EVALUATION OF PEAK FLOW DESIGN CRITERION FOR SEWERAGE SYSTEM IN TAMAN MAHKOTA

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ABSTRAK

Kriteria rekabentuk untuk faktor aliran puncak adalah salah satu elemen yang penting dalam rekabentuk sistem pembetungan di Malaysia. Rekabentuk sistem pembetungan berkaitan dengan analisis ciri-ciri aliran. Sistem pembetungan perlu direka berdasarkan kadar aliran yang paling kritikal. Rekabentuk sistem pembetungan akan menjadi tidak sesuai jika analisis ciri-ciri aliran tidak dijalankan. Tujuan kajian ini adalah untuk mengesahkan kriteria rekabentuk yang sesuai untuk sistem pembetungan seperti yang disyorkan dalam Standard Malaysia MS 1228:1991. Kajian ini juga untuk belajar kesan hujan pada corak aliran kumbahan dan analisis ciri-ciri aliran dalam sistem perbetungan. Dalam kajian ini, parameter kriteria rekabentuk telah dikaji. Kajian ini telah dijalankan pada lurang yang terletak di loji rawatan kumbahan Taman Mahkota di mana pemantauan aliran kumbahan telah dijalankan. ISCO 2150 Area-Velocity Flow Meter telah digunakan untuk mengumpul data aliran dan perisian Flowlink 5.1 telah digunakan untuk mendapatkan data serta paparan graf. Penentukuran flow meter dilakukan di Makmal Hidraulik dan Hidrologi UMP Gambang. Tempoh kajian adalah dari 1 Mac 2017, jam 11.00 pagi hingga 23 Mei 2017, jam 11.59 malam. Setiap set data mengandungi bacaan aliran kumbahan setiap lima minit untuk tempoh dua minggu dengan menggunakan Area-Velocity Method. Ukuran data yang sama telah digunakan untuk data hujan, dan dikumpul melalui ISCO 674 Rain Gauge terletak di loji rawatan kumbahan Taman Mahkota. Daripada data yang diperolehi, parameter dikaji akan berbanding dengan nilai yang dinyatakan dalam Standard Malaysia MS 1228:1991. Nilai purata aliran kapita dalam kajian ini adalah 0.375 m^3/hari/orang yang merupakan 66.7% lebih tinggi daripada aliran kapita dalam MS 1228:1991dengan jumlah 0.225 m^3/hari/orang. Nilai purata kriteria rekabentuk untuk factor aliran puncak sebenar dalam kajian ini adalah 2.9 dan 38.3% lebih rendah daripada kriteria rekabentuk 4.7 dinyata dalam MS 1228:1991. Melalui analisis ini, dapat disimpulkan bahawa ciri-ciri aliran dalam sistem pembetungan Taman Mahkota adalah mencukupi untuk menampung kesetaraan populasi dalam kajian ini.

ABSTRACT

The peak flow factor design criterion is one of the important elements in the design of sewerage systems in Malaysia. The design of sewerage systems is related to the analysis of flow characteristics. A sewerage system should be designed based on the most critical flow rate. Sewerage system design may become incorrect if the analysis of flow characteristics is not carried out. The purpose of this research is to verify the suitable design criterion for sewerage systems as recommended in Malaysia Standard 1228:1991. This research also aims to study the effect of rainfall on sewerage flow pattern and analyse the flow characteristics in the sewerage system. In this research study, the design criterion for sewerage system was investigated. The investigation was carried out on a selected manhole located in the sewerage treatment plant at Taman Mahkota where field monitoring of sewerage flows was conducted. ISCO 2150 Area-Velocity Flow Meter was used to collect the flow rate and Flowlink 5.1 software was used for data retrieval as well as graph display. Calibration of the flow meter was done in the Hydraulics and Hydrology Laboratory of UMP Gambang. The study duration was from 1 March 2017, 11.00 am to 23 May 2017, 11.59 pm. Each set of data consists of sewerage flow readings every five minutes for the duration of two weeks by using the Area-Velocity method. The same data measurement interval was applied to the rainfall data, collected through an ISCO 674 Rain Gauge also located within the sewerage treatment plant at Taman Mahkota. From the results obtained, the parameters investigated will be compared to their respective value stated in the Malaysia Standard 1228:1991. The value of average actual per capita flow in this research was 0.375 m^3/day/person which is 66.7% higher than the per capita flow stated in MS 1228:1991 having a value of 0.225 m^3/day/person. On the other hand, the value of average peak flow factor design criterion in this study was 2.9, 38.3% smaller than the design criterion 4.7 mentioned in MS 1228:1991. After the analysis of the results, it can be concluded that the flow characteristics in the sewerage system at Taman Mahkota is sufficient to serve the population equivalent in the study.

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LIST OF SYMBOLS

Q_{max}	Peak flow rate or maximum flow rate
Q_{min}	Minimum flow rate
Q_{avg}	Average flow rate
Q_{pcf}	Per capita flow
Q_{m}	Peak flow (Munksgaard and Young)
K	Design criterion of peak flow factor
L	Litre
m	Meter
p	Population in thousand
l/s	Litre per second
m^3/day	Cubic meter per day
mm	Millimeter
%	Percent
s	Second
ha	Hectare
d	Day
Q_{op}	Flow rate of open channel apparatus
Q_{2150}	Flow rate of flow meter ISCO 2150
H_{op}	Head of open channel apparatus
H_{2150}	Head of flow meter ISCO 2150

LIST OF ABBREVIATIONS

BOD	Biochemical Oxygen Demand
ICT	Communal Septic Tank
IST	Individual Septic Tank
ITs	Imhoff Tanks
IWK	Indah Water Konsortium Sdn Bhd
MS	Malaysia Standard
PE	Population Equivalent
PFF	Peak Flow Factor
PVC	Polyvinyl Chloride
RC	Reinforced Concrete
RCC	Reinforced Cement Concrete
STP	Sewerage Treatment Plant
UMP	Universiti Malaysia Pahang

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Sewerage system is one of the sanitary elements of any residential, commercial, institutional or industrial construction projects (Norhan et al., 2007). It is the infrastructure to collect, transfer, treat and dispose of sewage from domestic and industrial sources while the storm water is drained to rivers and seas in order to provide a comfortable environment. Wastewater or sewage is the effluent of water supply to the community or industry which has been used for different purposes and has been mixed with suspended or dissolved solids (Fahid, 2010). A sewerage system consists of different sizes of pipes linked together to transport wastewater to the sewerage treatment plant (Ansari et al., 2013). There are three types of sewerage system namely combined system, separate system and partially separate system.

Wastewater composition will affect by the design of sewer system. Separate sewer systems are used in most developing countries (Henze and Comeau, 2008). In Malaysia, the common sewerage system used is separate sewerage system, in which sewerage and stormwater flow in different pipelines. The sewage will be transported to sewerage treatment plants while storm water will be discharged into rivers without treatment. Wastewater can have a negative effect on the population, the economy and the environment of an area if it is not managed wisely. Thus, Malaysia is trying to improve the system for wastewater treatment which is both sustainable and suitable for the country's environments (Alexander and Oscar, 2010). This research is currently focused on the sewerage system for residential and commercial areas in Taman Mahkota. The type of sewerage system in Taman Mahkota is the separate sewerage system.

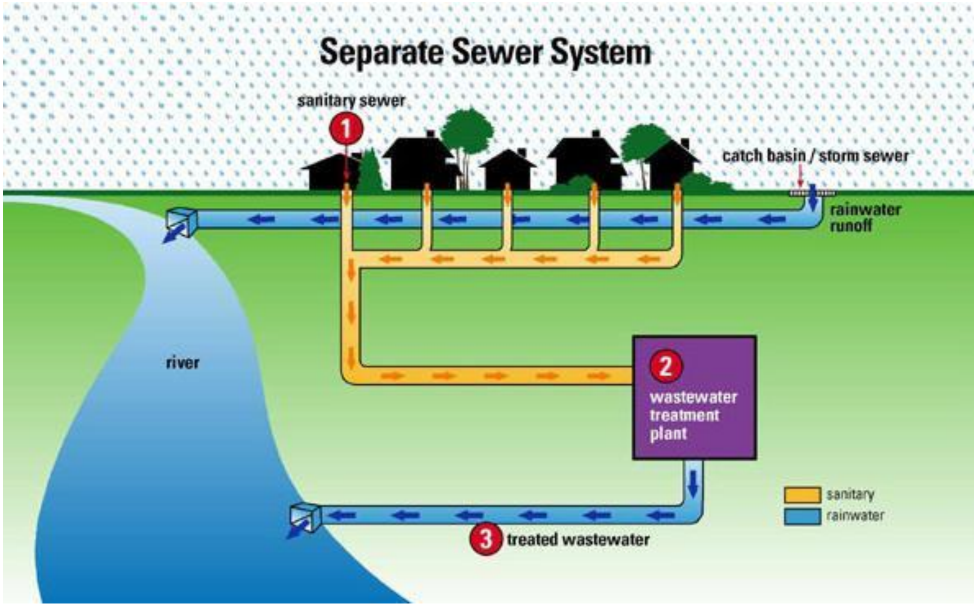

Figure 1.1 Separate sewerage system
Source: City of Winnipeg: Water and Waste Department (2014).

Industrial and residential wastewaters contain suspended, colloidal and dissolved (organic and mineral) solids, and they may be either excessively acid or alkaline (Alturkmani, 2013). Sewerage system is vital as it does the dirty work of daily waste disposal, which will prevent pollution and contamination to our environment if managed properly (Norhan et al., 2007). The design of sewerage system cannot just be based on the sewage produced from the expected sources, but need to consider the peak flow rates for a period of time-related to acceptable limits of behaviour (Imam and Elnakar, 2014). In designing sewerage system, both peak flow rates and its variation are important. Design criterion of sewerage system in Malaysia applies the Malaysia Standard MS 1228:1991, where the design criterion of peak flow factor is fixed at 4.7.

Sewerage system is placed underground, and sewage flows by gravity. Indah Water Konsortium (IWK) is responsible for the maintenance of sewerage treatment plants and sewerage systems (Yap, 2015). There are many types of sewerage treatment plants, such as activated sludge systems and stabilisation ponds. Wastewater will undergo several processes, which includes preliminary treatment (removal of rags, rubbish, oil and grease), primary treatment (removal of settleable and floatable materials), secondary treatment (biological treatment) and disposal of sludge (Azman et al., 2011).

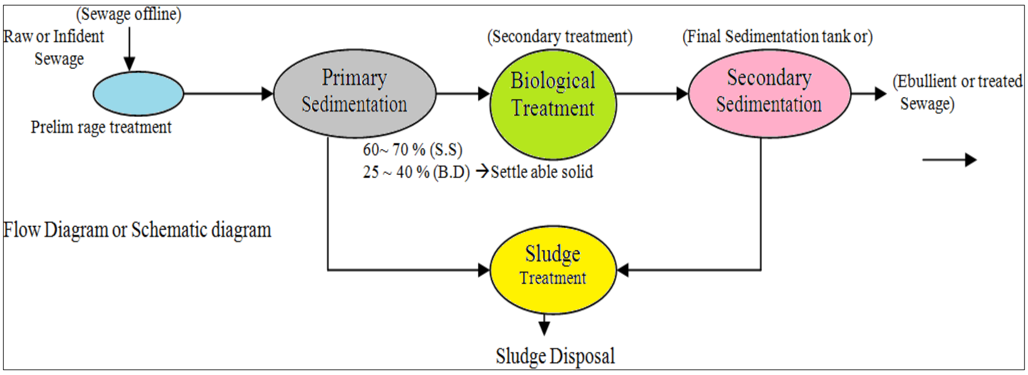

Figure 1.2 Sewer treatment flow diagram
Source: Civil Engineering Portal (2014).

Manholes are located along the sewer pipelines. Manholes are precast reinforced concrete chambers constructed normally at an interval of 100m for networks in Malaysia or whenever there is a change in the sewer gradient. They are used to allow access for carrying out inspection, cleaning and removing an obstruction in the sewer pipes. Flow readings will be taken at the selected manhole and rainfall data will also be collected. The purpose of collecting rainfall data is to study whether rainfall will affect the flow in the sewerage system (Yap and Ngien, 2015).

1.2 Problem Statement

According to a report of Recommended Standards for Wastewater Facilities (2014), sewer capacity is designed based on the estimated maximum of population equivalent (PE) for a specific amount of sewage. Flow variability will decrease when population increase, this is because the flow variability is reliable to the water usage of human on various purposes of activities every day (Imam and Elnakar, 2014). Peak flow is based on the amount of wastewater generated per person every day in a certain area and estimated population served (Butler and Graham, 1995). In Malaysia, design criterion of peak flow factor is fixed based on the standard MS 1228:1991 in the design of sewerage system, which is equal to 4.7. However, some previous studies indicate the lower value of design criterion of peak flow factor in Malaysia (Ngien and Ng, 2013). Thus, in this research, the validity of design criterion in peak flow factor at Taman Mahkota is checked include influence of rainfall. This is because the standard MS 1228:1991 is adopted from British standard; BS 8005:1987 and will not be suitable for Malaysia as the weather and season in these two countries is not similar. If the actual design criterion of peak flow factor smaller than the design peak flow factor’s design criterion during operation, the diameter of pipes will decrease while the cost will also decrease (Norhan et al., 2003). Thus, this research will help in determining a more suitable design criterion of sewerage system in Malaysia.

1.3 Research Objectives

I. To investigate the flow characteristics of sewerage system in Taman Mahkota
II. To study the effect of rainfall on peak flow factor of sewerage system in Taman Mahkota
III. To compare the actual peak flow factor design criterion of sewerage system in Taman Mahkota to the recommended peak flow factor design criterion in the standard MS 1228:1991

1.4 Scope of Study

This research is focused on the sewer flow in Taman Mahkota where a manhole was selected to carry out this study. Total six sets (twelve weeks) of data with the time interval of five minutes for each two weeks were collected from the selected manhole. Area-Velocity Flow Meter ISCO 2150 was calibrated in the Hydraulics and Hydrology Laboratory, UMP Gambang. Flow characteristics such as flow rate were collected using flow meter and sensor at the selected manhole and the data were analysed. The flow meter is hung on a bar attached to the wall in the selected manhole, while the sensor of the flow meter is fixed in the water pipeline by using a mounting ring size 300 mm to prevent the sensor being washed away by the high velocity of wastewater. The data collected were then analysed into a graph and calculated the design criterion by using equation. Rainfall reading was also collected to investigate the effect on the flow rate of sewerage system as mentioned in MS 1228:1991. The study is carried out at the sewerage treatment plant in Taman Mahkota.

1.5 Significance of Study

Existing design criterion of the sewerage system is not proposed to represent the actual conditions but rather as procedures for design purposes. As the population growth is hardly estimated after several years, the sewerage system may not be able to sustain the population. Thus, this research helps to collect more data and used to establish to the future design criterion and apply appropriate peak flow factor. Besides, by analysing the previous study in Malaysia, the results are not enough to give a clearer evidence of the design criterion of sewerage system in Malaysia especially Pahang state (Yap et al., 2016). Thus, this research will contribute to the future design of sewerage system. This research will also help in investigating the factors such as weather effect on the flow characteristics of sewerage system in Taman Mahkota as the MS 1228:1991 is adopted from British Standard especially in East Coast of Malaysia that contains more rain than other states.

CHAPTER 2

LITERATURE REVIEW

2.1 History and Sewage Transportation Technology

According to Hamid and Baki (2005), there were no appropriate sewerage systems and sewerage treatment is not needed in the early independence of Malaysia. This is due to the low population and inadequate urbanised developments of the country. The sewerage treatment at that time was just some way of simple methods, for example, over-hanging latrines, pit and bucket latrines and discharge directly to the rivers and seas. After when Malaysia started to develop from agriculture to the industry based economy, only the suitable sewerage system is introduced.

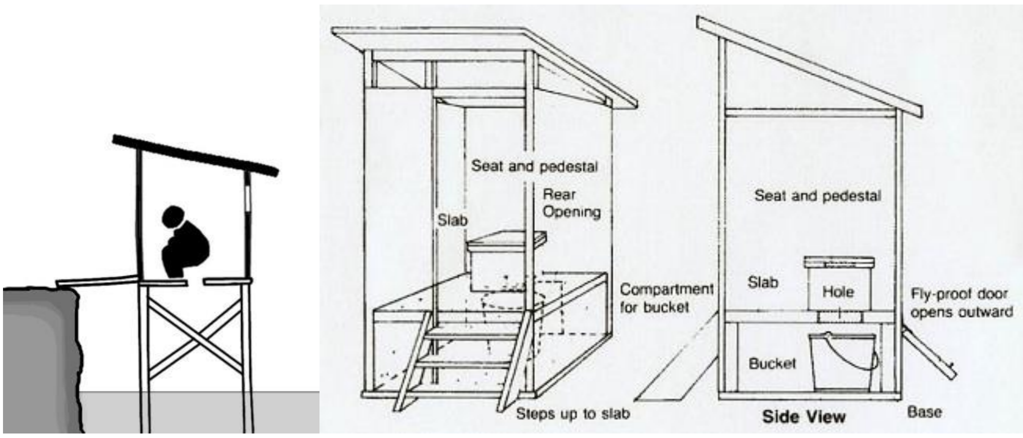

Figure 2.1 Overview of over-hanging latrines and pit and bucket latrines
Source: USAID (1910).

In the 1960s, sewerage treatment system using commonly is individual septic tanks (ISTs) and pour flush systems. Primary treatment like communal septic tanks (ICTs) and Imhoff tanks (ITs) started introduced to small communal systems (Zuzilawati, 2014). In the 1970s, biological treatment processes such as oxidation pond systems are introduced by using natural means of treatment. After that, some of the oxidation ponds are replaced by aerated lagoon systems as mechanised systems were introduced implemented in Malaysia in the 1980s (Japan Sanitation Consortium, 2011). In the late 1980s and 1990s, fully mechanised systems biological filters and activated sludge systems are used in Malaysia due to the rapid development of the country. Efforts on the control of mechanised systems which allowed for process optimisation of new systems are focused in the late 1990s (Kaur et al., 2011).

Treatment processes evolved from primitive to primary and developed to secondary treatment systems, from non-mechanical systems to more mechanical and then the automated system was mainly caused by the technology development in the sewerage sector. With the technological improvements, new and improved technology and equipment were continuously implemented. Indirectly, the expectation on environment principles and the skill level in the design, construction and operation of new sewerage systems is increased along with the time (Garc ía, 1997).

In early days of human civilisation, sanitation problems were treated by the nature such as rivers and seas as the population was very small compared to the civilisation of the human after that. As the population increased human start to invent a more appropriate sewerage treatment system (Hamid and Baki, 2005).

In Europe, the evolution of sewerage treatment followed the demands as the development of the township and increased the population. During the Middle Ages, sewage was discharged directly to the streets which act as sewage disposal area at that time. Occurrences of bubonic plague raised up the attention on improving the sanitation system (Burks and Minnis, 1994). In the 19th century, sewerage system is in the forms of pour flush system and discharged directly to the rivers and seas. When the population increased and pollution of rivers and seas became serious, sewerage farms were implemented to treat sewage and later developed into appropriate sewerage treatment plants before discharged to the rivers and seas (Hamid and Baki, 2005).

In Malaysia, the evolution of sewerage facilities was very little due to the demand for sanitation was not serious during the pre-independence period. Urban development and population increased in the 1950s, and indirectly the improvement of the sanitation sector also increased and mostly managed by Local Sanitary Board (Aini, 2011). Louis Moureas invented individual septic tanks used the concept of primary systems sedimentation processes in 1860. This system had reduced the pollution level to the environment, such as decreased the BOD concentration from 200-400 mg/l to 150-200 mg/l (Hamid and Baki, 2005).

In the late 1970s, an increase of population leads to use of aerated lagoons within a limited size of the land area for reservation of oxidation ponds. The capacity of the oxidation ponds is five times bigger than the original capacity by implemented aerators to the systems. Environmental Quality Regulations 1979 is introduced to improve the sewerage systems. Secondary treatment through mechanical sewage treatment plants such as extended aeration, rotating biological contactors and trickling filters are introduced (Kaur et al., 2011). In the 1990s, more capable pumps are introduced to the sewerage sector, improvements in the design of pumps, for example, aspirators and submersible aerators to allow more effective oxygen transfer. Advance in computer technology and microelectronics improved the sewerage treatment system. For example, control of sequencing batch reactors processes by using PLC is more convenient (JIL Engineering Consult, 2015).

2.2 Types of Sewerage System

Underground pipes that transport wastewater and stormwater to a treatment plant or storm water to disposal and treatment is called sewers. Sewers can be divided into three types: sanitary, storms and combined sanitary and storms. Public sewer systems can be categorised into separated and combined sewer systems according to their discharging types (Henry, 2004). Separate sewer systems are separate networks including sanitary sewers from household and commercial areas transfer to sewerage treatment plant and storm water sewer is discharged into the river without treatment (Umpi, 2011). Combined sewer systems are designed to collect and transport the sanitary sewage and storm water into the pipes and then to sewerage treatment plant. In the old US and European urban communities, combined sewer systems are commonly used (Lin, 2014).

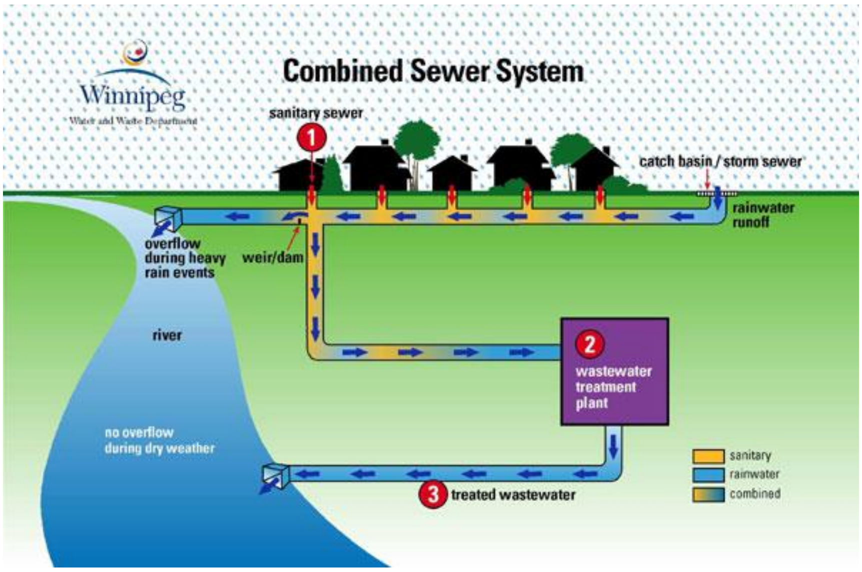

Figure 2.2 Combined sewerage system

Source: City of Winnipeg: Water and Waste Department (2014).

In Malaysia, public sewerage systems and individual septic tanks are more commonly used in communities. The sewerage systems are operated and maintained by Indah Water Konsortium (IWK) since 1994 (Hamid and Narendran, 1993). IWK also maintained all the underground pipes and provide desludging services to individual septic tanks (Aziz et al., 2011). IWK divided the underground pipes into two parts; public pipes and private pipes. This is to ensure that all underground pipes function without any problems. Public pipes are responsible by IWK while private pipes are responsible by an individual (Kadir, 2011). Individual need to pay for IWK services if need them to service the private pipes. The common public sewerage systems used in Malaysia is separate sewer systems.

Table 2.1 Public Sewerage Treatment Plants in Malaysia

No.	Types of Sewerage Treatment Plant	As At Oct 2014	Population Equivalent
1	Imhoff Tank	679	507,648
2	Oxidation Ponds	403	1,681,176
3	Mechanical Plants	4,902	18,665,408
4	Network Pump Stations	982	4,582,844
	TOTAL	6,966	25,707,076
	COMMUNAL SEPTIC TANK	3,625	405,432

Source: IWK Portal (2014).

2.3 Elements of Sewerage System

Sewerage system mainly consists of sewer pipelines and manholes. Sewer pipelines are used to transport the wastewater to the sewerage treatment plant before discharge to the rivers and seas. Manholes are used when carried out maintenance of sewer pipelines. There are various types of material can be used to construct the sewerage system such as concrete, wood, iron and pipe. Yap (2015) stated that some aspects need to be concerned before choosing the materials to be used such as life expectancy of material and expense of installation. Sewerage system must be designed to carry all sewage flows including sludge to the appropriate disposal plant. Illegal connections to surface water or too much of infiltration to the sewerage system are not allowed.

2.3.1 Sewer Pipelines

The structural design of an underground sewer can be categorised into two: rigid pipe and flexible pipe. Sewer pipelines act as a significant role in construction for example schools, hospitals and shopping malls. Sewer pipelines are pipes that transport the wastewater from household and commercial areas to the sewerage treatment plant and disposal. As stated in Malaysian Sewerage Industry Guidelines Volume 3, the material of sewer pipes that connecting between households are usually made by vitrified clay, ductile iron, reinforced concrete (RC), mild steel, stainless steel or polyvinyl chloride (PVC) and other types of pipes with a range of 100 to 3600 millimetres in diameter. The materials used depend on the soil and nature of the construction site. Sewer pipelines are usually buried under the ground and installed below than the water pipelines, thus more rely on gravity flow to transport the wastewater rather than use pressure to transport (Yap, 2015). As mentioned in Malaysia Standard MS 1228:1991, the pipe must be sloped to allow the wastewater to flow at a minimum velocity of 0.8 meters per second and maximum velocity of 4.0 metre per second. In design, the sewer pipelines, the gradient and the water flow must be considered with the gravity force to avoid problems such as overflow in the sewer pipelines. The pump may need at the sewers where lower altitudes than the sewerage treatment plant. Normally sewer pipelines are connected with manholes.

Figure 2.3 Sewer Pipelines
Source: E-Pembentungan (2015).

2.3.2 Manholes

Manholes are commonly masonry or RCC chambers constructed at suitable intervals with not more than 100m along the sewer lines for providing entrance into them for maintenance and inspection purpose when needed. Manholes also act as multiple pipe intersections and pressure relief (Lin, 2014). According to MS 1228:1991, the manhole is provided when at the upstream end of all sewer pipes, a change in slope of sewer pipelines, a change in direction with more than 600mm, a change in the size of sewer pipes and at the intersection of two or more sewer pipes. Manhole cover and frame shall be of cast iron and have enough strength to support the load and fit the holes to prevent seeping of surface runoff and rainfall into it (Frame, 1927). The cover also must be safeguarded so that it will not be removed and avoids blow-out during peak flooding (Lin, 2014). By referred to MS 1228:1991, there are three types of manhole; shallow manhole, normal manhole and deep manhole. A shallow manhole is provided at depth of 0.9 m to 1.0 m with light cover and not subjected to heavy traffic. A normal manhole is provided at depth of 1.5 m with a heavy cover and commonly in a square shape. A deep manhole is provided at depth of larger than 1.5 m with heavy cover and can be used in all types of traffic.

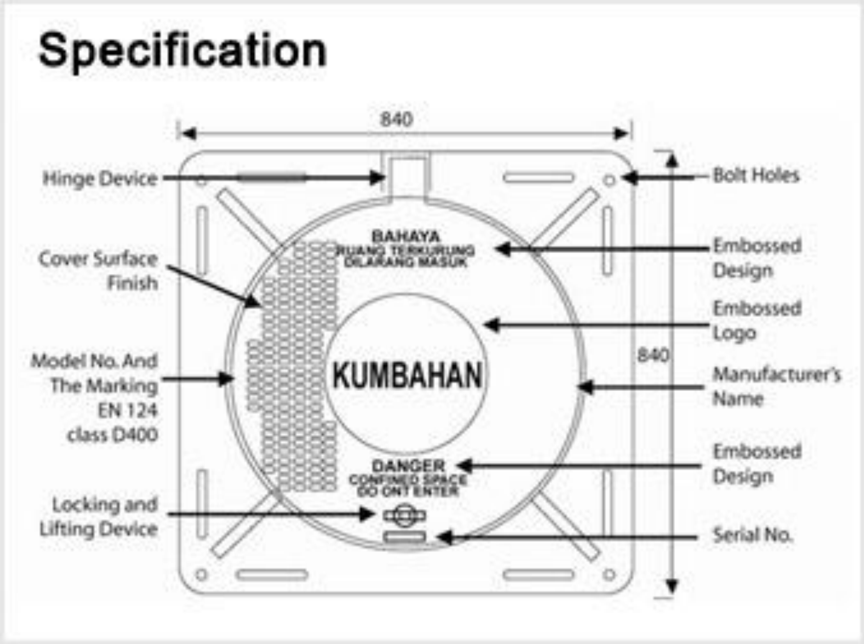

Figure 2.4 Manhole specification

Source: MSIG Volume 3 (2009).

Depth to Soffit from Cover Level (m)	DN Largest Pipe in Manhole (mm)	Min. Internal Dimensions[a] (mm)
< 1.5	< 150	1000
	225 to 300	1200
	375 to 450	1350
	525 to 710	1500
	820 to 900	1800
	> 900	Subject to designer's requirements based on site condition
≥ 1.5	≤ 300	1200
	375 to 450	1350
	525 to 710	1500
	820 to 900	1800
	> 900	Subject to designer's requirements based on site condition

Figure 2.5 Minimum diameter of manhole chambers

Source: MSIG Volume 3 (2009).

2.4 Design Parameters of Sewerage System

Population equivalent, peak flow factor, average daily flow, estimation of wastewater flow rates and its variation are very vital during design the sewerage treatment plants and during the operation (Imam and Elnakar, 2014). The efficiency of sewerage system will depend on the above listed parameters. The standard used to design sewerage system in Malaysia is MS 1228:1991. Flows in sewerage system will vary according to the usage of water in every residential houses and industry in a period of time (Moulton, 1999).

2.4.1 Population Equivalent (PE)

Population equivalent (PE) is an important parameter in designing sewerage system. PE reflects the equivalence between the water contaminating potential of an area in the forms of biodegradable organic matter to a certain population (Sperling, 2008). PE is also used to compare how many people it would take to produce the same amount of pollution as produced by the industrial wastewater effluent under consideration (Munter, 2003). For example, if an area has 10,000 PE, it can be said that the BOD concentration of the area will correspond to the wastewater produced by the 10,000 PE. In Malaysia, PE will refer to the standard MS 1228:1991 table 1. The PE for residential is 5 per unit, while PE for commercial is 3 per 100 m gross area. PE calculated will affect the characteristics of sewerage treatment plant as the PE is an important parameter to design the facilities (Yap, 2015).

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

Figure 2.6 Population equivalent

Source: Malaysia Standard 1228 (1991).

2.4.2 Average Daily Flow

Average daily flow is calculated by multiply the population equivalent from resident and non-resident area with the suitable per capita flow. It indicates the total volume of wastewater produced in 24 hours. From the standard MS 1228:1991, the average daily flow for residential areas is equal to 225 L/person/day while the average daily flow for industrial areas is 115 L/person/day. Average daily flow is also an important parameter in designing sewerage system.

2.4.3 Design Flow Rates

Maximum daily flow is the peak flow rate or the greatest volume of flow to be received during a continuous 24 hours' time or a day (Lin, 2014). It is used in the calculation of retention time for equalisation basin and chlorine contact time. Minimum daily flow is the minimum flow rate or the smallest volume of flow to be received during a 24 hours' time or a day (Lin, 2014). The minimum daily flow is vital in the sizing of pipes where solids might be accumulated at low flow rates. Peak hourly flow is the maximum flow rate during a one hour time. It is used for the design of collection and interceptor sewers, wet wells, wastewater pumping stations, settling basins and piping (Lin, 2014). These three parameters are important in the analysis of data collected from the flow meter.

2.4.4 Peak Flow Factor

Peak flow factor is the most important factor in designing the sewerage system, as it will affect the peak flow of the wastewater. Peak flow factor is used in calculating the average daily flow in the sewer which is the daily amount of wastewater produced per person in a certain area (Butler and Graham, 1995). Peak flow is recognised by multiplying the average flow by an appropriate factor. By referring to standard MS 1228 (1991) Clause 3.6; peak flow factor is taken a fixed value as 4.7. The sewerage systems are commonly designed based on the peak flow to make sure the sewer pipes able support the wastewater produced along with the time without any problem.

2.5 Definition of Sewer Terms

Many terms that will regularly use in this research are listed here together with their definition as taken from Hammer and Hammer (2004) and American Society of Civil Engineers (1982).

1) Wastewater: The used water of residential, commercial or industrial areas which contains dissolved or suspended materials. It is also known as sewage.

2) Sanitary Sewer: Sewer that carries wastes from residential, commercial or industrial areas, together with small quantities of ground surface water that are not admitted purposely.

3) Combined Sewer: Sewer that received both wastewater and storm water or ground surface runoff in one network.

4) Separated Sewer: Sewer consists of sanitary sewer and storm water sewer networks separately.

5) Population Equivalent: Number of persons required to contribute a sum of pollution load produced or wastewater in 24 hours related to the quantity of flow and strength of Biochemical Oxygen Demand (BOD).

6) Peak flow design criterion: A factor that used in the equation of peak flow factor, which equals to 4.7.

7) Infiltration: Groundwater entering sewers through faulty joints and damaged or broken pipe and manholes.

8) Peak flow factor: A factor that used to design sewer.

9) Sewerage treatment plant: A plant that consists a system to treat wastewater before delivers the effluent to rivers.

2.6 Factors Affecting Flow Characteristics

2.6.1 Population Equivalent

According to Malaysia Standard 1228:1991, population equivalent (PE) is an estimation of the quantity of people's waste that will flow into a sewerage system in a certain area. Recommended population equivalent can refer to Figure 2.4 as stated in MS 1228:1991. For example, the population for a residential house is equal to five per unit. Thus it means assume five persons in a house and use the value to design for sewerage system.

2.6.2 Rainfall Intensity

Rainfall will affect the flow characteristics measurements. Rainfall will become surface runoff into the ground and then become inflow to the sewerage system. Thus, when design sewerage system, rainfall need to be considered to avoid overflow problems. Rainfall intensity will be collected to analyse the effect on flow rate and design criterion in this research.

2.7 Previous Studies

After reading and studying previous researchers' works, the importance of the previous research can be retrieved and know what is the main point of the topic related that need to be explored. By study the research, a summary of the updated knowledge in the related area of research, detecting any strengths and weaknesses in previous research can be obtained, so that can identify them in this study and thus reduce the weaknesses and strengthen the strengths. Besides, an idea about the important aspects of this study can be obtained and also compare the research outcomes with other studies that have been done. Places or any methods that have been used as research study can be identified and then explore the differences between the places and methods and make it as a reference. The below are some statements retrieved from other studies regarding the peak flow design criterion.

This research will be concerned more with peak flow design criterion and factors that will affect this parameter by carrying out the data retrieved in Taman Mahkota. This residential and commercial area has not been studied yet for the peak flow design criterion. The value obtained will then compared to the recommended value in Malaysia Standard MS 1228:1991. The value estimated will be lower than recommended value according to previous research in Malaysia. The result of this research will help to provide opinion and data analysis in order to revise the parameters and values recommended in MS 1228:1991 for the design of sewerage system in the future.

Table 2.2 Previous Studies

Authors	Year Published	Statements
Moulton	1999	Standard used in the United States often set maximum design criterion of peak flow between 2 and 4, usually a function of pipe diameter.
Sleigh and Tayler	2001	The peak flow factor used in London for simplified sewerage is 1.8, while peak flow factor for combined sewerage system is 3 or 4.
Chow et al.	2010	The recommended per capita flow of Taiwan is 0.25 m^3/person/day, is higher than the recommended per capita flow in Malaysia, which equals to 0.225 m^3/person/day.
Chang	2011	The per capita flow of Shanghai, China in 2009 is 0.33 m^3/person/day, is higher than the recommended per capita flow in Malaysia, which equals to 0.225 m^3/person/day.
Tang and Ngu	2011	The adequate and effective design capacity of sewerage system plant needs to be determined from the flow and constituent characteristics of raw wastewater.
Ansari et al.	2013	In general, there are two peak flow rates will occur in a day, which is around 7.30 in the morning and 7.30 in the evening. This is due to working and study hour.
Ngien et al.	2014	The design criterion value calculated for the monsoon season was twice the value of the design criterion value calculated for the dry season.
Imam and Elnakar	2014	The design criterion usually given by the standard for sewer peak flow may not be applied same in the design of the components of the sewerage treatment plants.
Yap	2015	Two parameters, per capita flow and design criterion were assessed in UMP, and discover that is lower than the values stated in MS 1228:1991.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Methodology is a set of methods, guidelines, or concepts that are vital in how the research will be done. It is about the description of the research methods that plan to use includes the intention why to choose the method and reliability of the method based on previous research. In this chapter, surveys, interview transcripts and work instruction or SOP of machinery and equipment are not included. The methods to get the data such as flow rate and rainfall intensity will be shown in this chapter. In this research, readings will take continuously for several months in order to achieve the objectives of this research. With the reference to Standard Code of Practice for Design and Installation of Sewerage System (MS 1228: 1991), the design criteria and the factors to be considered for sewerage design is obtained. All the equations needed to calculate the peak flow are all obtainable in this standard code of practice. Figure 3.1 shows the flow of this research.

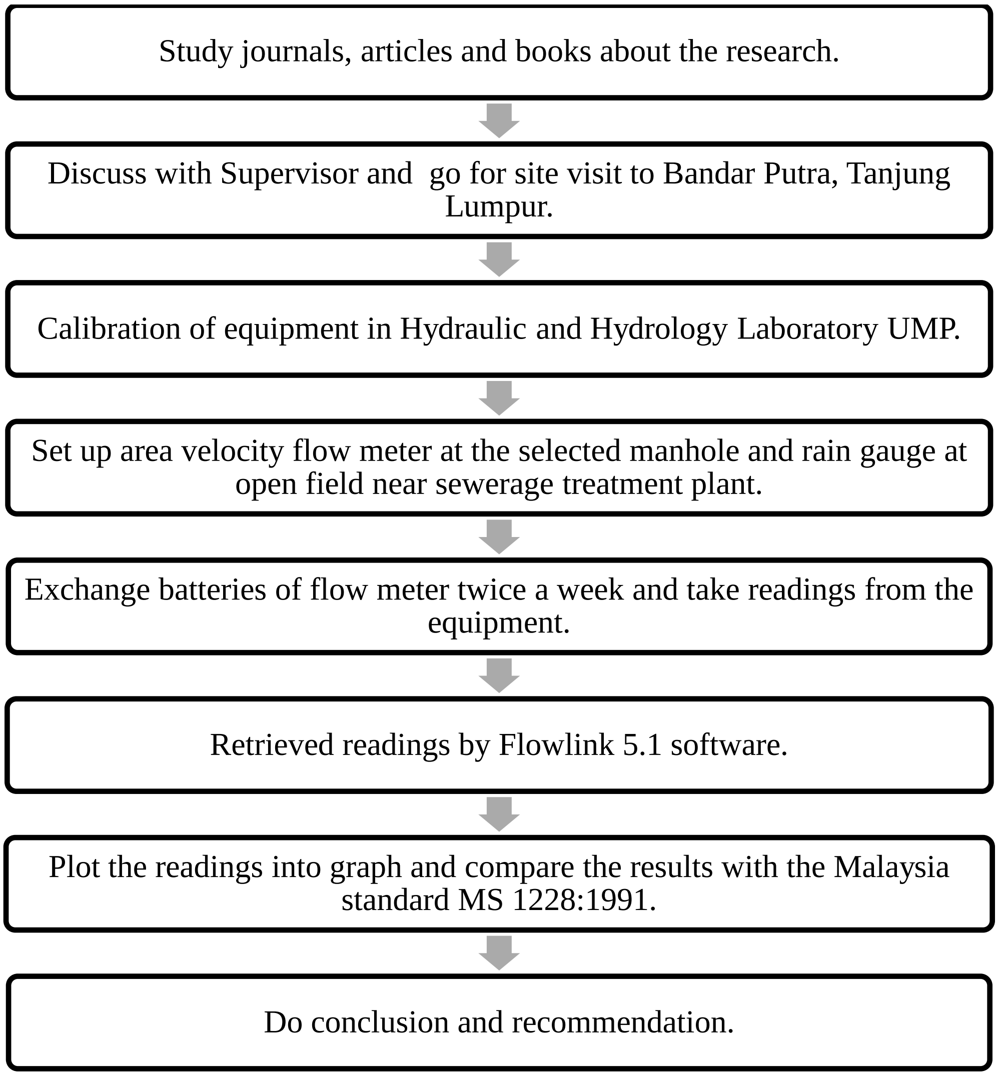

Figure 3.1 Flow Chart

3.2 Study Area

In this research, the equipment will be located and readings will be taken at a selected manhole in sewerage treatment plant (KUN 300) at Taman Mahkota, Kuantan, Pahang. The total PE for Taman Mahkota is 3860. At the beginning of this research, there was a meeting with Supervisor and Master Study’s student to know more about the procedure regarding this research. A site visit is also conducted to evaluate the circumstances and the select manhole to collect data. A study on journals, articles and books have been done in order to gain information on the peak flow design criteria of the sewerage system.

Figure 3.2 Location of sewerage treatment plant Taman Mahkota

Source: Google Map.

3.3 Selection Criteria of Sewer Line

By referring to Yap et al. (2016), preliminary test and data collection were carried out to know whether the sewage flow inside the sewer pipelines satisfies the criteria before choosing a proper manhole. The condition of the sewer pipeline will affect in choosing an appropriate manhole. The below criteria were used in the selection:

a) The manhole must connect to the nearest sewerage treatment plant.

b) No surcharge or backflow on the sewer pipeline of the research area.

c) The foul water flow in the sewer pipeline must be stable and has a little only head loss.

d) No turbulence occurred at the selected manhole in the sewer pipeline.

3.4 Equipment and Material

The flow rate measurement was carried out based on the area velocity method by using ISCO 2150 Area-Velocity Flow Meter in this research. Flow characteristics of the sewage flowing in the sewer line are measured by a flow meter (Ngien et al., 2014). The rainfall measurement was done by using ISCO 674 Rain Gauge and installed near to the sewerage treatment plant. A sensor equipped to the flow meter was placed at the bottom of sewer pipe while the flow meter was hung at above the manhole so that exchange of battery and reading download can be done easily. Readings in the form of the flow rate, water height and velocity were recorded once every 5 minutes. Silica gel is placed above the flow meter to absorb water during monsoon season. The reading obtained was extracted by using Flowlink 5.1 software. Flowlink 5.1 is an easy-to-use software and it will tabulate the flow rate of wastewater in the sewer pipeline and the rainfall measurement into graph form (Yap et al., 2016). The rain gauge was installed at an open field with distance not more than 400 m away from the sewer line (Yap et al., 2016).

Figure 3.3 ISCO 2150 Area-Velocity flow meter with sensor

Figure 3.4 ISCO 674 Rain Gauge

Figure 3.5 Silica gel

3.5 Calibration of Equipment

Accuracy and precision of flow meter and rain gauge are very vital to this research. The calibration of the area velocity flow meter and rain gauge is a must to ensure the accuracy and precision before the equipment are put at the site and start record readings (Yap et al., 2016). The purpose of calibration is to ensure that the both equipment are ready to use and the data obtained is trustworthy. Calibration of the flow meter, rain gauge and batteries were done in the Hydraulics and Hydrology Laboratory of Universiti Malaysia Pahang, Gambang campus. The calibration of the flow meter will compare the results to the readings of flow meter from the open channel apparatus. Any errors obtained from the flow rate were adjusted before analysis on the reading was done. The following procedure can be made through the calibration:

a) One to two minutes waiting time is needed before readings start to record in the flow meter because the sensor needs time to work after placed in the channel.

b) The depth of water (head, H) in the open channel apparatus is measured and flow is adjusted accordingly to get different values of flow rate.

c) By plotting the values of flow rate and head, the best fit line equation was obtained, which is y = 0.9547x-0.0208 with accuracy, R^2 = 0.938. This equation will be used for correcting the flow rate obtained from the flow meter.

Figure 3.6 Calibration of flow meter

3.6 Governing Equations

By referring to MS1228:1991, equations of design criterion were used. After PE was obtained, readings from flow meter were used to design the sewerage system. The design criterion needed to design the sewerage system can be obtained by using the following equations (Norhan et al., 2007). From Q average, per capita flow can be obtained by using the following equation:

$$Q_{\text{pcf}} = \frac{Q_{avg}}{\text{PE}} \qquad (1)$$

Where Q_{pcf} is the per capita flow in units of m^3/day/person;

Q_{avg} is the average daily flow in the sewerage system in units of m^3/day; and

PE is the population equivalent.

Equation 2 shows the peak flow calculation of sewerage system.

$$Q_{max} = PFF \times Q_{avg} \quad (2)$$

Where Q_{max} is the peak flow in units of m^3/day;

PFF is the peak flow factor; and

Q_{avg} is the average daily flow as mentioned in equation 1.

The peak flow factor equation listed in MS 1228:1991 (MS, 1991) is the following equation (Ngien and Ng, 2013):

$$PFF = K\left(\frac{PE}{1000}\right)^{-0.11} \quad (3)$$

Where K is the design criterion, which is unitless; and

PE is the population equivalent as mentioned in equation 1.

Equation 4 was obtained by combining and rearranging the Equations 1, 2 and 3 in order to get the value of the design criterion, K.

$$K = \frac{Q_{max}}{(Q_{pcf} \times PE)\left(\frac{PE}{1000}\right)^{-0.11}} \quad (4)$$

In Malaysia, the value of the design criterion, K used to design is 4.7 and the value of the per capita flow, Q_{pcf} is 0.225 m^3/day/person as listed in MS 1228:1991; Clause 3.6 and 3.2, respectively. Both parameters need to be proved in order to reach the objectives of this research.

3.7 Comparison of Peak Flow Factors

According to Imam and Elnakar (2013), there are some peak factor equations that used to estimate peak flow factors.

$$\text{Babbit and Baumann: } \frac{5}{p^{0.2}} \quad (5)$$

Where p is the population in thousands

$$\text{Harmon: } 1+\frac{14}{4+\sqrt{p}} \tag{6}$$

Where p is the population in thousands as mentioned in equation 5

$$\text{Munksgaard and Young: } \frac{2.97}{Q_m^{\ 0.0907}} \tag{7}$$

Where Q_m is the peak flow

Table 3.1 shows several equations used and will compare to the result obtained through this research. Table 3.2 shows design criteria of some cities in the United Kingdom.

Table 3.1 Equations Comparison

Method	Peaking Factor Formula	Sustained Duration	Conditions of Application
Babbit and Baumann	$\frac{5}{p^{0.2}}$	Instantaneous	1≤ P ≤1000, P in thousands
Harmon	2.5 > or $1+\frac{14}{4+\sqrt{P}} \approx \frac{4.2}{P^{0.16}}$	Hourly	P in thousands
Munksgaard and Young	$\frac{2.97}{Q_m^{\ 0.0907}}$	Extreme annual peak 4h	Q_m, in m^3/s
	$\frac{2.9}{Q_m^{\ 0.0902}}$	Extreme annual peak 8h	Q_m, in m^3/s
	$\frac{1.75}{Q_m^{\ 0.036}}$	Extreme annual peak day	Q_m, in m^3/s

Source: Imam and Elnakar (2013).

Table 3.2 Summary of Wastewater Flow Rate Criteria Review

Municipality	Avg Dry Weather Flow Criteria (L/cap/d)		Peaking Factor Methodology	Extraneous Flow (L/s/ha)
	Residential	Employment		
City of Cambridge (Waterloo Region and Area Municipalities)	350	I: 50 L/s/ha C: 0.3-1.6 L/s/ha I: MOE	Harmon	0.150
Ontario Ministry of the Environment (ON)	225-450	Varies	Harmon or Babbit Formula	No Value
City of Toronto (new or infill)	450	180,000 L/ha/d	Harmon Formula	0.260
City of Toronto (separated system w no downspout or foundation connections)	240	250	Harmon Formula	Established through separate study
City of London	250	I: 30,000 L/cap/d C: 250 L/cap/d I: 250 L/cap/d	Harmon	0.140-0.280
City of Hamilton (2006 Master Plan)	300	260	Babbitt	0.2-0.4
City of Windsor	363		Tabular Calc.	0.156
County of Brant	400	Light Ind: 45 m^3/ha/d Light Comm: 40.5 m^3/ha/d Inst (schools): 12.1 m^3/ha/d	Harmon	0.200-0.500
City of Niagara Falls	450		Babbitt	0.280
Halton Region	275	I: 410 L/cap/d C: 260 L/cap/d I: 135 L/cap/d	Harmon	0.286
Region of Peel (2007 Master Plan)	300	300	Harmon	0.2

Source: AECOM (2013).

3.8 Field Model

A manhole is selected in the sewerage treatment plant at Taman Mahkota. The selected manhole must be nearest to the sewerage treatment plant, in order to obtain the total flow rates from the residential area. The overflow problem must not occur in the selected manhole to prevent damage of flow meter. The flow meter is hung at the bar on the wall of the manhole. The rain gauge is installed at an open field near the sewerage treatment plant.

Figure 3.7 Set up of flow meter in the manhole

Figure 3.8 Set up of rain gauge in the open field

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This research is focused on the results and analysis of flow rate in sewerage treatment plant of Taman Mahkota, where flow meter is installed in a selected manhole. Data of the sewage flows as well as rainfall was collected continuously from 1 March 2017 to 23 May 2017. Each set of data was collected with the time interval of five minutes for two weeks. Depth, flow rate and velocity of sewage were obtained by using software, Flowlink 5.1 in the selected manhole. Rainfall data was collected by rain gauge with the same time interval of five minutes for two weeks. The rain gauge is installed in an open field near the selected manhole in the sewerage treatment plant. Rainfall intensity was obtained by using the same software, Flowlink 5.1.

4.2 Calibration of ISCO 2150 Area-Velocity Flow Meter

The calibration of ISCO 2150 Area-Velocity Flow Meter was done in the Hydraulics and Hydrology Laboratory, UMP Gambang. Table 4.1 shows readings collected and Figure 4.1 shows the graph plotted by using the readings to get an equation. The equation will be used for adjustment of raw data (flow rates) collected from the flow meter.

Table 4.1 Calibration Readings

Q_{op}	Q_{2150}	H_{op}	H_{2150}
9.08	8.67	0.145	0.145
8.07	7.71	0.135	0.134
7.20	6.62	0.125	0.122
6.26	5.91	0.110	0.110
6.53	6.19	0.115	0.114
4.32	5.25	0.085	0.086
3.69	5.13	0.075	0.077
3.38	1.76	0.070	0.072
3.14	1.70	0.067	0.068
2.72	1.53	0.060	0.062
2.38	1.39	0.055	0.056
2.10	1.26	0.050	0.051
1.88	1.16	0.045	0.047
1.62	1.04	0.040	0.042
1.33	0.88	0.036	0.036
1.18	2.08	0.031	0.032
0.78	0.56	0.023	0.023
9.58	9.07	0.150	0.150
9.98	9.28	0.154	0.154
10.55	9.80	0.159	0.159
10.93	10.47	0.164	0.164
11.55	10.86	0.169	0.169
3.82	4.93	0.080	0.079

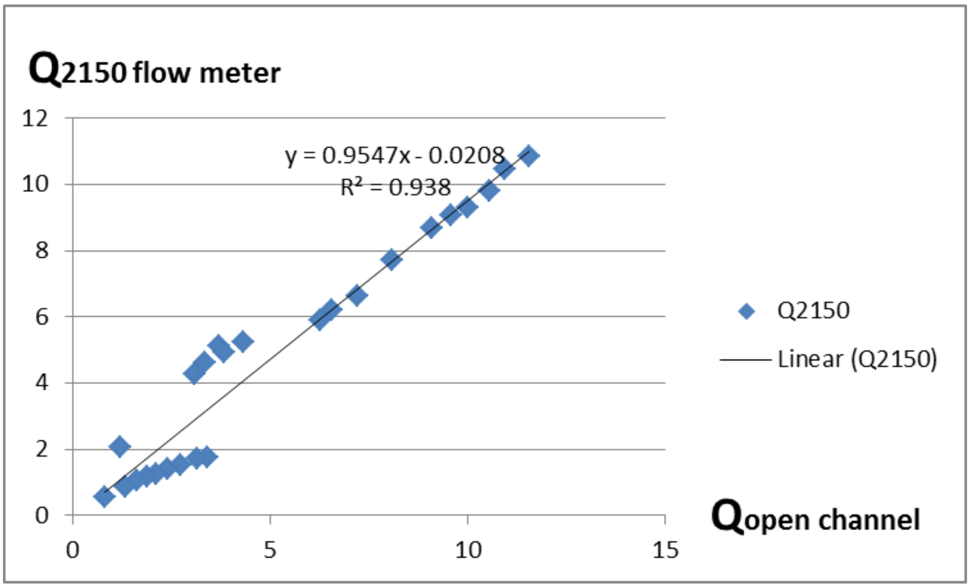

Figure 4.1 Best fit line equation

4.3 Data Collection in the Study

The total time recorded in this whole research is 2005 hours of flow rate and rainfall intensity. Graph had been plotted in the form of hydrograph and analysis has been done. Raw data (flow rates) collected from flow meter will then adjusted by using the equation obtained from calibration of the equation. Peak flow (Q_{max}), minimum flow (Q_{min}), and average flow (Q_{avg}) can be obtained by analysing the data collected from each hourly slot. The results shown in following sections are six sets of data from the study.

4.3.1 Flow Characteristics Analysis

For flow characteristics analysis at Taman Mahkota, a total of six sets measurement have been done by using ISCO 2150 Area-Velocity Flow Meter inside the selected manhole. The purpose of this analysis is to determine the daily hourly maximum flow rates (Q_{max}), daily hourly minimum flow rates (Q_{min}) and also daily hourly average flow rates (Q_{avg}). The maximum and minimum flow rates are determined for each hour every day for the study period. Average flow rates are calculated by taking an average of flow rates each hour every day. From this daily analysis, a summary of maximum, minimum and average flow rates for each two weeks can be obtained by taking the average of every 14 sets of daily hourly Q_{max}, Q_{min} and Q_{avg}. The following graphs show Q_{max}, Q_{min} and Q_{avg} summarised from the raw data obtained for each of six sets (refer Figure 4.2 to Figure 4.7).

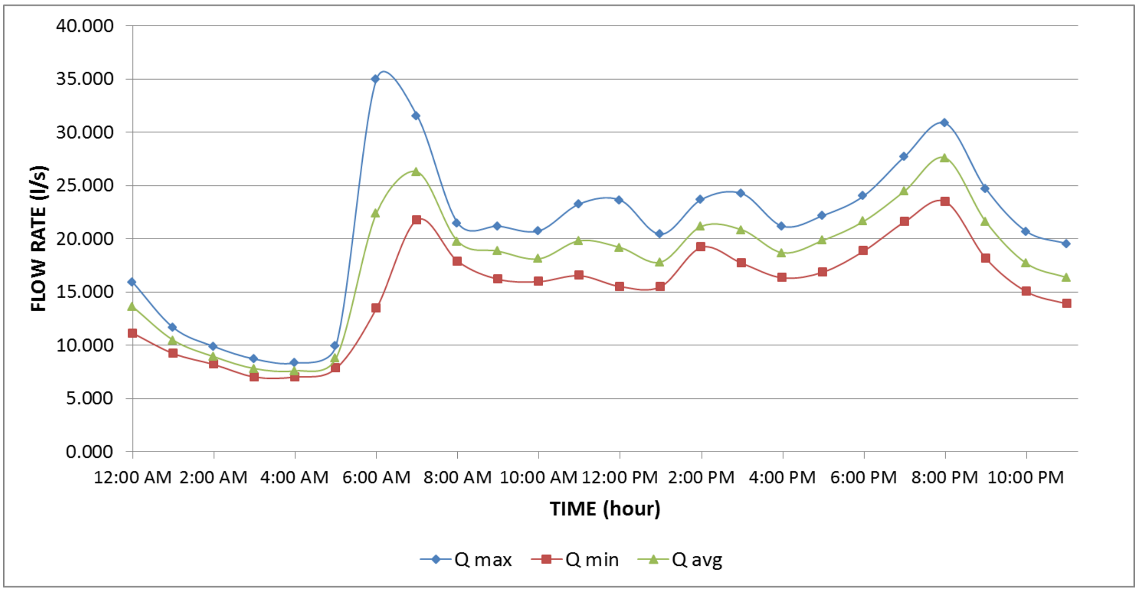

Figure 4.2 Hourly flow rate graph (1/3/2017 to 14/3/2017)

The peak flow occurs during 6 o'clock in the morning (35.009 l/s) and 8 o'clock at night (30.871 l/s). The minimum flow rate is at 3 to 4 o'clock in the morning (7.029 l/s).

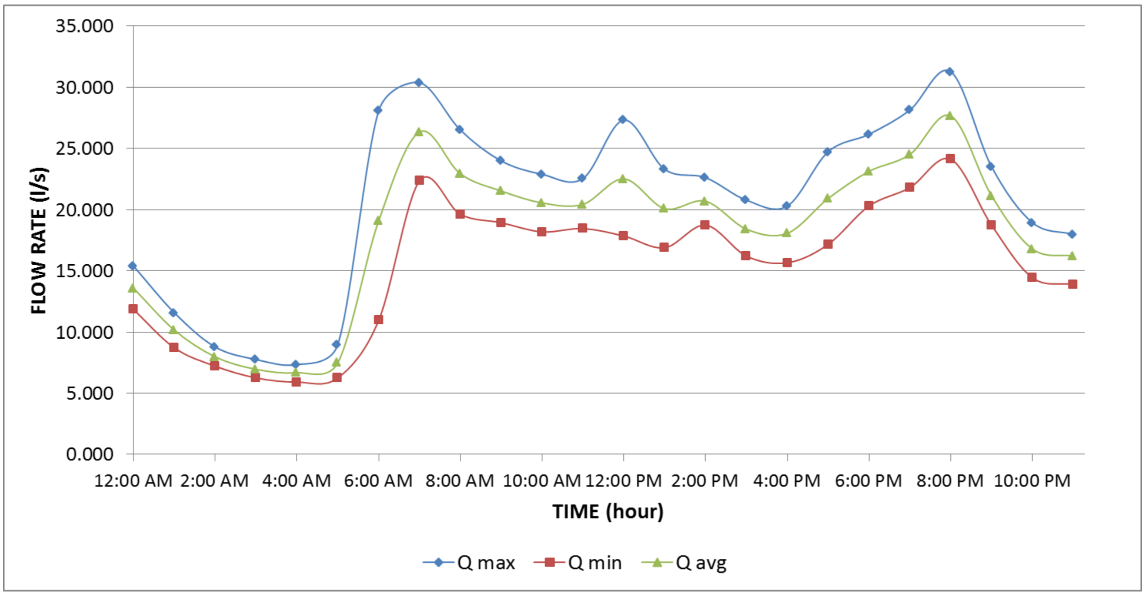

Figure 4.3 Hourly flow rate graph (15/3/2017 to 28/3/2017)

The peak flow occurs during 7 o'clock in the morning (30.393 l/s) and 8 o'clock at night (31.280 l/s). This graph also shows a peak during 12 o'clock (27.325 l/s). The minimum flow rate is at 4 o'clock in the morning (5.912 l/s).

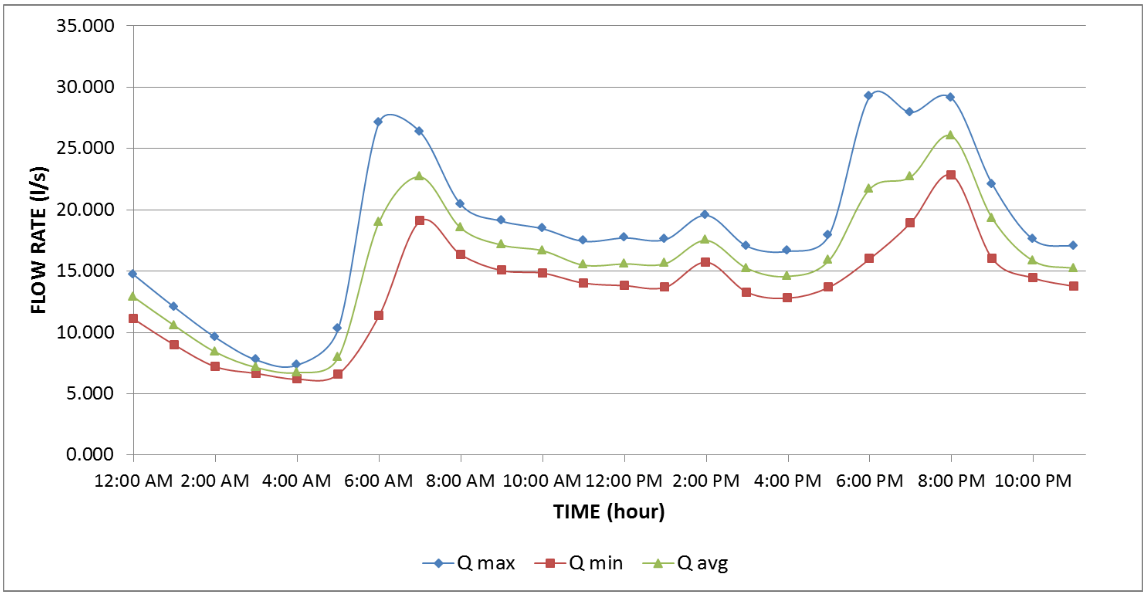

Figure 4.4 Hourly flow rate graph (29/3/2017 to 11/4/2017)

The peak flow occurs during 6 o'clock in the morning (27.120 l/s) and 6 o'clock in the evening (29.234 l/s). The minimum flow rate is at 4 o'clock in the morning (6.185 l/s).

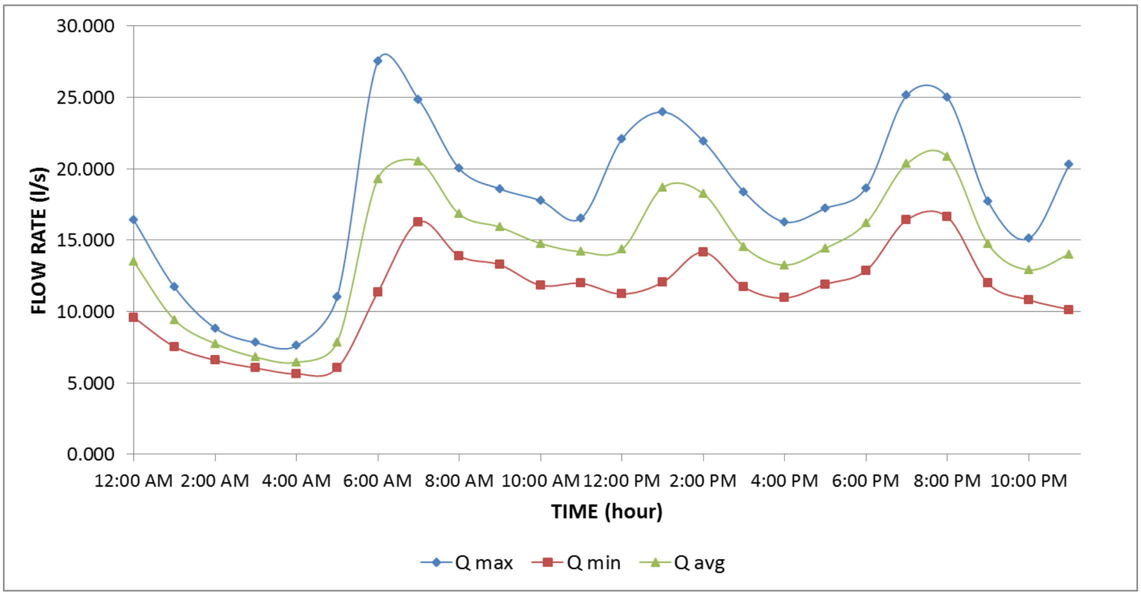

Figure 4.5 Hourly flow rate graph (12/4/2017 to 25/4/2017)

The peak flow occurs during 6 o'clock in the morning (26.511 l/s) and 7 o'clock at night (24.319 l/s). This graph also shows a peak during 1 o'clock (23.220 l/s). The minimum flow rate is at 4 o'clock in the morning (5.639 l/s).

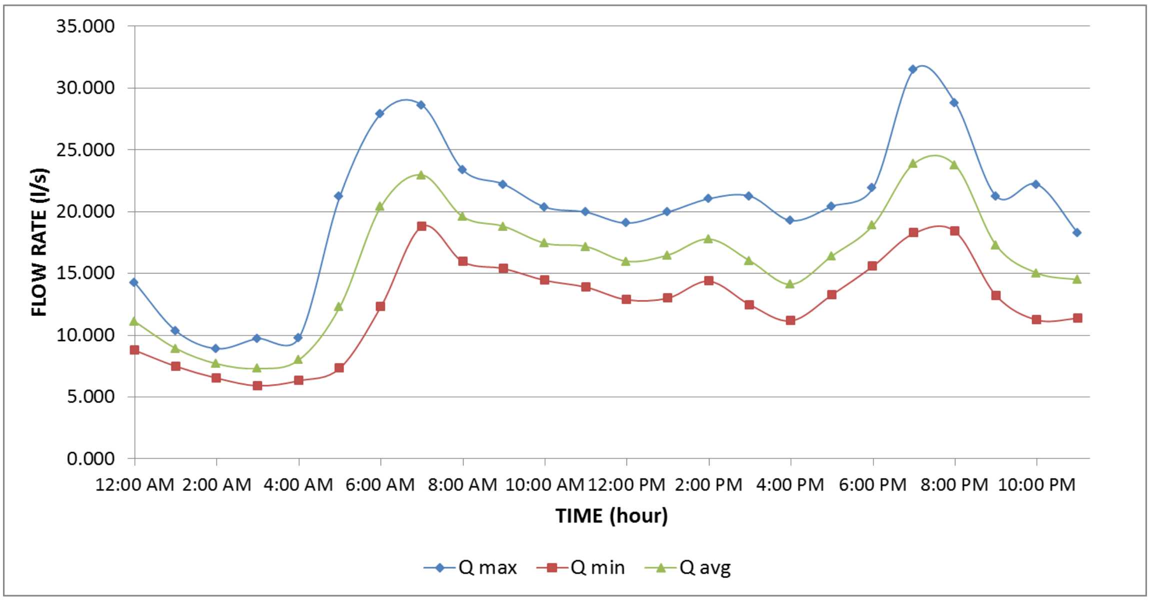

Figure 4.6 Hourly flow rate graph (26/4/2017 to 9/5/2017)

The peak flow occurs during 7 o'clock in the morning (28.620 l/s) and 7 o'clock at night (31.484 l/s). The minimum flow rate is at 3 o'clock in the morning (5.912 l/s).

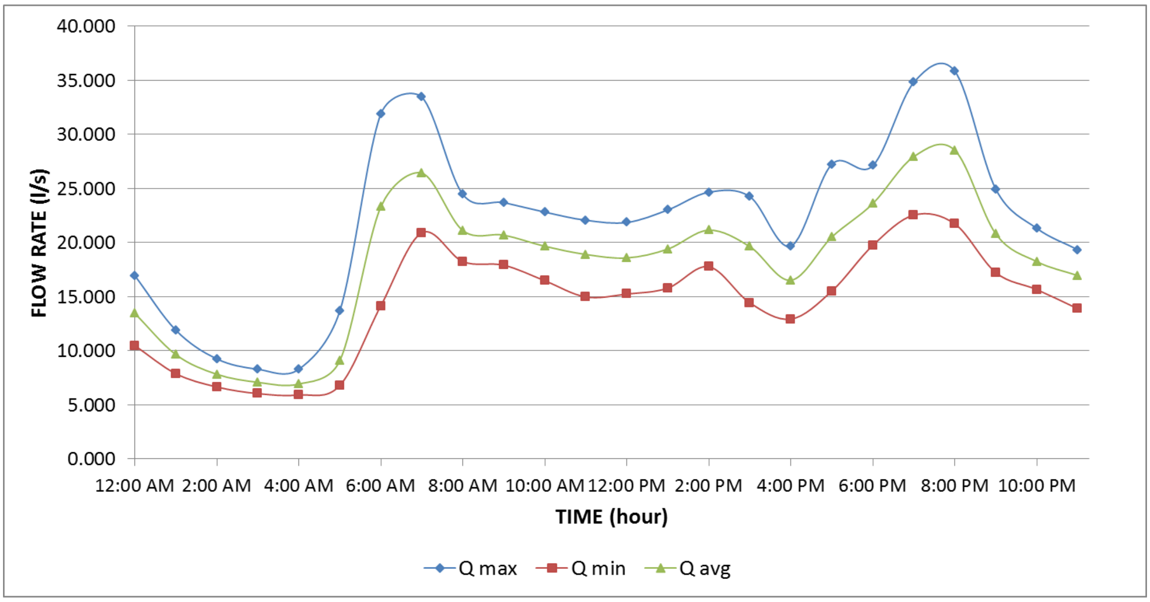

Figure 4.7 Hourly flow rate graph (10/5/2017 to 23/5/2017)

The peak flow occurs during 7 o'clock in the morning (33.462 l/s) and 8 o'clock at night (35.849 l/s). The minimum flow rate is at 4 o'clock in the morning (5.912 l/s).

From the data collected, it shows that the peak flow rate occurred at a pattern, which is at 6 o'clock to 7 o'clock during the morning, 12 o'clock to 1 o'clock in the afternoon and 6 o'clock to 8 o'clock during the evening. This may be due to children or adults taking bath and using the toilets before going to school or preparing for work in the morning while in the evening, the peak hour occurred because the children are back from school, workers are back home after work and preparing for dinner and bath. Minimum flow rate is likely to occur at midnight between 3.00 am to 4.00 am as residents are sleeping and there is not much usage of water during midnight.

4.3.2 Relationship between Flow Rates and Rainfall

Similar to flow characteristics analysis, rainfall data also conducted at sewerage treatment plant Taman Mahkota, and total six sets of readings have been collected using ISCO 2150 Area-Velocity Flow Meter and ISCO 674 Rain Gauge. The relationship between flow rates and rainfall will be analysed through the graphs plotted. The following graphs show the flow rates with rainfall intensity in the selected manhole (refer Figure 4.8 to Figure 4.13).

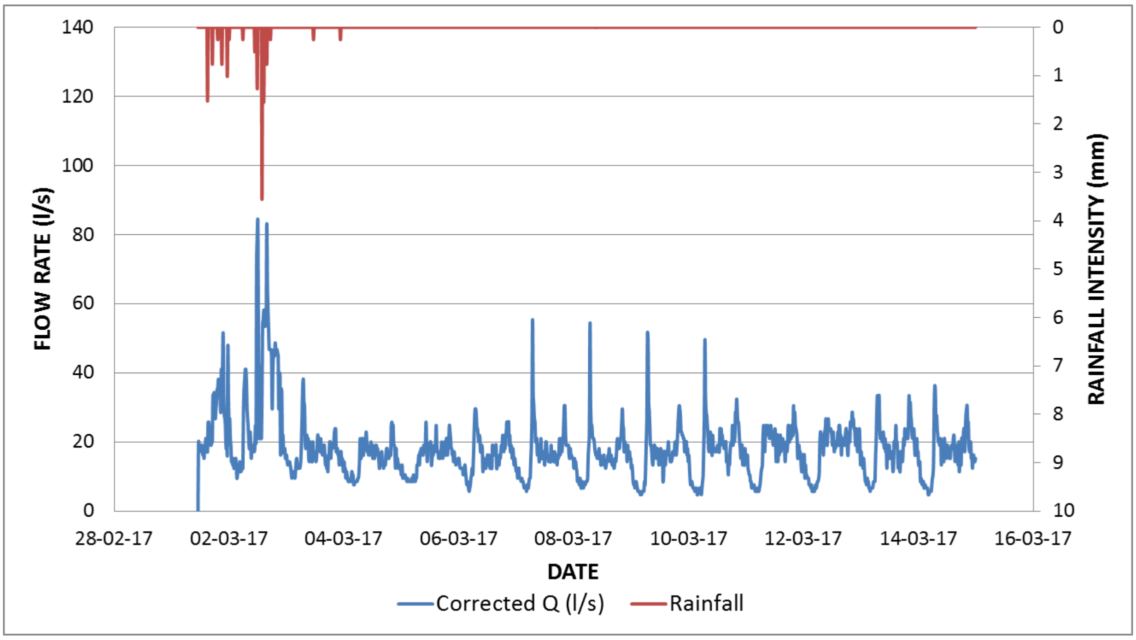

Figure 4.8 Flow rate with rainfall graph (1/3/2017 to 14/3/2017)

In Figure 4.8, a drastic increase in flow is observed on the 2 Mac 2017. The rainfall intensity on that day is 3.556 mm.

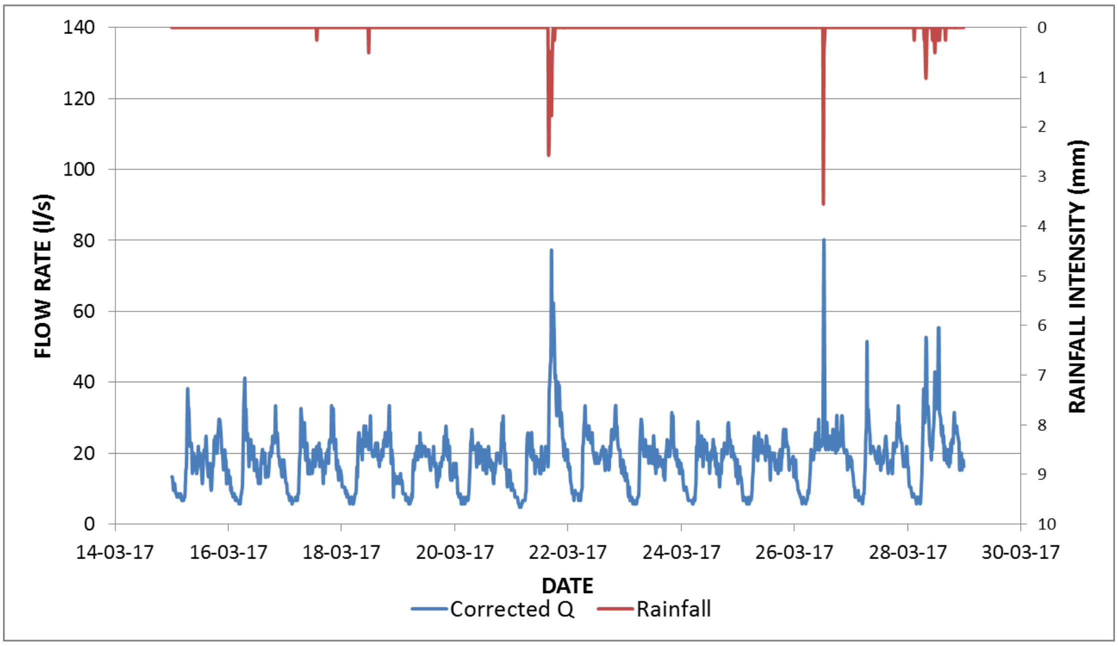

Figure 4.9 Flow rate with rainfall graph (15/3/2017 to 28/3/2017)

A drastic increase in flow is observed on the 21 Mac 2017 and 26 Mac 2017. The rainfall intensity on those days is 2.286 mm and 3.556 mm respectively.

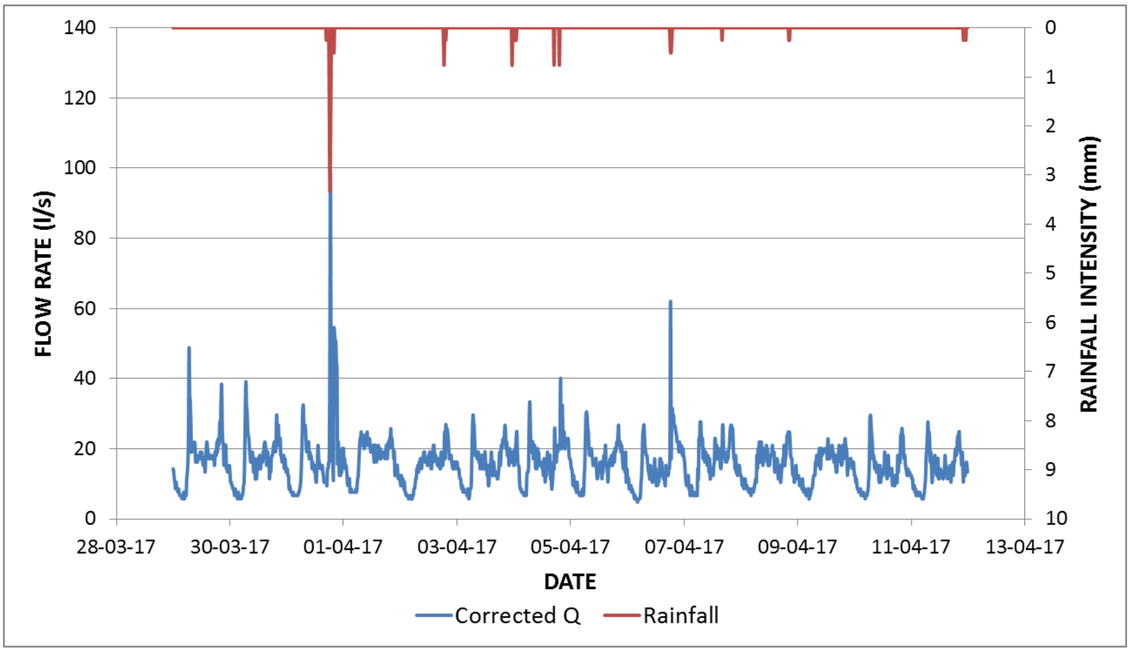

Figure 4.10 Flow rate with rainfall graph (29/3/2017 to 11/4/2017)

In Figure 4.10, a drastic increase in flow is observed on the 31 Mac 2017. The rainfall intensity on that day is 3.302 mm.

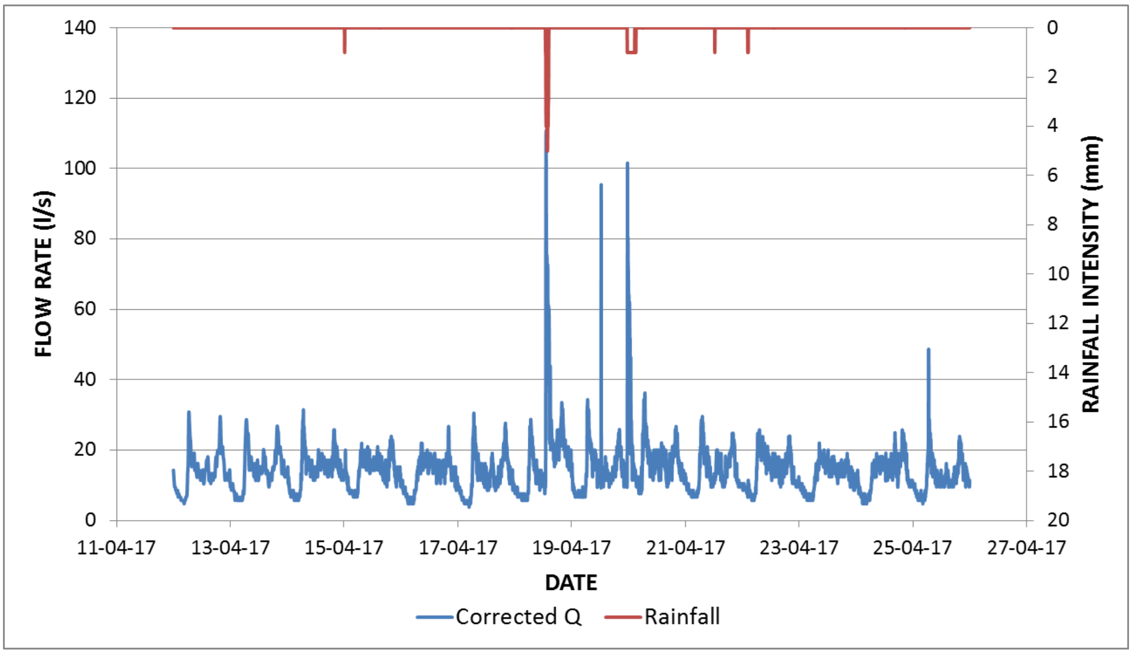

Figure 4.11 Flow rate with rainfall graph (12/4/2017 to 25/4/2017)

In Figure 4.11, a drastic increase in flow is observed on the 18 April 2017. The rainfall intensity on that day is 0.005 mm.

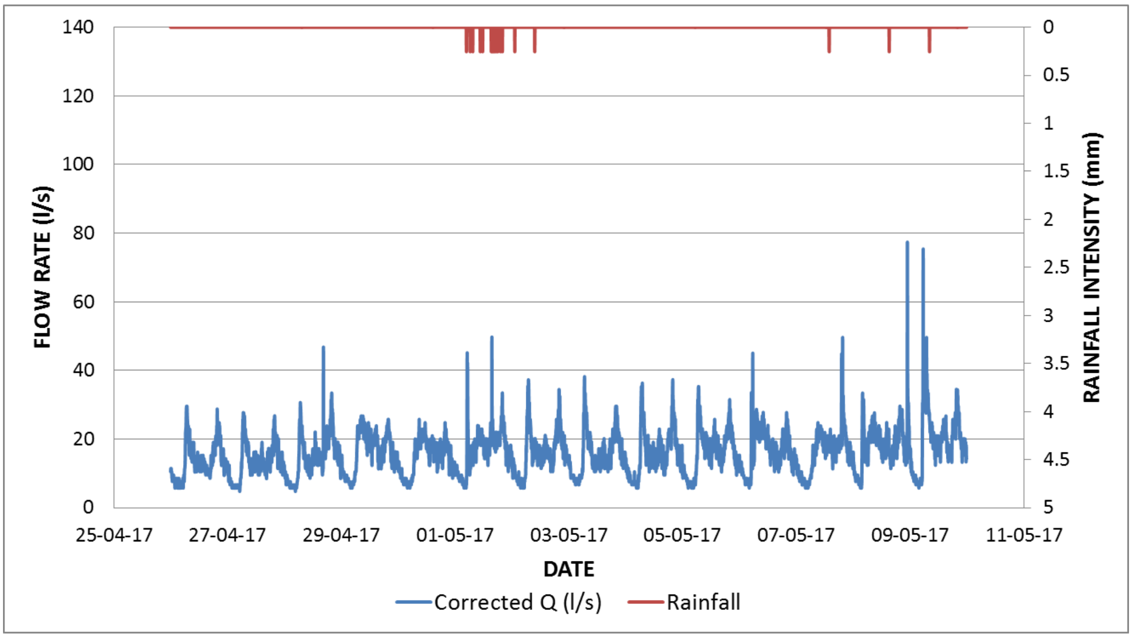

Figure 4.12 Flow rate with rainfall graph (26/4/2017 to 9/5/2017)

In Figure 4.12, a drastic increase in flow is observed on the 9 May 2017. The rainfall intensity on that day is 0.254 mm.

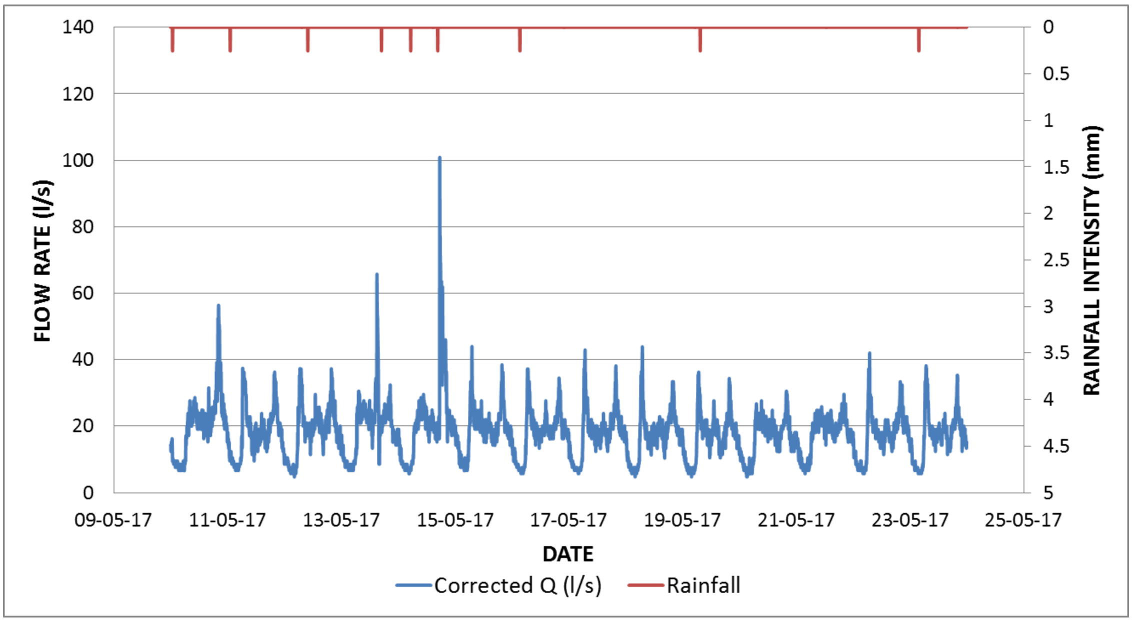

Figure 4.13 Flow rate with rainfall graph (10/5/2017 to 23/5/2017)

In Figure 4.13, a drastic increase in flow is observed on the 14 May 2017. The rainfall intensity on that day is 0.508 mm.

From graphs shown in Figure 4.8 to Figure 4.13, the maximum flow rate is likely to occur when having high rainfall intensity. This is due to the rainwater becoming surface flow and contributes to the flow rate (Zhang et al., 2007). Of course, there will be irregularities-like data set where the maximum flow rate does not occur during maximum rainfall intensity but that is to be expected in a research since we cannot control the residents' daily usage of water. This can be concluded that rainfall contributes to the sewerage flow. Thus, the design of sewerage system has to consider the rainfall to avoid overflow of sewage occur even though it is a separate sewer system. The effect of rainfall to the peak flow design criterion will further discuss in section 4.3.4.

4.3.3 Per Capita Flow

According to Malaysia Standard MS 1228:1991, the value of per capita flow is mentioned as 0.225 m^3/day/person. The population equivalent for Taman Mahkota is 3860. The average flow rate was calculated by taking an average of the daily flow rates obtained from the flow meter and per capita flow was calculated by using Equation 1. The purpose of the analysis is to determine the value of per capita flow in the current sewerage system. The following graphs show six sets of per capita flow analysed from average flow rate (refer Figure 4.14 to Figure 4.19). Table 4.2 shows the summary of the average per capita flow analysis for each two weeks.

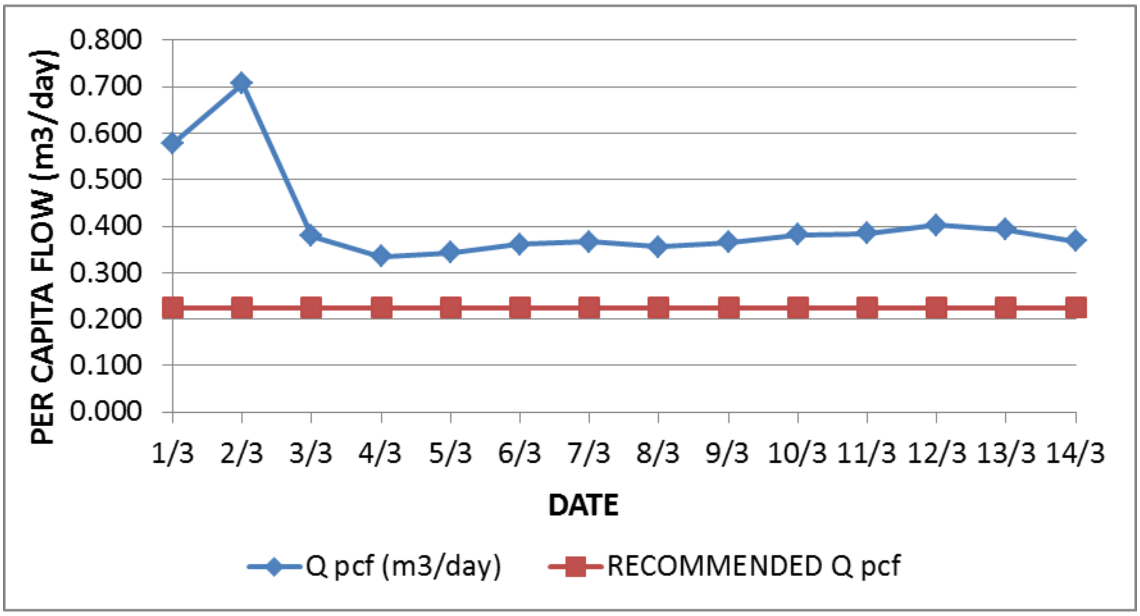

Figure 4.14 Per Capita Flow graph (1/3/2017 to 14/3/2017)

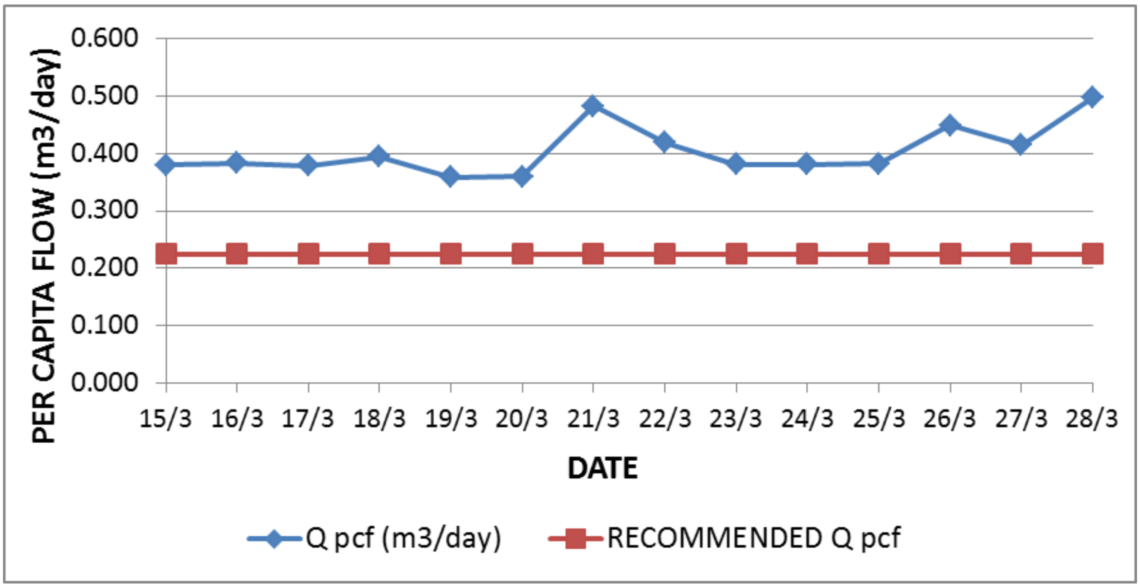

Figure 4.15 Per Capita Flow graph (15/3/2017 to 28/3/2017)

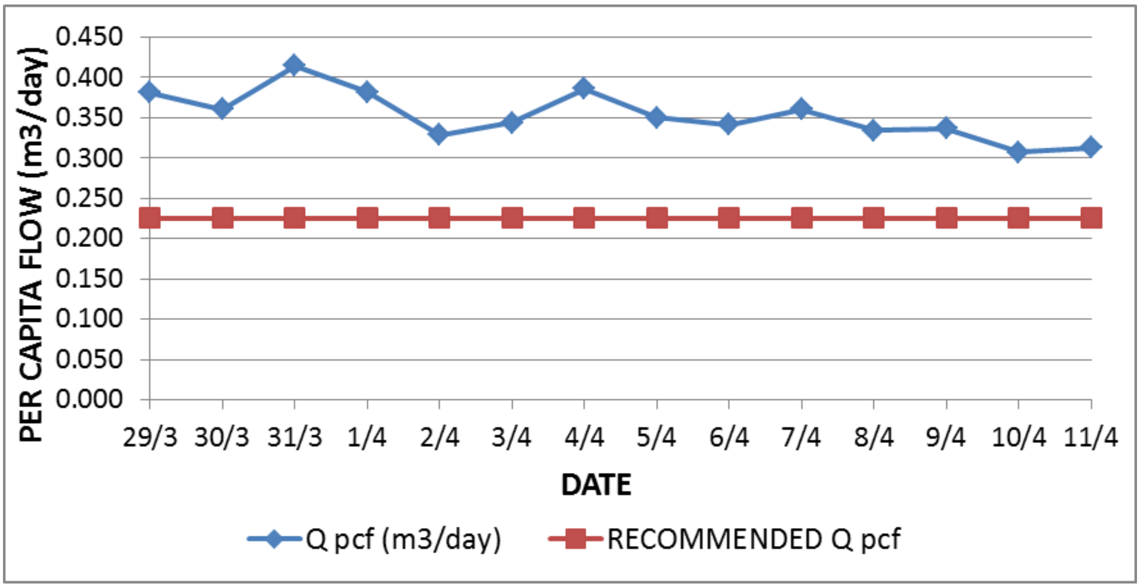

Figure 4.16 Per Capita Flow graph (29/3/2017 to 11/4/2017)

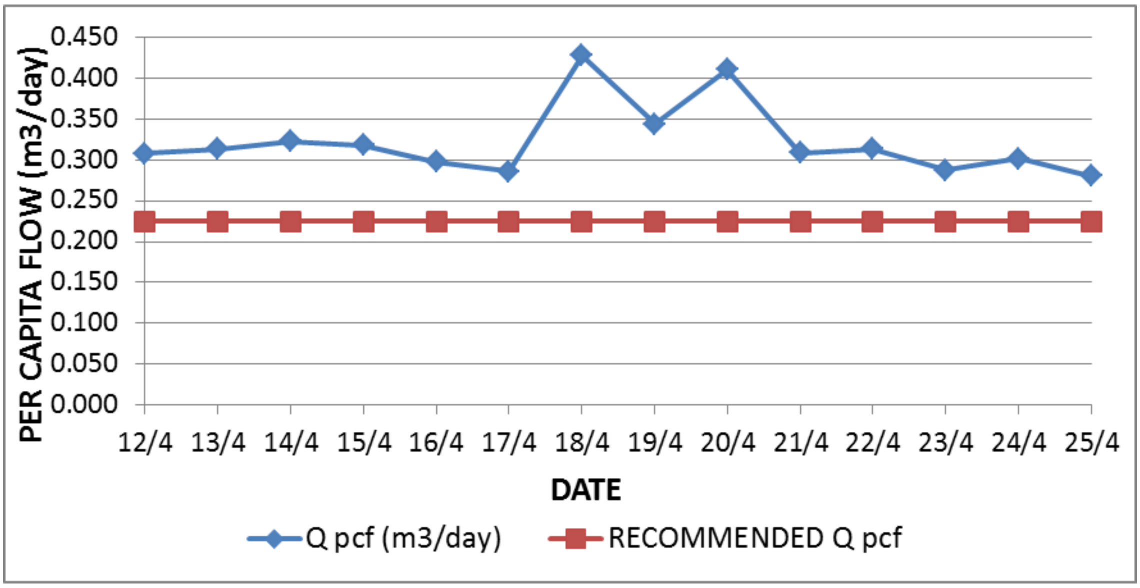

Figure 4.17 Per Capita Flow graph (12/4/2017 to 25/4/2017)

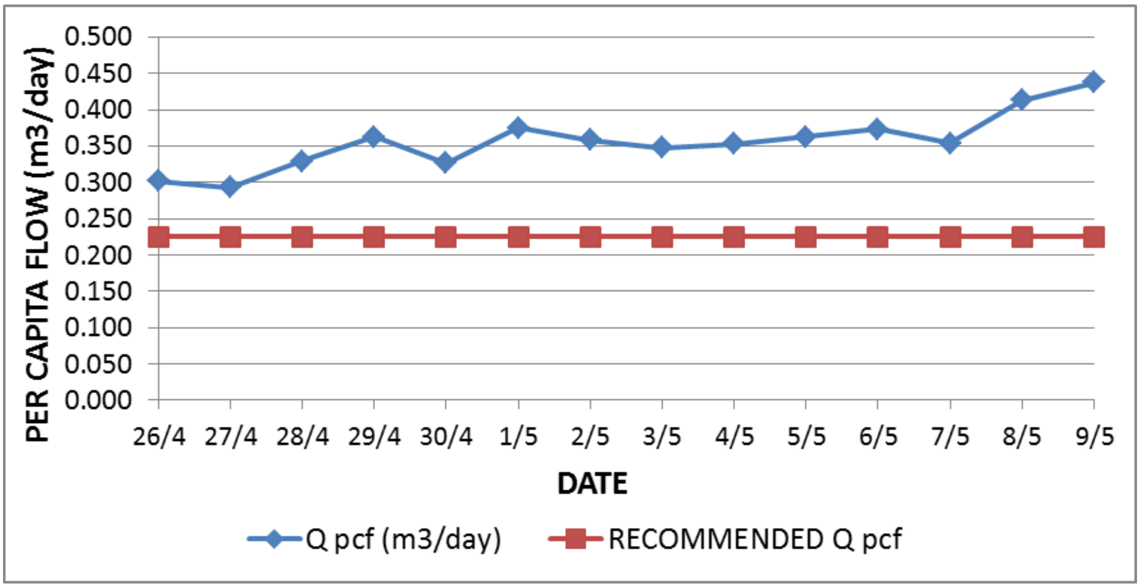

Figure 4.18 Per Capita Flow graph (26/4/2017 to 9/5/2017)

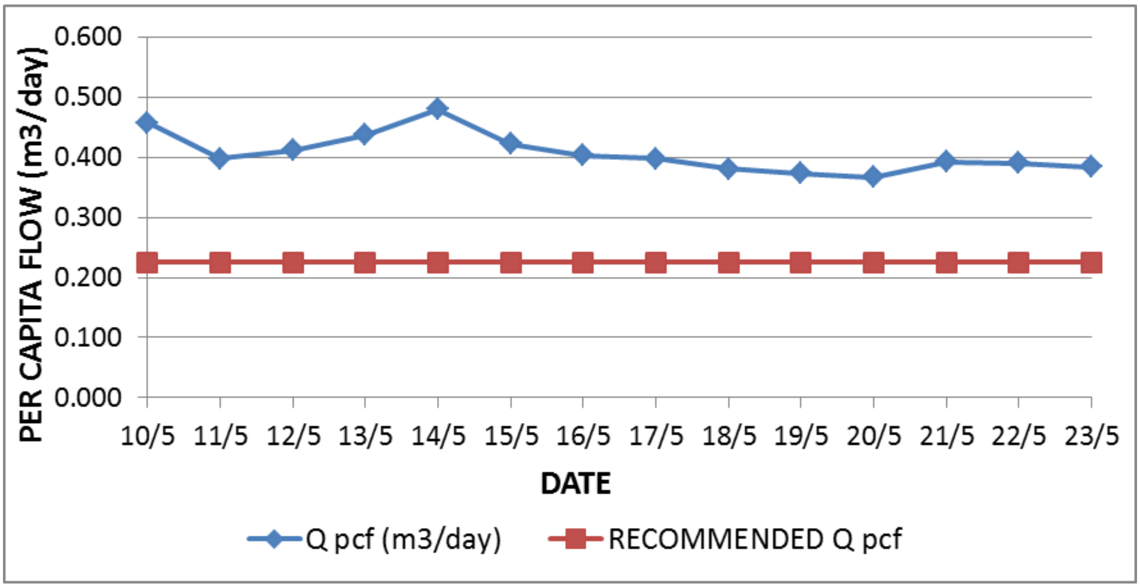

Figure 4.19 Per Capita Flow graph (10/5/2017 to 23/5/2017)

Table 4.2 Summary of Average Per Capita Flow Analysis

Date	Avg Per Capita Flow (m^3/day/person)	Recommended Per Capita Flow (m^3/day/person)	Percentage Difference (%)
1/3/17-14/3/17	0.408	0.225	81.33
15/3/17-28/3/17	0.405	0.225	80.00
29/3/17-11/4/17	0.353	0.225	56.89
12/4/17-25/4/17	0.323	0.225	43.56
26/4/17-9/5/17	0.356	0.225	58.22
10/5/17-23/5/17	0.407	0.225	80.89

From the analysis of data, the maximum value of per capita flow is 0.707 m^3/day/person, whereas the minimum value of per capita flow is 0.287 m^3/day/person. In MS 1228:1991, the value of per capita flow is stated as 0.225 m^3/day/person. From the graphs plotted, they clearly show that all the values of per capita flow are higher than the value given in MS 1228:1991. The average per capita flow during the period of study was calculated to be 0.375 m^3/day/person, which is 66.7% higher than the design per capita flow in MS 1228:1991.

4.3.4 Design Criterion for Peak Flow Factor

According to Malaysia Standard MS 1228:1991, the value of peak flow design criterion is recommended as 4.7. Peak flow design criterion can be calculated using Equation 4, and parameters involved have been discussed in previous sections which are peak flow, per capita flow and population equivalent. The purpose of the analysis is to determine the value of peak flow design criterion in the current sewerage system. The relationship between rainfall and peak flow design criterion also will be discussed in this section. Six sets of design criterion are calculated (refer Figure 4.19 to Figure 4.24). Table 4.3 shows the summary of the average peak flow design criterion analysis for each two weeks.

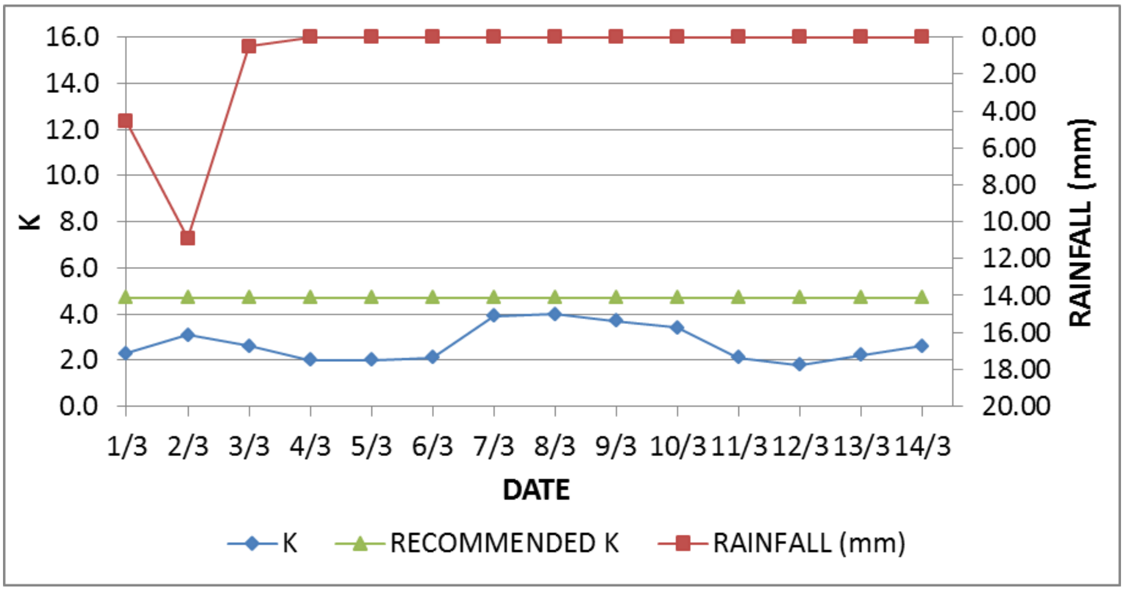

Figure 4.20 Design criterion graph (1/3/2017 to 14/3/2017)

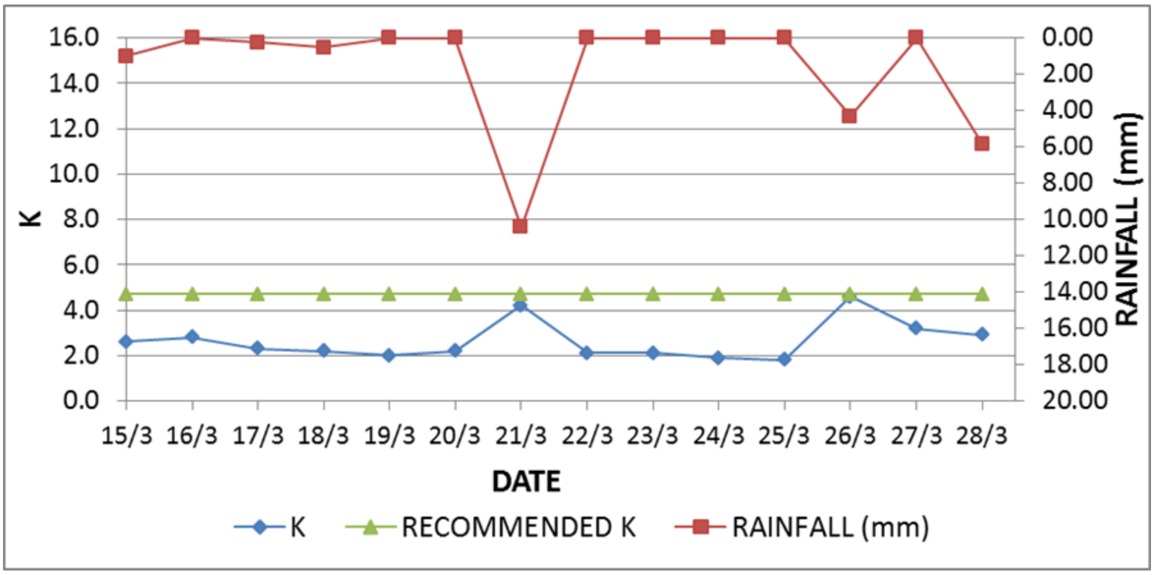

Figure 4.21 Design criterion graph (15/3/2017 to 28/3/2017)

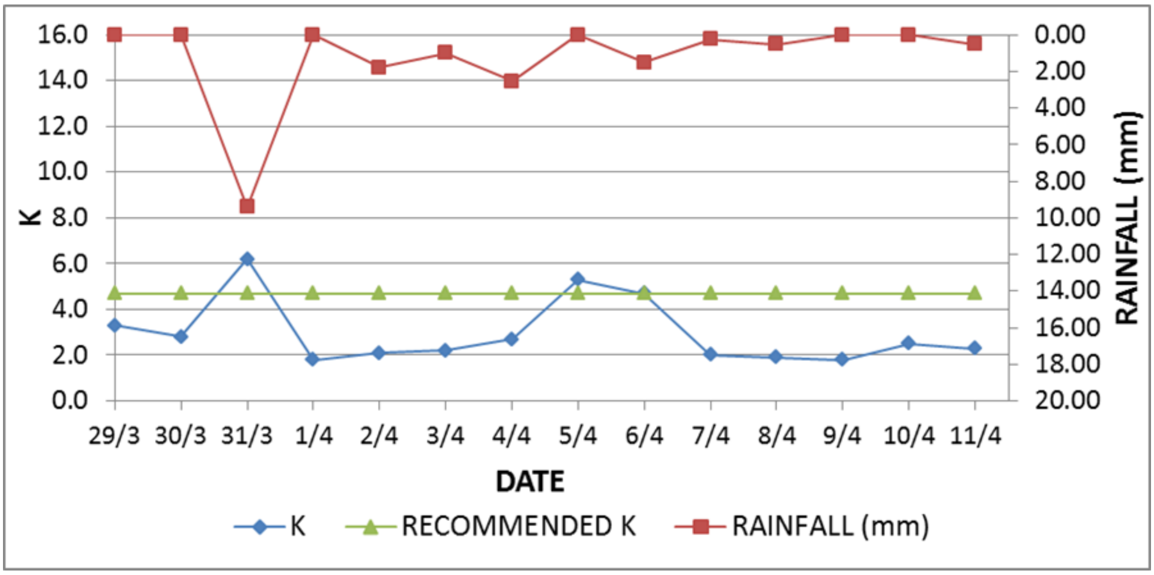

Figure 4.22 Design criterion graph (29/3/2017 to 11/4/2017)

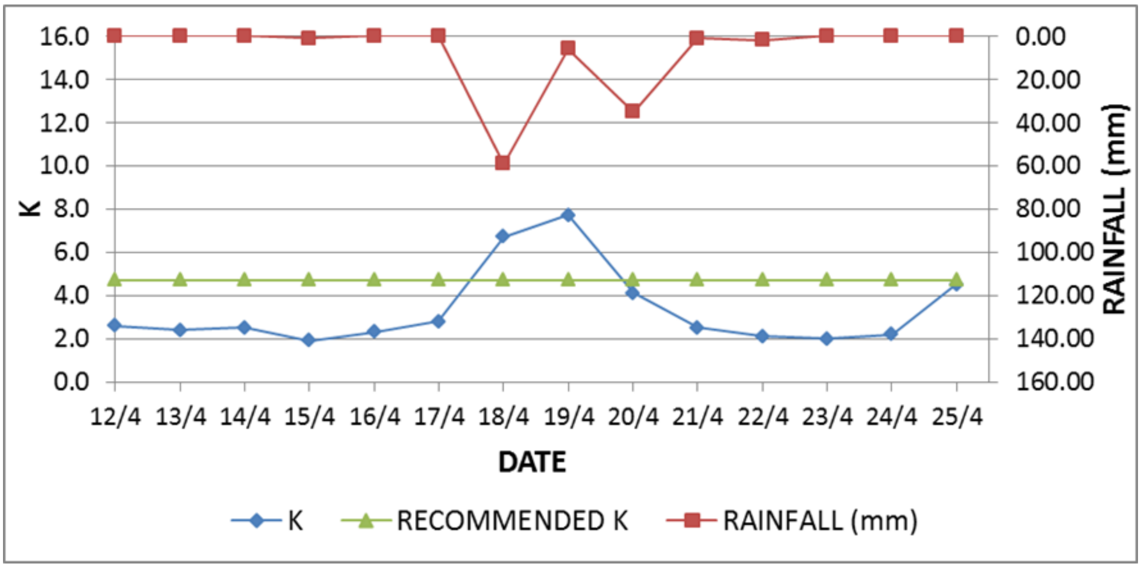

Figure 4.23 Design criterion graph (12/4/2017 to 25/4/2017)

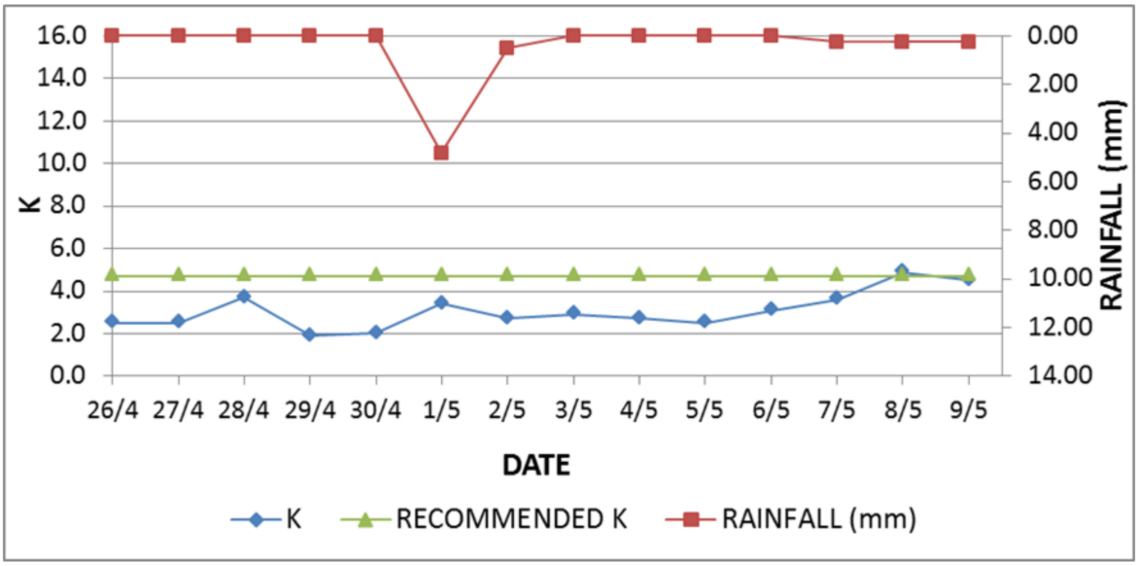

Figure 4.24 Design criterion graph (26/4/2017 to 9/5/2017)

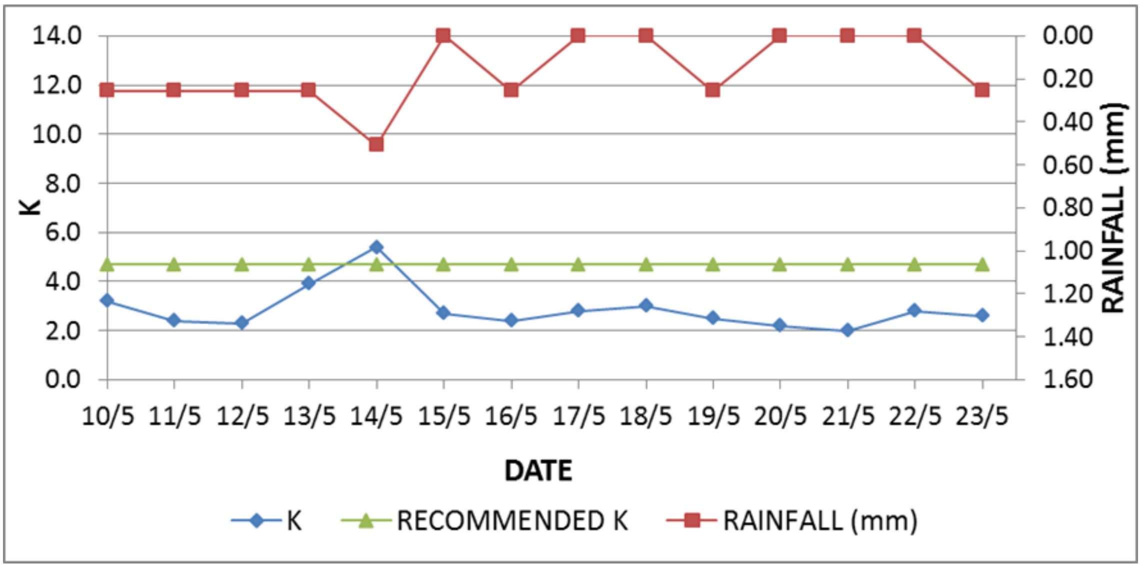

Figure 4.25 Design criterion graph (10/5/2017 to 23/5/2017)

Table 4.3 Summary of Average Peak Flow Design Criterion Analysis

Date	Avg Peak Flow Design Criterion	Recommended Peak Flow Design Criterion	Percentage Difference (%)
1/3/17-14/3/17	2.7	4.7	42.55
15/3/17-28/3/17	2.6	4.7	44.68
29/3/17-11/4/17	3.0	4.7	36.17
12/4/17-25/4/17	3.3	4.7	29.79
26/4/17-9/5/17	3.1	4.7	34.04
10/5/17-23/5/17	2.9	4.7	38.30

From the graphs shown above, it can be clearly seen that most of the values for design criterion are lower than the value stated in MS 1228:1991. Some of design criterion values exceeded 4.7, but this is likely due to the rainfall during the time. Thus, the flow rate will be increased and affect the values of design criterion of peak flow factor. The average value of design criterion during the period of study is 2.9 which is 38.3 % lower than the design criterion stated in MS 1228:1991. The bigger the peak flow factor used, the bigger the value of peak flow rate, thus results in bigger sizes of sewerage pipes needed. This will lead to unnecessary increase in costs of construction. Therefore, peak flow factor equation used in MS 1228:1991 should be revised.

CHAPTER 5

CONCLUSION

5.1 Conclusion

After carrying out the study on the sewerage system of Taman Mahkota, flow rates and rainfall intensity were collected and analysed. After analysing all the data collected, average peak flow design criterion and average per capita flow were obtained. Thus, several statements can be concluded from the results and discussions.

Initially, from the flow rate analysis (Q_{max}, Q_{min}, and Q_{avg}), it can be seen that normally there are three periods of time in a day when hourly peak flow is likely to happen, that is between 6 am to 7 am in the morning, 12 pm to 1 pm in the afternoon, and between 6 pm to 8 pm at night. Moreover, the daily peak flow will normally occur on weekdays as people tend to wake up at a different time on weekends since there is no need to go to school or work. These phenomena can be explained by the regular routine of the populations at Taman Mahkota daily, which is largely made up of schooling children and working adults. The maximum flow rate and average flow rate are important in calculating peak flow design criterion of the sewerage system to avoid problems occurring.

Other than that, the relationship between flow rates and rainfall was also analysed. From the graphs plotted, it is shown that whenever it rains, there will be rainfall intensity, which also means that the flow rate for that rainy day or for a few days after that will rise significantly compared to the previous day’s flow rate. The rain will seep into sewerage systems and contribute to the flow rate of sewage, and affect to the sewerage system. The maximum flow rate will increase when a rainy day occurs and affect the peak flow design criterion. Therefore, there is a proportional relationship between rainfall and peak flow design criterion in sewerage systems.

The value of average flow per capita was found to be higher than the value stated in MS 1228:1991 used during the design of the sewerage system which is 0.225 m^3/day/person. The average flow per capita obtained in this research is 0.375 m^3/day/person, which is 66.7% higher than the recommended per capita flow. Besides, from this research, it can be seen that the design criterion of peak flow factor is lower than the value recommended in MS 1228:1991 and used in current practice design. The average peak flow design criterion obtained is 2.9, 38.3% lower than the recommended value, 4.7. Therefore it can be assumed that the peak flow factor equation used to get the peak flow factor in sewerage systems design was greater than necessary, which will lead to significant cost savings in labour and material if revised.

From this study in Taman Mahkota, the design criterion of peak flow factor value obtained in the study is lower than the value in current sewerage system design practice. On the basis of this research, it can be said that the current sewerage system at Taman Mahkota may be adequate to support the sewage generated by the population there. The conclusion for this is there may be a need to revise the whole equation used in sewerage system design practice. Each sewerage system design should be based on its own population equivalent and flow factor with its acceptable limits of behaviour and help in reducing the cost of future development.

5.2 Recommendations

There are a few recommendations proposed to improve on this research as well as similar future studies by having adequate data and analysis.

1) The population equivalent (PE) of the study area should have always updated from time to time.

2) The selected manhole must make sure there is no overflow of sewage problem to avoid the damage of flow meter and inaccuracy of data collected.

3) More studies should be carried out in other sewerage systems with different population equivalent so as to have data from the sewerage systems to compare the results and revise the peak flow factor equation.

4) Inflow and flow rate studies should be focused also in the determination of the groundwater table level as well as the physical characteristics of the soil surrounding the sewerage systems in order to review the flow parameters of the peak flow factor equation.

5) Calibration discrepancies of equipment should be considered in the data before analysis start to get a better result.

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APPENDIX A

Flow Rate Analysis of Sewerage System Taman Mahkota.

1/3/2017-14/3/2017

Time	Q max	Q min	Q avg
12:00 AM	15.915	11.142	13.620
1:00 AM	11.656	9.232	10.481
2:00 AM	9.893	8.204	8.939
3:00 AM	8.718	7.029	7.819
4:00 AM	8.351	7.029	7.617
5:00 AM	9.967	7.837	8.792
6:00 AM	35.009	13.492	22.433
7:00 AM	31.558	21.790	26.307
8:00 AM	21.497	17.898	19.771
9:00 AM	21.203	16.209	18.853
10:00 AM	20.762	15.989	18.137
11:00 AM	23.301	16.550	19.835
12:00 PM	23.642	15.527	19.193
1:00 PM	20.437	15.527	17.829
2:00 PM	23.710	19.210	21.187
3:00 PM	24.256	17.709	20.846
4:00 PM	21.187	16.345	18.698
5:00 PM	22.210	16.891	19.874
6:00 PM	24.051	18.869	21.665
7:00 PM	27.734	21.596	24.495
8:00 PM	30.871	23.506	27.614
9:00 PM	24.733	18.187	21.630
10:00 PM	20.710	15.050	17.709
11:00 PM	19.551	13.891	16.363

15/3/2017-28/3/2017

Time	Q max	Q min	Q avg
12:00 AM	15.391	11.845	13.584
1:00 AM	11.572	8.708	10.157
2:00 AM	8.776	7.208	7.975
3:00 AM	7.753	6.253	6.952
4:00 AM	7.344	5.912	6.679
5:00 AM	8.981	6.253	7.497
6:00 AM	28.075	10.958	19.090
7:00 AM	30.393	22.346	26.353

8:00 AM	26.506	19.619	22.926
9:00 AM	23.983	18.937	21.528
10:00 AM	22.892	18.187	20.556
11:00 AM	22.551	18.459	20.437
12:00 PM	27.325	17.846	22.517
1:00 PM	23.301	16.891	20.079
2:00 PM	22.619	18.732	20.693
3:00 PM	20.778	16.209	18.408
4:00 PM	20.301	15.664	18.067
5:00 PM	24.733	17.164	20.914
6:00 PM	26.165	20.301	23.131
7:00 PM	28.143	21.801	24.512
8:00 PM	31.280	24.119	27.666
9:00 PM	23.506	18.732	21.136
10:00 PM	18.937	14.436	16.789
11:00 PM	17.982	13.891	16.209

29/3/2017-11/402017

Time	Q max	Q min	Q avg
12:00 AM	14.709	11.095	12.885
1:00 AM	12.049	8.981	10.549
2:00 AM	9.594	7.208	8.401
3:00 AM	7.753	6.662	7.139
4:00 AM	7.344	6.185	6.730
5:00 AM	10.276	6.594	7.941
6:00 AM	27.120	11.367	19.005
7:00 AM	26.370	19.073	22.687
8:00 AM	20.437	16.345	18.511
9:00 AM	19.073	15.050	17.130
10:00 AM	18.459	14.845	16.669
11:00 AM	17.437	14.027	15.493
12:00 PM	17.709	13.822	15.595
1:00 PM	17.573	13.686	15.612
2:00 PM	19.551	15.732	17.505
3:00 PM	17.027	13.277	15.220
4:00 PM	16.618	12.799	14.572
5:00 PM	17.914	13.686	15.868
6:00 PM	29.234	16.005	21.699
7:00 PM	27.938	18.937	22.687
8:00 PM	29.098	22.824	26.012
9:00 PM	22.074	16.005	19.278
10:00 PM	17.573	14.436	15.834
11:00 PM	17.027	13.754	15.220

12/4/2017-25/4/2017

Time	Q max	Q min	Q avg
12:00 AM	16.119	9.594	13.493
1:00 AM	11.731	7.549	9.430
2:00 AM	9.060	6.594	7.759
3:00 AM	8.108	6.048	6.810
4:00 AM	7.920	5.639	6.452
5:00 AM	11.105	6.048	7.861
6:00 AM	26.511	11.367	19.306
7:00 AM	24.031	16.277	20.545
8:00 AM	19.515	13.891	16.834
9:00 AM	18.181	13.277	15.919
10:00 AM	17.420	11.845	14.777
11:00 AM	16.277	11.981	14.192
12:00 PM	21.435	11.231	14.357
1:00 PM	23.220	12.049	18.681
2:00 PM	21.314	14.163	18.261
3:00 PM	18.007	11.708	14.555
4:00 PM	16.037	10.958	13.260
5:00 PM	16.930	11.913	14.430
6:00 PM	18.270	12.868	16.198
7:00 PM	24.319	16.414	20.346
8:00 PM	24.194	16.618	20.841
9:00 PM	17.387	11.981	14.737
10:00 PM	14.971	10.822	12.924
11:00 PM	19.811	10.140	14.021

26/4/2017-9/5/2017

Time	**Q max**	**Q min**	**Q avg**
12:00 AM	14.232	8.776	11.095
1:00 AM	10.345	7.480	8.924
2:00 AM	8.912	6.526	7.685
3:00 AM	9.731	5.912	7.299
4:00 AM	9.799	6.321	8.009
5:00 AM	21.255	7.344	12.322
6:00 AM	27.938	12.322	20.420
7:00 AM	28.620	18.800	22.972
8:00 AM	23.369	15.936	19.579
9:00 AM	22.210	15.391	18.806
10:00 AM	20.369	14.436	17.442
11:00 AM	19.960	13.891	17.181
12:00 PM	19.073	12.868	15.982
1:00 PM	19.960	13.004	16.488

2:00 PM	21.051	14.368	17.789
3:00 PM	21.255	12.458	16.016
4:00 PM	19.278	11.163	14.124
5:00 PM	20.437	13.277	16.425
6:00 PM	21.937	15.595	18.908
7:00 PM	31.484	18.255	23.904
8:00 PM	28.825	18.391	23.767
9:00 PM	21.255	13.209	17.289
10:00 PM	22.210	11.231	15.033
11:00 PM	18.255	11.367	14.487

10/5/2017-23/5/2017

Time	**Q max**	**Q min**	**Q avg**
12:00 AM	16.959	10.481	13.464
1:00 AM	11.913	7.890	9.657
2:00 AM	9.253	6.662	7.833
3:00 AM	8.299	6.048	7.094
4:00 AM	8.299	5.912	6.935
5:00 AM	13.686	6.798	9.089
6:00 AM	31.893	14.163	23.307
7:00 AM	33.462	20.914	26.438
8:00 AM	24.460	18.255	21.125
9:00 AM	23.710	17.914	20.698
10:00 AM	22.824	16.482	19.670
11:00 AM	22.074	14.982	18.914
12:00 PM	21.869	15.254	18.590
1:00 PM	23.028	15.800	19.408
2:00 PM	24.665	17.778	21.159
3:00 PM	24.256	14.436	19.636
4:00 PM	19.687	12.936	16.527
5:00 PM	27.256	15.527	20.522
6:00 PM	27.120	19.755	23.619
7:00 PM	34.826	22.551	27.955
8:00 PM	35.849	21.733	28.535
9:00 PM	24.938	17.232	20.812
10:00 PM	21.324	15.664	18.249
11:00 PM	19.346	13.891	16.959

APPENDIX B

Analysis between Flow Rates and Rainfall of Sewerage System Taman Mahkota (Selected date-18/4/2017).

Date & Time	Flow Rate, Q (m^3/s)	Q (l/s)	Corrected Q (l/s)	Rainfall (mm)
18-04-17 0:00	0.009	9	8.5715	0
18-04-17 0:05	0.009	9	8.5715	0
18-04-17 0:10	0.008	8	7.6168	0
18-04-17 0:15	0.009	9	8.5715	0
18-04-17 0:20	0.009	9	8.5715	0
18-04-17 0:25	0.008	8	7.6168	0
18-04-17 0:30	0.008	8	7.6168	0
18-04-17 0:35	0.009	9	8.5715	0
18-04-17 0:40	0.010	10	9.5262	0
18-04-17 0:45	0.010	10	9.5262	0
18-04-17 0:50	0.009	9	8.5715	0
18-04-17 0:55	0.008	8	7.6168	0
18-04-17 1:00	0.010	10	9.5262	0
18-04-17 1:05	0.010	10	9.5262	0
18-04-17 1:10	0.009	9	8.5715	0
18-04-17 1:15	0.007	7	6.6621	0
18-04-17 1:20	0.008	8	7.6168	0
18-04-17 1:25	0.008	8	7.6168	0
18-04-17 1:30	0.008	8	7.6168	0
18-04-17 1:35	0.007	7	6.6621	0
18-04-17 1:40	0.007	7	6.6621	0
18-04-17 1:45	0.007	7	6.6621	0
18-04-17 1:50	0.008	8	7.6168	0
18-04-17 1:55	0.007	7	6.6621	0
18-04-17 2:00	0.007	7	6.6621	0
18-04-17 2:05	0.007	7	6.6621	0
18-04-17 2:10	0.007	7	6.6621	0
18-04-17 2:15	0.007	7	6.6621	0
18-04-17 2:20	0.008	8	7.6168	0
18-04-17 2:25	0.008	8	7.6168	0
18-04-17 2:30	0.007	7	6.6621	0
18-04-17 2:35	0.008	8	7.6168	0
18-04-17 2:40	0.007	7	6.6621	0
18-04-17 2:45	0.007	7	6.6621	0
18-04-17 2:50	0.007	7	6.6621	0
18-04-17 2:55	0.007	7	6.6621	0

18-04-17 3:00	0.006	6	5.7074	0
18-04-17 3:05	0.007	7	6.6621	0
18-04-17 3:10	0.006	6	5.7074	0
18-04-17 3:15	0.006	6	5.7074	0
18-04-17 3:20	0.007	7	6.6621	0
18-04-17 3:25	0.008	8	7.6168	0
18-04-17 3:30	0.006	6	5.7074	0
18-04-17 3:35	0.007	7	6.6621	0
18-04-17 3:40	0.006	6	5.7074	0
18-04-17 3:45	0.007	7	6.6621	0
18-04-17 3:50	0.006	6	5.7074	0
18-04-17 3:55	0.006	6	5.7074	0
18-04-17 4:00	0.007	7	6.6621	0
18-04-17 4:05	0.006	6	5.7074	0
18-04-17 4:10	0.008	8	7.6168	0
18-04-17 4:15	0.007	7	6.6621	0
18-04-17 4:20	0.006	6	5.7074	0
18-04-17 4:25	0.006	6	5.7074	0
18-04-17 4:30	0.007	7	6.6621	0
18-04-17 4:35	0.007	7	6.6621	0
18-04-17 4:40	0.006	6	5.7074	0
18-04-17 4:45	0.007	7	6.6621	0
18-04-17 4:50	0.007	7	6.6621	0
18-04-17 4:55	0.007	7	6.6621	0
18-04-17 5:00	0.007	7	6.6621	0
18-04-17 5:05	0.006	6	5.7074	0
18-04-17 5:10	0.007	7	6.6621	0
18-04-17 5:15	0.007	7	6.6621	0
18-04-17 5:20	0.006	6	5.7074	0
18-04-17 5:25	0.008	8	7.6168	0
18-04-17 5:30	0.008	8	7.6168	0
18-04-17 5:35	0.008	8	7.6168	0
18-04-17 5:40	0.009	9	8.5715	0
18-04-17 5:45	0.008	8	7.6168	0
18-04-17 5:50	0.011	11	10.4809	0
18-04-17 5:55	0.016	16	15.2544	0
18-04-17 6:00	0.012	12	11.4356	0
18-04-17 6:05	0.016	16	15.2544	0
18-04-17 6:10	0.017	17	16.2091	0
18-04-17 6:15	0.021	21	20.0279	0
18-04-17 6:20	0.021	21	20.0279	0
18-04-17 6:25	0.028	28	26.7108	0
18-04-17 6:30	0.025	25	23.8467	0
18-04-17 6:35	0.026	26	24.8014	0

18-04-17 6:40	0.024	24	22.892	0
18-04-17 6:45	0.030	30	28.6202	0
18-04-17 6:50	0.029	29	27.6655	0
18-04-17 6:55	0.028	28	26.7108	0
18-04-17 7:00	0.027	27	25.7561	0
18-04-17 7:05	0.025	25	23.8467	0
18-04-17 7:10	0.025	25	23.8467	0
18-04-17 7:15	0.021	21	20.0279	0
18-04-17 7:20	0.023	23	21.9373	0
18-04-17 7:25	0.025	25	23.8467	0
18-04-17 7:30	0.022	22	20.9826	0
18-04-17 7:35	0.020	20	19.0732	0
18-04-17 7:40	0.019	19	18.1185	0
18-04-17 7:45	0.022	22	20.9826	0
18-04-17 7:50	0.018	18	17.1638	0
18-04-17 7:55	0.020	20	19.0732	0
18-04-17 8:00	0.016	16	15.2544	0
18-04-17 8:05	0.016	16	15.2544	0
18-04-17 8:10	0.015	15	14.2997	0
18-04-17 8:15	0.016	16	15.2544	0
18-04-17 8:20	0.015	15	14.2997	0
18-04-17 8:25	0.016	16	15.2544	0
18-04-17 8:30	0.017	17	16.2091	0
18-04-17 8:35	0.015	15	14.2997	0
18-04-17 8:40	0.014	14	13.345	0
18-04-17 8:45	0.015	15	14.2997	0
18-04-17 8:50	0.015	15	14.2997	0
18-04-17 8:55	0.012	12	11.4356	0
18-04-17 9:00	0.011	11	10.4809	0
18-04-17 9:05	0.014	14	13.345	0
18-04-17 9:10	0.018	18	17.1638	0
18-04-17 9:15	0.016	16	15.2544	0
18-04-17 9:20	0.016	16	15.2544	0
18-04-17 9:25	0.014	14	13.345	0
18-04-17 9:30	0.015	15	14.2997	0
18-04-17 9:35	0.013	13	12.3903	0
18-04-17 9:40	0.011	11	10.4809	0
18-04-17 9:45	0.015	15	14.2997	0
18-04-17 9:50	0.014	14	13.345	0
18-04-17 9:55	0.015	15	14.2997	0
18-04-17 10:00	0.013	13	12.3903	0
18-04-17 10:05	0.013	13	12.3903	0
18-04-17 10:10	0.013	13	12.3903	0
18-04-17 10:15	0.012	12	11.4356	0

18-04-17 10:20	0.011	11	10.4809	0
18-04-17 10:25	0.012	12	11.4356	0
18-04-17 10:30	0.013	13	12.3903	0
18-04-17 10:35	0.009	9	8.5715	0
18-04-17 10:40	0.012	12	11.4356	0
18-04-17 10:45	0.010	10	9.5262	0
18-04-17 10:50	0.015	15	14.2997	0
18-04-17 10:55	0.012	12	11.4356	0
18-04-17 11:00	0.014	14	13.345	0
18-04-17 11:05	0.015	15	14.2997	0
18-04-17 11:10	0.013	13	12.3903	0
18-04-17 11:15	0.010	10	9.5262	0
18-04-17 11:20	0.012	12	11.4356	0
18-04-17 11:25	0.012	12	11.4356	0
18-04-17 11:30	0.012	12	11.4356	0
18-04-17 11:35	0.011	11	10.4809	0
18-04-17 11:40	0.012	12	11.4356	0
18-04-17 11:45	0.011	11	10.4809	0
18-04-17 11:50	0.013	13	12.3903	0
18-04-17 11:55	0.012	12	11.4356	0
18-04-17 12:00	0.013	13	12.3903	0
18-04-17 12:05	0.012	12	11.4356	0
18-04-17 12:10	0.014	14	13.345	0
18-04-17 12:15	0.013	13	12.3903	0
18-04-17 12:20	0.012	12	11.4356	0
18-04-17 12:25	0.013	13	12.3903	0
18-04-17 12:30	0.011	11	10.4809	0
18-04-17 12:35	0.010	10	9.5262	0
18-04-17 12:40	0.008	8	7.6168	0
18-04-17 12:45	0.009	9	8.5715	0
18-04-17 12:50	0.010	10	9.5262	0
18-04-17 12:55	0.010	10	9.5262	0
18-04-17 13:00	0.010	10	9.5262	0.001
18-04-17 13:05	0.032	32	30.5296	0.001
18-04-17 13:10	0.093	93	88.7663	0.003
18-04-17 13:15	0.116	116	110.7244	0.004
18-04-17 13:20	0.090	90	85.9022	0.004
18-04-17 13:25	0.076	76	72.5364	0.004
18-04-17 13:30	0.077	77	73.4911	0.004
18-04-17 13:35	0.079	79	75.4005	0.004
18-04-17 13:40	0.075	75	71.5817	0.005
18-04-17 13:45	0.071	71	67.7629	0.005
18-04-17 13:50	0.071	71	67.7629	0.005
18-04-17 13:55	0.076	76	72.5364	0.004

18-04-17 14:00	0.064	64	61.08	0.004
18-04-17 14:05	0.064	64	61.08	0.004
18-04-17 14:10	0.057	57	54.3971	0.003
18-04-17 14:15	0.064	64	61.08	0.003
18-04-17 14:20	0.055	55	52.4877	0.001
18-04-17 14:25	0.063	63	60.1253	0
18-04-17 14:30	0.060	60	57.2612	0
18-04-17 14:35	0.050	50	47.7142	0
18-04-17 14:40	0.024	24	22.892	0
18-04-17 14:45	0.024	24	22.892	0
18-04-17 14:50	0.023	23	21.9373	0
18-04-17 14:55	0.033	33	31.4843	0
18-04-17 15:00	0.046	46	43.8954	0
18-04-17 15:05	0.030	30	28.6202	0
18-04-17 15:10	0.021	21	20.0279	0
18-04-17 15:15	0.028	28	26.7108	0
18-04-17 15:20	0.029	29	27.6655	0
18-04-17 15:25	0.030	30	28.6202	0
18-04-17 15:30	0.028	28	26.7108	0
18-04-17 15:35	0.026	26	24.8014	0
18-04-17 15:40	0.024	24	22.892	0
18-04-17 15:45	0.024	24	22.892	0
18-04-17 15:50	0.021	21	20.0279	0
18-04-17 15:55	0.024	24	22.892	0
18-04-17 16:00	0.024	24	22.892	0
18-04-17 16:05	0.021	21	20.0279	0
18-04-17 16:10	0.021	21	20.0279	0
18-04-17 16:15	0.022	22	20.9826	0
18-04-17 16:20	0.021	21	20.0279	0
18-04-17 16:25	0.018	18	17.1638	0
18-04-17 16:30	0.019	19	18.1185	0
18-04-17 16:35	0.019	19	18.1185	0
18-04-17 16:40	0.022	22	20.9826	0
18-04-17 16:45	0.016	16	15.2544	0
18-04-17 16:50	0.020	20	19.0732	0
18-04-17 16:55	0.021	21	20.0279	0
18-04-17 17:00	0.019	19	18.1185	0
18-04-17 17:05	0.020	20	19.0732	0
18-04-17 17:10	0.018	18	17.1638	0
18-04-17 17:15	0.017	17	16.2091	0
18-04-17 17:20	0.020	20	19.0732	0
18-04-17 17:25	0.023	23	21.9373	0
18-04-17 17:30	0.020	20	19.0732	0
18-04-17 17:35	0.021	21	20.0279	0

18-04-17 17:40	0.020	20	19.0732	0
18-04-17 17:45	0.022	22	20.9826	0
18-04-17 17:50	0.024	24	22.892	0
18-04-17 17:55	0.025	25	23.8467	0
18-04-17 18:00	0.027	27	25.7561	0
18-04-17 18:05	0.024	24	22.892	0
18-04-17 18:10	0.024	24	22.892	0
18-04-17 18:15	0.024	24	22.892	0
18-04-17 18:20	0.025	25	23.8467	0
18-04-17 18:25	0.024	24	22.892	0
18-04-17 18:30	0.025	25	23.8467	0
18-04-17 18:35	0.021	21	20.0279	0
18-04-17 18:40	0.018	18	17.1638	0
18-04-17 18:45	0.023	23	21.9373	0
18-04-17 18:50	0.027	27	25.7561	0
18-04-17 18:55	0.026	26	24.8014	0
18-04-17 19:00	0.023	23	21.9373	0
18-04-17 19:05	0.022	22	20.9826	0
18-04-17 19:10	0.023	23	21.9373	0
18-04-17 19:15	0.022	22	20.9826	0
18-04-17 19:20	0.023	23	21.9373	0
18-04-17 19:25	0.027	27	25.7561	0
18-04-17 19:30	0.029	29	27.6655	0
18-04-17 19:35	0.030	30	28.6202	0
18-04-17 19:40	0.031	31	29.5749	0
18-04-17 19:45	0.029	29	27.6655	0
18-04-17 19:50	0.035	35	33.3937	0
18-04-17 19:55	0.034	34	32.439	0
18-04-17 20:00	0.032	32	30.5296	0
18-04-17 20:05	0.025	25	23.8467	0
18-04-17 20:10	0.026	26	24.8014	0
18-04-17 20:15	0.033	33	31.4843	0
18-04-17 20:20	0.031	31	29.5749	0
18-04-17 20:25	0.029	29	27.6655	0
18-04-17 20:30	0.028	28	26.7108	0
18-04-17 20:35	0.027	27	25.7561	0
18-04-17 20:40	0.025	25	23.8467	0
18-04-17 20:45	0.021	21	20.0279	0
18-04-17 20:50	0.021	21	20.0279	0
18-04-17 20:55	0.022	22	20.9826	0
18-04-17 21:00	0.024	24	22.892	0
18-04-17 21:05	0.022	22	20.9826	0
18-04-17 21:10	0.021	21	20.0279	0
18-04-17 21:15	0.019	19	18.1185	0

18-04-17 21:20	0.024	24	22.892	0
18-04-17 21:25	0.021	21	20.0279	0
18-04-17 21:30	0.021	21	20.0279	0
18-04-17 21:35	0.020	20	19.0732	0
18-04-17 21:40	0.020	20	19.0732	0
18-04-17 21:45	0.019	19	18.1185	0
18-04-17 21:50	0.019	19	18.1185	0
18-04-17 21:55	0.021	21	20.0279	0
18-04-17 22:00	0.018	18	17.1638	0
18-04-17 22:05	0.020	20	19.0732	0
18-04-17 22:10	0.017	17	16.2091	0
18-04-17 22:15	0.016	16	15.2544	0
18-04-17 22:20	0.017	17	16.2091	0
18-04-17 22:25	0.019	19	18.1185	0
18-04-17 22:30	0.021	21	20.0279	0
18-04-17 22:35	0.022	22	20.9826	0
18-04-17 22:40	0.020	20	19.0732	0
18-04-17 22:45	0.019	19	18.1185	0
18-04-17 22:50	0.017	17	16.2091	0
18-04-17 22:55	0.015	15	14.2997	0
18-04-17 23:00	0.015	15	14.2997	0
18-04-17 23:05	0.019	19	18.1185	0
18-04-17 23:10	0.021	21	20.0279	0
18-04-17 23:15	0.020	20	19.0732	0
18-04-17 23:20	0.021	21	20.0279	0
18-04-17 23:25	0.019	19	18.1185	0
18-04-17 23:30	0.017	17	16.2091	0
18-04-17 23:35	0.019	19	18.1185	0
18-04-17 23:40	0.018	18	17.1638	0
18-04-17 23:45	0.021	21	20.0279	0
18-04-17 23:50	0.015	15	14.2997	0
18-04-17 23:55	0.014	14	13.345	0

APPENDIX C

Peak Flow Design Criterion Analysis of Sewerage System Taman Mahkota.

Date	Q peak (l/s)	Q avg (l/s)	K	Q pcf (m^3/day)
01-03-17	51.533	25.775	2.3	0.577
02-03-17	83.993	31.594	3.1	0.707
03-03-17	38.167	16.935	2.6	0.379
04-03-17	25.756	14.986	2.0	0.335
05-03-17	25.756	15.304	2.0	0.343
06-03-17	29.575	16.100	2.1	0.360
07-03-17	55.352	16.398	3.9	0.367
08-03-17	54.397	15.911	4.0	0.356
09-03-17	51.533	16.338	3.7	0.366
10-03-17	49.624	17.054	3.4	0.382
11-03-17	30.530	17.154	2.1	0.384
12-03-17	28.620	17.959	1.8	0.402
13-03-17	33.394	17.562	2.2	0.393
14-03-17	36.258	16.428	2.6	0.368
15-03-17	38.167	16.985	2.6	0.380
16-03-17	41.031	17.144	2.8	0.384
17-03-17	33.394	16.955	2.3	0.380
18-03-17	33.394	17.621	2.2	0.394
19-03-17	27.666	16.040	2.0	0.359
20-03-17	30.530	16.100	2.2	0.360
21-03-17	77.310	21.589	4.2	0.483
22-03-17	33.394	18.705	2.1	0.419
23-03-17	31.484	17.025	2.1	0.381
24-03-17	28.620	17.044	1.9	0.382
25-03-17	26.711	17.064	1.8	0.382
26-03-17	80.174	20.068	4.6	0.449
27-03-17	51.533	18.516	3.2	0.414
28-03-17	55.352	22.226	2.9	0.497
29-03-17	48.669	17.035	3.3	0.381
30-03-17	39.122	16.090	2.8	0.360
31-03-17	99.268	18.516	6.2	0.414
01-04-17	25.756	17.054	1.8	0.382
02-04-17	26.711	14.678	2.1	0.329
03-04-17	29.575	15.354	2.2	0.344
04-04-17	40.077	17.253	2.7	0.386
05-04-17	30.530	15.642	5.3	0.350
06-04-17	62.035	15.264	4.7	0.342
07-04-17	27.666	16.090	2.0	0.360
08-04-17	24.801	14.936	1.9	0.334
09-04-17	22.892	15.056	1.8	0.337
10-04-17	29.575	13.713	2.5	0.307
11-04-17	27.666	13.962	2.3	0.313
12-04-17	30.530	13.743	2.6	0.308
13-04-17	28.620	13.991	2.4	0.313

14-04-17	31.484	14.419	2.5	0.323
15-04-17	23.847	14.214	1.9	0.318
16-04-17	26.711	13.289	2.3	0.297
17-04-17	30.530	12.781	2.8	0.286
18-04-17	110.724	19.113	6.7	0.428
19-04-17	101.177	15.341	7.7	0.343
20-04-17	64.899	18.324	4.1	0.410
21-04-17	29.575	13.796	2.5	0.309
22-04-17	25.756	13.978	2.1	0.313
23-04-17	21.937	12.841	2.0	0.287
24-04-17	25.756	13.461	2.2	0.301
25-04-17	48.669	12.536	4.5	0.281
26-04-17	29.575	13.484	2.5	0.302
27-04-17	27.666	13.083	2.5	0.293
28-04-17	46.760	14.697	3.7	0.329
29-04-17	26.711	16.189	1.9	0.362
30-04-17	25.756	14.595	2.0	0.327
01-05-17	49.624	16.773	3.4	0.375
02-05-17	37.213	15.997	2.7	0.358
03-05-17	38.167	15.526	2.9	0.348
04-05-17	37.213	15.758	2.7	0.353
05-05-17	35.303	16.202	2.5	0.363
06-05-17	44.850	16.670	3.1	0.373
07-05-17	49.624	15.798	3.6	0.354
08-05-17	77.310	18.460	4.9	0.413
09-05-17	75.401	19.567	4.5	0.438
10-05-17	56.307	20.432	3.2	0.457
11-05-17	37.213	17.787	2.4	0.398
12-05-17	37.213	18.387	2.3	0.412
13-05-17	64.899	19.541	3.9	0.437
14-05-17	99.268	21.437	5.4	0.480
15-05-17	43.895	18.884	2.7	0.423
16-05-17	37.213	18.012	2.4	0.403
17-05-17	42.941	17.790	2.8	0.398
18-05-17	43.895	17.011	3.0	0.381
19-05-17	36.258	16.696	2.5	0.374
20-05-17	30.530	16.372	2.2	0.366
21-05-17	29.575	17.552	2.0	0.393
22-05-17	41.986	17.416	2.8	0.390
23-05-17	38.167	17.131	2.6	0.383