
2	35.00	31.30	0.74	0.58	7.75	5.32	31.35
3	41.00	41.90	0.92	0.66	11.30	8.30	26.55
4	65.00	67.00	0.82	0.84	16.00	17.05	6.56
5	50.00	45.70	0.63	0.57	9.50	7.93	16.53
6	80.00	81.70	0.81	0.87	19.50	21.27	9.08
7	88.00	85.30	0.95	0.91	25.00	23.24	7.04
8	90.00	86.30	1.00	0.93	27.00	24.75	8.33

**Table 5.2:** Calibration of Sensor Number 2 with Area Velocity Flow Meter

No	Height, (mm) (Actual)	Height, (mm) f/meter	velocity, (m/s) (actual)	velocity, (m/s) f/meter	q, (l/s) (actual)	q, (l/s) f/meter	% Error
1	30.00	29.40	0.50	0.00	4.50	0.00	
2	40.00	37.00	0.60	0.58	7.25	6.48	10.62
3	50.00	45.10	0.73	0.64	11.00	8.75	20.45
4	60.00	52.20	0.72	0.68	13.00	10.45	19.62
5	67.00	57.30	0.76	0.75	15.25	12.45	18.36
6	73.00	63.40	0.86	0.80	18.80	15.17	19.31
7	80.00	80.00	0.92	0.87	22.00	21.62	1.73
8	86.00	88.10	0.97	0.94	25.00	24.72	1.12

**Table 5.3:** Calibration of Area Velocity Flow Meter at very Low Water Level

No.	Height, (mm) (Actual)	Height, (mm) f/meter	velocity, (m/s) (actual)	velocity, (m/s) f/meter	q, (l/s) (actual)	q, (l/s) f/meter	% Error
1	34.00	36.90	0.64	0.52	6.50	5.68	12.62
2	29.00	32.00	0.57	0.47	5.00	4.50	10.00
3	26.00	30.30	0.00	0.00	0.00	0.00	

### 5.1.2 Flow Characteristics Measurement

From Figures 4.1 to 4.9, we can obtain the flow characteristics for each set of measurement, which is been summaries below in Table 5.4.

It can be seen that for Taman Sri Pulai and Taman Universiti, Skudai, Johor there is a pattern for the time of peak flow occurrence. As can be seen from the figure 4.1 to 4.9, for most of the data set, the peak flow occurs either between 6 to 7 o'clock in the morning or between 7 to 8 o'clock at night or both. It can be seen also that for the sets of measurement which includes weekdays and weekends, the peak flow occurred on a weekday.

This is largely due to the fact that weekdays are school days and working days; so people tend to get up at roughly the same time, between 6 to 7 o'clock in the morning, to prepare themselves for either school or work. This applies to all residential areas, not only Taman Sri Pulai and Taman Universiti. Thus, in between 6 to 7 o'clock in the morning, there will be a concentration of sewage flowing through the sewerage system and very likely, the peak flow will occur during that period of concentrated flow.

**Table 5.4: Result Summaries**

No	Location	Date	PE	Peak flows l/s	Average flows l/s	Actual peak flow factor	Constant value of peak flow Factor, K	Flow per capita l/day/person
1	T.Sri Pulai (MH11)	30/6-3/7/05	1705	6.00	2.41	2.49	2.64	122.13
2	T.Sri Pulai (MH11)	6-9/8/05	1705	4.50	2.13	2.11	2.24	107.94
3	T.Sri Pulai (MH11)	27-31/8/05	1705	5.83	2.60	2.24	2.38	131.75
4	T.Sri Pulai (MH11)	6-10/9/05	1705	6.58	3.00	2.19	2.33	152.02
5	T.Sri Pulai (MH11)	17-20/1/06	1705	8.47	3.84	2.21	2.34	194.59
6	T.Universiti (MH299)	22-27/9/05	3456	7.30	3.54	2.06	2.36	88.50
7	T.Universiti (MH299)	1-6/10/05	3456	8.52	4.85	1.76	2.01	121.25
8	T.Universiti (MH299)	13-20/6/06	3456	4.97	2.43	2.05	2.34	60.75
9	T.Universiti (MH306)	13-20/6/06	3456	6.39	2.64	2.42	2.77	66.00
10	T.Universiti (MH154)	9-12/12/05	9905	13.83	9.47	1.46	1.88	82.61
11	T.Universiti (MH154)	30/12/05-2/1/06	9905	16.40	9.46	1.73	2.23	82.52
12	T.Universiti (MH154)	17-24/5/06	9905	21.56	10.80	2.00	2.57	94.21
13	T.Universiti (MH154a)	17-24/5/06	9905	25.00	10.96	2.28	2.94	95.60
14	T.Universiti (MH154)	11-18/10/06	9905	25.64	6.78	3.78	4.87	59.14
15	T.Universiti (MH154a)	11-18/10/06	9905	25.1	8.93	2.81	3.62	77.90
16	T.Universiti (MH154)	18-25/12/06	9905	29.74	15.06	1.97	2.54	131.37
17	T.Universiti (MH154a)	18-25/12/06	9905	47.26	26.83	1.76	2.27	234.03
18*	Putrajaya (PS-1)	11/05-1/06	10743	82.78	58.62	1.41	1.83	471.45
19*	Putrajaya (PS-2)	11/05-1/06	19869	205.83	172.02	1.20	1.66	748.03
20*	Putrajaya (PS-3)	11/05-1/06	20469	253.89	229.86	1.10	1.54	970.24
21*	Putrajaya (PS-10)	11/05-1/06	51463	527.78	417.57	1.26	1.95	701.05
22*	Putrajaya (PS-5)	11/05-1/06	80591	747.42	692.11	1.08	1.75	742.00

\* Additional data given by IWK Head Quarter



The same scene can be seen between 7 to 8 o'clock at night when people return home to freshen and clean themselves up after a long day at work or school in the afternoon session. When the bathrooms and toilets in most of the houses are used at roughly the same time between 7 to 8 o'clock at night, there will be a concentration of sewage flow in the sewerage system so there is a big chance of the peak flow occurring during that period of time. Of course, there will be anomalies like data set in certain figure where the peak flow occurs between 10 to 11 o'clock in the morning but that is to be expected in a research like this.

The average flow for Taman Sri Pulai is taken as the average of the Q average for 1705 PE data, which is 2.8 litres/second. The minimum flow for all the measurements is 0.1 litres/second.

The average flow for Taman Universiti (MH299 and MH 154) is taken as the average of the Q average for 3456 PE and 9905 PE data, which is 3.37 litres/second and 12.29 litres/second. The minimum flow for all the measurements is 0.1 litres/second.

From Tables 5.4, it can be seen that Taman Universiti has bigger average flows and peak flows compared to Taman Sri Pulai. This is due to the fact that the population equivalent for the sewerage line in which we did our study is much bigger than the population equivalent for the sewerage line studied in Taman Sri Pulai.

### **5.1.3 Flow Per Capita Contribution**

After determining the flow characteristics for each of the flow measurement, the per capita flow contribution can be obtain for each measurement set by dividing the Q average for each set of measurement with the population equivalent of the study area, which is 1705, 3456 and 9905. The results are tabled below in Table 5.4.

From Table 5.4, the flow per capita obtained for each set of measurement is significantly lower than the design flow per capita of  $0.225\text{m}^3/\text{day-person}$  suggested in MS1228:1991. The average flow per capita for Taman Sri Pulai sets of measurement is  $0.142\text{ m}^3/\text{day-person}$ , which is 37% lower than the design flow per capita of  $0.225\text{ m}^3/\text{day-person}$  recommended in MS1228:1991.

The average flow per capita from the Taman Universiti data sets is  $0.1\text{ m}^3/\text{day-person}$ , 56% lower than the  $0.225\text{ m}^3/\text{day-person}$  recommended in MS1228:1991.

Thus, it can be deduced from the actual flow per capita results obtained that the current sewerage design is more than sufficient to cater for the daily sewage disposal needs of the residents in Taman Sri Pulai and Taman Universiti.

#### 5.1.4 Peak Flow Factor

Next after obtaining the actual flow per capita contribution of the study area, the peak flow factor, can be calculated from Equation 3.4 by rearranging the parameters in the equation. The actual peak flow factor value calculated using actual flow per capita contribution is compared with the design peak flow factor value calculated using MS1228:1991 recommended equation. The results of peak flow factor value calculation is in Table 5.4 and note that the current practice in design of sewerage systems uses peak flow factor equation of  $4.7p^{-0.11}$ .

By using the actual flow per capita calculated for each set of data, the peak flow factor value for each data set is found to be less than the value of the design peak flow factor recommended by MS1228:1991 and used in current design practice. The average peak flow factor value calculated using actual flow per capita for Taman Sri Pulai sets of measurement is 2.25. This is 49% lower than the design peak flow factor value used in current design practice.

As for Taman Universiti, the actual peak flow factor values obtained by using the actual flow per capita calculated is also less than the design peak flow factor. The average peak flow factor value for 3456 PE site calculated using actual flow per capita contribution is 2.07, which is 50% lower than the design peak flow factor value used in current sewerage system design practice. And the average peak flow factor value for 9905 PE site calculated using actual flow per capita contribution is 2.32, which is 39% lower than the design peak flow factor value used in current sewerage system design practice.

This means that the current sewerage system design in Malaysia is over design or in another word the design peak flow factor recommended by MS1228:1991 is too high for designing sewerages system in this country.

If the actual peak flow factor is calculated using the MS1228:1991 recommended flow per capita contribution of  $0.225\text{m}^3/\text{day-person}$ , the value that were obtain is even lower than the actual peak flow factor result that were calculated using the actual flow per capita contribution measured from the field experiment.

In this study we are looking for the optimum design criterion for sewerage systems in a tropical climate. Since the peak flow factor is used in conjunction with the average flow and population equivalent to obtain the estimated peak flow to be used in the design of a sewerage system, it is the design criterion in Equation 3.4 that is looked into in this study.

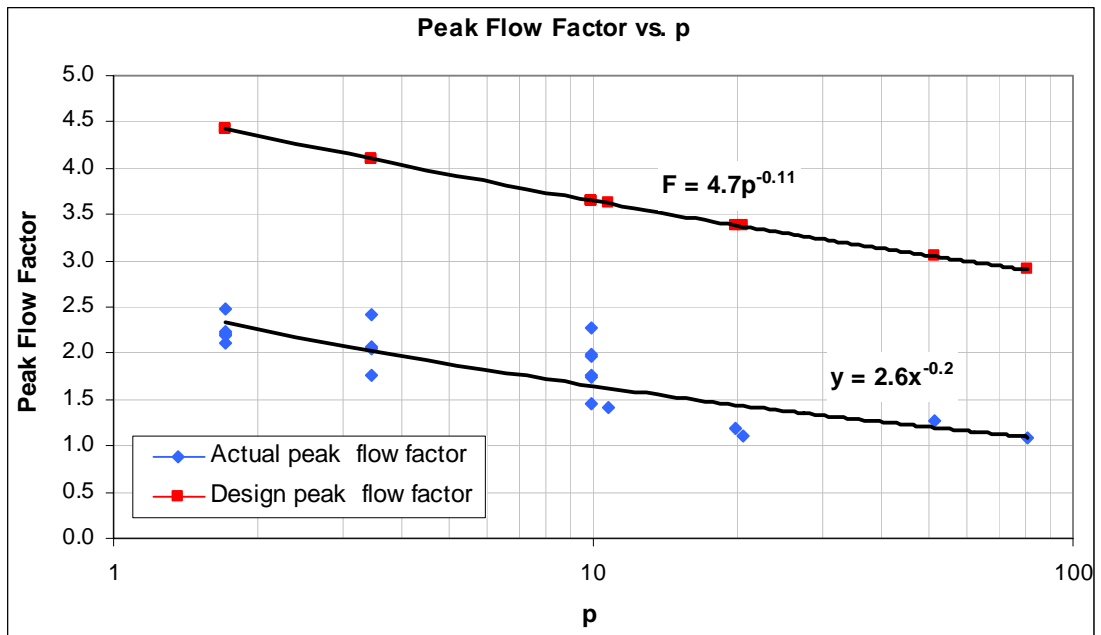
From Equation 3.4, we can see that there is a proportional relationship between peak flow factor value and the Q peak. The bigger the peak flow factor value used, the bigger the Q peak value will be get. A higher value of Q peak used in sewerage system designs will result in bigger sizes of sewerage pipes needed since velocity of sewage flow is limited to a particular range only. This translates to higher cost of material and works for construction of the sewerage system. All this is can be avoided because from the actual results obtained from site, the peak flow factor value to be used need not be as high as recommended.

In view of the peak flow factor value obtained from this study in Taman Sri Pulai and Taman Universiti, it can be said that the sewerage system in this two residential areas is over designed since it was designed using the MS1228:1991 recommended peak flow factor value of  $4.7p^{-0.11}$  whereas the actual peak flow factor value can range from 1.46 to 3.78, depending on the flow per capita used during the design process.

The comparison of results and analysis of this study conducted in Taman Sri Pulai and Taman Universiti shows that the sewerage system in this two residential areas is indeed designed for more than necessary and the parties involved in constructing the sewerage system could have avoided the extra cost if they were to use a smaller but suitable peak flow factor value in the calculation for peak flow to design the sewerage system.

The results of the actual peak flow factor and design peak flow factor value that was obtained through analysis was plotted again 'p' ( $p = PE/1000$ ) value using a semi log graph. And then from the plotted graph, a new power equation of peak flow factor for designing sewerage system was produce. Figure 5.1 demonstrates the actual peak flow factor equation is different from the design peak flow factor equation currently used in sewerage system design.

It obviously illustrate that both of the graph lines are parallel as depicted in Figure 5.1. So, from this study, the design peak flow factor equation used by Malaysian Standard, MS 1228:1991 that is  $4.7 \times p^{-0.11}$  can be replaced with a new equation as equation 4.1 below. This equation hopefully can assist in designing and developing a future vitrified clay pipe sewerage system.



**Figure 5.1:** The Design Peak Flow Factor Compared with the Actual Peak Flow Factor from this Study

$$\text{Study peak flow factor} = 2.6 \times p^{-0.2} \quad (4.1)$$

Note:  $p = PE/1000$

## 5.2 Infiltration Study

The infiltration study is conducted on Taman Universiti sewerage system and two physical models; one is a laboratory model and the other is the field model. The results and analysis of the tests is given below:

### 5.2.1 Infiltration Study - Taman Universiti Sewerage

In this section, the flow rates for the total period of selected monitoring will be discussed. The effect of rainfall on the flow rates can also be observed.

Referring to Figure 4.10, it demonstrates the characteristics of flow that was obtained from measurement conducted at manhole MH299 (upstream) and MH306 (downstream), Taman Universiti, Johor Bahru. The measurement was conducted for 7 days beginning on 13/6/06 and ending on 20/6/06.

In Figure 4.10 a drastic increase in flow is observed on the 13/6/06. The rain intensity on that day is recorded as 14.7 mm. This contributed to the highest flow recorded, which is 13.3 l/s. Consequently, this difference and increment illustrates prove that there is an inflow and infiltration occurrence in the sewerage pipe during rain fall. Infiltration can also be seen to occur a lot as the value of upstream flow rate is lower than the downstream flow rate ( $Q_{out} > Q_{in}$ ). However, there were also instances when ( $Q_{out} < Q_{in}$ ), or the downstream flow rate is lesser than that of the upstream. During such instances, leakage is happening.

Referring to Figure 4.11, it demonstrates the characteristics of flow that was obtained from measurement conducted at manhole MH154 (upstream) and MH154a (downstream), Taman Universiti, Johor Bahru. The measurement was conducted for 7 days beginning on 17/5/06 and ending on 24/5/06.

In Figure 4.11 a drastic increase in flow is observed on the 19/5/06. The rain intensity on that day is recorded as 20.9 mm. This contributed to the highest flow recorded, which is 80.53 l/s. Consequently, this difference and increment illustrates prove that there is an inflow and infiltration occurrence in the sewerage pipe during rain fall. Infiltration can also be seen to occur a lot as the value of upstream flow rate is lower than the downstream flow rate ( $Q_{out} > Q_{in}$ ). However, there were also instances when ( $Q_{out} < Q_{in}$ ), or the downstream flow rate is lesser than that of the upstream. During such instances, leakage is happening.

Referring to Figure 4.12, the characteristics of flow that was obtained from measurement conducted at the same sewer line is shown. The measurement was conducted for 7 days beginning on 11/10/06 and ending on 18/10/06.

In Figure 4.12 a drastic increase in flow is observed on the 15/10/06. The rain intensity on that day is recorded as 45.72 mm. This contributed to the highest flow recorded, which is 129.4 l/s. Consequently, this difference and increment illustrates prove that there is an inflow and infiltration occurrence in the sewerage pipe during rain fall. Infiltration can also be seen to occur a lot as the value of upstream flow rate is lower than the downstream flow rate ( $Q_{out} > Q_{in}$ ). However, there were also instances when ( $Q_{out} < Q_{in}$ ), or the downstream flow rate is lesser than that of the upstream. During such instances, leakage is happening.

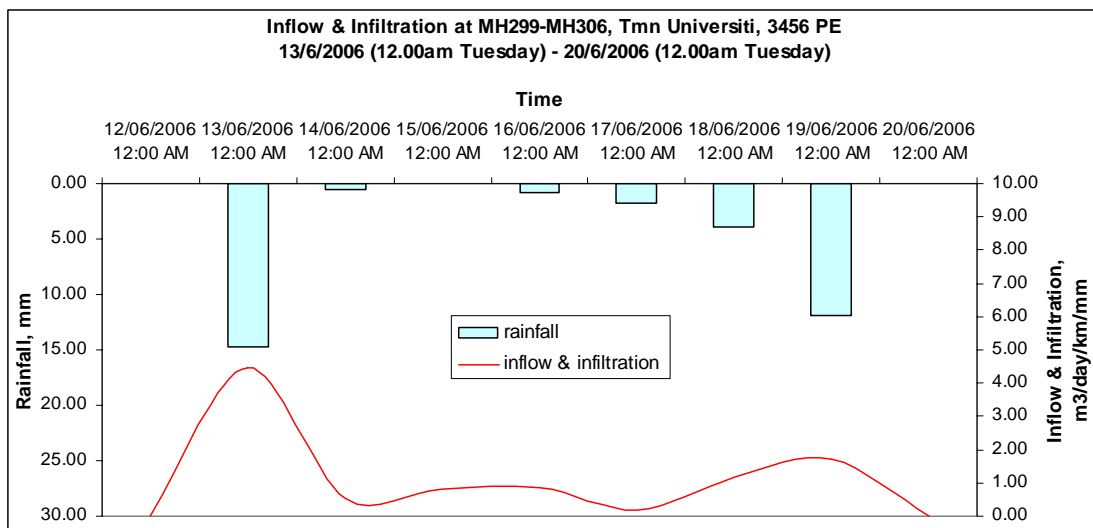
Referring to Figure 4.13, the characteristics of flow that was obtained from measurement conducted at the same sewer line is shown. The measurement was conducted for 7 days beginning on 18/12/06 and ending on 25/12/06.

Just as the previous monitoring, it is observed that the flow rate is vastly influenced by the rainfall. Here the rain intensity was very much higher and the recorded value for the 19/12/06 alone was 282.6 mm. Heavy rain was experienced on other days as well. Due to this, the flow rates recorded showed peaks which tallied

with the occurrence of rain. The highest flow rate recorded on that day is 146.2 l/s. The infiltration and leakage can be seen much clearer in this graph as the flow rates are very unstable and the scale of the graph allows for easier observance on the differences in flow that has occurred.

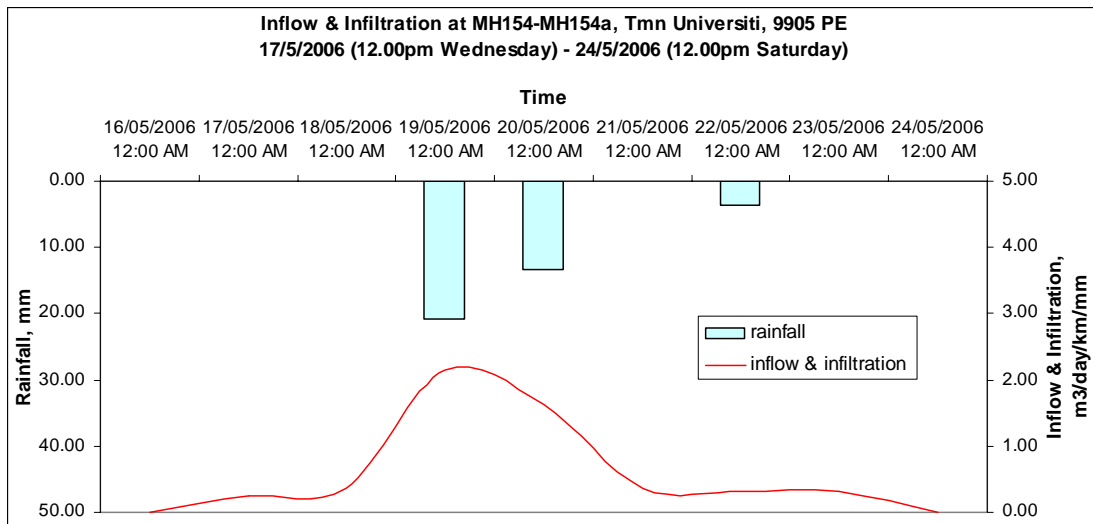
### 5.2.1.1 Infiltration Analysis

In Figure 5.2, the infiltration that occurred between 13.6.2007 to 20.6.2007 is shown. The highest rate of infiltration recorded is 4.47 m<sup>3</sup>/day/km-length/mm-diameter. There was not much infiltration due to less rainfall occurs that week. What can be noticed is the rapid increase of infiltration that occurs after rain. The recommended rate by MS1228:1991 and Hammer & Hammer (2004), is 0.05 m<sup>3</sup>/day/km-length/mm-diameter. The difference observed is 8840% higher.



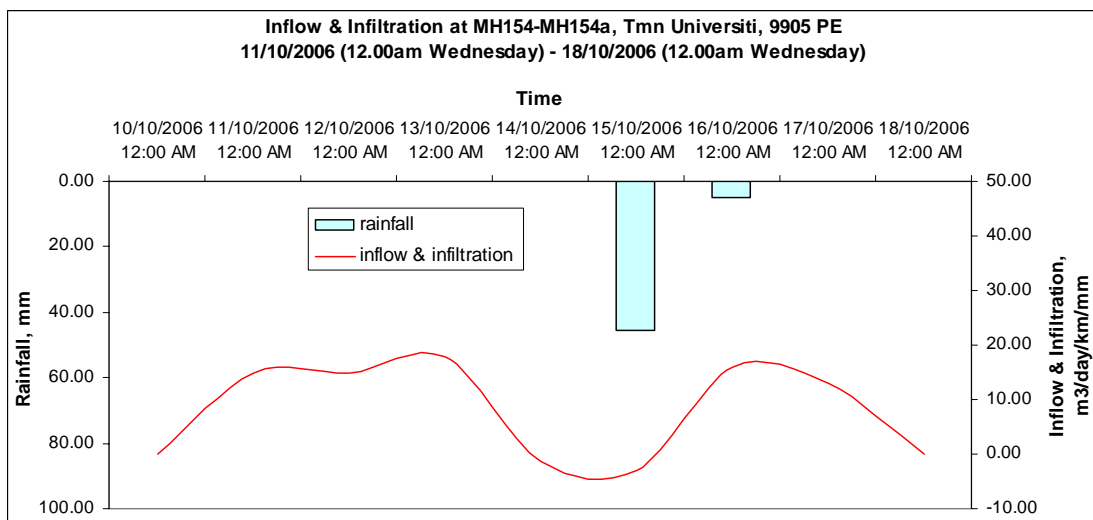
**Figure 5.2:** Infiltration against Rainfall Graph (13.6.2006 to 20.6.2006)

Refer to Figure 5.3, the infiltration occurring between 17.5.2006 to 24.5.2006 is shown. The highest rate of infiltration that occurred is 2.15 m<sup>3</sup>/day/km-length/mm-diameter. There was not much infiltration due to less rainfall occurs that week. What can be noticed is the rapid increase of infiltration that occurs after rain. The recommended rate by MS1228:1991 and Hammer & Hammer (2004), is 0.05 m<sup>3</sup>/day/km-length/mm-diameter. The difference observed is 4200% higher.

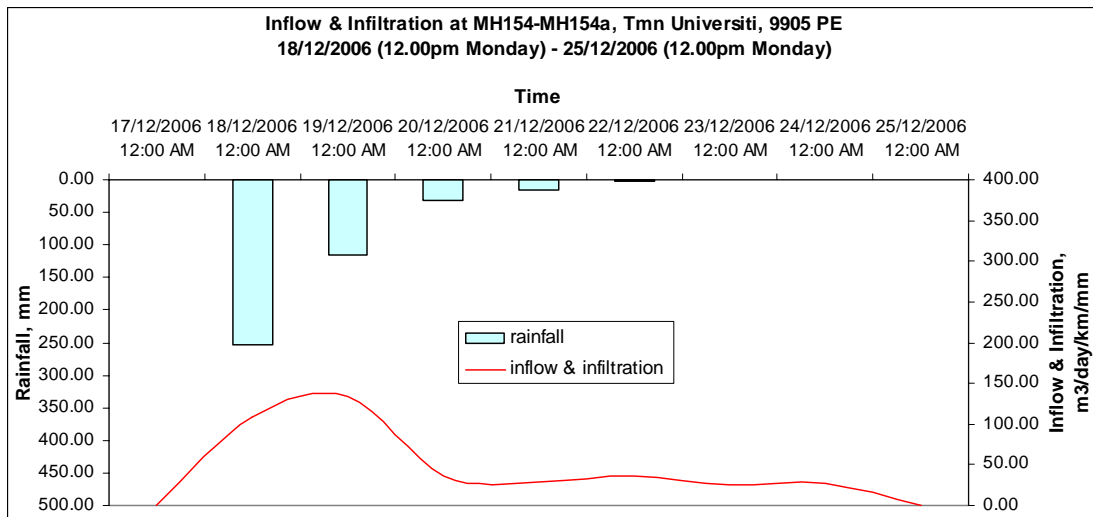


**Figure 5.3:** Infiltration against Rainfall Graph (17.5.2006 to 24.5.2006)

Refer to Figure 5.4, the infiltration occurring between 11.10.2006 to 18.10.2006 is shown. The highest rate of infiltration that occurred is 17.89  $\text{m}^3/\text{day}/\text{km-length}/\text{mm-diameter}$ . There were also instances of leakage occurring during the experiment. What can be noticed is the rapid increase of infiltration that occurs after rain. The recommended rate by MS1228:1991 and Hammer & Hammer (2004), is  $0.05 \text{ m}^3/\text{day}/\text{km-length}/\text{mm-diameter}$ . The difference observed is 35680% higher.



**Figure 5.4:** Infiltration against Rainfall Graph (11.10.2006 to 18.10.2006)



**Figure 5.5:** Infiltration against Rainfall Graph (18.12.2006 to 25.12.2006)

In Figure 5.5, the infiltration between 18.12.2006 to 25.12.2006 is illustrated. The highest infiltration value recorded is  $134.18 \text{ m}^3/\text{day}/\text{km-length}/\text{mm-diameter}$ . This is almost 357700% higher than value allowed. This shows that infiltration is happening at an alarming rate yet unnoticed. The high value of infiltration can be accounted for due to the very high rain fall. On the same day (19/12/06) that the highest infiltration occurred, the rainfall intensity was 282.6mm. This is a 100 year return period rainfall. So it clearly shows the direct relationship between rainfall and infiltration.



## 5.2.2 Infiltration Study - Laboratory Model

Infiltration in the laboratory is studied by subjecting the model to two types of tests, leakage test and infiltration test. The infiltration test is carried out under both saturated and unsaturated conditions. The aim of these tests is to determine the infiltration in a sewer pipe in controlled environment.

### 5.2.2.1 Leakage Test

For the laboratory experiment, the leakage rates for the VCP pipe in the model have been determined and the results summary is shown in Table 5.5. The procedure for the conduction of leakage test is already discussed in chapter 3. All the leakage rates are smaller than the allowable rate that permitted by section 4.4.2.2, MS1228:1991 which is 1 liter/hour/m/m-dia. The leakage rate is slightly increasing from test-1 to test-3. The increment may be due to the deterioration in the physical condition of the sewer after each laboratory test, where each laboratory test may have disturbed the model condition. The leakage rates will be used as an indicated value to show the influence of leakage to the infiltration rate.

**Table 5.5:** Results Summary for the Laboratory Leakage Tests

Leakage Test	Date	Leakage Rate (liter/hour/m/m-dia)	Percentage compare with allowable leakage rate by MS:1228
Test-1	21/08/2004	0.2122	21.22 %
Test-2	08/09/2004	0.2324	23.24 %
Test-3	28/12/2004	0.3060	30.60 %

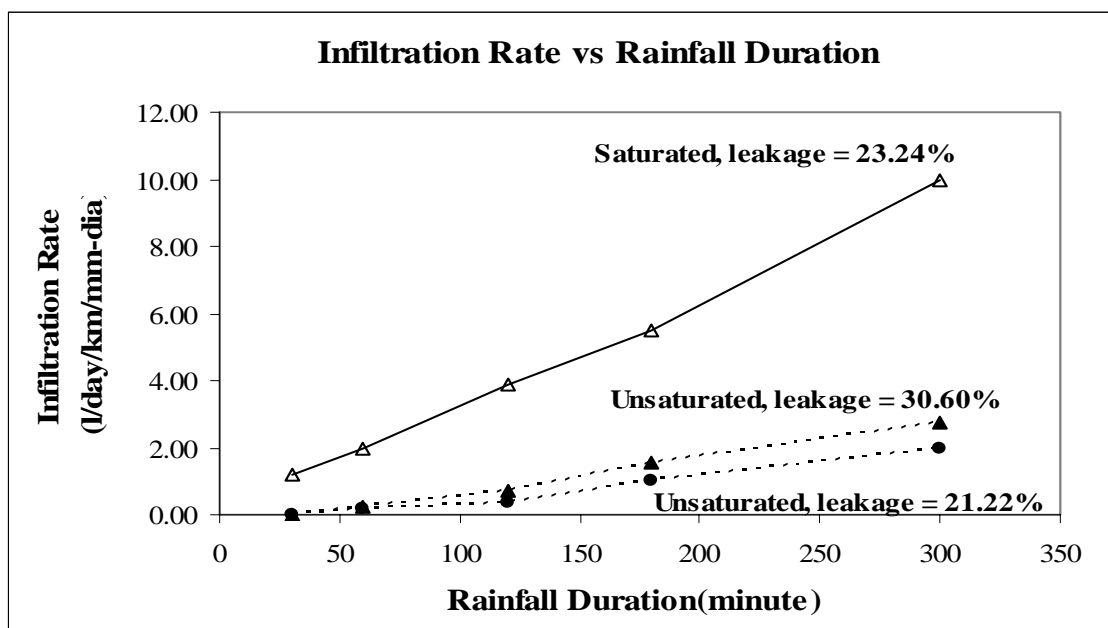
### 5.2.2.2 Infiltration Test

The laboratory infiltration tests have been conducted to verify the infiltration rate and factors that influence the infiltration rate include the rainfall duration, soil condition of physical model and leakage rate. Table 5.6 shows the results summary for the maximum laboratory infiltration rate for VCP and the Figure 5.6 shows the relation between infiltration rates corresponding to leakage rate to versus rainfall duration. For physical model under unsaturated condition, the first test conducted in August 2004 with the maximum infiltration rate of 1.95 l/day/km/mm-dia and the corresponding leakage rate is 0.2122 liter/hour/m/m-dia or 21.22%. The second test conducted in December 2004 with the maximum infiltration rate of 2.77 l/day/km/mm-dia and the corresponding leakage rate is 0.3060 liter/hour/m/m-dia or

30.60 %. The infiltration rate for the second test is slightly greater than the first test, the corresponding leakage rate shows that the increment of infiltration rate possibly due to mild deterioration of model at joints. The VCP model which has larger leakage rate may cause large infiltration. For the physical model under saturated condition, the test conducted in September 2004 has the maximum infiltration rate of 9.95 liter/day/km/mm-dia with the corresponding leakage rate of 0.2324 liter/hour/m/m-dia or 23.24%. It is obvious that the infiltration rate for physical model under saturated condition is much greater than the infiltration rate when model under unsaturated condition. The reason is that, the soil condition which is under saturated condition is potentially stored more water rather than unsaturated condition. Figure 5 shows also the infiltration rates are increased with the increment of rainfall duration for the model under both saturated and unsaturated condition. All the maximum infiltration rates are smaller than the design maximum infiltration rate which is 50 l/day/km/mm-dia (as mentions in MS1228:1991) and 46 l/day/km/mm-dia (as suggested by Hammer & Hammer). Both design infiltration rate are adequate for laboratory infiltration rates. The percentages of comparison are shown in Table 3 as well.

**Table 5.6:** Result Summary for the Laboratory Infiltration Test

Date	Model's Condition	Maximum Infiltration (l/day/km/mm-dia)	Percentage compare with MS1228:1991	Percentage compare with Hammer & Hammer (2001)
Aug'04	Unsaturated	1.95	3.90 %	4.20 %
Dec'04	Unsaturated	2.77	5.54 %	6.02 %
Sept'04	Saturated	9.95	19.9 %	21.6 %



**Figure 5.6:** Infiltration Rate Corresponding to Leakage Rate vs. Rainfall Duration.

### **5.2.3 Infiltration Study - Field Model**

The infiltration study was conducted on the field test model which is an abandoned sewer section between manholes MH74 and MH74a. The data was collected continuously for one year starting from February 2005 and up to February 2006. The details of the infiltrated water collected daily in liters/day and the corresponding infiltration rate in liters/day/km-length/mm-diameter is given in Appendix - A. The one year data includes both wet and dry periods. The rainfall volume for the same 24-hour period is also measured with the help of automatic rain gauge measuring rainfall volume every five minutes of interval.

#### **5.2.3.1 Infiltration Measurement**

For infiltration measurement, Figure 4.14 shows the infiltration rate versus rainfall for one year that the infiltration rate at the abandoned sewer line of MH74-MH74a is measured.

As can be seen from the graphs in Figure 4.14, whenever there is a significant rainfall (the blue bars extending downwards) on a particular day, the infiltration rate will increase for that day, the graph line forming a peak. In some cases, the peaks for the infiltration graph line will appear a few days after a heavy rainfall. This is usually the case when it rains after a period of dryness. The rain will take time to seep through the dry soil to infiltrate into the abandoned sewer.

Most of the time, the infiltration rate will be below 50 litres/day/kilometre-length/millimetre-diameter as recommended by MS1228:1991 when there is no rain or little rain (below 10mm) unless the rain happens suddenly after a period of dryness.

From Figure 4.14, it can be seen that the highest infiltration rate, 310.19 litres/day/kilometre-length/millimetre-diameter occurred on 16.10.2005. This rate is over six times that of the allowable infiltration rate 50 litres/day/kilometre-length/millimetre-diameter stated in MS1228:1991.

Out of the 365 days, 100 days or approximately 27.4% of the days experienced infiltration rate exceeding the recommended rate by MS1228:1991 as well as Hammer & Hammer (2004), which is 50 litres/day/kilometre-length/millimetre-diameter and 46 litres/day/kilometre-length/millimetre-diameter respectively.

As can be seen from Figure 4.14, the infiltration rate of a sewer line increases with the passing of time. When infiltration rate measurement works at the abandoned sewer line MH74-MH74a started on the 10<sup>th</sup> of February 2005, the rate of infiltration did not exceed 50 litres/day/kilometre-length/millimetre-diameter for six consecutive weeks because the sewer line was newly sealed with concrete. But after six weeks, infiltration rates exceeding 50 litres/day/kilometre-length/millimetre-diameter started to appear, the values growing ever higher whenever subsequent heavy rainfall occurred.

The graph in Figure 4.14 can be divided into two main periods, the dry period and the wet period. Dry period is a period of a few days where there is little or no rainfall while wet period constitutes duration of days where there is heavy rainfall or consecutive rainfalls. By looking at Figure 4.14, we can see that infiltration rate is more significant during wet periods. Therefore, wet periods contribute more infiltration compared to dry periods.

## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 Conclusion

After performing the study on Taman Sri Pulai and Taman Universiti, gathering as well as analyzing all the data, several conclusions can be gleaned from the result and analysis.

As can be seen that there are two periods of time in a day when hourly peak flow is likely to occur, that is between 6am to 7am in the morning and between 7pm to 8pm at night. Also, the daily peak flow will fall on a weekday. These phenomena can be explained by the lifestyle of the residents at Taman Sri Pulai and Taman Universiti, which is largely made up of working adults and schooling children.

The average flow per capita contribution at Taman Sri Pulai and Taman Universiti is lower than the design flow per capita used during the design of the sewerage system ( $0.225 \text{ m}^3/\text{day-person}$ ). So it can be said that the current sewerage system at Taman Sri Pulai and Taman Universiti is adequate to support the sewage generated by the residents there.

From this analysis, it can be seen that the peak flow factor recommended by MS1228:1991 and used in current practice design is in fact very much bigger than necessary. Thus can be deduced that the peak flow factor equation used to get the peak flow in sewerage systems design is bigger than necessary, which will lead to unnecessary cost in material and labour.

From this study in Taman Sri Pulai and Taman Universiti, the peak flow factor value obtained in each study is lower than the value used in current sewerage system design practice. The conclusion for this is there may be a need to review the whole equation used in sewerage system design practice, including the peak flow factor, the flow per capita contribution assumed as well as the hyper scripted  $-0.11$  value for the population equivalent in thousands.

The infiltration measurement at the abandoned sewer line of MH74-MH74a in Taman Sri Pulai show and explain us whenever it rains, the infiltration rate for that day or for a few days after that will rise sharply compared to the previous date's infiltration rate. It may thus be concluded that there is tremendous amount of extraneous water that seeps into the sewerage system as inflow/infiltration. Also it can be concluded that there is a proportional relationship between rainfall and infiltration rate in sewerage systems and that wet periods contribute significantly more infiltration into sewerage systems than dry periods. This is evident from the results of the study conducted on the field test model. Infiltration as high as 310 liters/day/km-length/mm-diameter has been found on the October 2005, which is much higher than the limit as given by Malaysian Standard MS1228:1991 which is 50 liters/day/km-length/mm-diameter and also much higher than the value given by Hammer & Hammer (2001) which is 46 liters/day/km-length/mm-diameter. This shows the effect of the rainfall on the infiltration in the sewers. During the dry period however the infiltration is within the design limits as given by Malaysian Standard MS1228:1991 and also the value given by Hammer & Hammer (2001).

The test conducted on the laboratory model show a very encouraging picture. There were two type of tests conducted to measure the infiltration in a VCP sewer in the controlled environment. All the results of the leakage and infiltration tests show that the leakage and infiltration rate are within the limits prescribed by Malaysian Standard MS1228:1991. This shows that with proper supervision during the construction period we can reduce the amount of infiltration in our sewerage system and indirectly reduce the load on our treatment plants. Therefore the workmanship during the construction process may be improved so that the undue pressure on the treatment plants during the wet periods may be removed.

## **6.2 Recommendations**

These are a few of the recommendations suggested to improve on this study as well as similar future studies by having more comprehensive data and analysis.

- i) Recount and reconfirm the population equivalent (PE) of the study area
- ii) Usage of 2 flowmeters in a suitable stretch of sewer line, one in the upstream manhole and the other in the downstream manhole to register the amount of infiltration into the stretch of sewer line. This data is invaluable because it represents the actual infiltration rate happening in sewerage systems in Malaysia.
- iii) Studies should be carried out in sewer lines catering to other different population equivalent so as to have data from sewerage lines with different population equivalent.

- iv) All inflow and infiltration studies should be accompanied by the determination of the groundwater table level as well as the characteristics of the soil surrounding the sewer pipes.
- v) Smoke testing can be conducted in sewer lines suspected of leakage to detect the exact location of leakage.

## REFERENCES

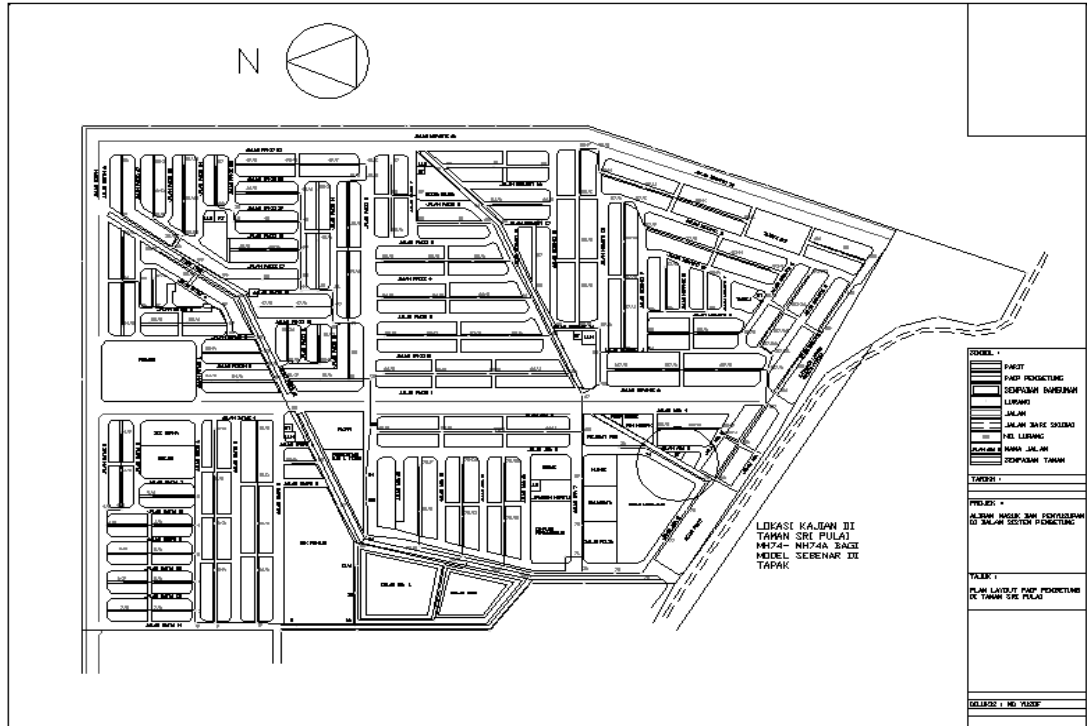
- American Society of Civil Engineers (1982). *Gravity Sanitary Sewer Design and Construction*. WPCF-Manuals Of Practice-No. FD-5.
- Cheah Sau Wei (2002). *Kajian Aliran Masuk Dan Penyusupan Dalam Sistem Pembetulan Di Taman Skudai Baru Dan Bandar Sri Alam Johor Bahru*. Universiti Teknologi Malaysia : Thesis, B.Sc.
- Hammer, M. J. and Hammer, M.J. Jr. (2004). *Water and Wastewater Technology*. 5<sup>th</sup> Edition. Pearson Prentice Hall
- Ho Jenn Shing (2002). *Kajian Aliran Masuk Dan Penyusupan Dalam Sistem Pembetulan Di Taman Sri Pulai Dan Taman Timor Johor Bahru*. Universiti Teknologi Malaysia : Thesis, B.Sc.
- Kamran (2005). *Evaluation Of Inflow/Infiltration And Flow Characteristics For Design Of Sanitary Sewers In Skudai, Johor Bahru*. Universiti Teknologi Malaysia : Thesis, M.Sc.
- Kek Meng Liang (1999). *Aliran Masuk Dan Penyusupan Dalam Sistem Pembetulan*. Universiti Teknologi Malaysia : Thesis, B.Sc.
- Liu, C. and Evett, J. B. (2005). *Soils and Foundations*. SI Edition. Pearson Prentice Hall.
- Malaysian Standard (1991). *Code of Practice for Design and Installation of Sewerage Systems*. Malaysia:(MS 1228)
- Mays, L. W. (2001). *Stormwater Collection Systems Design Handbook*. McGraw-Hill
- Mok Hun Yew (2005). *Kajian Penyusupan Dan Kebocoran Bagi Paip Pembetulan VCP Dalam Sistem Pembetulan*. Universiti Teknologi Malaysia : Thesis, B.Sc.
- Ngoi Si Cheng (2003). *Kajian Penyusupan Dalam Sistem Pembetulan Di Johor Bahru*. Universiti Teknologi Malaysia : Thesis, B.Sc.
- Norhan Abdul Rahman (2003). *Research Collaboration Between Indah Water Konsortium Sdn. Bhd. and Universiti Teknologi Malaysia Final Report Inflow & Infiltration In Sewerage Systems*. Faculty of Civil Engineering, Universiti Teknologi Malaysia.



- Novotny V., Imhoff, K. R., Olthof, M., Krenkel, P. A., (1989), *Karl Imhoff's Handbook Of Urban Drainage And Wastewater Disposal*. John Wiley & Sons,
- Onn bin Abdul Rani (2000). *Kajian Aliran Masuk Dan Penyusupan Di Dalam Sistem Pembetulan*. Universiti Teknologi Malaysia : Thesis, B.Sc.
- Stenis, J. (2004). *Industrial Management Models with Emphasis Construction Waste*. Lund Institute of Technology : Doctoral Thesis.
- Teh Woan Jin (2001). *Kajian Tapak Dan Model Penyusupan Dan Aliran Dalam Sistem Pembetulan Di Taman Sri Pulai Johor Bahru*. Universiti Teknologi Malaysia : Thesis, B. Sc.
- Terzaghi, K., R. B. Peck, and G. Mesri (1996), *Soil Mechanics in Engineering Practice*, 3<sup>rd</sup> ed., John Wiley & Sons, Inc., New York.
- Viessman W. Jr., Hammer M. J. (1985). *Water Supply and Pollution Control*. New York : Harper & Row, Publishers.
- White, J. B. (1970). *The Design of Sewers and Sewage Treatment Works*. London : Edward Arnold (Publishers) Ltd.Inc.
- Yusof Sukarti (2004). *Kesan Aliran Masuk Dan Penyusupan Terhadap Sistem Pembetulan Di Beberapa Kawasan Taman Perumahan Di Johor Bahru*. Universiti Teknologi Malaysia : Thesis, M.Sc.

# APPENDIX A

Location of Abandoned Sewer (MH74-MH74a) at Taman Sri Pulai



## APPENDIX B

1 Year Data from Abandoned Sewer Line (10<sup>th</sup> February 2005 to 10<sup>th</sup> February 2006)

Date	Volume of Infiltration (litres)	Infiltration Rate (l/d/km/mm-dia)	Rainfall (mm)
2/10/2005	4.60	0.43	0.0
2/11/2005	7.30	0.68	0.0
2/12/2005	14.60	1.35	0.0
2/13/2005	19.00	1.76	0.0
2/14/2005	15.50	1.44	0.0
2/15/2005	14.00	1.30	0.0
2/16/2005	11.90	1.10	0.0
2/17/2005	10.00	0.93	0.0
2/18/2005	5.20	0.48	0.0
2/19/2005	4.40	0.41	0.0
2/20/2005	0.00	0.00	0.0
2/21/2005	0.00	0.00	0.0
2/22/2005	0.00	0.00	0.0
2/23/2005	0.00	0.00	0.0
2/24/2005	0.00	0.00	16.1
2/25/2005	5.50	0.51	1.3
2/26/2005	246.00	22.78	18.8
2/27/2005	214.00	19.81	0.1
2/28/2005	66.50	6.16	0.0
3/1/2005	28.00	2.59	0.0
3/2/2005	5.70	0.53	4.1
3/3/2005	5.60	0.52	2.1
3/4/2005	20.50	1.90	0.1
3/5/2005	5.80	0.54	0.0
3/6/2005	147.00	13.61	14.7
3/7/2005	360.00	33.33	0.7
3/8/2005	99.00	9.17	0.0
3/9/2005	41.50	3.84	0.0
3/10/2005	16.50	1.53	0.0
3/11/2005	11.80	1.09	0.7
3/12/2005	6.50	0.60	0.1
3/13/2005	4.50	0.42	0.9
3/14/2005	3.50	0.32	0.0
3/15/2005	2.00	0.19	0.0
3/16/2005	1.90	0.18	0.0
3/17/2005	0.00	0.00	0.0

3/18/2005	0.00	0.00	0.0
3/19/2005	0.00	0.00	0.0
3/20/2005	0.00	0.00	0.0
3/21/2005	0.00	0.00	0.0
3/22/2005	0.00	0.00	20.4
3/23/2005	479.00	44.35	1.3
3/24/2005	99.00	9.17	0.0
3/25/2005	18.50	1.71	15.7
3/26/2005	1495.00	138.43	11.7
3/27/2005	1170.00	108.33	11.3
3/28/2005	715.00	66.20	0.1
3/29/2005	150.00	13.89	0.6
3/30/2005	78.00	7.22	0.0
3/31/2005	91.00	8.43	0.5
4/1/2005	128.00	11.85	0.0
4/2/2005	115.50	10.69	0.9
4/3/2005	84.00	7.78	0.6
4/4/2005	123.00	11.39	6.8
4/5/2005	205.00	18.98	0.0
4/6/2005	139.00	12.87	0.1
4/7/2005	115.00	10.65	0.9
4/8/2005	86.00	7.96	0.0
4/9/2005	767.00	71.02	14.1
4/10/2005	368.00	34.07	0.0
4/11/2005	1416.00	131.11	10.5
4/12/2005	524.00	48.52	0.0
4/13/2005	1036.00	95.93	8.9
4/14/2005	1227.00	113.61	15.6
4/15/2005	340.00	31.48	6.4
4/16/2005	2058.00	190.56	22.1
4/17/2005	1625.00	150.46	0.0
4/18/2005	638.00	59.07	4.0
4/19/2005	552	51.11	0.0
4/20/2005	351	32.50	0.0
4/21/2005	325	30.09	8.1
4/22/2005	507	46.94	0.0
4/23/2005	586	54.26	0.0
4/24/2005	2591	239.91	38.4
4/25/2005	885	81.94	0.1
4/26/2005	374	34.63	0.0
4/27/2005	392	36.30	0.1
4/28/2005	270	25.00	2.5
4/29/2005	351	32.50	0.3
4/30/2005	338	31.30	3.7
5/1/2005	2345	217.13	41.8
5/2/2005	1326	122.78	0.3
5/3/2005	980	90.74	2.6
5/4/2005	473	43.80	0.6

5/5/2005	2098	194.26	13.8
5/6/2005	1440	133.33	0.9
5/7/2005	608	56.30	0.0
5/8/2005	1760	162.96	13.5
5/9/2005	993	91.94	0.0
5/10/2005	756	70.00	5.3
5/11/2005	870	80.56	0.2
5/12/2005	2560	237.04	18.0
5/13/2005	1085	100.46	0.0
5/14/2005	668	61.85	1.5
5/15/2005	480	44.44	0.0
5/16/2005	1784	165.19	18.0
5/17/2005	770	71.30	0.0
5/18/2005	494	45.74	0.2
5/19/2005	481	44.54	0.0
5/20/2005	377	34.91	1.4
5/21/2005	2623	242.87	34.3
5/22/2005	949	87.87	0.0
5/23/2005	2408	222.96	57.1
5/24/2005	1251	115.83	13.1
5/25/2005	938	86.85	7.0
5/26/2005	720	66.67	0.0
5/27/2005	454	42.04	3.0
5/28/2005	553	51.20	0.0
5/29/2005	425	39.35	1.1
5/30/2005	289	26.76	0.0
5/31/2005	323	29.91	0.0
6/1/2005	292	27.04	0.0
6/2/2005	240	22.22	0.0
6/3/2005	202	18.70	0.0
6/4/2005	181	16.76	3.3
6/5/2005	155	14.35	0.0
6/6/2005	139	12.87	0.0
6/7/2005	120	11.11	0.0
6/8/2005	156	14.44	4.6
6/9/2005	148	13.70	3.0
6/10/2005	212	19.63	0.0
6/11/2005	159	14.72	0.0
6/12/2005	125	11.57	0.0
6/13/2005	112	10.37	0.8
6/14/2005	85	7.87	0.2
6/15/2005	155	14.35	4.9
6/16/2005	172	15.93	0.0
6/17/2005	118	10.93	0.0
6/18/2005	171	15.83	0.0
6/19/2005	139	12.87	0.0
6/20/2005	128	11.85	0.0
6/21/2005	137	12.69	4.2

6/22/2005	125	11.57	0.0
6/23/2005	115	10.65	0.0
6/24/2005	119	11.02	4.5
6/25/2005	106	9.81	0.0
6/26/2005	89	8.24	0.0
6/27/2005	76	7.04	0.1
6/28/2005	65	6.02	0.0
6/29/2005	59	5.46	1.8
6/30/2005	51	4.72	0.0
7/1/2005	53	4.91	0.0
7/2/2005	52	4.81	0.0
7/3/2005	49	4.54	0.0
7/4/2005	400	37.04	0.0
7/5/2005	191	17.69	0.0
7/6/2005	125	11.57	0.0
7/7/2005	90	8.33	0.0
7/8/2005	82	7.59	0.0
7/9/2005	85	7.87	0.0
7/10/2005	239	22.13	0.0
7/11/2005	940	87.04	0.0
7/12/2005	618	57.22	0.0
7/13/2005	209	19.35	0.0
7/14/2005	142	13.15	0.0
7/15/2005	445	41.20	0.0
7/16/2005	1450	134.26	0.0
7/17/2005	750	69.44	0.0
7/18/2005	550	50.93	0.0
7/19/2005	440	40.74	0.0
7/20/2005	380	35.19	0.0
7/21/2005	162	15.00	0.0
7/22/2005	272	25.19	0.0
7/23/2005	250	23.15	0.0
7/24/2005	214	19.81	0.0
7/25/2005	1250	115.74	0.0
7/26/2005	637	58.98	0.0
7/27/2005	288	26.67	0.0
7/28/2005	215	19.91	0.0
7/29/2005	275	25.46	0.0
7/30/2005	342	31.67	0.0
7/31/2005	348	32.22	0.0
8/1/2005	315	29.17	0.0
8/2/2005	247	22.87	0.0
8/3/2005	177	16.39	2.1
8/4/2005	935	86.57	24.9
8/5/2005	475	43.98	0.1
8/6/2005	386	35.74	0.0
8/7/2005	307	28.43	0.0
8/8/2005	166	15.37	0.1

8/9/2005	141	13.06	0.1
8/10/2005	105	9.72	0.0
8/11/2005	90	8.33	0.0
8/12/2005	84	7.78	3.6
8/13/2005	81	7.50	0.0
8/14/2005	75	6.94	0.0
8/15/2005	64	5.93	6.5
8/16/2005	91	8.43	4.6
8/17/2005	482	44.63	1.7
8/18/2005	2975	275.46	45.3
8/19/2005	360	33.33	0.8
8/20/2005	540	50.00	9.8
8/21/2005	1453	134.54	25.4
8/22/2005	495	45.83	0.1
8/23/2005	285	26.39	0.9
8/24/2005	191	17.69	0.0
8/25/2005	138	12.78	0.0
8/26/2005	106	9.81	6.3
8/27/2005	90	8.33	0.3
8/28/2005	104	9.63	2.5
8/29/2005	78	7.22	0.0
8/30/2005	1710	158.33	34.1
8/31/2005	619	57.31	0.0
9/1/2005	427	39.54	0.0
9/2/2005	243	22.50	0.1
9/3/2005	153	14.17	0.0
9/4/2005	864	80.00	7.8
9/5/2005	635	58.80	0.0
9/6/2005	452	41.85	0.0
9/7/2005	271	25.09	0.0
9/8/2005	162	15.00	1.3
9/9/2005	112	10.37	0.0
9/10/2005	109	10.09	0.0
9/11/2005	104	9.63	0.0
9/12/2005	101	9.35	0.0
9/13/2005	98	9.07	0.0
9/14/2005	96	8.89	0.0
9/15/2005	95	8.80	0.0
9/16/2005	87	8.06	0.0
9/17/2005	80	7.41	0.0
9/18/2005	788	72.96	0.0
9/19/2005	1140	105.56	0.0
9/20/2005	2945	272.69	0.0
9/21/2005	1620	150.00	0.0
9/22/2005	1415	131.02	0.0
9/23/2005	800	74.07	0.0
9/24/2005	510	47.22	0.0
9/25/2005	435	40.28	0.0

9/26/2005	290	26.85	0.0
9/27/2005	240	22.22	0.0
9/28/2005	180	16.67	0.0
9/29/2005	260	24.07	0.0
9/30/2005	600	55.56	0.0
10/1/2005	973	90.09	0.0
10/2/2005	650	60.19	0.0
10/3/2005	500	46.30	0.0
10/4/2005	400	37.04	0.0
10/5/2005	1300	120.37	0.0
10/6/2005	680	62.96	0.0
10/7/2005	480	44.44	0.0
10/8/2005	650	60.19	0.0
10/9/2005	714	66.11	0.0
10/10/2005	540	50.00	0.0
10/11/2005	360	33.33	0.0
10/12/2005	760	70.37	0.0
10/13/2005	1040	96.30	0.0
10/14/2005	3100	287.04	0.0
10/15/2005	1918	177.59	0.0
10/16/2005	3350	310.19	0.0
10/17/2005	2500	231.48	0.0
10/18/2005	1560	144.44	0.0
10/19/2005	510	47.22	0.0
10/20/2005	760	70.37	0.0
10/21/2005	440	40.74	0.0
10/22/2005	420	38.89	0.0
10/23/2005	260	24.07	0.0
10/24/2005	280	25.93	0.0
10/25/2005	260	24.07	0.0
10/26/2005	240	22.22	0.0
10/27/2005	220	20.37	0.0
10/28/2005	240	22.22	0.0
10/29/2005	220	20.37	0.0
10/30/2005	160	14.81	0.0
10/31/2005	160	14.81	0.0
11/1/2005	160	14.81	0.0
11/2/2005	140	12.96	0.0
11/3/2005	160	14.81	0.0
11/4/2005	400	37.04	0.0
11/5/2005	320	29.63	0.0
11/6/2005	260	24.07	0.0
11/7/2005	200	18.52	0.0
11/8/2005	280	25.93	0.0
11/9/2005	1320	122.22	0.0
11/10/2005	1300	120.37	0.0
11/11/2005	460	42.59	0.0
11/12/2005	1220	112.96	0.0



11/13/2005	520	48.15	0.0
11/14/2005	360	33.33	0.0
11/15/2005	280	25.93	0.0
11/16/2005	180	16.67	0.0
11/17/2005	860	79.63	0.0
11/18/2005	500	46.30	18.7
11/19/2005	2460	227.78	57.1
11/20/2005	1240	114.81	27.0
11/21/2005	1000	92.59	4.1
11/22/2005	1920	177.78	24.4
11/23/2005	2860	264.81	4.0
11/24/2005	2840	262.96	0.1
11/25/2005	1600	148.15	0.2
11/26/2005	900	83.33	9.3
11/27/2005	500	46.30	0.2
11/28/2005	640	59.26	0.0
11/29/2005	340	31.48	6.7
11/30/2005	320	29.63	0.8
12/1/2005	260	24.07	0.3
12/2/2005	260	24.07	16.3
12/3/2005	740	68.52	0.9
12/4/2005	500	46.30	0.0
12/5/2005	340	31.48	1.2
12/6/2005	260	24.07	0.0
12/7/2005	220	20.37	7.1
12/8/2005	1900	175.93	39.3
12/9/2005	940	87.04	3.4
12/10/2005	720	66.67	0.1
12/11/2005	740	68.52	15.9
12/12/2005	780	72.22	0.0
12/13/2005	440	40.74	0.3
12/14/2005	320	29.63	0.4
12/15/2005	240	22.22	0.0
12/16/2005	200	18.52	0.3
12/17/2005	180	16.67	4.4
12/18/2005	140	12.96	2.8
12/19/2005	140	12.96	0.0
12/20/2005	140	12.96	0.0
12/21/2005	120	11.11	0.6
12/22/2005	100	9.26	2.8
12/23/2005	120	11.11	1.3
12/24/2005	120	11.11	3.1
12/25/2005	260	24.07	6.9
12/26/2005	240	22.22	0.0
12/27/2005	200	18.52	33.3
12/28/2005	860	79.63	0.0
12/29/2005	320	29.63	5.3
12/30/2005	0	0.00	0.0

12/31/2005	340	31.48	4.8
1/1/2006	360	33.33	2.6
1/2/2006	260	24.07	10.2
1/3/2006	260	24.07	0.0
1/4/2006	260	24.07	4.5
1/5/2006	480	44.44	27.8
1/6/2006	1620	150.00	1.8
1/7/2006	620	57.41	1.4
1/8/2006	3280	303.70	0.4
1/9/2006	2600	240.74	0.6
1/10/2006	2260	209.26	0.0
1/11/2006	2060	190.74	12.4
1/12/2006	2220	205.56	12.2
1/13/2006	2420	224.07	27.6
1/14/2006	920	85.19	0.0
1/15/2006	520	48.15	0.0
1/16/2006	420	38.89	0.0
1/17/2006	340	31.48	0.0
1/18/2006	320	29.63	0.0
1/19/2006	360	33.33	0.0
1/20/2006	300	27.78	0.3
1/21/2006	160	14.81	38.3
1/22/2006	180	16.67	22.4
1/23/2006	600	55.56	0.3
1/24/2006	420	38.89	0.0
1/25/2006	400	37.04	7.9
1/26/2006	300	27.78	0.0
1/27/2006	200	18.52	0.0
1/28/2006	380	35.19	0.0
1/29/2006	500	46.30	0.0
1/30/2006	200	18.52	0.0
1/31/2006	180	16.67	0.0
2/1/2006	260	24.07	1.7
2/2/2006	340	31.48	0.0
2/3/2006	340	31.48	0.0
2/4/2006	160	14.81	2.5
2/5/2006	120	11.11	0.3
2/6/2006	100	9.26	9.5
2/7/2006	100	9.26	0.0
2/8/2006	120	11.11	6.4
2/9/2006	100	9.26	17.5
2/10/2006	500	46.30	29.5