ANALYSIS OF FLOW CHARACTERISTICS IN THE SEWERAGE SYSTEM OF RESIDENTIAL AREAS WITHIN KUANTAN

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ANALYSIS OF FLOW CHARACTERISTICS IN THE SEWERAGE SYSTEM OF RESIDENTIAL AREAS WITHIN KUANTAN

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
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ABSTRACT

The evaluation of flow characteristic for sewerage systems analysis is essential in designing sewerage systems. Sewerage system plays an important role in collecting sewage from the community before transporting them to the sewerage treatment plant. Flow characteristics of sewage flow will be influenced by the population equivalent at the research area. There are several steps in measuring the flow characteristics which include collecting data in the manhole by using flowmeter and performing data analysis to investigate per capita flow, design criterion as well as peak flow factor. This study was carried out in three selected residential areas namely Taman Lepar Hilir Saujana (MH 84), Taman Pandan Damai (MH K) and Taman Bandar Putra (MH 92a). These locations are located in Kuantan, Pahang. From September 2015 to April 2016, this study was carried out in which the main equipment used is the ISCO 2150 area-velocity flowmeter and sensor. Equipment calibration was done in the Hydraulics and Hydrology Laboratory of UMP Gambang before the commencement of field work. In this study, sensor plays an important role in detecting the sewerage flow and generating the data for the flowmeter. Besides that, rainfall data collection was carried out to determine whether or not the flow rate is affected by the rain. Both data of flow rate and rainfall were retrieved using Flowlink 5.1 software. Data collected from the area-velocity flowmeter was converted into graph foam before the analysis. Data collection was performed on weekdays and weekends as well as during day time and night time. From this, data obtained will be divided into sets. One set of data is taken for a duration of two weeks with measurement done at every time interval of five minutes. The resulting analysis of flow characteristics obtained was compared with the standard limit stated in MS 1228:1991. Based on the MS 1228:1991, the per capita flow is 0.225 m^3/day/person and design criterion is 4.7. In this case, per capita flow at Taman Lepar Hilir Saujana is lower than the Malaysia Standard. However, the results from Taman Pandan Damai and Taman Bandar Putra show higher values in that they are more than 0.225m^3/day/person. In terms of design criterion, Taman Pandan Damai recorded lower than 4.7. In contrast, Taman Lepar Hilir Saujana and Taman Bandar Putra gave a higher value than 4.7. The results obtained will ease the researchers who are interested to further their study in this field.

ABSTRAK

Analisis untuk ciri-ciri aliran kumbahan amat penting bagi reka bentuk sistem kumbahan. Sistem kumbahan memainkan peranan penting dalam mengumpulkan hasil kumbahan daripada orang ramai sebelum menghantar ke loji rawatan kumbahan. Pengukuran ciri-ciri aliran kumbahan akan dipengaruhi oleh populasi di kawasan kajian. Antara langkah untuk mengukuh ciri-ciri aliran termasuk menggunakan meter aliran mengumpul data daripada lurang dan menghasilkan data aliran per kapita, kriteria reka bentuk dan faktor aliran puncak. Kajian ini telah dilaksanakan di tiga kawasan perumahan terpilih iaitu Taman Lepar Hilir Saujana (MH 84), Taman Pandan Damai (MH K) dan Taman Bandar Putra (MH 92a). Ketiga-tiga kawasan perumahan ini terletak di Kuantan Pahang. Jangka masa kajian ini bermula dilaksanakan pada September 2015 hingga April 2016. Antara peralatan utama digunakan dalam kajian ini ialah ISCO 2150 meter aliran dan sensor. Sebelum kajian dilakukan di tapak kajian, kalibrasi peralatan telah dijalankan di makmal Hidraulik dan Hidrologi UMP Gambang. Dalam kajian ini, sensor berperanan penting dalam mengesan aliran kumbahan dan menjanakan data aliran bagi meter aliran. Selain itu, data hujan juga dikumpulkan untuk mengkaji sama ada aliran kumbahan dipengaruhi oleh kejadian hujan. Perisian Flowlink 5.1 telah digunakan dalam analisis ini untuk mendapatkan data aliran kumbahan dan data hujan. Data aliran kumbahan daripada meter aliran ditukarkan kepada betuk graf sebelum membuat analisis. Data yang dianalisis termasuk data aliran kumbahan pada hari minggu dan hujung minggu sama ada pada waktu pagi atau waktu malam. Data yang didapati akan dibahagikan dengan set data. Satu set data mengambil masa selama dua minggu dengan selang masa lima minit. Selepas analisis, hasil data analisis dibandingkan dengan aliran per kapita dan kriteria reka bentuk yang dinyatakan dalam MS 1228:1991. Dalam MS 1228:1991, aliran per kapita mencatatkan 0.225 m^3/hari/orang manakala kriteria reka bentuk menunjukkan 4.7. Keputusan analisis menunjukkan aliran per kapita di Taman Lepar Hilir Sauajana rendah daripada Malaysia Standard. Namun demikian, aliran per kapita analisis di Taman Pandan Damai dan Taman Bandar Putra lebih tinggi daripada 0.225 m^3/hari/orang. Bagi parameter kriteria reka bentuk, keputusan analisis di Taman Pandan Damai lebih rendah daripada 4.7. Di sebaliknya, analisis kriteria reka bentuk di Taman Lepar Hilir Saujana dan Taman Bandar Putra telah melebihi 4.7. Hasil analisis yang didapati akan memudahkan kajian kepada penyelidik yang berminat dalam kajian ini.

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LIST OF SYMBOLS

g	gram
H	depth
k	design criterion
l	liter
m	meter
p	estimated equivalent population, in thousand
Q	flow rate
Q_{ave}	average daily flow
Q_{pcf}	per capita flow
Q_{peak}	peak flow

LIST OF ABBREVIATIONS

BOD	Biochemical oxygen demand
CSTs	Communal septic tanks
ISTs	Individual septic tanks
ITs	Imhoff tanks
IWK	Indah Water Konsortium
PE	Population equivalent
PFF	Peak flow factor
PVC	Polyvinyl chloride
STP	Sewage treatment plant
TSP	Taman Sri Pulai
TU	Taman Universiti
UMP	Universiti Malaysia Pahang
VCP	Vitrified clay pipe

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Sewerage system is a connection of pipes and pumps which serve to collect wastewater from the community such as from housing areas, commercial, institutional and industrial areas before discharging it into the treatment facilities (Novotny et al., 1989). The facilities include oxidation ponds, aerated lagoons and biological treatment using bio filters. After treatment, the sewage can be used for aquaculture and agriculture. The amount of the sewage produced and the volume of the flow rate largely depend on the population equivalent (PE) of the area. This research focuses mainly on the sewerage system in residential areas within Kuantan and is carried out with joint effort between Indah Water Konsortium (IWK) and Universiti Malaysia Pahang (UMP).

Vast development in urban areas has increased the population density. Therefore, there is a need to have proper sewerage systems. When sewerage system is able to perform effectively and properly functions, it will be an effective method to remove the sewage. However, if the existing sewerage system is not able to operate effectively this will cause a lot of major problems especially to human health, environment pollution and affecting the living standard of the community. The effectiveness of the sewerage system depends on the pipe condition, soil permeability and groundwater level. This explains the importance in making sure the sewerage system always can be operated properly.

In Malaysia, the code of practice used for design and installation of sewerage system is the Malaysia Standard MS 1228:1991. The design criterions as well as the population equivalent will influence the peak flow factor in the sewer design. The peak flow factor is important to ensure the effectiveness of the amount of potential flow of wastewater within the sewerage system. The main purpose of this research is to evaluate the design criteria of the flow characteristics of the sewerage system at housing areas and the pattern of the flow characteristics throughout the research area.

1.2 PROBLEM STATEMENT

Sewerage system is initially designed to deliver a specific amount of the wastewater based on the population equivalent served at the time of design before transport to the discharge point. The effectiveness of the sewerage system to function well will be reduced if the flow characteristics of the sewer line are not designed based on the standard. The design criterion of sewerage system is important in that it affects the efficiency of the flow in the sewer line. Thus, this will not only result in reduction of design life for the sewerage system but also increases the cost of services and maintenance of the sewer pipe line.

1.3 OBJECTIVES OF STUDY

The objectives of study are as follows:

i. To evaluate the influence of flow characteristics factors in residential areas within Kuantan.
ii. To determine the peak flow factor and flow per capita distribution for the sewerage system at certain housing areas in Kuantan.
iii. To compare the results obtained from this research with the recommended values in Malaysia Standard MS 1228:1991.

1.4 SCOPE OF WORK

The scope of this research includes collecting data in selected manholes for the flow characteristics of the sewerage system as well as rainfall measurement data. For the purpose of this study, several locations of residential area which included Taman Lepar Hilir Saujana, Taman Pandan Damai and Taman Bandar Putra were selected. Manholes were selected after the confirmation of locations. The identified manholes were labeled as MH 84 in Taman Lepar Hilir Saujana, MH K in Taman Pandan Damai and MH 92a in Taman Bandar Putra. As shown in Figure 1.1, manhole MH 84 is where the measurements were made and it is located near the Sewerage Treatment Plant (STP) of Taman Lepar Hilir Saujana (Figure 1.2). It is situated at the bend connection of sewer before the STP. The tipping bucket rain gauge was installed at the free space inside the STP of Taman Lepar Hilir Saujana. Similar method of installation for flowmeter and rain gauge equipment was carried out at Taman Pandan Damai and Taman Bandar Putra research area. The flow rate of the sewage in the manhole was collected by using the flowmeter and sensor which were installed inside the manhole and pipeline respectively. The rainfall data was collected using a rain gauge which was set up in a corner of the sewage treatment plant. Both flow rate and rainfall data were collected and analyzed at the same time. Continuous data was recorded in both flowmeter and tipping bucket rain gauge during the process. The purpose of collecting data of rainfall intensity is to investigate the effect of rainfall to the flow characteristics of the sewerage system.

The measurement of data collection is based on the number of data set. One set of data is taken for a duration of two weeks with interval of five minutes between each reading. In this study, the period of fieldwork began from September 2015 to April 2016. The research was carried out at different residential areas at different time. Site work in Taman Lepar Hilir Saujana was conducted from September 2015 to October 2015. Two sets of data were collected within the period. In Taman Pandan Damai, the field work began from November 2015 to January 2016 and four sets of data were collected. The work in Taman Bandar Putra began from February 2016 to April 2016 and three sets of data were collected.

A survey was conducted in all the selected residential areas in order to obtain the exact number of residents staying in each particular housing area. In this case, Taman Lepar Hilir Saujana was chosen due to the convenience factor as the site is near to UMP. Other than that, the residential area in Taman Pandan Damai was selected for this study as it covers a large number of PE. Due to Taman Bandar Putra being a new residential area, this location was chosen. However, these were not the major considerations involved when choosing the site locations. A suitable location is determined based on the suitability of equipment installation which will definitely ease the work. Therefore, site reconnaissance for every research area to observe the suitability of site for this study was carried out.

Figure 1.1: MH 84 selected

Figure 1.2: Sewage Treatment Plant (STP) at Taman Lepar Hilir Saujana

1.5 SIGNIFICANCE OF RESEARCH

This research will enhance our knowledge of the pattern of flow characteristics in the sewerage system. By conducting this study, flow characteristics of the sewer line during day and night time as well as weekdays and weekends will be acquired. Furthermore, this study will also help in determining the suitability of the current available design standard for the sewerage system. To do this, comparison will be done with the Malaysia Standard in which the design is based on a foreign standard. This explains the importance of conducting this research as the result can be used as reference for future researches. There are limitations in conducting this research as the design standard used was adopted from another country in which the climate condition is different compared to Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

2.1.1 History of Sewage Management

Waste water management has affected human history in many ways. In the Mesopotamian Empire (3500 to 2500 BC) certain homes were connected to storm water drainage system to transport sewage. Latrines which were connected to 450 mm diameter vertical shafts lined with perforated clay pipes leading to cesspools in Babylon (Lens et al., 2001). From 2000 BC, Crete Island had a drainage system which made up of terracotta pipes with bell and spigot joints sealed with cement to transfer storm water as well as human waste. In 1700 BC, King Minos installed the first known closet with a flushing device which joined cement into stone sewers in Knossos Palace, Crete.

The Ancient Greeks (300 BC to 500 AD) manage the waste problem with public latrines which were drained into sewers and conveyed the sewage and storm water to a collection basin outside the city. In 500 BC, Romans constructed the Cloaca Maxima, the central waste water collector to drain the marsh (Wiesmann et al., 2007). In the year 1370, the first covered sewer was built which dumped the sewage into River Seine. When plagues swept Europe in 1539, King Francois ordered house owners to build cesspools for sewage collection in new houses. Cesspools were existed in London at 1189 and the contents transport to countryside for land application (Wolfe, 1999).

Diseases like cholera and typhus were spread widely at the early part of the nineteenth century. In the year 1842, Chadwick produced a report entitle “Report on the

Sanitary Conditions of the Labouring Population of Great Britain" which argued about the importance of sewage treatment facilities to improve public health (Holland et al., 1984). The main outcome of this report was that Public Health Act 1848 set up Local Boards of Health to construct sewers. Chadwick proposed a hydraulic system that transferred potable water into home which equipped with water closets to be sewage out to public sewer lines (Melosi, 2000). Rather than putting the sewer connections through the front of the houses, he also proposed the 'backyard tubular drainage' system. According to him, this system drained effluent from the back of back-to-back houses.

In the late 1700s, the water closet began to be adopted by Londoners. Due to their ability, sewage can be removed immediately once it is connected to the sewer. The water closet became popular in 1800s and this had improved the living standard. The construction of Bazalgette sewer systems in London was started in 1858 and its construction completed by 1865 (Lofrano and Brown, 2010). However, this system was not effective to remove the pollutants. In the year 1848, William Lindley, the English engineer begun the first comprehensive sewer network in Hamburg, Europe. It was not until the 1890s that the municipal authorities could claim that the entire city was completed with sewer system. In the year 1906, Imhoff tank was designed in Germany. In 1800s, septic tanks for primary treatment of wastewater were introduced and discharged of tank effluent into gravel-lined subsurface drains became common in the middle of the 20th century.

Scientists, engineers, and manufacturers have put great effort in the wastewater treatment industry to remove the sewage through the proper and well managed system. Alternative treatment technologies have improved the sewerage treatment system.

2.1.2 Overview of Sewage Treatment in Malaysia

Sewage treatment in Malaysia develops gradually over the last half of century. Before Malaysia declared its independence, there were no proper sewage treatment system and it was mainly manage by way of primitive methods such as over-hanging latrines, pit and bucket latrines and discharge directly to sea and rivers (Hamid and Mohd Baki, 2005).

Hamid and Baki (2005) stated that in 1950s, due to the increasing population densities, the sanitation systems have to be improved. During that time, this treatment concept was applied in primary systems of sedimentation process as well as Individual Septic Tanks (ISTs). In 1960s, ISTs and pour flush systems were introduced in Malaysia. Primary treatment such as communal septic tanks (CSTs) and Imhoff tanks (ITs) started to be used for the small communal systems.

In 1970s, the technology of sewerage treatment has expanded to biological treatment process in the form of oxidation pond by using natural means of treatment. In the year of 1974, an enactment of Environmental Quality Act Partial Secondary treatment systems such as oxidation was introduced to improve the environmental impact which arose.

In 1980s, the mechanized systems of the sewerage treatment were introduced in Malaysia and the oxidation ponds were transformed into aerated lagoon systems. Between 1980s and 1990s, a fully mechanized system in the foam of biological filters and sludge system were developed in Malaysia. According to Hamid and Baki (2005), in the late 1990s, it can be seen that the effort which focused on the control of mechanized systems had allowed the optimization of new systems process.

Due to technology development in the sewerage treatment industry, the evolution of treatment process in Malaysia can be clearly seen, from primitive to primary and then to secondary system. The evolution also transform from a non-mechanical system to mechanical and automated system. Advance equipment was continuously introduced to the sewerage treatment system due to the improvement of the technology. The technology improvement can be shown through design, construction and operations of the sewerage system.

2.2 TYPE OF SEWERAGE SYSTEM

Basically, there are two types of sewerage system mainly, the combined sewerage system (Figure 2.1) and separate sewerage system (Figure 2.2). A combined sewer system is a type of system in which single pipe carries both the wastewater and storm water together whereas a separate sewer system is a system which carries wastewater and storm water separately in two pipes. Combined sewer design is an old design which no longer be used in the new community but it continues to operate in many old cities. This system is preferred when the both wastewater and storm water need treatment at the same time. When runoff enters the system, it will affect the high flow in the combined sewer system in which the wastewater in the pipe line will be higher than the height of the weir. This resulted in untreated overflows. In contrast, separate sewerage system is a new design and is commonly used by the community nowadays. By comparison, separate sewer system is more effective as it separates the sanitary sewers from the runoff. Thus, this system is favored when only the sanitary sewage need for treatment but not storm sewer or vice versa. The cases of overflow will not happens unless the separate sewer design is not enough to deliver the both the sanitary and storm sewer.

It is known that Malaysia implemented separated sewer system in which the sanitary will be discharged to sanitation facilities and storm sewer flow into the stream, river or sea.

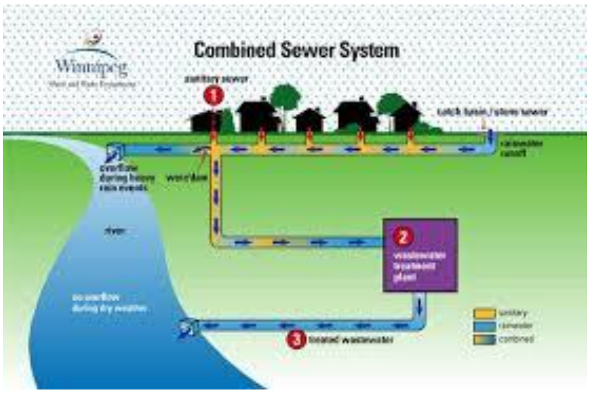


Figure 2.1: Combined sewerage system

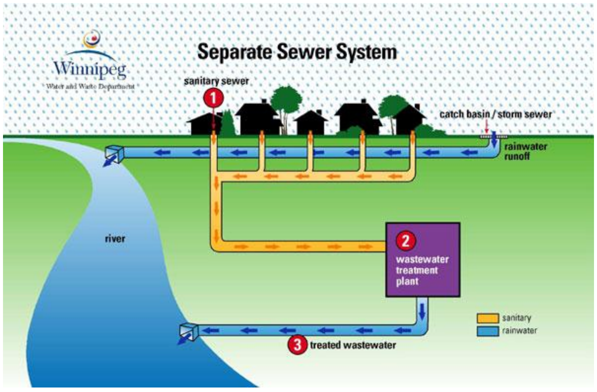


Figure 2.2: Separate sewerage system

2.3 TRANSPORTATION OF WASTEWATER

Wastewater flow through the piping systems channels before discharged to the treatment facility. Basically the pipe system consists of main pipe and branch pipes. Main pipe flows through the center of the system and branch lines extend from them. All the pipes are set up in straight lines whenever possible and meet at perpendicular way although the connection may be curved to ease the flow. There is no sewer line located above the main sewer unless the pipe is fully protected. A common main pipe has diameter of 200 mm to 300 mm whereas the branch pipes have diameter of 100 mm (Tilley et al., 2014). The selection of pipe diameter depends on the peak flows and projected average. In general the materials of the pipe used are polyvinyl chloride

(PVC), concrete and cast or ductile iron pipes. For the housing area, the suitable pipe commonly used is vitrified clay pipe (VCP) with diameter 100 mm to 300 mm and joint length of 0.6 m to 1.0 m.

Wastewater flows through the pipes via gravity system rather than the pump system. The gravity system is carried out by using the gravity force. It is suitable when the start point of the wastewater to flow is located higher than the discharged point. Gravity system requires low cost and effective. The slope gradient for the pipe system to flow must be at a velocity of at least 0.8 meter per second and maximum velocity of flow is 4.0 meter per second (SIRIM, 1991). The pump method has to be used when the wastewater is required to flow from a low discharge point to a high discharge point. Hence, this system requires a pumping station. The pump system is costly as an extra pumping station is required.

The sewer line is safe and hygienic if the sewer system is well constructed and good maintenance in the process of transporting wastewater. Along the transportation of sewage, the particles are not allowed to accumulate in order to maintain self-cleaning velocity and efficiency of the flow.

2.4 FLOW DESIGN AND LOADING IN SEWERAGE SYSTEMS

This research is conducted in Malaysia. Therefore the code of practice used is based on Malaysia Standard Code of Practice. For the design and installation of sewerage systems, Malaysia Standard MS 1228:1991 is used. The purpose of sewerage system design is to design the capacity of the sewerage system required according to the population equivalent estimated and including the infiltration influence. In design considerations, allowance should be made for future population changes caused by master planning projections and facility personnel requirements.

The average design flow of sewage produced is based on 225 liter per person in a day. The estimation of sewage daily flow can be determined by multiplying the estimated population equivalent for the particular premise with average daily flow per capita (SIRIM, 1991). The estimated population equivalent can be determined based on the Table 2.1. In the design of sewerage system, the peak hourly flow can be evaluated based on the following formula:

$$\text{Peak flow factor} = 4.7 \text{ x } p^{-0.11}$$

where *p* is estimated equivalent population, in thousand.

The allowance infiltration should be included in the sewerage system design. The unpredictable amount of infiltration such as porous or cracked sewer pipes and manholes, faulty pipe joints and poor workmanship have to put into the design consideration. The maximum infiltration to cater the sewerage system is 50 liter per mm. diameter per km of sewer per day (SIRIM, 1991).

For organic loadings design, normally the organic loading from the sewerage system is based on 55 g of Biochemical Oxygen Demand (BOD) per person per day and 68 g of suspended solids per person per day (SIRIM, 1991).

A proper design of the sewerage system will ensure the system is able to function well and achieve the effectiveness of the system. Thus, the expectation design life of the sewerage system can be prolonged and the cost of service and maintenance will be reduced.

Table 2.1: Equivalent Population (SIRIM, 1991)

No.	Type of Premise/ Establishment	Population equivalent (recommended)
1	Residential	5 per unit*
2	Commercial: (includes entertainment/ recreational centers, restaurants, cafeteria, theatres)	3 per 100 m gross area
3	Schools/ Educational Institutions: - Day schools/ institutions - Fully residential - Partial residential	 - 0.2 per student - 1 per student - 0.2 per student for non-residential student and 1 per student for residential student
4	Hospitals	4 per bed
5	Hotels (with dining and 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

*1 peak flow is equivalent to 225 liter per person

2.5 FACTORS CONTRIBUTING TO FLOW CHARACTERISTICS IN SEWERAGE SYSTEM

2.5.1 Time

Time is one of the main factors which contribute to the flow characteristics in sewerage system. For this research, the data of the flow rate in sewerage system is collected within five minutes interval. The flow characteristics of the effluent in the sewer line between day and night time as well as weekdays and weekends can be observed through the data collected. The maximum and minimum flow of sewage for the residents staying in the housing area can be determined through the research conducted. Thus, different pattern of flow characteristics is able to be observed through different time taken.

Due to the passage of time, the performance of the pipe systems may affect the flow characteristics in the sewer line. The wear and tear of the pipe will cause the pipe system to perform inefficiency. Cracking and fissuring of the pipe inside the sewer line which causes to leakage may affect the result of the flow characteristics.

2.5.2 Climate Change

Malaysia is situated at equatorial position. Due to its position, the characteristic of climate feature in Malaysia is uniformly high temperatures, high humidity, relatively light winds and abundant rainfall throughout the year (McGinley, 2015).

This research is conducted at district Kuantan area which is located at east coast of Malaysia. It will be conducted from September to April. The flows characteristics of the sewerage system may be affected due to November to January in the state of east coast Malaysia, which are the wettest months. Hence, the rainfall data collected will be used to evaluate the flow characteristics in the sewerage system during these changes of climate.

2.5.3 Population Equivalent

The design of the sewerage system is mainly determined by the estimated population equivalent as well as the expected design life. Thus, changing the number of residents staying in the housing area will affect the flow characteristics in the sewerage system. If the number of population equivalent increase, the flow rate in the sewer line will be increased and it will affect the capacity of the sewerage system to support additional sewage. Additional sewage may overburden the sewerage system to perform at its optimum function. Therefore, changes of the population equivalent that occur which exceed the limit of population density required will contribute to the need of redesign the entire system.

2.6 PAST RELATED STUDIES ON FLOW CHARACTERISTICS

Recently, there are several researchers related to flow characteristics of sewerage system has been conducted. The scope of study include factor affecting the flow characteristics and the effect of flow characteristics. Different types of result analysis were done by the researchers. In order to better understand the concept and background of the study, studies of the past related studies will help in improve the research to be done. Summary on the past related studies are shown below.

Lately, a research study has been done by Yap and Ngien (2015) related to analysis of flow characteristics in sewerage system. The area of the study is located between library and sports complex within UMP Gambang Campus. The study duration was done from 17th of November 2014 to 9th of February 2015 (12 weeks). The population equivalent for this study research is 1473 PE. Instrument ISCO 2150 area velocity flowmeter was used to collect the flow data and Flowlink 5.1 software was used to retrieve the data. Besides, equipment ISCO 674 rain gauge was used to collect the rainfall data. The flowmeter was installed inside a manhole at the area of research whereas the rain gauge was installed in the field area of Residential College 2 at UMP Gambang Campus. Each set of the data collected is within five minutes interval for two weeks period. A total of six set of data has been collected. The same data measurement interval was applied for the rainfall data. The flow characteristic of the sewerage system was determined and two parameters, the per capita flow and the design criterion were investigated. This research also includes the study on effect of rainfall pattern on the sewerage flow beside the flow characteristics in the sewerage system in UMP area. The results obtained for both parameters were compared with the Malaysia Standard MS 1228:1991. From the result analysis, it is found that per capita flow obtained was 0.076 m^3 per day per person and design criterion obtained 2.49. Both parameters for the area research were lower than the Malaysia Standard. Based on the MS 1228:1991, the per capita flow and design criterion are 0.225 m^3 per day per person and 4.7 respectively. Thus, it can be concluded that the sewerage system in UMP Gambang Campus was designed for high flow capacity and it was sufficient for the population equivalent to use the sewerage system.

Furthermore, an investigation of sewage flows in Universiti Malaysia Pahang's Sewerage System was done by Ngien et al. (2014). This research is mainly focus on the effect of dry and wet period to the flow characteristics of the sewerage system. The area-velocity flowmeter was installed inside the manhole chosen for measurement is located beside block C15 of Residential College 1 with a total 942 PE involved. Besides, the rain gauge was installed at on open filed within the area of UMP Campus Gambang. Two data sets were prepared. 2nd of May 2014 to 4th of May 2014 for dry period whereas 9th of May 2014 to 11st of May 2014 for wet period. Both data collected from Friday to Sunday to make a proper comparison. The maximum flow on the dry period obtained was 424.05 m^3 per day which fall on Friday may due to the prayer activities carried out on the mosque nearby. In contrast, the minimum flow rate obtained was 1.04 m^3 per day and the average flow rate during this dry period was 111.2 m^3 per day. For wet period, the maximum flow rate obtained was 848.97 m^3 per day at 6 pm on Sunday which coincides with 2.5 mm rainfall intensity. Oppositely, the minimum flow rate obtained during the wet period was 6.31 m^3 per day and the average flow rate was 153.19 m^3 per day. The design criterion calculated for the dry period was 1.99 whereas for wet period was 3.98. Both design criterion obtained is lower than the 4.7 as recommended in MS 1228:1991. The value of design criterion for wet period was double than the dry period. Thus, it can be concluded that the rainfall affect the results of the data of flow characteristics in this study. This may due to the infiltration of rainfall occurred through cracking of pipelines, manholes or faculty of joints.

Besides, in year 2013, Ngien and Pian (2013) have done a research study with topic an evaluation of the design criterion for sewerage peak flow factor at SEGi University hostel. A manhole within the SEGi University' compound was selected. The research was done from 11 am on the 15th of March 2013 to 11 am on 22nd of March 2013 (7 days). A total population equivalent of 251 PE was involved in this study. A portable ISCO 2150 Area-Velocity Flowmeter was used to measure the sewage flow characteristics inside the selected sewer line and the Flowlink software was used to extract the recorded data. The data recorded is within 15 minutes interval. The main objective of this research is to evaluate the suitability of the design criterion and peak flow factor for sewerage system as recommended in Malaysia Standard MS 1228:1991. Based on the results shown, the per capita flow on this area is 35.6% higher than the design per capita flow of 0.225 m^3 per day per person stipulated in the MS 1228:1991 whereas the design criterion obtained is 2.88 , lower than the design criterion of 4.7 as stated in MS 1228:1991. The results also show that maximum flow occurred between 9 pm to 10 pm with 259.3 m^3 per day whereas the minimum flow occurred between 2 am to 6 am with little or zero flow. In conclusion, the design criterion for peak flow factor as stated in the MS 1228:1991 is sufficient to cater the population equivalent in this study.

In addition, another research with evaluation of design criteria for inflow and infiltration of medium scale sewerage catchment system was done by the student from Universiti Teknologi Malaysia (UTM), Rahman et al. (2007). The main of this research done is to verify the suitability of the design value in the Malaysia Standard MS 1228:1991 for sewerage system design. The research area is situated at Taman Sri Pulai (TSP) and Taman Universiti (TU). The population equivalent at TSP was 1705 PE whereas at TU was consists of 3456 PE and 9905 PE. This research was conducted at TSP from 30th of June 2005 to 20th of January 2006 while the duration of this research conducted at TU was from 22nd of September 2005 to 25th of December 2005. From the result obtained, the per capita flow in the sewerage system at TSP was 0.142m^3 per day per person whereas at TU was 0.1 m^3 per day per person. Both values of per capita flow obtained were much lower than the value given in MS 1228:1991. Meanwhile, the peak flow factor at TSP was 2.25 for 1705 PE whereas at TU was 2.07 for 3456 PE and 2.32 for 9905 PE. The result shown also lower than the value stated in the MS 1228:1991, 4.7. Thus, it can be concluded that the per capita and peak flow factor shown in the sewerage system design was much bigger than the necessary. A necessarily of review the design value in the code of practice MS 1228:1991 is needed.

Moreover, a study research on an estimation of parameters and flow characteristics for the design of sanitary sewers in Malaysia was done by Ansari et al. (2012). The main purpose of this research is to determine the parameters of per capita flow and peak flow factor for the flow characteristics at the two different residential areas where located at Taman Sri Pulai (TSP) and Taman Universiti (TU) with population equivalent of 1705 and 3456 respectively. Both locations are located at Johor Bahru, Malaysia. The manhole MH 11 and MH 299 were selected at TSP and TU respectively. The area-velocity flow meter with model ISCO 4250 was installed inside the manhole selected and the data was retrieved with the help of ISCO Flowlink 4.1. Besides, the equipment ISCO 674 rain gauge was also used to measure the rainfall data. Every five minutes of time interval was recorded. This research was divided into 10 different phases to conduct in the months of June, August, September, and October 2005. The flow meter was installed at the TSP in the period of June, August and September 2005 whereas it was installed at the TU in September and October 2005. Result of analysis was classified into weekend and weekday. The maximum peak flow at during the weekend was 442.37 m^3 per day whereas on weekday was 504.58 m^3 per day. The minimum flow obtained on weekend was 19.87 m^3 per day while on weekday was 5.18 m^3 per day. From this research done, the mean value of the per capita flow obtained was 0.096 m^3 per day per person which was lower than the 0.225 m^3 per day per person as stated in MS 1228:1991. Besides, the mean value of the peak flow factor obtained in this analysis was 2.84, which was also lower than the 4.7 as given in the MS 1228:1991. In short, the results of the analysis show that the flow characteristics of sewerage system in both locations are enough to cater the population equivalent at the area of study.

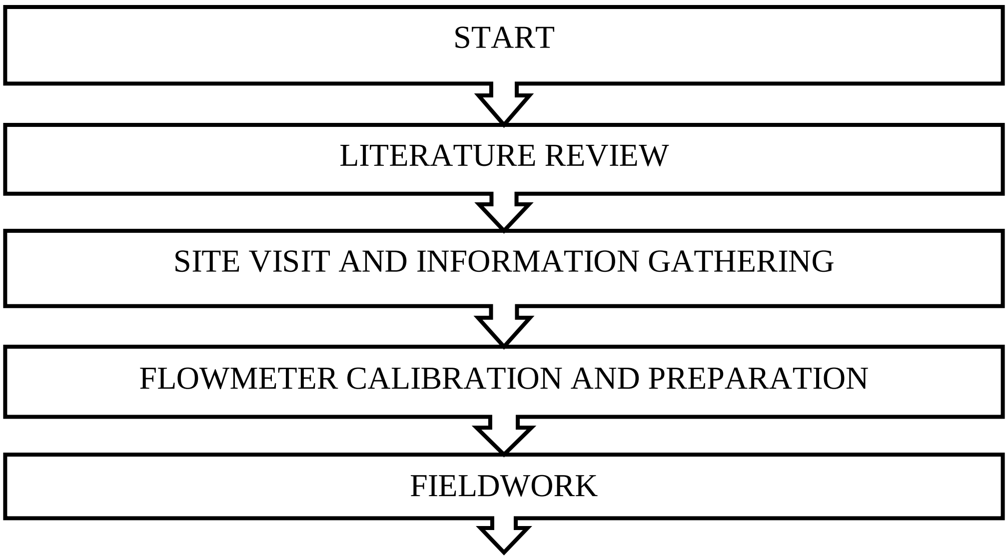
In short, the research related to flow characteristics of sewerage system still need to carry out to find out not conclusive. This research is important to contribute to the efficiency of the sewerage system. Through this research done, the maximum flow, minimum flow of sewage in the sewer line can be determined as well as the effect due to changes of climate. Thus, further data is needed in different area and PE to continue conducts the research. The data obtained is then compared with the Malaysia Standard MS 1228:1991 to ensure the design of the sewerage system for flow characteristics is sufficient to cater the population.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Methodology is the concept of how the proposed research will be conducted. The methodology of this research involves initial preparation and field work experiment. The different types of measurement will be taken to perform analysis of the data obtained in order to achieve the objectives in this research. Throughout this chapter, the techniques used to obtain the data analysis will be shown. It includes preliminary works, equipment and software used in the research, site work and the method of calculation. Figure 3.1 shows the methodology flows of this research.



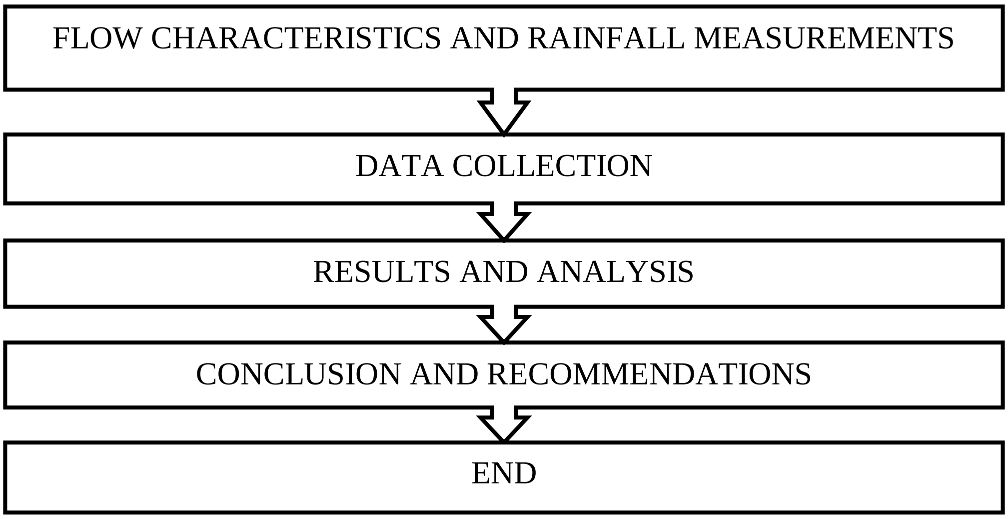


Figure 3.1: Methodology Flow Chart of Flow Characteristics Measurements

3.2 PRELIMINARY WORK

Preliminary work is the initial work to be prepared before starting the field work to ensure the work is done smoothly and completely. The works include information gathering to collect as much information as possible related to the research topics for further understanding of the research. Site visits were done to ensure the site is suitable for carrying out the data collection. Besides, in order to ensure the material and equipment to be used are available as well as in good condition, equipment provision work is required. Calibration of equipment is necessary to ensure the available equipment is able to perform well, functioning with the reading error minimized.

3.2.1 Information Gathering

Before the research experiment was carry out, as much information gathering of the related research topics as possible was done in order to get more understanding on the research to be done and to gain more knowledge about the research topic. The information on flow characteristics of sewerage system was obtained through reading articles, books and journals. This information include Malaysian studies and overseas studies. The information obtained will be filtered to find the most suitable and related topics. Information regarding the past studies conducted by other the researchers include the location of the study area, method of the experiment used as well as the result and analysis obtained. This may improve the result of the study to be conducted as well as to facilitate the research to be done smoothly.

3.2.2 Site Visits

After the information gathering, a site visit is required to find out the most suitable location to carry out the research. This has to be done before all the field works were carried out. The visits area to Taman Lepar Hilir Saujana, Taman Pandan Damai and Taman Bandar Putra were conducted with the help of a location map obtained from IWK, Kuantan. Location map for the three research areas may referred to Appendix A. The main purpose for the site visit is to check the available manhole and sewerage system at the study area according to the drawing provided and to select suitable manholes for carrying out site work. Result from the site visits show that the sewerage system at Taman Lepar Hilir Saujana was suitable for the research and MH 84 was selected due to its convenience and it being a new manhole. MH K at Taman Pandan Damai was chosen as it is easy to install the equipment inside the manhole. Other than that, the sewerage system at Taman Bandar Putra was chosen for its suitability and it being a new manhole. Besides, a site visit for doing the calculation of PE was carried out to obtain the number of total residents staying at each particular area. The PE obtained for Taman Lepar Hilir Saujana was 1254 PE. The PE obtained for Taman Pandan Damai was 2243 PE whereas Taman Bandar Putra has 1694 PE. The results for the PE survey can be referred to in Chapter 4 for more details.

3.2.3 Provision of Equipment

Before starting the field work of this research, it has to be ensured that all the equipment and materials to be used are available inside the laboratory. A thorough check for functionality and adequacy was required. Basically, the equipment and materials needed to conduct this research is 1 unit of ISCO 2150 area-velocity flowmeter, 1 unit of ISCO rain gauge, 1 unit of area-velocity sensor, 1 unit of mount ring, 1 manhole opener, 4 units of batteries, 1 battery charger and 1 tripod stand. All this equipment has to be calibrated first before the work starts.

3.3 EQUIPMENT AND SOFTWARE

3.3.1 ISCO Area-Velocity Flowmeter

The instrument ISCO 2150 Area-Velocity Flowmeter as shown in Figure 3.2 was adopted to monitor the flow of sewage inside the sewer pipelines. This area-velocity flowmeter is the main equipment used in this research. The flowmeter measures both level of flow and flow velocity passing through the pipe system to calculate flow of sewage inside the channel. The flow rate is then calculated by multiplying the area of the flow by its average velocity.

This field monitoring equipment is a microprocessor-based digital probe that ensures calibration stability as well as prevents level drift. It operates through the area velocity sensor and uses continuous-wave Doppler technology to measure mean velocity of the flow inside the sewer pipe line.

The high power efficiency of the flowmeter enables it to provide the power supply up to 15 months with 15 minutes data storage interval. The power is supported by two rechargeable lead-acid lantern batteries.

Furthermore, this area-velocity flowmeter has a large memory which can store up to 65000 readings in a database at intervals from 15 seconds to 24 hours (ISCO, 2008). All the data is stored in "flash" memory to protect the data from being lost forever. The stored data is then retrieved and analyzed using Flowlink 5.1 through an interrogator cable.

This flowmeter was put inside the manhole using a rope hanging at the ladder of the manhole and wrapped with plastic bag to prevent water damage as shown in Figure 3.3.

Figure 3.2: ISCO 2150 Area-Velocity Flowmeter

Figure 3.3: Flowmeter hanging at the manhole ladder

3.3.2 Area-Velocity Sensor

The ISCO's Area-Velocity Sensor is shown in Figure 3.4. This sensor is connected to the ISCO 2150 Area-Velocity Flowmeter and mounted at the bottom of the manhole to directly measure the depth of the flow of the sewage. The ISCO 2150 area-velocity flowmeter is unable to function without the connection to the sensor. The sensor transmits a continuous ultrasonic wave and measures the frequency shift of returned echoes reflected by the air bubbles or particles in the flow (ISCO, 2008). The low profile feature with 0.625 inches of the sensor is able to minimize the flow obstruction and to maximize demand to measure shallow flows in the small pipes. The sensor is only functional when it is fully immersed within the flow inside the pipe lines and the flow rate data will be recorded and stored in the flowmeter. No data will be shown if the sensor is not able to detect the flow inside the pipelines.

For ease of installing of the area-velocity sensor in the pipeline inside the manhole, a stainless steel mounting ring was used as shown in Figure 3.5 and placed at the bottom of the manhole for the sensor to detect the flow of the sewage. Pipe size inside the sewerage system at Taman Bandar Putra is large and the mounting ring is not large enough for the pipe size. Thus, the mounting ring is replaced with the steel plate. A 40 mm steel bar was used and welded to a 2 mm thick steel plate as shown in Figure 3.6. The steel plate contains a few holes for tightening the sensor. Cable-tight was used to tighten the steel plate and sensor as shown in Figure 3.7.

Figure 3.4: Area-Velocity Sensor

Figure 3.5: Sensor connected to mounting ring

Figure 3.6: Sensor connected to steel plate and steel bar

Figure 3.7: Sensor tightened at steel plate with cable tight

3.3.3 Tipping Bucket Rain Gauge

The tipping bucket rain gauge of the model ISCO 674 as shown in Figure 3.8 was used to record rainfall measurement. The figure shows the rain gauge being placed inside the free space of STP at Taman Lepar Hilir Saujana near the study area. In order to get accurate reading, rain gauge was installed at an open space area where it is easy to collect rain water without disturbance from trees and other types of interference.

The rain gauge was mounted inside a steel cylinder to collect rain. The rainfall data collection starts when the rain falls through a screen into a funnel called the collector. Once collected, the rain water is funneled to a mechanical device known as a tipping bucket. The bucket works on the seesaw method. The seesaw tips when the bucket collect 0.01 inches of rain water. During the tipping process, a magnet will move past a reed switch sensor and the bucket will tip to the other side. The rain gauge is connected to the flowmeter to store rainfall data in the memory (ISCO, 2011). The rainfall data is then retrieve and analyzed through Flowlink 5.1 software, similar to data retrieval in the flowmeter.

Figure 3.8: ISCO 674 Tipping Bucket Rain Gauge

3.3.4 Flowlink 5.1

The flowlink software was installed on the laptop to retrieve and analyze stored data from the area-velocity flowmeter and rain gauge. The Flowlink 5.1 software shown in Figure 3.9 was used in this research to do the analysis of the flow characteristics. It can generate the stored data such as flow rate data and rainfall data into graphs and tables form in Microsoft Excel, Word and Power Point. The data retrieved process will be carried out onsite and it only takes a few minutes. A cable adapter will connect the laptop to the flowmeter or rain gauge to retrieve the data.

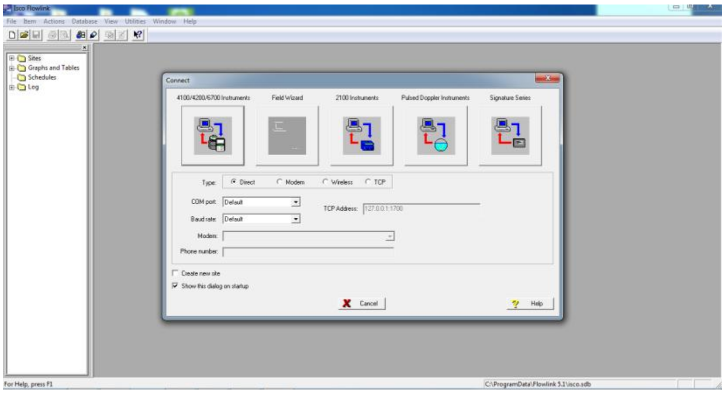


Figure 3.9: Flowlink 5.1

3.3.5 Calibration of Equipment

Calibration of flowmeter and batteries were carried out in the Hydraulics and Hydrology Laboratory in UMP Gambang before the equipment was used in the research areas. The aim of calibration is to ensure the equipment is able to function well. This will also make sure that the data collected is accurate, precise and minimize the error to the minimum.

Experimental procedure for calibration is as follows:

1. The size for the open channel is recorded.
2. The slope of the open channel is adjusted.
3. The switch of the open channel is flipped on.

4. Area-velocity sensor is placed at the bottom of the channel and connected to the flowmeter.
5. Readings of depth and flow rate for both flowmeter and open channel are recorded.
6. The error percentage between the readings of the flowmeter and the open channel is determined by using the following equations (Equation 3.1 and Equation 3.2):

$$Percent\ error\ (depth) = \frac{H_{open\ channel} - H_{flowmeter}}{H_{open\ channel}} \times 100\% \quad (3.1)$$

$$Percent\ error\ (flow\ rate) = \frac{Q_{open\ channel} - Q_{flowmeter}}{Q_{open\ channel}} \times 100\% \quad (3.2)$$

3.4 SITE WORK

The site work, also known as field monitoring work, started after the preliminary work was completely done. It is the work to be conducted at the site chosen. The site location in this research study was selected based on the results of site visit conducted. The site work includes determining the population equivalent at the study area, measuring the flow characteristics of the sewage inside the manhole selected and collecting the rainfall data at the research area.

3.4.1 Population Equivalent Determination

In order to measure the population who uses the sewerage system in each of the research area, a determination of population equivalent at the residential area was needed. The population equivalent of every research area was obtained from the authority, IWK. In order to ascertain the accuracy of the number of residents staying at the particular area, a site survey to determine the number of population equivalent was conducted. From the survey results, the PE for MH 84 in Taman Lepar Hilir Saujana was 1254, PE for MH K at Taman Pandan Damai was 2243 and Taman Bandar Putra has 1694 PE.

3.4.2 Flow Characteristics Measurement

The main task for the site work in this research is to obtain the measurement of flow characteristics for sewerage system at the residential areas of Taman Lepar Hilir Saujana, Taman Pandan Damai and Taman Bandar Putra. In this research, the measurement of the flow characteristics was done by 1 unit ISCO 2150 of area-velocity flowmeter with 2 units of rechargeable batteries and 1 unit of ISCO area-velocity sensor. The measurements taken include velocity of the sewer flow, level of the flow and flow rate inside the sewer pipelines. All the data obtained will be recorded and stored in the memory of the flowmeter. The data is recorded based on the 5 minutes interval which has been set before the flowmeter start measuring. The analysis was done through the data recorded. The maximum and minimum flow of sewage inside the sewerage system on weekdays and weekends as well as day time and night time were evaluated.

First and foremost, the selected location of the manhole is identified and population equivalent of the study area is determined. Before the installation of the flowmeter inside the manhole, the permission from the relevant authority IWK is required. After receiving approval from IWK, the staff from IWK will be assigned to open the manhole chosen by using the manhole opener as shown in Figure 3.10.

The size of the channel is determined to choose for a suitable sized of mounting ring. The sensor is connected to the mounting ring by screw as shown in Figure 3.11. The mounting ring with sensor is then placed at the bottom level of the manhole as shown in Figure 3.12 at the sewer connection where the flow of the sewage will pass through before bend to the STP. However, due to the large channel size at Taman Bandar Putra, the mounting ring is unable to be fixed inside the pipeline. Hence, the solution is solved by attaching the sensor to a steel plate and steel bar as shown Figure 3.6. Then sensor cable is connected to the ISCO 2150 Area-Velocity Flowmeter to start recording the data. Two units of rechargeable batteries are installed inside the flowmeter. The other two units of rechargeable batteries are inter-changed for every field monitoring work conducted. The flowmeter is then suspended at the manhole ladder with the help of a rope and is protected by a plastic bag to prevent infiltration of water into the flowmeter. After the flowmeter is fixed in position, the manhole is closed.

The measurement of velocity flow, level of sewage flow and flow rate in the sewer line was retrieved from the flowmeter through an interrogator cable to a laptop. During every field work, inspection of the flow of sewage inside the sewer line is carried out to ensure no blockage at the channel, which will affect the reading taken. If there is any blockage discovered, cleaning work is required.

Figure 3.10: Staff from IWK using manhole opener to open manhole

Figure 3.11: Lab assistant screws the sensor to mounting ring

Figure 3.12: The sensor is located at the bottom level of the manhole

3.4.3 Rainfall Data Collection

Besides the flow characteristics data obtained, rainfall data was also collected to compare against the flow rate of sewerage system. Changing of climate is one of the factors that may contribute to flow characteristics. Thus, the rainfall data is collected to check whether it affect the flow rate of sewage.

In this research, the rainfall data was collected using an ISCO 674 tipping bucket rain gauge with the help of a tripod stand. Approval of permission from IWK was required as the rain gauge has to be installed inside the STP. The rain gauge was placed near the study area to ensure relevancy. A free space without interference of trees or shelters inside the STP at every research area was selected to locate the rain gauge for easy collection of the rainfall data as shown in Figure 3.13. The bubble is adjusted to the center in order to obtain accurate rainfall reading. The rainfall data collection started when the rain starts. The depth and duration of rainfall was obtained through rain gauge.

The rainfall data is then retrieve through an interrogator cable to the laptop and analyze through the Flowlink 5.1 software.

Figure 3.13: The ISCO 674 tipping bucket rain gauge installed at the free space

3.5 METHOD OF CALCULATION

The population equivalent (PE) of the study area was determined in the previous section. Measurement data such as Q maximum hourly, Q minimum hourly and Q average were extracted through the flowmeter. Per capita flow and peak flow factor were the main parameters to analyze the flow characteristics in the sewer line in order to design sewerage system.

3.5.1 Per Capita Flow

Per capita flow in the sewerage system can be calculated as shown in Equation 3.3,

$$Q_{pcf} = \frac{Q_{ave}}{PE} \quad (3.3)$$

where Q_{pcf} is per capita flow measured in m^3/day/person, Q_{ave} is average daily flow of sewage obtained from the flowmeter data and measured in unit m^3/day and PE is population equivalent in the study area.

3.5.2 Peak Flow Factor

Peak flow in the sewerage system can be calculated through Equation 3.4,

$$Q_{peak} = PFF \times Q_{ave} \quad (3.4)$$

where Q_{peak} is peak flow with unit of m^3/day, PFF is the peak flow factor and Q_{ave} as described before. The peak flow factor equation is based on MS 1228:1991 and shown in Equation 3.5,

$$PFF = K \left(\frac{PE}{1000}\right)^{-0.11} \quad (3.5)$$

where K is the design criterion and PE as stated earlier. In order to obtain the value of design criterion in the research area, Equations 3.3 to 3.5 were combined and rearranged, giving Equation 3.6,

$$K = \frac{Q_{peak}}{(Q_{pcf} \times PE)\left(\frac{PE}{1000}\right)^{-0.11}} \quad (3.6)$$

Based on Malaysia Standard MS 1228:1991, Clause 3.2 and Clause 3.6 state that the standard value for per capita flow, Q_{pcf} is 0.225 m^3 per day per person while the value for design criterion, K is 4.7. Hence, the calculation obtained from the equations 3.3 and 3.6 were compared with the standard to determine the suitability for the sewer line design.

CHAPTER 4

RESULTS

4.1 INTRODUCTION

In this dissertation, all the results will be presented which include the area-velocity flowmeter calibration, PE survey results done before the site work started and details of the data collected from the research area.

4.2 CALIBRATION OF ISCO 2150 AREA-VELOCITY FLOWMETER

For the purpose of collecting the flow rate and level data, the ISCO 2150 area-velocity flowmeter was calibrated in the Hydraulics and Hydrology Laboratory of UMP Gambang. Calibration was carried out first before conducting site field work in every research area. The calibration results for every research area can be referred to Appendix B. The calibration graph is plotted and the linear equation is obtained.

4.2.1 Taman Lepar Hilir Saujana

Calibration graph is plotted between flow rate of flowmeter and open channel as shown in Figure 4.1. The linear equation obtained is $y=0.9815x-0.1553$. Thus, the equation will be applied to the flow rate obtained at site in order to acquire accurate flow rate data for Taman Lepar Hilir Saujana site area.

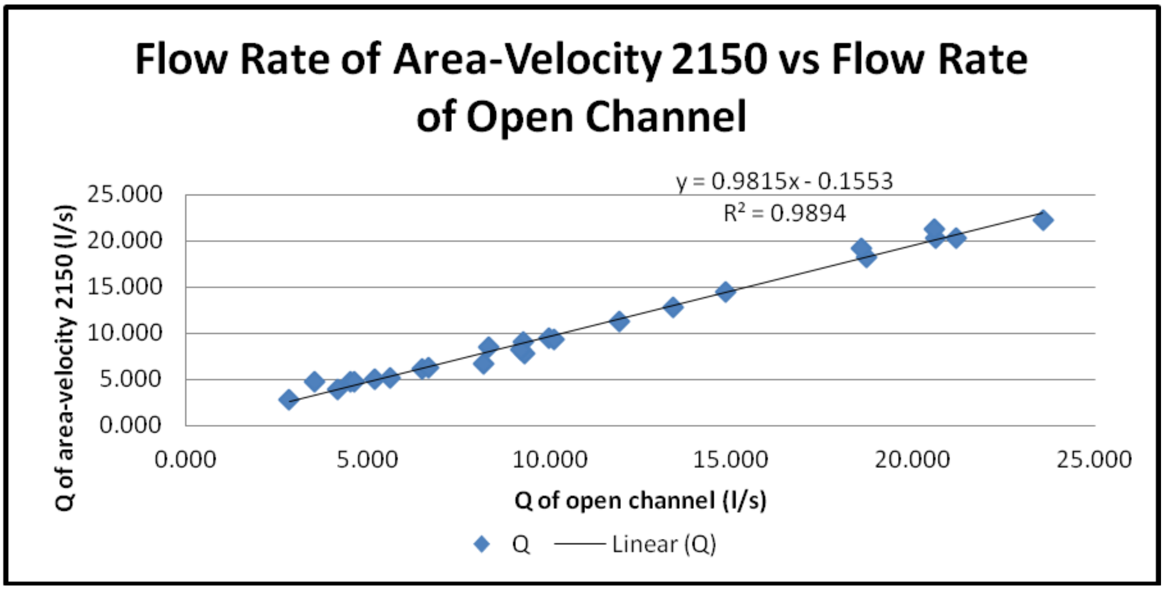


Figure 4.1: Calibration graph at Taman Lepar Hilir Saujana

4.2.2 Taman Pandan Damai

Figure 4.2 shows the calibration graph between flow rate of flowmeter and open channel. The linear equation obtained is y=0.9659x-0.0296. Thus, the equation will be applied to the flow rate obtained at site in order to acquire accurate flow rate data.

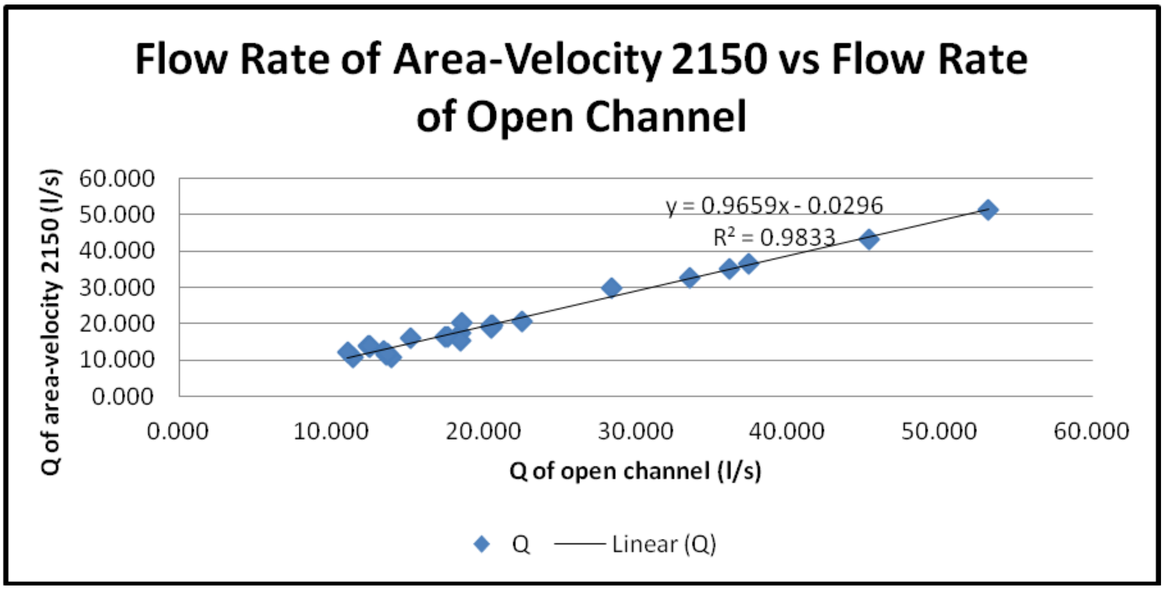


Figure 4.2: Calibration graph at Taman Pandan Damai

4.2.3 Taman Bandar Putra

Calibration graph is plotted between flow rate of flowmeter and open channel as shown in Figure 4.3. The linear equation obtained is y=0.9893x-0.2672. Thus, the equation obtained at Taman Bandar Putra site will be substitute into the flow rate in order to acquire accurate flow rate data.

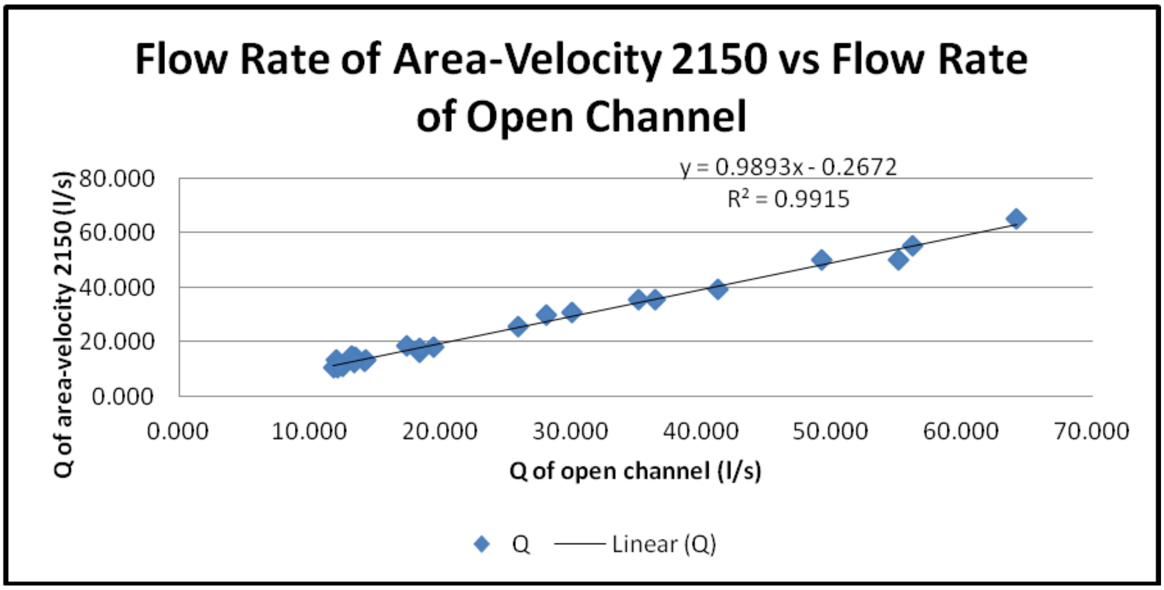


Figure 4.3: Calibration graph at Taman Bandar Putra

4.3 SITE SURVEY AT RESEARCH AREA

4.3.1 Taman Lepar Hilir Saujana

Results from the site survey in Taman Lepar Hilir Saujana is shown in Table 4.1.

Table 4.1: PE survey at Taman Lepar Hilir Saujana

ESTABLISHMENT	TYPE	UNIT/AREA	REQUIREMENT	PE
Commercial	Shop Lot	819.47 m^2	3 per 100 m^2 gross area	25
Residential	Residential Houses	250 units	On site survey	1229
			Total PE	1254

4.3.2 Taman Pandan Damai

Results from the site survey in Taman Pandan Damai is shown in Table 4.2.

Table 4.2: PE Survey at Taman Pandan Damai

ESTABLISHMENT	TYPE	UNIT/AREA	REQUIREMENT	PE
Commercial	Shop Lot	4760 m^2	3 per 100 m^2 gross area	143
Commercial	Shop Lot	3340 m^2	3 per 100 m^2 gross area	100
Commercial	Shop Lot	4080 m^2	3 per 100 m^2 gross area	122
Residential	Residential Houses	293 units	On site survey	1878
			Total PE	2243

4.3.3 Taman Bandar Putra

Results from the site survey in Taman Bandar Putra is shown in Table 4.3

Table 4.3: PE Survey at Taman Bandar Putra

ESTABLISHMENT	TYPE	UNIT/ AREA	REQUIREMENT	PE
Commercial	Shop Lot	800 m^2	3 per 100 m^2 gross area	24
School	Kindergarten	20 persons	0.2 per non-residential	4
		3 persons	1 per residential	3
Residential	Residential Houses	334 units	On site survey	1663
			Total PE	1694

4.4 FLOW CHARACTERISTICS MEASUREMENT IN RESEARCH AREA

4.4.1 Taman Lepar Hilir Saujana

Measurements for flow characteristics of sewerage were taken at MH 84 Taman Lepar Hilir Saujana with PE 1254. A total of 4 weeks data was collected beginning from 22nd September 2015 (Tuesday) at 10.30am to 19th October 2015 (Monday) at 10.30am. Continuous data was taken. The data collected was divided into two sets. The details of the data collected are shown in Table 4.4.

Table 4.4: Data collected from MH 84 at Taman Lepar Hilir Saujana

Data Set	Period of data taken	Time interval of data (minutes)	Duration of 1 set of data (days)	Duration of data collection (hours)	Rainfall during the time
MH 84 – 01	22/9/2015 Tuesday 10.30am – 6/10/2015 Tuesday 10.30am	5	14	336	No
MH 84 – 02	6/10/2015 Tuesday 10.30am – 19/10/2015 Monday 10.30am	5	13	312	Yes

4.4.2 Taman Pandan Damai

For research area at Taman Pandan Damai, measurements for flow characteristics of sewerage were taken at MH K with PE 2243. A total of 8 weeks data was collected, beginning from 27th November 2015 (Friday) at 0.00am to 22nd January 2016 (Monday) at 0.00am. The data collected was divided into four sets. Every set of data is taken for the duration for two weeks period or 14 days. The details of the data collected are shown in Table 4.5.

Table 4.5: Data collected from MH K at Taman Pandan Damai

Data Set	Period of data taken	Time interval of data (minutes)	Duration of 1 set of data (days)	Duration of data collection (hours)	Rainfall during the time
MH K – 01	27/11/2015 Friday 0.00am – 11/12/2015 Friday 0.00am	5	14	336	No
MH K – 02	11/12/2015 Friday 0.00am – 25/12/2015 Friday 0.00am	5	14	336	No
MH K – 03	25/12/2015 Friday 0.00am – 8/1/2016 Friday 0.00am	5	14	336	No
MH K – 04	8/1/2016 Friday 0.00am – 22/1/2016 Friday 0.00am	5	14	336	Yes

4.4.3 Taman Bandar Putra

Measurements for flow characteristics of sewerage were taken at MH 92a Taman Bandar Putra with PE 1694. A total of 6 weeks data was collected, beginning from 23rd February 2016 (Tuesday) at 0.00am to 8th April 2016 (Friday) at 0.00am. The data collected was divided into three sets. The details of the data collected are shown in Table 4.6.

Table 4.6: Data collected from MH 92a at Taman Bandar Putra

Data Set	Period of data taken	Time interval of data (minutes)	Duration of 1 set of data (days)	Duration of data collection (hours)	Rainfall during the time
MH 92a – 01	23/2/2016 Tuesday 0.00am – 8/3/2016 Tuesday 0.00am	5	14	336	Yes
MH 92a – 02	8/3/2016 Tuesday 0.00am – 22/3/2016 Tuesday 0.00am	5	14	336	No
MH 92a – 03	25/3/2016 Friday 0.00am – 8/4/2016 Friday 0.00am	5	14	336	Yes

CHAPTER 5

ANALYSIS AND DISCUSSION

5.1 INTRODUCTION

Analysis for the data collected was conducted to determine the flow characteristics in the sewerage system of the research area. The value of Q_{peak} and Q_{ave} respectively is calculated after the data collected. The parameters of the resulting analysis are compared with the Malaysia Standard MS 1228:1991 after the calculation. The discussion in this chapter includes the flow characteristics in the research area, per capita flow and peak flow factor in every research area.

5.2 ANALYSIS OF FLOW CHARACTERISTICS AT RESEARCH AREA

Before begin analyzing the results, data obtained from the area velocity flowmeter and rain gauge equipment at every research area are required to be exported from the Flowlink 5.1 software to the Microsoft Excel. For this study, the research area consists of Taman Lepar Hilir Saujana, Taman Pandan Damai and Taman Bandar Putra.

5.2.1 Taman Lepar Hilir Saujana

Two sets of flow characteristics data in Taman Lepar Hilir Saujana was analyzed at MH 84. The first set taken was 14 days which are from 22nd September 2015 (Tuesday) at 10.30am to 6th October 2015 (Tuesday) at 10.30am. For the second set, the data taken was analyzed for 13 days which are from 6th October 2015 (Tuesday) at 10.30am to 19th October 2015 (Monday) at 10.30am. Besides the flow rate data, the rainfall data is also included in the analysis. The resulting analysis of the both data sets is shown in the Figure 5.1 and Figure 5.2. The unit of flow rate shown in the graph is in liter per second whereas the rainfall measurement is in millimeter.

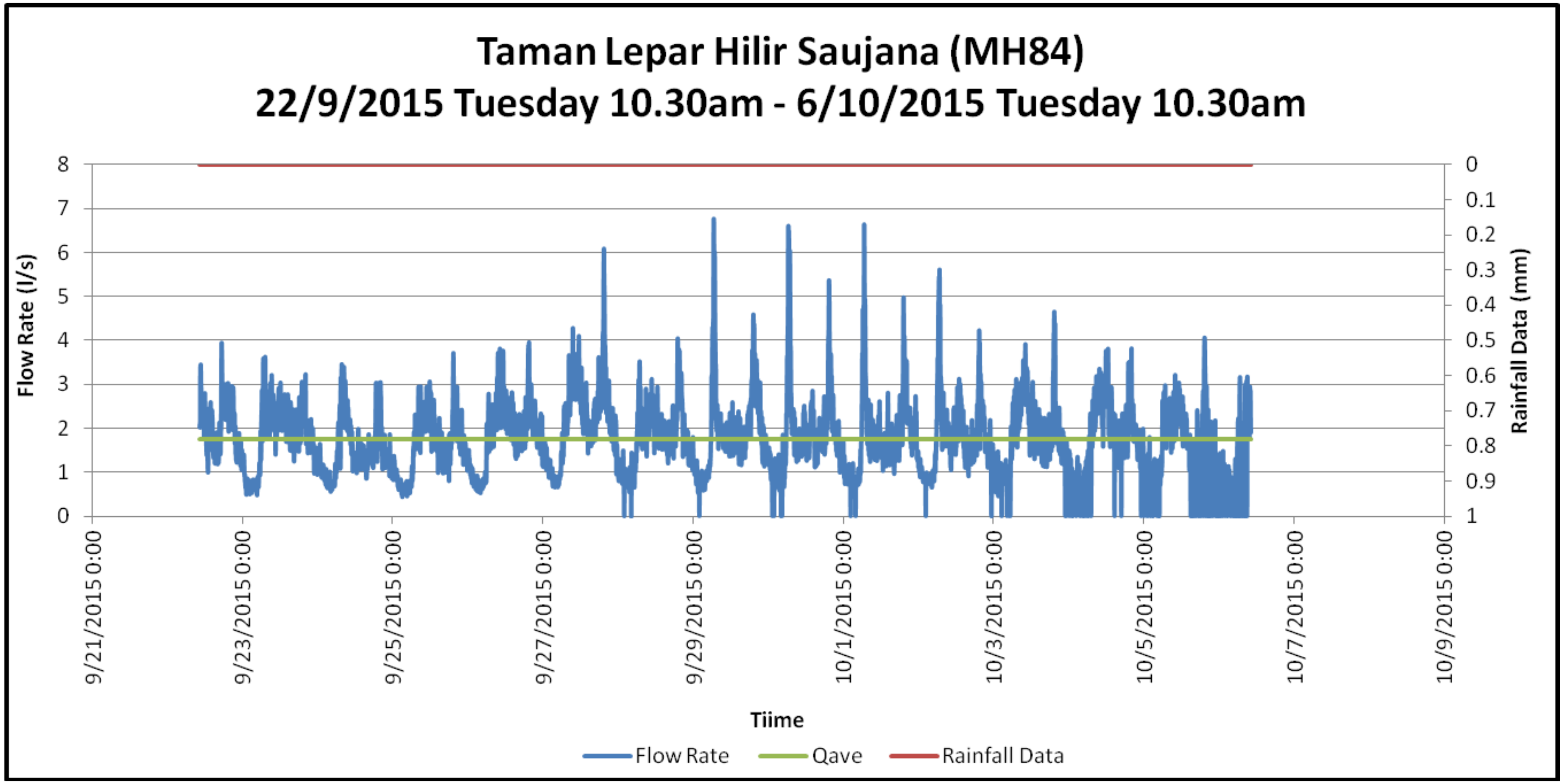


Figure 5.1: Result analysis from 22nd September 2015 (Tuesday) 10.30am to 6th October 2015 (Tuesday) 10.30am

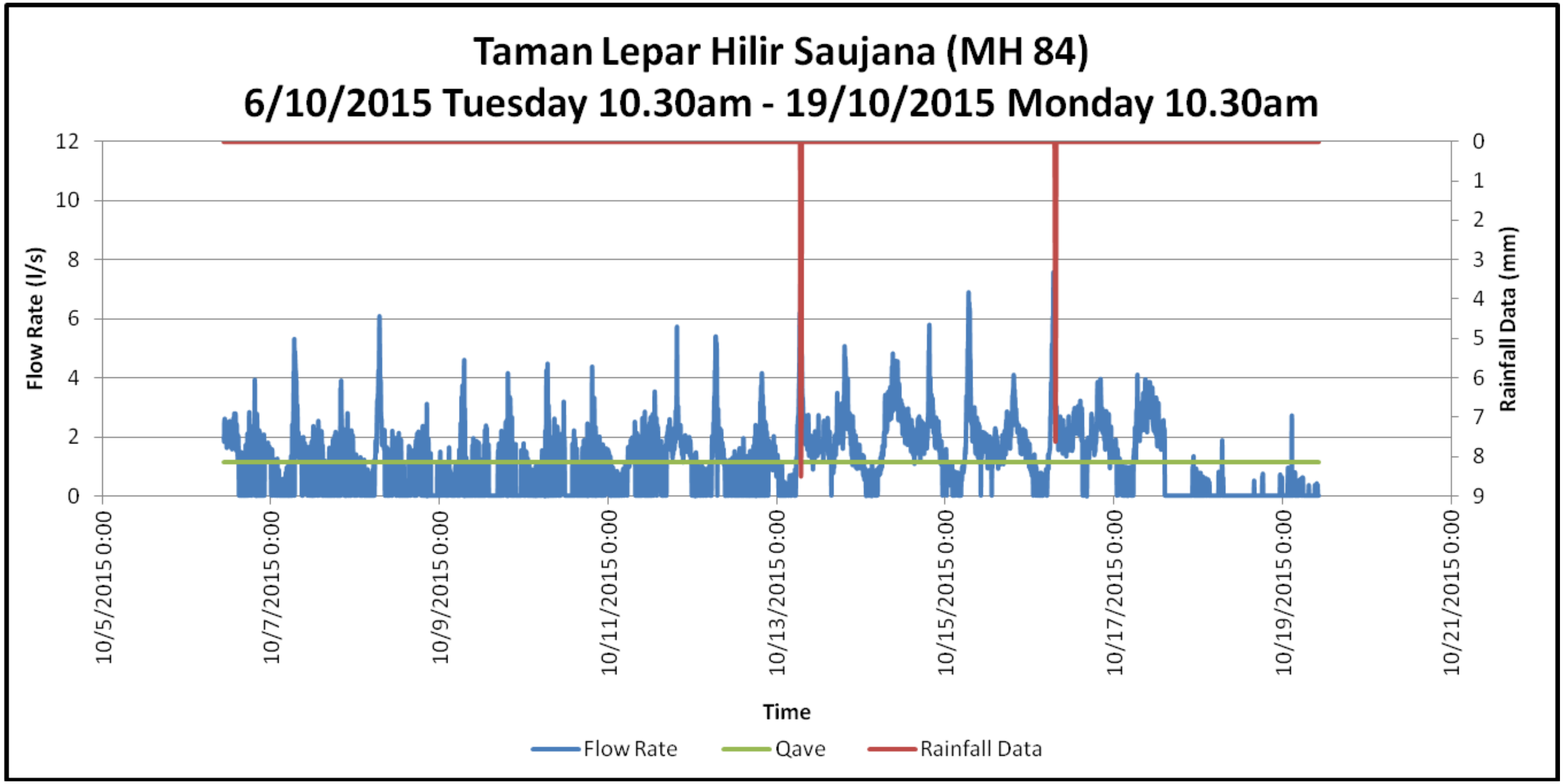


Figure 5.2: Result analysis from 6th October 2015 (Tuesday) 10.30am to 19th October 2015 (Monday) 10.30am

The analysis of the data included weekday and weekend period. There is no rainfall data for the first set of data. However, rainfall data is recorded in the second set of data. From the Figure 5.1, the Q_{peak} at the research area is 6.705 l/s which equal to 579.312 m^3/day whereas in the Figure 2, Q_{peak} show 11.335 l/s which equal to 979.344 m^3/day. According to the figure, it is clearly shown that at the peak flow of sewage, the rainfall data is matched with the peak flow during the rainy days. Thus, it can be explained that infiltration may occur at the pipe system inside the sewerage system and the rain water is flow into the pipe system.

Minimum flow rate was recorded to be 0 for both sets of data. This indicates that there is no flow inside the sewerage system. The negative values for the flow rate data is merged into zero flow rates. Negative values of flow rate occurred may due to the sewerage flow was too small and it is below the sensor detection limit.

Q_{ave} for set 1 data is 1.760 l/s which are equivalent to 152.064 m^3/ day. The Q_{ave} for the set 2 data is 1.159 l/s or 100.138 m^3/day which is lower than the Q_{ave} of set 1.

5.2.2 Taman Pandan Damai

Four sets of data were analyzed at MH K for Taman Pandan Damai research area. Every set of data is analyzed for two weeks with the time interval of five minutes. The period for this field work is from 27th November 2015 (Friday) at 0.00am to 22nd January 2016 (Friday) to 0.00am. A total of 8 weeks field work was carried out in Taman Pandan Damai. Analysis result of the four sets of data is shown in the Figure 5.3, Figure 5.4, Figure 5.5 and Figure 5.6.

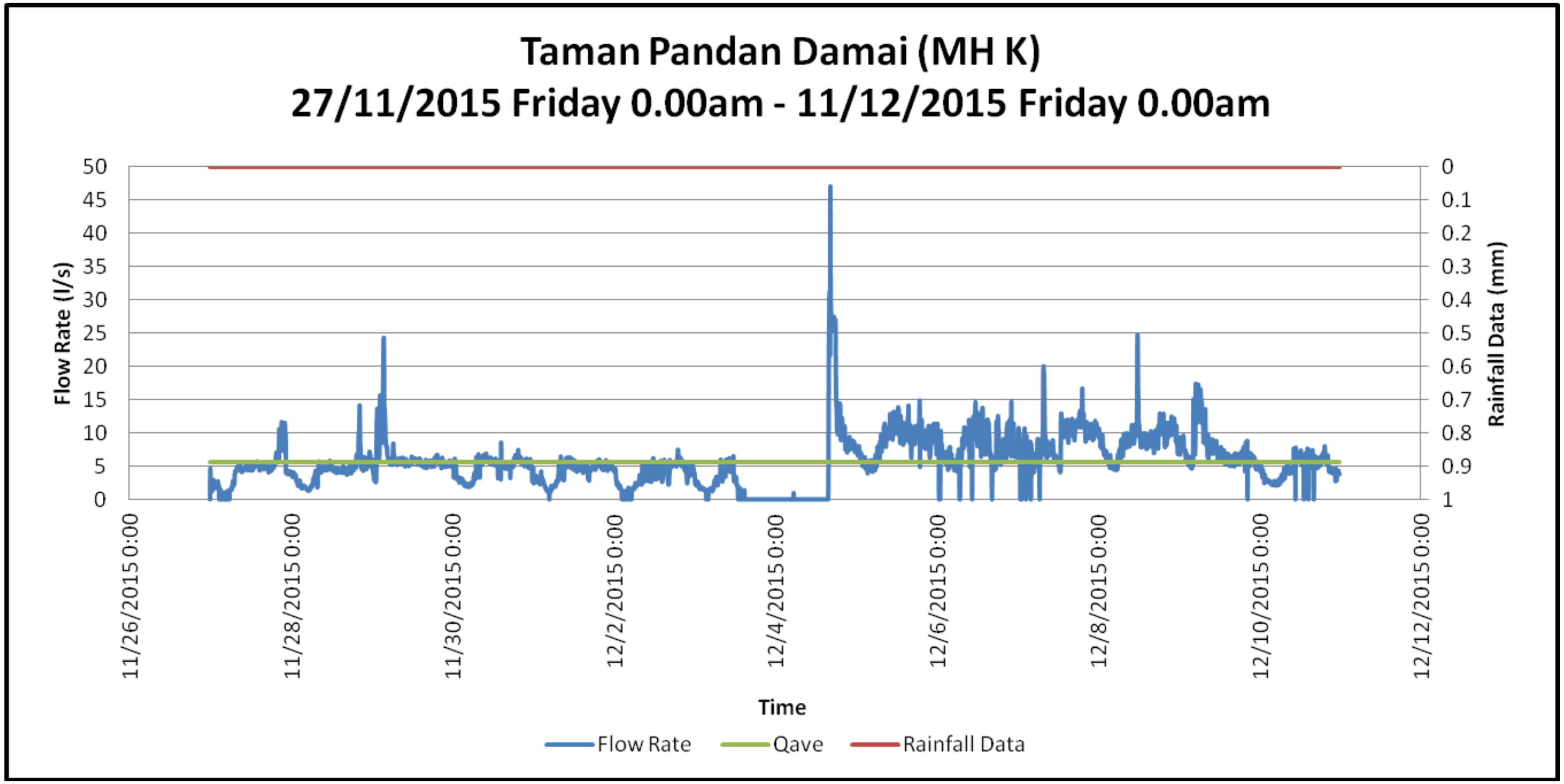


Figure 5.3: Result analysis from 27th November 2015 (Friday) 0.00am to 11th December 2015 (Friday) 0.00am

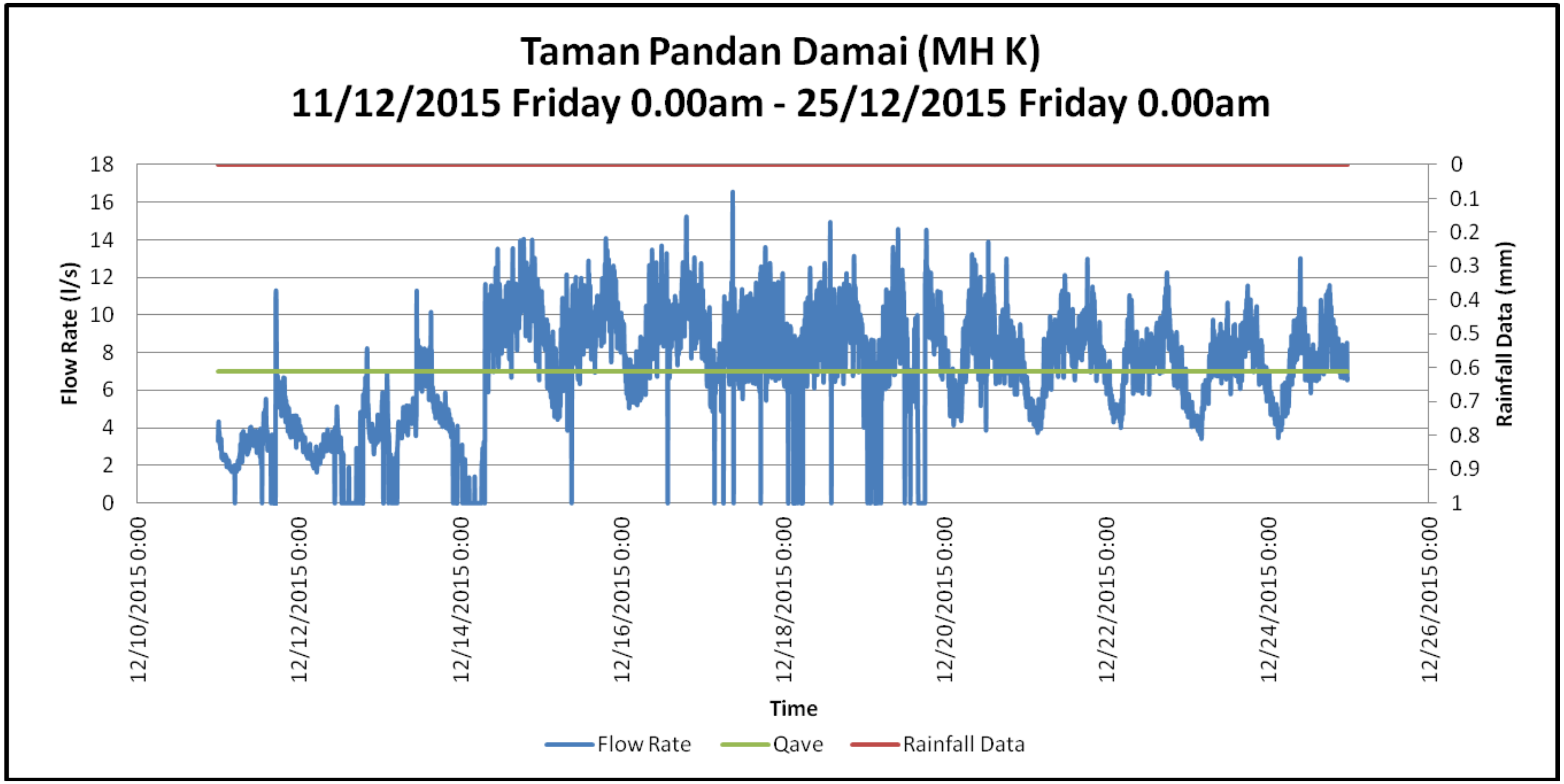


Figure 5.4: Result analysis from 11th December 2015 (Friday) 0.00am to 25th December 2015 (Friday) 0.00am

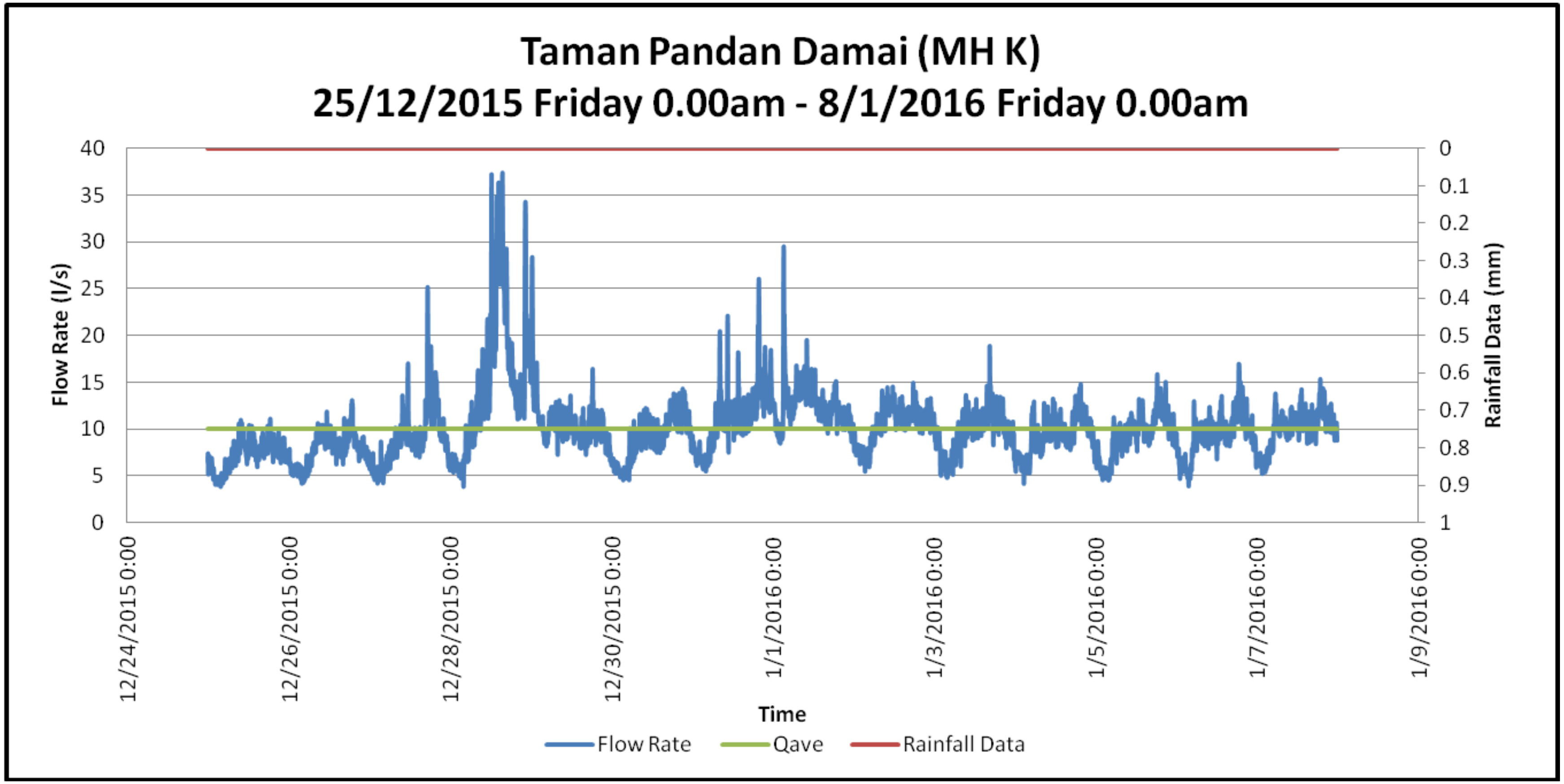


Figure 5.5: Result analysis from 25th December 2015 (Friday) 0.00am to 8th January 2016 (Friday) 0.00am

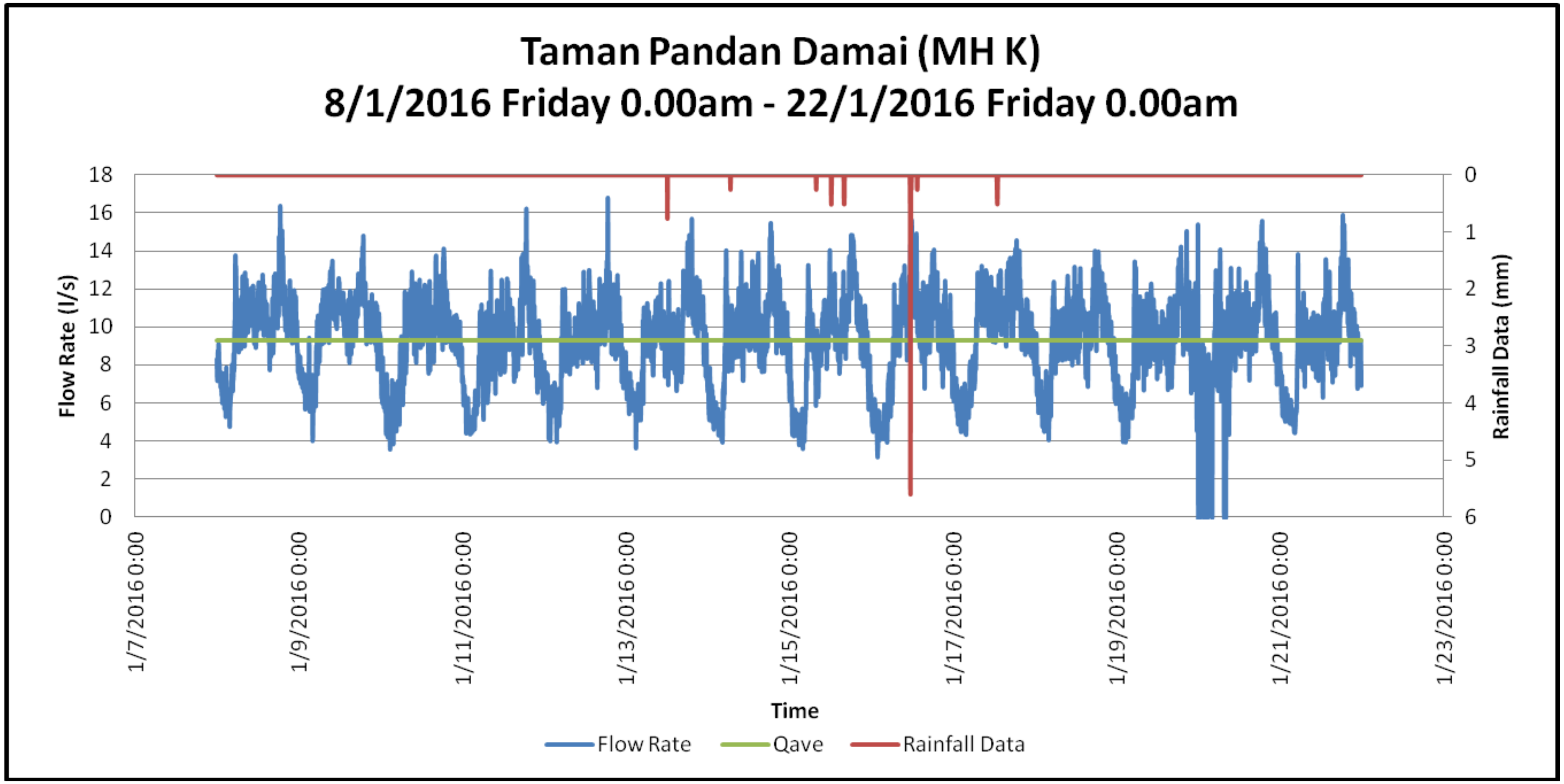


Figure 5.6: Result analysis from 8th January 2016 (Friday) 0.00am to 22nd January 2016 (Friday) 0.00am

The flow characteristic of sewerage system analysis data in Taman Pandan Damai includes weekday and weekend. The rainfall data is recorded in every set of data. From the rainfall result, there is no rainfall for the first three set of data. However, rainfall data was recorded for the fourth data set. For the first data set, the Q_{peak} shows 46.938 l/s which are equivalent to 4055.443 m^3/day. This value shows the highest Q_{peak} among the other four data sets in Taman Pandan Damai. The second set of data shows Q_{peak} is 16.449 l/s which are equal to 1421.194 m^3/day. This value is the lowest Q_{peak} among the data set analysis in Taman Pandan Damai. Next, the Q_{peak} in third data set shows 37.406 l/s which is similar as 3231.878 m^3/day and Q_{peak} in fourth data set obtained is 16.766 l/s or 1448.582 m^3/day. From Figure 5.6, it can be clearly seen that the rainfall data at the fourth data set do not match with the maximum flow rate data. Thus, the flow rate of flow characteristic of sewerage system in Taman Pandan Damai is not affected by the rainfall data.

Q_{min} for the first, second and fourth data set is zero whereas Q_{min} for third data set is 3.815 l/s which is similar as 329.616 m^3/day. The negative flow rate value in the analysis has merged into zero value.

Q_{ave} for set 1 data is 5.712 l/s which are equal to 493.517 m^3/day. Q_{ave} for set 2 is 7.024 l/s, similar to 606.874 m^3/day, which is higher than Q_{ave} of set 1. Q_{ave} for set 3 analyses show the highest Q_{ave} among the four data sets which are 10.033 l/s or 866.851 m^3/day. Fourth data set shows Q_{ave} equal to 9.259 l/s or 799.978 m^3/day.

5.2.3 Taman Bandar Putra

Six weeks of field work in Taman Bandar Putra was carried out to analyze flow characteristics at MH 92a with 1694 PE. All data sets were taken for the duration for 14 days with five minutes as the time interval. The first set of data taken is from 23rd February 2016 (Tuesday) at 0.00am to 8th March 2016 (Tuesday) at 0.00am. For the second set of data taken was analyzed from 8th March 2016 (Tuesday) at 0.00am to 22nd March 2016 (Tuesday) at 0.00am. Third data set was taken from 25th March 2016 (Friday) at 0.00am to 8th April 2016 (Friday) at 0.00am. Besides the flow rate data, the rainfall data is also included in the analysis. Analysis results of the both data sets are shown in the Figure 5.7, Figure 5.8 and Figure 5.9.

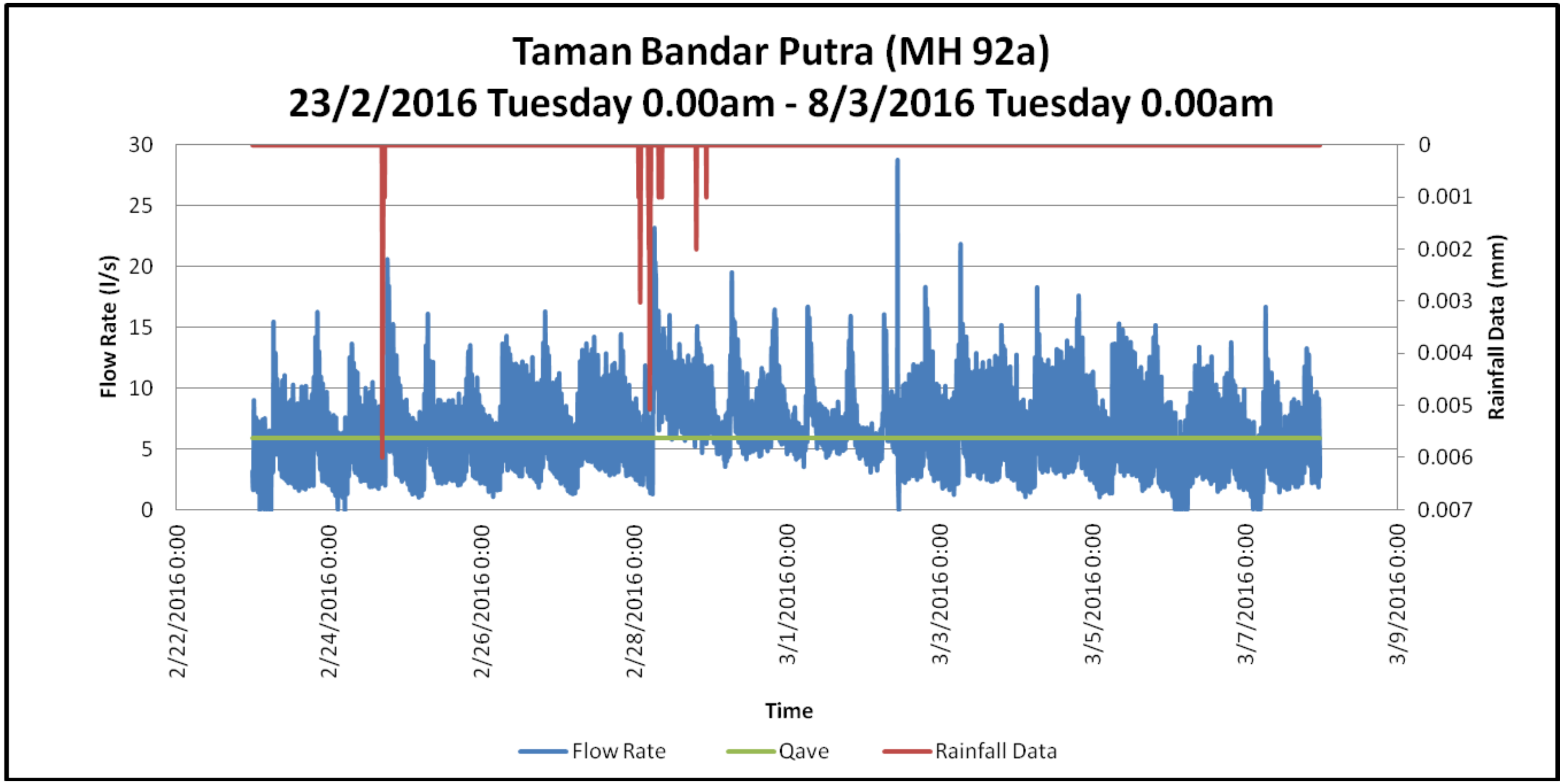


Figure 5.7: Result analysis from 23rd February 2016 (Tuesday) 0.00am to 8th March 2016 (Tuesday) 0.00am

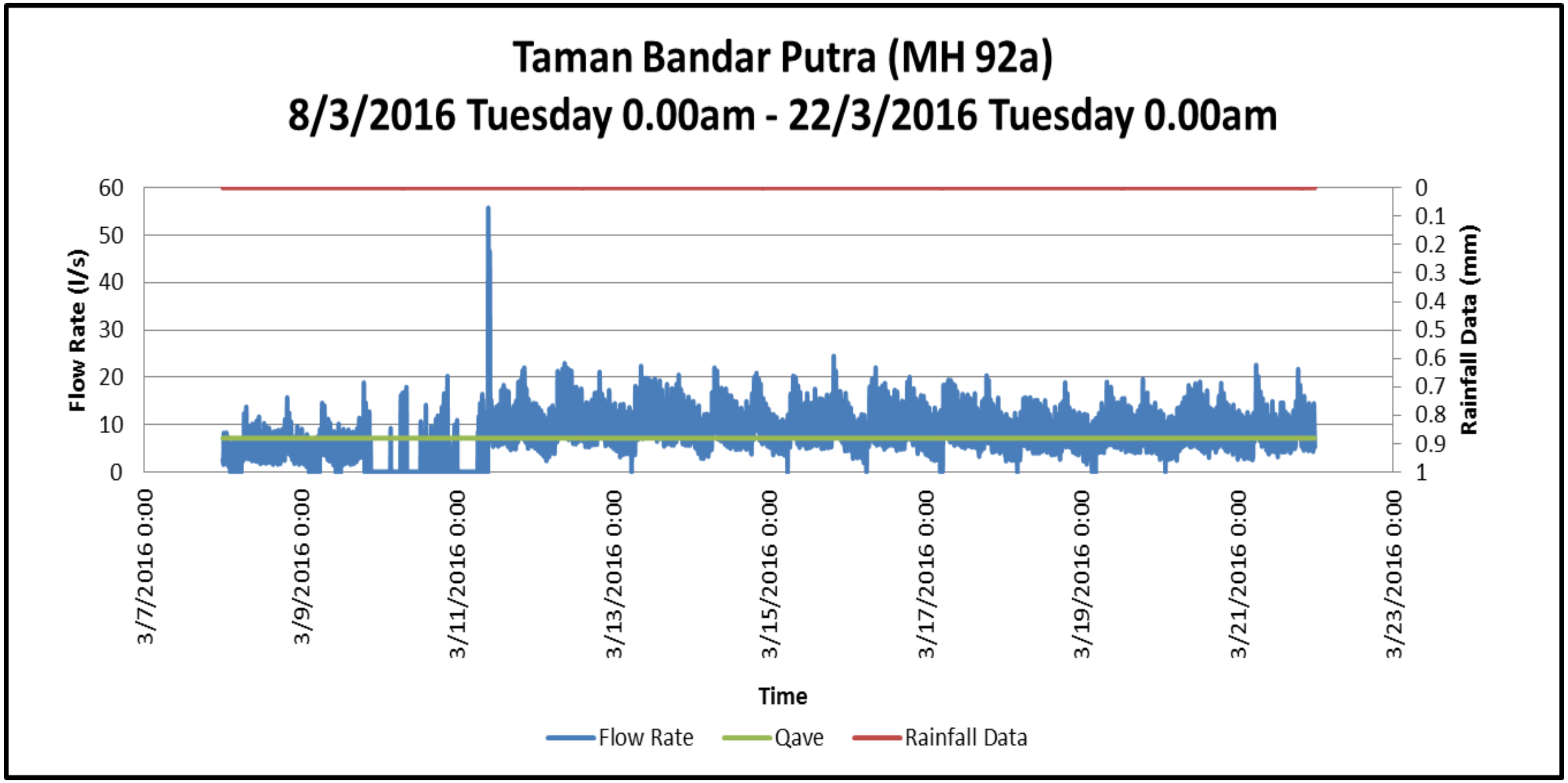


Figure 5.8: Result analysis from 8th March 2016 (Tuesday) 0.00am to 22nd March 2016 (Tuesday) 0.00am

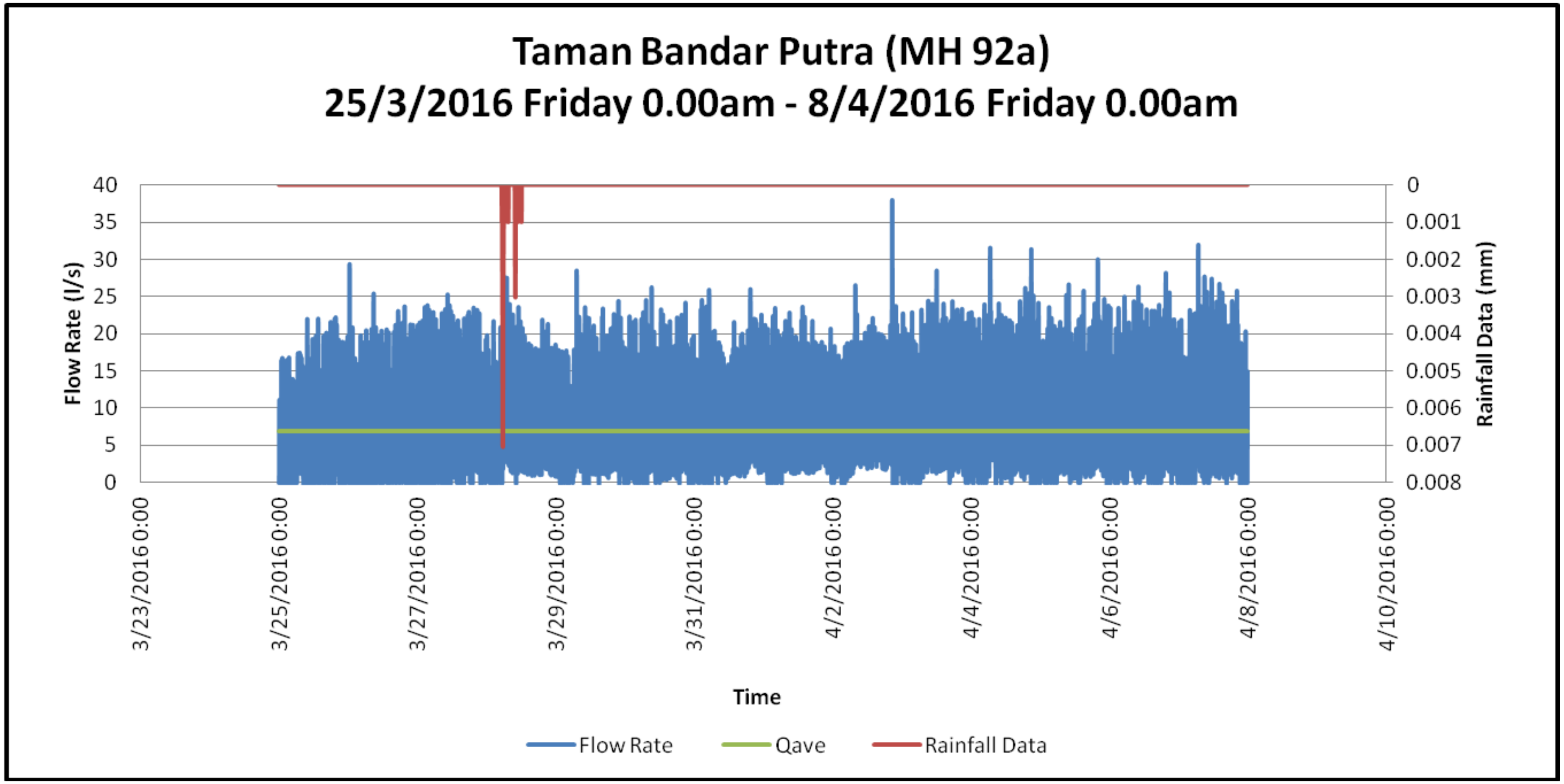


Figure 5.9: Result analysis from 25th March 2016 (Friday) 0.00am to 8th April 2016 (Friday) 0.00am

The analysis of flow characteristics of sewerage system at Taman Bandar Putra is included both weekday and weekend data. From the rainfall result, there is rainfall for the second data set but there is rainfall data recorded for the first and third data set. For the first data set, the Q_{peak} show 28.758 l/s which are similar to 2484.691 m^3/day. The second set of data show Q_{peak} is 54.773 l/s in which equal to 4732.387 m^3/day. This value is the highest Q_{peak} among the data set analysis at the Taman Bandar Putra. The Q_{peak} in third data set shows 37.167 l/s which same as 3211.229 m^3/day. Through Figure 5.7 and Figure 5.9, it can be clearly seen that the rainfall data record at the first and third data set do not match with the maximum flow rate data. Thus, the flow rate of flow characteristic of sewerage system at Taman Bandar Putra is not affect by the rainfall data. This situation can be predicted that there is no infiltration happen at the particular area.

Minimum flow rate recorded zero for all three set of the data. This happens as there is no flow inside the sewerage system. The negative values for the flow rate data is merge into zero flow rates. Negative values of flow rate occur may due to the sewerage flow was too small and the sensor is not able to detect. Back flow happen in the flow may result the negative value for the flow rate.

The lowest Q_{ave} among three data sets in Taman Bandar Putra show 5.848 l/s which equal to 505.267 m^3/day happen in data set 1 whereas the highest Q_{ave} is 7.155 l/s which similar to 618.192 m^3/day happen in data set 2. Q_{ave} for set 3 is 6.836 l/s or 590.630 m^3/day.

5.3 PER CAPITA FLOW

Per capita flow in the sewerage system is calculated for every data set based on the formula as listed in Equation 3.3. The resulting calculated value of the per capita flow obtained is compared with the MS 1228:1991.

5.3.1 Taman Lepar Hilir Saujana

The per capita flow for the set 1 data in the Taman Lepar Hilir Saujana obtained is 0.121 m^3/day/person whereas for the set 2 data recorded to be 0.080 m^3/day/person. The average per capita flow for the both sets of data is 0.101 m^3/day/person which is 55.11% lower than Q_{pcf}. Based on the MS 1228:1991, the value is 0.225 m^3/day/person.

5.3.2 Taman Pandan Damai

The per capita flow for set 1 in Taman Pandan Damai is 0.220 m^3/day/person. Q_{pcf} for set 2, set 3 and set 4 are 0.271 m^3/day/person, 0.386 m^3/day/person and 0.357 m^3/day/person respectively. The average of the per capita flow is 0.308 m^3/day/person which is 36.89% higher than Q_{pcf} from MS 1228:1991 which is 0.225 m^3/day/person.

5.3.3 Taman Bandar Putra

The per capita flow for set 1 at Taman Bandar Putra is 0.298 m^3/day/person. Q_{pcf} for set 2 and set 3 are 0.365 m^3/day/person and 0.349 m^3/day/person respectively. The average of the per capita flow is 0.337 m^3/day/person which is 49.78% higher than Q_{pcf} from MS 1228:1991 which is 0.225 m^3/day/person.

5.4 PEAK FLOW FACTOR

Design criterion for all the data set in every research area is calculated based on the Equation 3.6 after the per capita flow and peak flow were determined. After the design criterion was calculated, peak flow factor is determined from the Equation 3.5. After the parameter is calculated it is then compared with the MS 1228:1991.

5.4.1 Taman Lepar Hilir Saujana

After calculating using the formula, the design criterion for the set 1 data is 3.91 while the set 2 data obtained 10.03 for 1254 PE. The average design criterion is 6.97. Thus, the design criterion in this research area is 48.30% higher than the design criterion in MS 1228:1991 which is 4.7.

The peak flow factor for set 1 data is 3.81 whereas peak flow for set 2 is 9.78. Average of the peak flow factor for the both data set is 6.79. It is 48.25% higher than the standard limit which is 4.58.

From the overall results obtained, both Q_{peak} and Q_{ave} are recalculated by using the using the standard value of Q_{pcf} and K value. The parameter of Q_{pcf} and K obtained are interchanged within the standard with the value obtained at the research area. The result of this parametric study is shown in the Table 5.1.

Table 5.1: Parametric study at Taman Lepar Hilir Saujana

No.	Q_{pcf} (m^3/day/person)	K	Q_{peak} (m^3/day)	Q_{ave} (m^3/day)
1	0.225	4.7	1292.247	282.150
2	0.225	6.97	1867.833	282.150
3	0.101	4.7	580.075	126.654
4	0.101	6.97	861.247	126.654

It can be concluded that although the K value obtained (6.97) is much higher than the Malaysia Standard (4.7), the sewerage system in Taman Lepar Hilir Saujana is still enough to provide the sewerage system service in accordance to the design standard. Design standard states that, the $Q_{peak\ is}$ able to accommodate 1292.247 m^3/day of flow and Q_{ave} able to support 282.150 m^3/day of flow. The field work result obtained at the research area for Q_{peak} is 861.247 m^3/day whereas Q_{ave} is 126.654 m^3/day. Both Q_{peak} and Q_{ave} are lower than the design standard capacity. Thus, the capacity for the sewerage system in Taman Lepar Hilir Saujana is sufficient to provide sewerage service for the 1254 PE at research area.

5.4.2 Taman Pandan Damai

After calculating using the equation, the design criterion for set 1 is 8.98 which is the highest design criterion among the four data sets. Design criterion for data set 2, data set 3 and data set 4 shows 2.56, 4.07 and 1.98 respectively. The average for this four design criterion is 4.4 which are 6.38% lower than the design criterion show in the MS 1228:1991 which is 4.7.

Peak flow factor for the data set 1 is 8.22 which is the highest peak flow factor among the four data sets at Taman Pandan Damai. Peak flow factor for data set 2, data set 3, and data set 4 shows 2.34, 3.73 and 1.81 respectively. Average of peak flow factor for this four data sets are 4.02. It is 6.51% higher than the standard limit which is 4.3.

From the overall results obtained, the Q_{peak} and Q_{ave} are recalculated by using the using the standard value of Q_{pcf} and K value like the analysis result at Taman Lepar Hilir Saujana. The parameter of Q_{pcf} and K are interchanged within the standard with the value obtained at the research area. The result of this parametric study is shown in the Table 5.2.

Table 5.2: Parametric study at Taman Pandan Damai

No.	Q_{pcf} (m^3/day/person)	K	Q_{peak} (m^3/day)	Q_{ave} (m^3/day)
1	0.225	4.7	2170.103	504.675
2	0.225	4.4	2033.840	504.675
3	0.308	4.7	2970.629	690.844
4	0.308	4.4	2784.101	690.844

From the parametric study, it can be concluded that the K value obtained is lower than the Malaysia Standard but the Q_{pcf} obtained is much higher when compared with the Malaysia Standard. From the parametric study result, based on the design standard, Q_{peak} is only able to provide sewerage service for 2170.103 m^3/day and Q_{ave} is only sufficient to provide sewerage service for 504.675 m^3/day but from the result analysis Q_{peak} is need for 2784.101 m^3/day whereas Q_{ave} need capacity for 690.844 m^3/day. From this, Q_{peak} and Q_{ave} is 28.29% and 36.89% respectively exceeds the standard limit. In this case, it looks like the existing capacity for sewerage system at

Taman Pandan Damai is not sufficient to provide sewerage service for the 2243 PE at particular research area. The flow rate of the sewerage system is depends on the area of the pipe size and velocity of the flow. Hence, the pipe system in the sewerage system may change to bigger size to provide sufficient sewerage service for the 2243 PE at Taman Pandan Damai.

5.4.3 Taman Bandar Putra

The design criterion for data set 1 shows 5.21 which is the smallest design criterion value among the three data sets whereas design criterion for data set 2 is the highest among the three data sets which shows 8.11. Meanwhile, design criterion for data set 3 shows 5.76. Result for the entire design criterion at Taman Bandar Putra is higher than the design criterion show in the MS 1228:1991, 4.7. The average for this three design criterion is 6.36 which are 35.32% higher than 4.7.

For peak flow factor, data set 1 shows 4.92 which is the lowest peak flow factor among the three data sets at Taman Bandar Putra whereas the peak flow factor for data set 2 shows 7.66 which is the highest among the data sets. Peak flow factor for third data set shows 5.44. Average of peak flow factor for all these three data sets are 6.00. This value is 35.14% higher than the standard limit which is 4.44.

From the overall results obtained, the Q_{peak} and Q_{ave} are recalculated by using the using the standard value of Q_{pcf} and K value in the MS1228:1991. The parameter of Q_{pcf} and K are interchanged within the standard with the value obtained at the research area. The result of this parametric study is shown in the Table 5.3.

Table 5.3: Parametric study at Taman Bandar Putra

No.	Q_{pcf} (m^3/day/person)	K	Q_{peak} (m^3/day)	Q_{ave} (m^3/day)
1	0.225	4.7	1692.306	381.150
2	0.225	6.36	2286.900	381.150
3	0.337	4.7	2534.698	570.878
4	0.337	6.36	3425.268	570.878

It can be summarize that both Q_{pcf} and K value obtained is much higher than the Malaysia Standard. From the parametric study result, based on the design standard, Q_{peak} is only able to provide sewerage service for 1692.306 m^3/day and Q_{ave} is only sufficient to provide sewerage service for 381.15 m^3/day but from the result analysis Q_{peak} is need for 3425.268 m^3/day whereas Q_{ave} need capacity for 570.878 m^3/day. From this, Q_{peak} and Q_{ave} are 102.402% and 49.78% respectively exceeds the standard limit. From this parametric study, it looks like the existing capacity for sewerage system at Taman Bandar Putra is not enough to provide sewerage service for the 1694 PE at particular research area. The flow rate of the sewerage system is depends on the area of the pipe size and velocity of the flow. Hence, the pipe system in the sewerage system may change to bigger size to provide sufficient sewerage service for the 1694 PE at Taman Bandar Putra.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The parameters of peak flow factor and flow per capita distribution were obtained in this study and analysis of results was performed. The resulting analysis was the compared with the Malaysia Standard MS128:1991. Therefore, the objectives of research were achieved successfully.

Based on the analysis of results from the data collected in Taman Lepar Hilir Saujana, Taman Pandan Damai and Taman Bandar Putra, there are several conclusions that can be from the flow characteristics and design criterion perspectives.

In terms of the flow characteristics study, the average flow per capita at Taman Lepar Hilir Saujana is recorded to be lower than the design flow per capita as stated in the MS 1228:1991 which is 0.225 m^3/day/person. However, the average flow per capita flow at Taman Pandan Damai and Taman Bandar Putra are higher than the design standard.

Next, the design criterion obtained at both locations in Taman Lepar Hilir Saujana and Taman Bandar Putra are higher than the design criterion as recommended in MS 1228:1991, which is 4.7. In contrast, the design criterion at Taman Pandan Damai is lower than the required value.

From the analysis in which the PE is provided, the peak flow factor for Taman Lepar Hilir Saujana and Taman Bandar Putra are higher than the standard limit. However, the peak flow factor value obtained for Taman Pandan Damai is lower than the value as recommended in sewerage system design practice.

Besides that, in this research study, the rainfall did not happen much during the research conducted. It can be concluded that rainfall is not a factor influencing the flow rate as the resulting analysis did not show much changes for the flow characteristics of sewerage system in every research area after rainfall.

6.2 RECOMMENDATIONS

For further research, recommendations are suggested in this chapter in order to increase the comprehensiveness and accuracy of data collection and analysis. The PE of the study area has to be recalculated in order to increase the accuracy as PE is one of the main factors in contributing to the parameters calculation. As sensor and flowmeter are the main equipment in this research, care should be taken to ensure the process of analysis can be performed in good condition. Field work at site should be conducted frequently to ensure that the flow is not affect by blockage. More flowmeters can be provided to carry out the study at the same time at different sites. If this is done, more flow data can be collected. Furthermore, the study can be improved by carrying out the field work during rainfall season. Locations to carry out the site survey should be chosen thoroughly in order to ease the installation of equipment work as well as in conducting the fieldwork.

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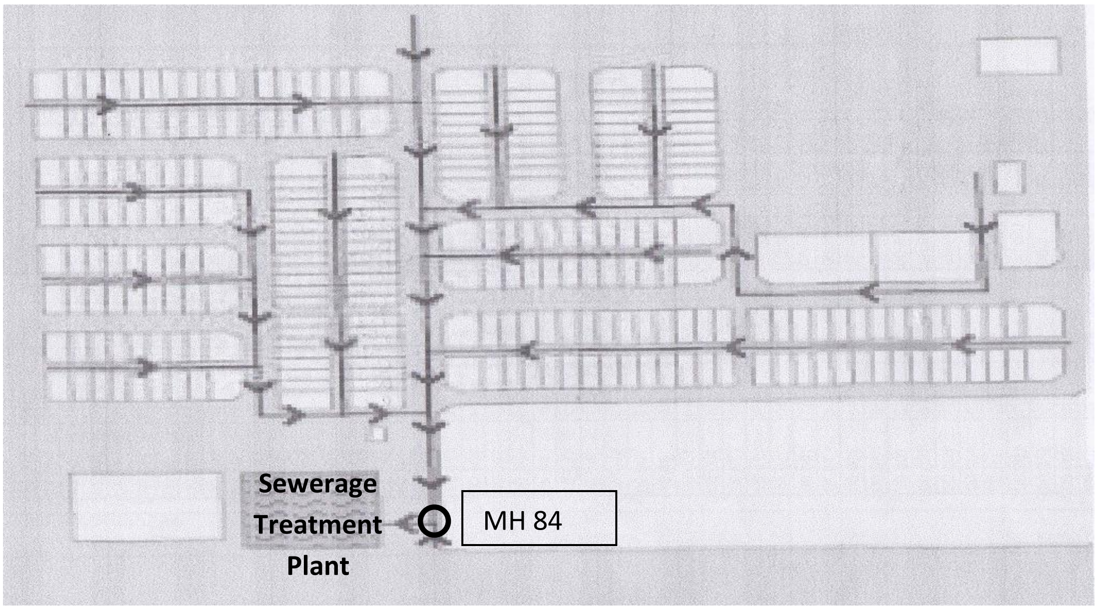
APPENDICES

APPENDIX A1

Location Map at Taman Lepar Hilir Saujana

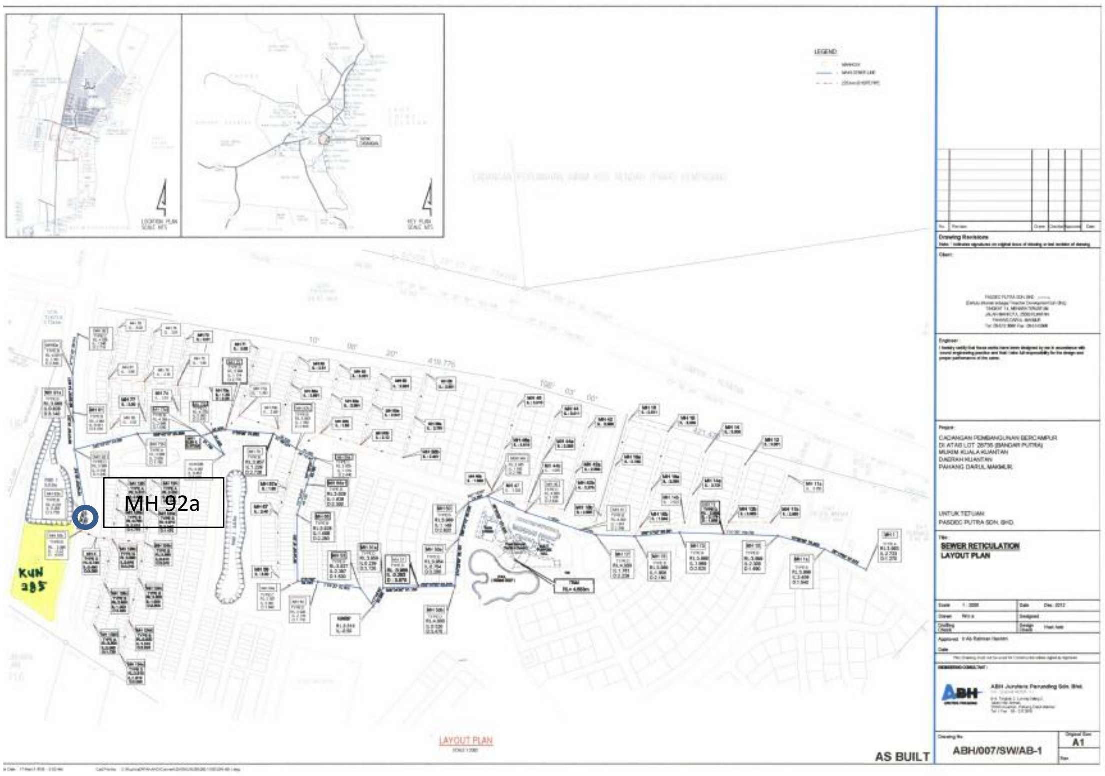


APPENDIX A2

Location Map at Taman Pandan Damai

APPENDIX A3

Location Map at Taman Bandar Putra



APPENDIX B1

Calibration data of ISCO 2150 Area-Velocity Flowmeter at Taman Lepar Hilir Saujana

No.	Depth of flowmeter, mm	Depth of open channel, mm	Percent error of depth, %	Flow rate of flowmeter, l/s	Flow rate of open channel, l/s	Percent error of flow rate, %
1	9.270	9.300	0.323	4.690	3.520	33.239
2	10.780	10.800	0.185	6.100	6.480	5.864
3	12.100	12.800	5.469	6.640	8.180	18.826
4	8.200	8.500	3.529	4.770	4.500	6.000
5	14.020	14.200	1.268	9.030	9.270	2.589
6	14.780	15.000	1.467	9.460	9.960	5.020
7	11.100	11.800	5.932	6.200	6.660	6.907
8	9.730	10.300	5.534	5.200	5.620	7.473
9	8.410	8.900	5.506	4.660	4.620	0.866
10	5.880	6.000	2.000	2.760	2.830	2.473
11	7.800	8.000	2.500	3.950	4.150	4.819
12	42.967	43.000	0.077	5.009	5.200	3.673
13	61.916	64.000	3.256	9.283	10.110	8.180
14	80.300	80.000	0.375	14.451	14.830	2.556
15	92.335	95.000	2.805	18.267	18.710	2.368
16	107.410	108.000	0.546	22.212	23.580	5.802
17	9.520	9.700	1.856	7.820	9.320	16.094
18	15.800	16.300	3.067	8.520	8.320	2.404
19	95.200	97.800	2.658	20.320	20.630	1.503
20	88.900	89.300	0.448	19.230	18.590	3.443
21	105.200	107.500	2.140	21.300	20.600	3.398
22	53.100	55.300	3.978	11.300	11.900	5.042
23	72.400	75.200	3.723	20.300	21.200	4.245
24	40.300	41.500	2.892	12.800	13.400	4.478
25	12.700	13.400	5.224	8.200	9.200	10.870

APPENDIX B2

Calibration data of ISCO 2150 Area-Velocity Flowmeter at Taman Pandan Damai

No.	Depth of flowmeter, mm	Depth of open channel, mm	Percent error of depth, %	Flow rate of flowmeter, l/s	Flow rate of open channel, l/s	Percent error of flow rate, %
1	22.500	21.000	7.143	10.640	11.440	6.993
2	31.500	32.000	1.563	11.630	13.630	14.674
3	50.600	55.000	8.000	13.960	12.430	12.309
4	80.900	81.000	0.123	17.620	18.530	4.911
5	101.600	102.000	0.392	35.150	36.210	2.927
6	136.500	135.000	1.111	51.430	53.210	3.345
7	82.800	85.000	2.588	19.630	20.560	4.523
8	71.300	73.000	2.329	16.100	15.210	5.851
9	44.200	43.000	2.791	12.060	11.060	9.042
10	18.350	19.000	3.421	10.590	13.960	24.140
11	71.200	70.000	1.714	16.540	17.520	5.594
12	91.400	90.000	1.556	20.410	18.630	9.554
13	113.200	115.000	1.565	32.580	33.540	2.862
14	86.200	85.000	1.412	19.470	20.570	5.348
15	78.600	79.000	0.506	16.440	17.630	6.750
16	51.300	52.000	1.346	13.630	12.560	8.519
17	41.500	43.000	3.488	12.590	13.450	6.394
18	33.400	32.000	4.375	11.640	13.690	14.974
19	20.900	20.000	4.500	20.560	22.560	8.865
20	59.230	62.000	4.468	13.960	12.520	11.502
21	72.610	74.000	1.878	15.320	18.520	17.279
22	80.510	82.000	1.817	18.740	20.490	8.541
23	99.500	97.000	2.577	29.650	28.450	4.218
24	130.230	132.000	1.341	43.230	45.360	4.696
25	106.200	104.000	2.115	36.460	37.450	2.644

APPENDIX B3

Calibration data of ISCO 2150 Area-Velocity Flowmeter at Taman Bandar Putra

No.	Depth of flowmeter, mm	Depth of open channel, mm	Percent error of depth, %	Flow rate of flowmeter, l/s	Flow rate of open channel, l/s	Percent error of flow rate, %
1	134.250	136.000	1.287	50.230	55.210	9.020
2	126.420	127.000	0.457	39.160	41.320	5.227
3	109.520	114.000	3.930	29.860	28.210	5.849
4	80.880	83.000	2.554	18.300	19.520	6.250
5	76.520	74.000	3.405	16.320	18.460	11.593
6	55.230	56.000	1.375	13.580	14.330	5.234
7	32.510	30.000	8.367	11.520	12.580	8.426
8	22.230	23.000	3.348	10.460	12.210	14.333
9	49.240	50.000	1.520	12.990	14.230	8.714
10	60.310	61.000	1.131	14.180	13.520	4.882
11	99.850	100.000	0.150	31.020	30.110	3.022
12	115.230	112.000	2.884	35.460	35.220	0.681
13	135.980	132.000	3.015	55.220	56.210	1.761
14	145.330	146.000	0.459	65.210	64.210	1.557
15	130.250	133.000	2.068	50.120	49.320	1.622
16	121.310	123.000	1.374	35.470	36.470	2.742
17	95.230	93.000	2.398	25.460	26.050	2.265
18	88.130	85.000	3.682	18.650	17.510	6.511
19	79.520	78.000	1.949	17.550	18.450	4.878
20	62.450	63.000	0.873	14.860	13.220	12.405
21	55.120	53.000	4.000	13.520	12.110	11.643
22	30.210	33.000	8.455	11.250	12.510	10.072
23	22.250	25.000	11.000	10.560	11.850	10.886
24	35.260	36.000	2.056	11.580	12.220	5.237
25	44.120	46.000	4.087	12.460	13.470	7.498

APPENDIX C1

Flow rate data at Taman Lepar Hilir Saujana

Flow rate data at MH 84 – 01 from 9/22/2015 Tuesday 10.30am to 10/6/2015 Tuesday 10.30am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
9/22/2015 10.30am - 9/23/2015 10.30am	3.914	0.485	1.819	0.000
9/23/2015 10.30am - 9/24/2015 10.30am	3.415	0.554	1.784	0.000
9/24/2015 10.30am - 9/25/2016 10.30am	3.038	0.434	1.400	0.000
9/25/2015 10.30am - 9/26/2016 10.30am	3.810	0.523	1.676	0.000
9/26/2015 10.30am - 9/27/2016 10.30am	4.279	0.654	1.947	0.000
9/27/2015 10.30am - 9/28/2016 10.30am	6.088	0.000	2.028	0.000
9/28/2015 10.30am - 9/29/2016 10.30am	6.705	0.000	1.890	0.000
9/29/2015 10.30am - 9/30/2016 10.30am	6.565	0.000	1.904	0.000
9/30/2015 10.30am - 10/1/2016 10.30am	6.637	0.000	1.828	0.000
10/1/2015 10.30am - 10/2/2016 10.30am	5.571	0.000	1.816	0.000
10/2/2015 10.30am - 10/3/2016 10.30am	4.227	0.000	1.766	0.000
10/3/2015 10.30am - 10/4/2016 10.30am	4.630	0.000	1.691	0.000
10/4/2015 10.30am - 10/5/2016 10.30am	3.801	0.000	1.788	0.000
10/5/2015 10.30am - 10/6/2016 10.30am	4.059	0.000	1.299	0.000

Flow rate data at MH 84 – 02 from 10/6/2015 Tuesday 10.30am to 10/19/2015 Monday 10.30am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
10/6/2015 10.30am - 10/7/2016 10.30am	5.168	0.000	1.246	0.000
10/7/2015 10.30am - 10/8/2016 10.30am	6.069	0.000	1.040	0.000
10/8/2015 10.30am - 10/9/2016 10.30am	4.562	0.000	0.683	0.000
10/9/2015 10.30am - 10/10/2016 10.30am	4.356	0.000	0.755	0.000
10/10/2015 10.30am - 10/11/2016 10.30am	4.314	0.000	0.772	0.000
10/11/2015 10.30am - 10/12/2016 10.30am	5.724	0.000	1.400	0.000
10/12/2015 10.30am - 10/13/2016 10.30am	11.335	0.000	1.115	0.000
10/13/2015 10.30am - 10/14/2016 10.30am	5.020	0.000	1.834	7.260
10/14/2015 10.30am - 10/15/2016 10.30am	6.889	0.000	1.963	0.000
10/15/2015 10.30am - 10/16/2016 10.30am	7.536	0.000	1.797	0.000
10/16/2015 10.30am - 10/17/2016 10.30am	4.094	0.000	1.924	4.980
10/17/2015 10.30am - 10/18/2016 10.30am	3.661	0.000	0.477	0.000
10/18/2015 10.30am - 10/19/2016 10.30am	2.713	0.000	0.064	0.000

APPENDIX C2

Flow rate data at Taman Pandan Damai

Flow rate data at MH K – 01 from 27/11/2015 Friday 0.00am to 11/12/2015 Friday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
11/27/2015	16.629	0.000	4.226	0.000
11/28/2015	14.124	1.295	4.210	0.000
11/29/2015	24.296	2.587	6.282	0.000
11/30/2015	8.495	1.842	4.780	0.000
12/1/2015	6.467	0.000	4.096	0.000
12/2/2015	7.467	0.000	3.677	0.000
12/3/2015	6.488	0.000	1.589	0.000
12/4/2015	46.938	0.000	4.781	0.000
12/5/2015	14.682	3.926	8.675	0.000
12/6/2015	14.671	0.000	7.858	0.000
12/7/2015	20.010	0.000	8.823	0.000
12/8/2015	24.602	4.404	8.760	0.000
12/9/2015	17.236	0.000	7.626	0.000
12/10/2015	8.000	0.000	4.590	0.000

Flow rate data at MH K – 02 from 12/11/2015 Friday 0.00am to 12/25/2015 Friday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
12/11/2015	11.327	0.000	3.466	0.000
12/12/2015	8.247	0.000	2.571	0.000
12/13/2015	11.294	0.000	4.510	0.000
12/14/2015	14.073	0.000	7.345	0.000
12/15/2015	14.086	0.000	9.020	0.000
12/16/2015	15.250	0.000	9.118	0.000
12/17/2015	16.449	0.000	8.614	0.000
12/18/2015	14.913	0.000	8.521	0.000
12/19/2015	14.593	0.000	7.316	0.000
12/20/2015	13.920	3.951	8.099	0.000
12/21/2015	12.946	3.743	7.721	0.000
12/22/2015	12.277	4.011	7.405	0.000
12/23/2015	11.544	3.430	7.228	0.000
12/24/2015	12.975	3.487	7.399	0.000

Flow rate data at MH K – 03 from 12/25/2015 Friday 0.00am to 1/7/2016 Friday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
12/25/2015	11.081	3.815	7.188	0.000
12/26/2015	13.027	4.154	7.784	0.000
12/27/2015	25.167	4.199	9.000	0.000
12/28/2015	37.406	3.816	14.901	0.000
12/29/2015	28.359	6.623	10.637	0.000
12/30/2015	14.291	4.524	8.972	0.000
12/31/2015	26.040	5.458	11.169	0.000
1/1/2016	29.416	8.469	12.568	0.000
1/2/2016	14.931	5.430	10.437	0.000
1/3/2016	18.763	4.776	9.671	0.000
1/4/2016	14.776	4.140	9.267	0.000
1/5/2016	15.852	4.495	9.365	0.000
1/6/2016	16.951	3.879	9.424	0.000
1/7/2016	15.324	5.199	10.075	0.000

Flow rate data at MH K – 04 from 1/8/2016 Friday 0.00am to 1/21/2016 Friday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
1/8/2016	16.352	4.762	9.985	0.000
1/9/2016	14.719	4.044	9.863	0.000
1/10/2016	14.090	3.569	9.168	0.000
1/11/2016	16.205	4.375	8.753	0.000
1/12/2016	16.776	3.985	9.029	0.000
1/13/2016	15.674	3.630	9.344	0.762
1/14/2016	15.435	3.987	9.338	0.254
1/15/2016	14.828	3.602	9.119	0.406
1/16/2016	15.588	3.173	9.018	1.524
1/17/2016	14.532	4.351	9.600	0.339
1/18/2016	13.994	4.063	9.353	0.000
1/19/2016	14.965	3.943	9.022	0.000
1/20/2016	15.511	0.000	9.034	0.000
1/21/2016	15.875	4.453	8.995	0.000

APPENDIX C3

Flow rate data at Taman Bandar Putra

Flow rate data at MH 92a – 01 from 2/23/2016 Tuesday 0.00am to 8/3/2016 Tuesday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
2/23/2016	16.188	0.000	4.789	0.000
2/24/2016	20.300	0.000	5.109	0.002
2/25/2016	16.043	0.981	5.065	0.000
2/26/2016	16.010	1.077	5.606	0.000
2/27/2016	14.167	1.283	5.680	0.000
2/28/2016	23.140	1.320	8.523	0.016
2/29/2016	19.332	3.555	7.804	0.000
3/1/2016	16.672	3.493	6.994	0.000
3/2/2016	28.758	0.000	6.093	0.000
3/3/2016	21.656	1.236	5.985	0.000
3/4/2016	18.172	1.067	5.910	0.000
3/5/2016	14.981	1.048	5.301	0.000
3/6/2016	13.722	0.000	4.474	0.000
3/7/2016	16.308	0.000	4.548	0.000

Flow rate data at MH 92a – 02 from 3/8/2016 Tuesday 0.00am to 3/22/2016 Tuesday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
3/8/2016	15.507	0.000	4.441	0.000
3/9/2016	18.820	0.000	3.700	0.000
3/10/2016	19.811	0.000	1.534	0.000
3/11/2016	54.773	0.000	7.087	0.000
3/12/2016	22.715	2.383	9.380	0.000
3/13/2016	22.391	0.000	9.555	0.000
3/14/2016	21.762	2.873	8.927	0.000
3/15/2016	24.141	0.000	8.845	0.000
3/16/2016	22.032	0.000	8.479	0.000
3/17/2016	20.034	0.000	8.222	0.000
3/18/2016	18.838	0.000	7.047	0.000
3/19/2016	19.491	0.000	7.396	0.000
3/20/2016	18.971	0.000	7.914	0.000
3/21/2016	22.569	2.591	7.646	0.000

Flow rate data at MH 92a – 03 from 3/25/2016 Friday 0.00am to 8/4/2016 Friday 0.00am				
Date	Q_{max} (l/s)	Q_{min} (l/s)	Q_{ave} (l/s)	Rainfall (mm)
3/25/2016	22.061	0.000	4.910	0.000
3/26/2016	29.260	0.000	5.493	0.000
3/27/2016	25.248	0.000	6.470	0.000
3/28/2016	27.511	0.000	7.515	0.018
3/29/2016	28.444	0.000	6.833	0.000
3/30/2016	26.007	0.000	6.544	0.000
3/31/2016	26.016	0.000	6.835	0.000
4/1/2016	23.584	0.000	7.355	0.000
4/2/2016	37.167	0.000	7.974	0.000
4/3/2016	28.280	0.000	7.541	0.000
4/4/2016	31.412	0.000	7.305	0.000
4/5/2016	29.872	0.000	6.944	0.000
4/6/2016	27.934	0.000	7.006	0.000
4/7/2016	31.830	0.000	6.982	0.000