SEWERAGE INFLOW AND INFILTRATION IN UNIVERSITI MALAYSIA PAHANG (GAMBANG)

LIEW PEI QI

BACHELOR (HONS.) OF CIVIL ENGINEERING
UNIVERSITI MALAYSIA PAHANG

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SEWERAGE INFLOW AND INFILTRATION IN UNIVERSITI MALAYSIA PAHANG (GAMBANG)

LIEW PEI QI

Thesis submitted in fulfillment of the requirements
for the award of the degree of Bachelor
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SUPERVISOR'S DECLARATION

I hereby declare I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Civil Engineering (Hons.).

Signature :

Name of Supervisor : DR.NGIEN SU KONG

Position : SENIOR LECTURER

Date : 26 JUNE 2015

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:	
Name	:	LIEW PEI QI
ID Number	:	AA11093
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Dedicated to my parents,

Who always support and encourage me

in my life.

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ABSTRACT

There are several problems occurring during heavy rain which public infrastructure defects will allow unwanted water to enter the sewer system. The sewer pipe system that had cracked or broken causes the excess water from inflow and infiltration to enter the sewer system. This will affect the flow rate and flow capacity of wastewater inside the sewer pipe. The main purpose of this research is to study the inflow and infiltration in the sewerage system by collecting data from field runs in UMP area. Besides, it also studies the relationship of rainfall intensity with inflow and infiltration rate in the sewerage system and to detect whether there are any leakage present in the sewer lines studied which may affect the flow rate in the sewer. This study about sewerage inflow and infiltration in selected sewer in both dry and wet periods, which using the two area velocity flow-meters to measure the sewer flow rate and rainfall data is collected using a rain gauge to achieve the objectives of the research. Thus, the differences between the two periods of inflow and infiltration, and its relationship with rainfall can be clearly seen. This is done on selected sewer line connecting two manholes with no lateral branches in between at Universiti Malaysia Pahang (UMP) area. The result of the inflow and infiltration analysis are compared with the inflow and infiltration rate design limits prescribed in Malaysia Standard MS 1228:1991, previous case studies on inflow and infiltration that carried out in Skudai, Johor and inflow and infiltration estimation range that mention in Hammer & Hammer. The highest infiltration rate that obtained (19.71 liter/day/km/mm-dia) is within the range of design limits prescribed in MS 1228: 1991(50 liter/day/km/mm-dia.) as well as the estimation range that suggested by Hammer & Hammer (18-46 liter/day/km/mm-dia.).

ABSTRAK

Terdapat beberapa masalah berlaku semasa hujan lebat di dalam infrastruktur awam yang mempunyai kerosakan atau kebocoran terutamanya bagi paip pembetung yang retak dan ini menyebabkan air berlebihan daripada aliran masuk dan penyusupan untuk memasuki sistem pembetung. Ini akan memberi kesan kepada kadar aliran dan aliran kapasiti air kumbahan di dalam paip pembetung. Tujuan utama kajian ini adalah untuk mengkaji aliran masuk dan penyusupan dalam sistem pembetungan di kawasan UMP. Selain itu, ia juga mengkaji hubungan antara keamatan hujan dengan aliran masuk dan kadar penyusupan dalam sistem pembetungan dan untuk mengesan sama ada terdapat sebarang kebocoran berlaku dalam pembetung talian dikaji yang boleh menjejaskan kadar aliran dalam pembetung. Kajian ini dijalankan dengan menggunakan dua buah meter aliran bagi mengukur aliran di dalam pembetungan yang tidak mempunyai cabang di sepanjang paip pembetung di kawasan Universiti Malaysia Pahang (UMP) dalam tempoh musim basah dan kering. Tolok alat hujan juga digunakan untuk mendapatkan keamatan hujan. Perbezaan antara kedua-dua tempoh aliran masuk dan penyusupan, dan hubungannya dengan hujan dapat dilihat dengan jelas. Hasil data daripada aliran masuk dan penyusupan analisis dibandingkan dengan aliran masuk dan kadar penyusupan had reka bentuk yang ditetapkan dan dibernakan dalam Standard Malaysia MS 1228: 1991, kajian kes sebelum ini mengenai aliran masuk dan penyusupan yang dijalankan di Skudai, Johor dan aliran masuk dan penyusupan pelbagai anggaran yang telah dinyatakan dalam Hammer & Hammer. Kadar penyusupan tertinggi yang diperolehi (19.71 liter/day/km/mm-dia) adalah dalam julat had reka bentuk yang ditetapkan dalam MS 1228:1991 iaitu, (50 liter / hari / km / mm-dia) dan juga dalam anggaran yang dicadangkan oleh Hammer & Hammer (18-46 liter / hari / km / mm-dia.).

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LIST OF ABBREVIATIONS

APUSS	Assessing Infiltration nor Exfiltration on the Performance of Urban Sewer Systems
CSOs	Combine Sewer Overflow
CSTs	Combine Septic Tanks
HDPE	High Density Polyethylene
IDEA	Intermittent Decanted Extended Aeration Systems
I/I	Inflow and Infiltration
ISTs	Imhoff Tanks
JPPH	Jabatan Pembangunan and Pengurusan Harta
KK2	Kolej Kediaman 2
KK3	Kolej Kediaman 3
MMSD	Milwaukee Metropolitan Sewerage District
M6	Manhole 6
M7	Manhole 7
PE	Population Equivalent
Q1	Sewer Flow in Manhole 6
Q2	Sewer Flow in Manhole 7
ROW	Public Right of Way
UMP	Universiti Malaysia Pahang
UTM	Universiti Teknologi Malaysia

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Inflow is the average volume of excess water, (rain water) per unit time that enters the sanitary sewer through improper plumbing outside residences connection, hoses, manhole covers and catch basins. Infiltration is the process of ground water that slips into the sanitary sewer through cracks or bad joints on the sewer pipe. Unwanted rain water or ground water will become inflow and infiltration when they enter sanitary sewers, which may cause sewage overflows and overwhelming of wastewater treatment plants.

Malaysia is a country that has copious rainfall with varied seasonal rainfall. During the monsoon seasons, the exposed area of Peninsular Malaysia will experience heavy rain. Heavy rain will cause the increase of flow in sewerage pipes and sometimes may result in flooding. Therefore, a good design and maintenance in sewerage systems is important to assist the collection and transportation of wastewater from community and industrial areas as well as excess water from runoff to wastewater treatment plant.

Basically, in wastewater collection and transport system, Malaysia widely practices the separate sewerage system where the storm water drainage is separate from the sanitary sewerage system. This is to ensure the safety of residences and the environment. Besides that, it is also to avoid the combine sewer overflow (CSOs) problem that obviously can be found in combined sewer system.

Even though there is a separation systems between the sanitary sewer and storm sewer, some problems such as leakage of pipe, manhole and manhole covers which allow ground water into the sewer or unwanted street water into the sewer and street drain connected to sewer system which result in excess sewage flow will still occur in the sewerage system during heavy rain. The increased flow consume the capacity needed for future growth in a region and can damage the environment as well as sensitive ecosystems besides increasing also the cost of wastewater infrastructure. Therefore, a research is carried out in University Malaysia Pahang (UMP) Gambang Campus to investigate and collect inflow and infiltration data in sewerage system within the UMP area. In addition, this research is also conducted to detect the existence of leakage in sewer line by determining the equality of discharge between inflow and outflow in sewer line. The flow rate and flow velocity data in selected sewers are measured and collected using area velocity flow-meter and rainfall data is collected using rain gauge to achieve the objectives of the research.

1.2 PROBLEM STATEMENT

There are several problems that often occur during heavy rain. When it rains, public infrastructure defects will allow unwanted water to enter the sewer system. The public property defects such as street drain connected to sewer, leaky pipes and manholes, leaky manhole covers, leaky pipe connections, and manhole cross connections will allow ground water as well as unwanted street water to enter the sewer and this will lead to increase of sewage flow with high flow rate that can cause sewer manhole overflow and floods on the road. Additionally, the sewer pipes system that didn’t undergo any inspection or repair for a long time are likely to be cracked or broken and may cause the excess water from inflow and infiltration to enter the sewer system through open joints, cracks, and breaks in pipes. Sometimes the sewer pipe is unable to transport the capacity of overflow wastewater due to the overwhelmed sewer transport capability. The leakage of sewer pipes will also affect the flow rate of wastewater inside the sewer pipe.

1.3 OBJECTIVES OF STUDY

The main purpose is to study inflow and infiltration in sewerage system by collecting data from field runs into UMP area. The more precise objectives of this study are:

1. To study the relationship of rainfall intensity with inflow and infiltration rate in sewerage system.

2. To detect whether there are any leakage present in the sewer lines studied which may affect the flow rate in sewer.

3. To reduce the potential problems that may arise due to inflow and infiltration in sewerage system by providing the feedback of the results obtained to the relevant authority.

1.4 SCOPE OF STUDY

In this study, the location to carry out the research is within UMP area. Population equivalent will be based on UMP selected area. Two specific manholes will be selected where the sewer is straight throughout without any branches. Two area velocity flow-meters will be used to determine the flow rate within the selected sewer pipes. Six sets of inflow and infiltration data in sewerage system are aimed to be collected by using the area velocity flow-meter. Rainfall data will be collected from the rain gauge located at Kolej Kediaman 2 (KK2). The duration for each set of data collected is two weeks. From the data collected, graphs will be produced to determine the relationship of flow rate with rainfall intensity. Malaysia Standard Code of Practice for Design and Installation of Sewerage System, MS 1228:1991 is used as a guide for the data collected and result analysis. Indah Water Konsortium Population Equivalent Table is used as a guide to determine population equivalent within area covered by the sewer reticulation system studied.

1.5 RESEARCH SIGNIFICANCE

This research is carried out to determine the result of inflow and infiltration in the sewerage systems of UMP Gambang Campus. Most people seldom pay heed to the sewerage system that exists underground. In addition people don’t realize that inflow and infiltration issues may arise from roots of trees planted near the sewer lines and from lack of inspection as well as maintenance on manhole and sewer line. Therefore, this study is conducted to convey the information of inflow and infiltration in sewerage system as well as to provide feedback for improvement on the sewerage system. Besides, this research also carried out to provide useful data and information for further studies on the inflow and infiltration in sewerage systems in Malaysia.

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY

Development of the 6000 year technological history in sewerage systems has become a vital contribution to human history. Minoans and Harappans in Crete and Indus Valley civilizations are known as pioneers in developing basic sewerage and drainage systems (Feo et al, 2014). Indus Valley civilization (3200-2800BC) was the first civilization that contained sewer facility's system such as masonry rectangular X-sections, drainage systems, brick-lined cesspools (soak-pits) which conveyed to the local river for discharge and bathrooms as well as latrines in houses connected to sewers in the streets. Since then there were more sophisticated sewers in the Indus Valley featuring brick-lined pits similar to modern septic tanks and enclosed drains that carried both sewage and storm water out of the ancient city of Mohenjo Daro. By far the Mohenjo Daro ancient sewer system was the most advanced and complete sewer disposal system that can be put into use till pre-planned modern cities of the 20 century (Schladweiler, 2002). Romans and Hellenes further developed the sewerage systems by widespread use of sewer. Until year 1850 onwards, modern sewerage was renascent but there are many principles predominated by the ancients that are still in use today (Feo et al, 2014).

In the past metropolises of Renaissance Europe, sewer systems were built as open-air style systems which had caused unpleasant odour and is environmentally unsanitary until diseases spread across Europe. After years of development in Europe, the sewerage systems were developed to cater to the increase of population and the rise of civilization. Today sewer systems are enclosed beneath street manholes and curbside steel gratings which are more environmentally friendly compared to more ancient systems (Joaquin, 2010).The earliest sewers in the 19th century were designed to carry street runoff away from inhabited areas and were drained into combined sewer without undergoing any treatment process. After several decades, combined sewers were found to be ineffective and not economical for wastewater treatment during raining. Therefore, sanitary sewers were built and operated separately from storm sewers that only carry away the runoff from precipitation.

"Urban man today still unnecessarily pollutes streams, bathing beaches, bays and estuaries, without benefit of the excuse of ignorance which was available to his ancestors" (Harold, 1940). Hence, sewerage systems are critical for clarifying and treating wastewater before releasing the treated effluent into nearby watercourses.

Malaysia's sewerage industry has evolved over the last half a century where prior to the country's independence in 1957, there were no proper sewerage systems as well as a proper sewage treatment due to the low population densities and very limited urbanized developments. The improvement of sanitation was made by providing partial primary treatment of sewage such as Communal Septic Tanks (CSTs) and Imhoff Tanks (ISTs) which are able to serve a bigger population via a series of pipes connecting a row of tanks to improve the quality of effluent in the 1960s. While in the 1970s, partial secondary systems such as oxidation ponds were introduced to the community which produces a better effluent quality. In the 1980s, fully mechanized systems were introduced which are able to provide full secondary treatment that can meet the Department of Environment's effluent standards systematically.

The technological development and advancement in computer technology and microelectronics allow for enhancement and optimization of sewage treatment systems, like the PLC are used for better control of the sequencing batch reactor processes or intermittent decanted extended aeration (IDEA) systems (Hamid and Baki, 2002).

2.2 SEWERAGE SYSTEMS

Sewerage system is vital to civilization; this is to provide a good sanitary environment and development for a city. The role of sewerage systems has changed and widen in scope from year to year with changes in socioeconomic conditions, city structures, and the environment. The basic role of sewerage systems such as to improve the living environment by drainage and treatment of wastewater, prevent floods occur through removal of rainwater and preserve the water quality of public bodies. The additional role of sewerage systems such as reuse of treated wastewater, advanced wastewater treatment and used wastewater as a heat source by using heat exchange technology and conversion of sludge into resources is also within the scope practiced widely in many countries especially in Japan.

Sewerage systems consist of several components such as drain, manhole and pumping station. These components play their role in the sewage discharge in a sewerage system. There are three common types of sewer that exist in a town or city, which are sanitary sewer, storm water sewer and combined sewer. Among the three types of sewer, sanitary and storm water is considered as separate sewer system. In modern cities, the separate sewer system are widely practiced where sanitary sewer act as sewage carriage from houses, commercial buildings and industrial by being directly connected to main sewer and bringing the sewage to treatment plant. Meanwhile, storm water sewer only collects rain water from street runoff with the help of gutters and catch basins and flows to watercourses or the sea. This helps to increase the efficiency and cost effectiveness in sewage treatment. Malaysia is a country that widely practices the separate sewer system. The Figure 2.1 below shows the flow in separate sewer system.

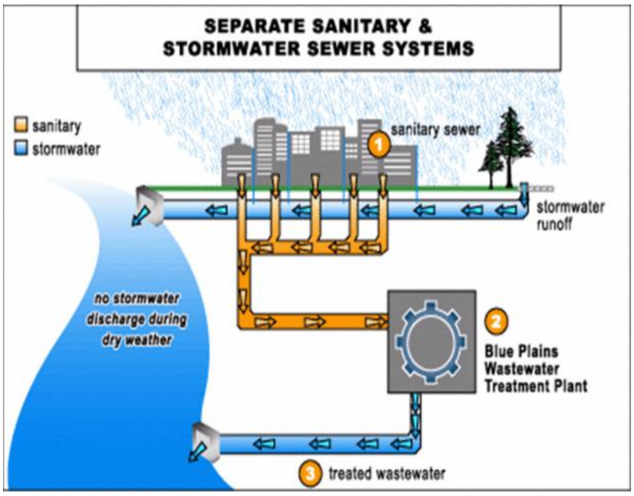


Figure 2.1: Separate Sewer Systems

For the combined sewer system which carries both sewage and storm water, they are usually practiced in older sections of urban areas. This combined sewerage system commonly causes water overflow from manholes during heavy rain and water pollution as well. This is because storm water in high flow volume can increase the sewage flow rate and cause the volume of sewage to increase and this may cause the wastewater to be not well treated and high expenditure required for lots of time to treat it. The Figure 2.2 shows the flows of sewage and storm water in a combined sewer system during rain.

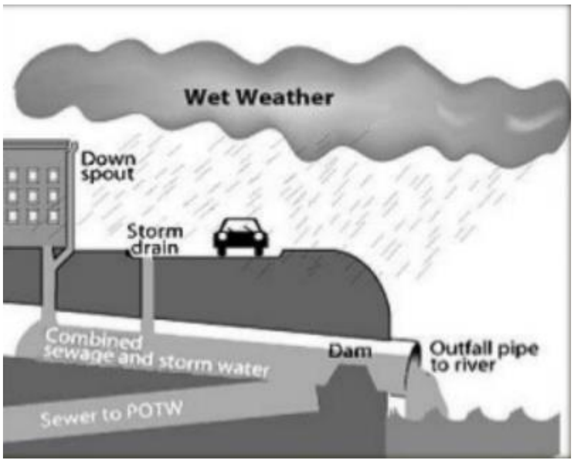


Figure 2.2: Combined Sewers System during Rain

2.3 INFLOW AND INFILTRATION IN SEWERAGE SYSTEM

Inflow and infiltration are the ways that ground water and storm water enter into dedicated wastewater or sanitary sewer systems (Donohue, 2012). Previously, most of the wastewater collection mangers didn't pay much attention to quantifying sewer performance except for the occurrences of overflow in sewers (Burian and Edwards, 2002). Malaysia is a high rainfall distribution country. When significant rain occurs, inflow and infiltration will occur in the sewer lines that have cracks and leakage or misconnection of joints. The excess of wastewater entering the sanitary sewer system can cause the flow in the sanitary sewer system to overwhelm the capacity of the pipe to transport wastewater. Since the sanitary sewer lines are small compared to storm sewer (Hammer & Hammer, 2012). The increase of flow in the sanitary sewer system due to the inflow and infiltration will lead to the overflow of sanitary sewer manhole and more expenses in wastewater treatment where excess storm water in the system are being unnecessarily treated as well. Normally, quantity of infiltration and water that entering into a sewer depends on the number and condition of the pipe, joints, ground water level, manholes and structures construction practices (Hammer & Hammer, 2012). Therefore, there is a need to reduce the excess water entering the sanitary system by removing the sources of inflow and infiltration.

The advantages of removing the sources of inflow and infiltration are basement backup, claims about the costs associated with backup and treatment cost can be reduced and the environment is well protected from the impact of overflows. To reduce the inflow and infiltration in sewerage system, it is necessary to evaluate, maintain and repair the sanitary sewer system constantly by using technology such as a portable video camera through pipes to detect and remove roots as well as visual inspections.

When the sanitary sewer systems have reached their capacity or become over-loaded, wastewater flows at much higher water level than normal and if sanitary fixtures or drains are below this overload level, water will flow backward through the sanitary sewer pipe, flooding basements or households and causing manholes to pop open, releasing wastewater onto the street (Xylem Inc, 2011).

Normally, inflow and infiltration, reduce the ability of sanitary systems and treatment facilities to transport and treat domestic as well as industrial wastewater (Xylem Inc, 2011). The Figure 2.3 shows inflow and infiltration sources in sanitary sewer and storm water sewer.

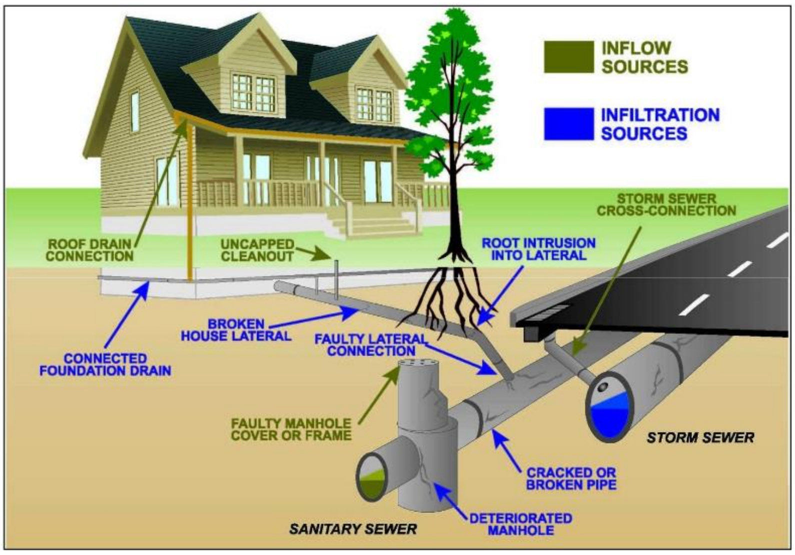


Figure 2.3: Typical Sources of Inflow and Infiltration

2.4 FACTORS OF INFLOW AND INFILTRATION IN SEWERAGE SYSTEMS

Normally, inflow and infiltration in sewerage systems does occur based on several factors that are caused by man and natural phenomenon. Poor quality control during the sewer pipes construction and supervision work acts as the main factor that contributes to the occurrence of inflow and infiltration in sewerage systems. Problems arise if cracked pipes, defect pipe fittings, joints connection between pipes and manhole are too loose or rigid due to no rigorous action made during construction and supervision work for sewerage systems.

Besides that, the population kept increasing in an area is also considered as one of the factors that can lead to the problem of inflow and infiltration. When the population increase until it exceeds the population equivalent initial, this will overburden of the sewerage system cause cracks or leakages in sewer and sometimes may even cause whole sewerage systems to break down. Infiltration problems arise from sewer leakages or cracks.

Sewerage systems that lack maintenance and inspection as time goes by also experience inflow and infiltration. The materials such as pipes, joints and pipe fittings used in sewerage systems construction will get defect and deteriorate due to the continuous transport of the sewage. Siltation will also occur within the sewerage system due to the lack of inspection. This can affect the flow of sewage due to the blockage of sewer pipes and thus excessive pressure can cause leakage of the sewer pipes.

Inflow and infiltration may be by natural phenomena too. Precipitation plays a vital role in the inflow and infiltration of sewerage systems. It can be clearly seen between the rain season and without rain season. During the raining season, the inflow and infiltration rate will increase when rain intensity increase. While for non-raining rain season, inflow and infiltration rate will be less compared to during the raining season.

The vegetation such as grass or trees that exist above or nearby the sewer system will also contribute to infiltration within the systems. Infiltration rate through soil is high due to the slow surface runoff among the vegetation. Trees that have long roots also have a high tendency to cause a pipe cracks and leakages as time goes by since a roots have its own ability to help the trees to find water resources. This can contribute to the infiltration in sewerage systems.

The existence of ground water table located either above or at the same level as sewer pipes may cause infiltration to occur. This is due to the fact that surrounding ground water will penetrate through the pipes if there are cracks and leakages. Besides that, soil properties also will affect the infiltration rate during raining. Different properties of soil will give different infiltration rate. For example, sand have a high rate of infiltration due to its high permeability.

2.5 PREVIOUS CASE STUDIES

Inflow and infiltration are often identified as a problem in sewer systems (Fleming et al, 2005). Generally inflow and infiltration into sewer systems is unwanted because this can reduce the performance of wastewater treatment plants and increase combined sewage overflows. Sewer rehabilitation is costly, even though it can reduce the problem of inflow and infiltration. In this study, sewer rehabilitation was shown to reduce ground water infiltration as well as the inflow of storm water. However, the necessary quality assurance is often lacking due to the methods that explicitly take into consideration the variability of the climatic and hydrologic conditions are lacking. Therefore an additional monitoring campaign in a reference catchment and regression analysis to test the significance of an observed inflow and infiltration reduction were conducted. This provides a reliable performance assessment that may lead to more effective in inflow and infiltration management and sewer maintenance (Staufer et al, 2012).

Information about the discharge and variability of typical wastewater sources in urban catchments is required for the sewer systems management especially for the infiltration of ground water and inflow of surface water which play vital role in making decisions about sewer rehabilitation and sewer reticulation operation. In the case study for estimation of contributions to the wastewater flow in the sewer system of the Dresden City, Germany, inflow and infiltration as well as quantity of the flows were identified and estimated. The characteristic of infiltration was gained by clustering and grouping sewer pipes according to the attributes construction year and ground water influence by relating to infiltration behavior. It also show that infiltration potential of sewer pipes can be estimated based on the condition that shown by CCTV data. In the test case, a relationship between infiltration potential and pipe condition was detected and the result is reliable for infiltration determination according to the pipe condition. In the study, the ground water influence and the year of construction were identified as indicators to forecast the infiltration potential of sewer pipes (Karpf and Krebs, 2011).

A portion of rainfall that gets into a sewer system in the form of inflow and infiltration can cause excess flow in the sewer system. A serious inflow and infiltration in a system is undesirable which can increase the operating costs and often requires facilities to be built with capacities greater than otherwise would be needed. This study is carried out to produce more reliable estimates for rain derived inflow and infiltration characteristics in a sanitary sewer basin. Therefore, a good forecast requires in modeling techniques. The autoregressive model described provides a natural platform for flow forecast under hypothetical storm conditions. However some modeling details need yet to be worked out to support a working model. The practical need for flow forecast also warrants further research (Zhang, 2007).

Reduction of extraneous flows into sanitary systems is recognized as a difficult and expensive task. The best strategy is to invest in good quality construction and supervision. However, the existing of low performance sewer systems should also be noted and carefully included in the planning. Therefore application to systems managed by AGUAS DO AVE service area is needed to minimize the inflow and infiltration in separate sanitary sewer systems. This Ad Ave wastewater interceptor and treatment systems presently caters to eight municipalities in Portugal. This approach, innovative in Portugal of collaboration between different stakeholders is believed to allow for future improvements in the performance and efficiency of wastewater systems as a whole contribute to a better knowledge of the current situation (Novatech, 2007).

While for the Milwaukee Metropolitan Sewerage District (MMSD)'s private property inflow/infiltration pilot project in U.S, MMSD determined that 4500 homes in Whitefish Bay, U.S, there are 78 percent have foundation drains connected to the sanitary sewer laterals supporting the result of foundation drains could be contribute a significant amount wet weather inflow to sanitary in 1981 (Donohue, 2012).

In 2002, sewer main video inspections approximately 95 percent of village main were reviewed with observation included in Village Whitefish Bay's 2002 Sanitary Sewer Facility Plan. Village staff noted that structural defects such as broken and collapse pipes, missing pipes and defective or missing lateral connection, manhole defects, broken or missing pipes and lateral connections are significant sources of inflow. This plan also examined Village- wide inflow and infiltration reduction by repair and replace the sewer and manhole. The hydraulic analysis showed at least six of the Village's by passes between the sanitary and storm water sewer systems have the tendency of backflow causing storm water runoff to flow into the sanitary sewer systems. Since 2004, the village has implemented plan elements within the public right-of-way (ROW) based upon this plan. Thus far approximately 25 percent of the sanitary sewers had been rehabilitated or replaced. Choose a correct strategies and techniques before begin a project can contribute successful inflow and infiltration studies which assist in precisely identification of inflow and infiltration severity and distribution. Managers and engineers are required to change their fundamental conception to wet weather analysis based on the strategies that chosen and the change is compel. Every project that use are smaller basins and higher accuracy measurements, so same benefits are realized. Bottlenecks can reveal by using the scatter graphs which provide additional tool for carrying capacity visualization (Donohue, 2012).

According to Malaysian case study in Johor, the infiltration measurement at an abandoned sewer line in Taman Sri Pulai, Skudai showed that the infiltration rate will rise sharply when it rains compare to the infiltration rate during periods that have no rain. This leads to the conclusion that the relationship between rainfall and infiltration rate in sewerage systems is proportional and tremendous amount of extraneous water are seeping into the sewerage systems (Rahman et al, 2007). In addition, there are several factors that will affect the inflow and infiltration such as leakage of sewer pipe, strength of channel, the type of soils, the incorrect way of sewer connection, high runoff, rainfall factor, and the soil conditions where the ground water level is over the level of the sewer pipe from the study carried out in Taman Sri Pulai, Skudai (Rahman et al, 2003).

2.6 SUMMARY OF CASE STUDIES

According to the previous case studies discussed in the previous, a systematic investigation of the sewer system had identified the presence of flow rate and type of inflow and infiltration conditions which exist in the sewer system at Village of Whitefish Bay, Wisconsin. The result of this is consistent with previous studies that wet weather flows in the sanitary sewer system are excessive, and primary cause of basement backups. While groundwater infiltration rates are generally low, peak wet weather flows can be extreme and exceed sewer capacities. Therefore, Village decided to develop and execute a PPII reduction program, including pre-habilitation flow monitoring, sewer and building inspections and testing, rehabilitation, and post- rehabilitation flow monitoring to improve and reduce inflow and infiltration in the sewer system (Donohue, 2012). Inflow and infiltration cause numerous problems in the operation of sewer systems and treatment plants alike, and many rehabilitation projects aim to reduce inflow and infiltration. However, the necessary quality assurance is often lacking. In this study, an additional monitoring campaign in a reference catchment as control data is implemented to overcome the problems. Regression analysis is used to test the significance of an observed inflow and infiltration reduction. For successful practical applications, it might be necessary to develop new ways to communicate the significance of an observed effect. Although decision makers might have difficulties to accept the possibility failure, this is probably the most efficient way to learn from unsuccessful rehabilitation projects. This gives the reliable performance assessment to more effective inflow and infiltration or management and sewer maintenance in the long term (Staufer et al, 2012).

In addition, the quantity of infiltration, water entering a sewer depends on the number and condition of the pipe and pipe joints, ground water level, manholes and structures and construction practices. The actual inflow and infiltration rates for a system may be determined by comparing wet weather versus dry weather flows. For planning purposes, infiltration allowances are used to set a standard for sewer design and construction practices.

This is to determine a policy allocating the cost of sewer construction versus treatment. Estimation of infiltration is based on pipe diameter and its length. Infiltration estimates range is from 185 to 146 l/d/cm-dia./km. For new construction, inflow is not expected, however, some municipalities make allowances for inflow ranging from zero, where the inflow is included with 460 l/d/capita to 190 l/d/capita (Hammer & Hammer, 2012). Sewer systems constitute a very significant patrimony in European cities. Their structural quality and functional efficiency are key parameters to guarantee the transfer of domestic and trade wastewater to treatment plants without infiltration nor exfiltration. During the period 2001 to 2004, the European research project Assessing Infiltration nor Exfiltration on the Performance of Urban Sewer Systems (APUSS) was devoted to sewer infiltration nor exfiltration questions. This project structured in three main Work Areas dealing with the development of new measurement methods based on tracer experiments and accounting uncertainty analyses. The implementation of models and software tools and the integration of economic and operational questions by means of cost estimation methods applied to investment or rehabilitation strategies, also described synthetically to get a better knowledge about phenomena and make decisions based on more accurate and elaborated information (Bertrand-Krajewski et al, 2006).

Besides the abroad case studies, a local case study which was carried out at Skudai, Johor, Malaysia also provided useful information for the inflow and infiltration study. This study provides the appropriateness of some of the design parameters used by the local engineers. Particulars attention is also given to the variation of inflow and infiltration with respect to rainfall occurrence which is found to be very large. The data used in making the evaluation are obtained using flow-meters for measuring the flow in a running sewer line in two different residential areas, and collecting and measuring the amount of water trapped in an abandoned sewer line as the field model, continuously for nearly eight months, which include both dry and wet periods and by performing infiltration tests on a laboratory model under saturated and unsaturated conditions to obtain the results in a controlled environment. The rainfall is also measured as well. The results show that infiltration into sewers, are higher than the allowable range under the Malaysia Standard MS1228:1991 during the wet periods while for the laboratory tests, it show results are within allowable limits. (Kamran, 2005)

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

The research of inflow and infiltration in sewerage systems is done through field work. In this research, a sewer line connecting two manholes with no lateral branches in between is required and located within UMP Gambang Campus at the area near the sports complex and library. The two selected manholes are labeled as manhole 6 and manhole 7 (Refer to Appendix A & B). There are six sets and above of data are carried out in this research. Each set of sewage flow rate data and rainfall intensity data are collected respectively for two weeks. The below shows Figure 3.1and Figure 3.2: Manhole 6 & Manhole 7 respectively. While Figure 3.3 shows an inflow and infiltration study of methodology flow chart.

Figure3.1: Manhole 6

Figure 3.2: Manhole 7

3.1.1 FLOW CHART OF METHODOLOGY

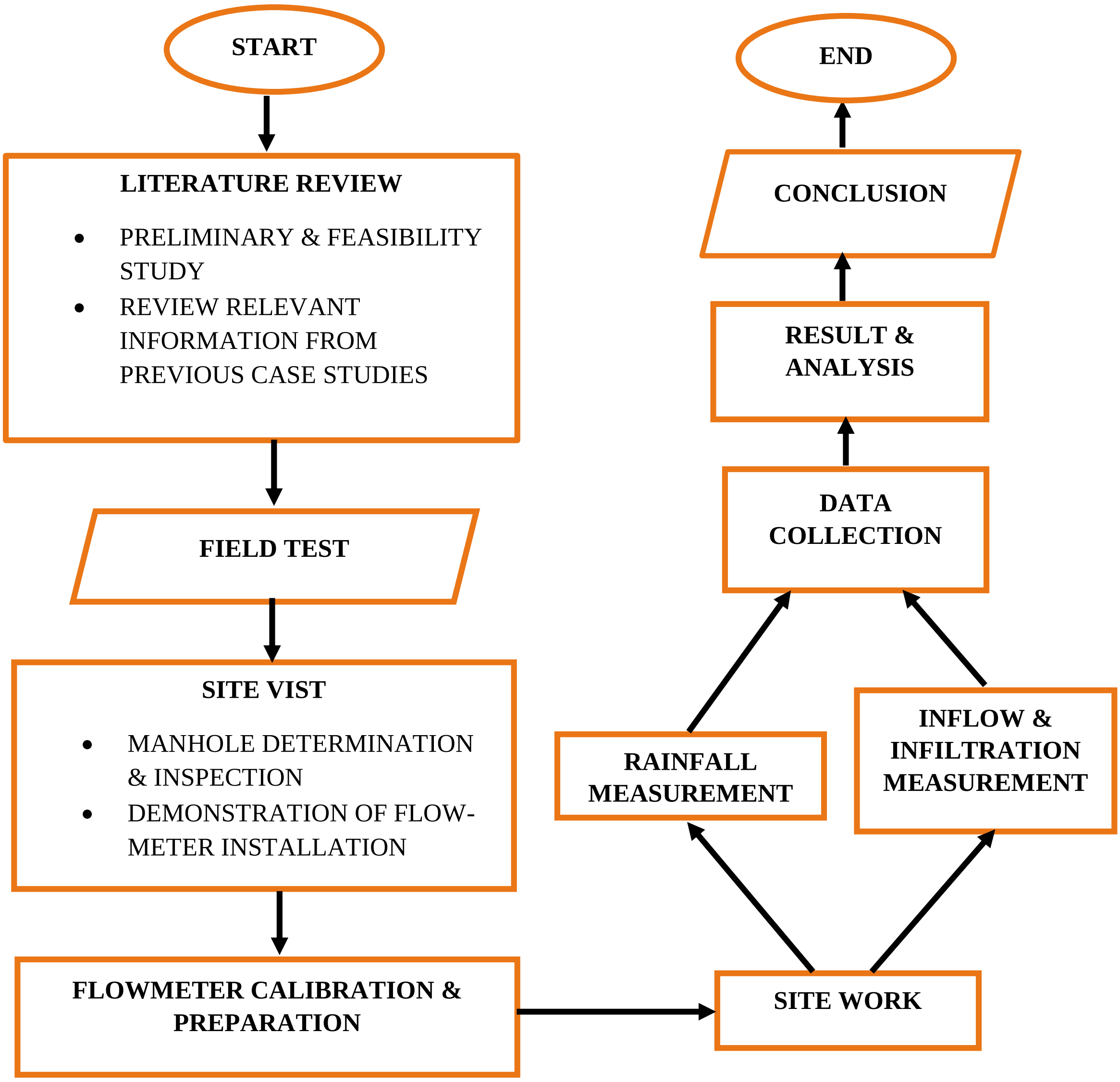
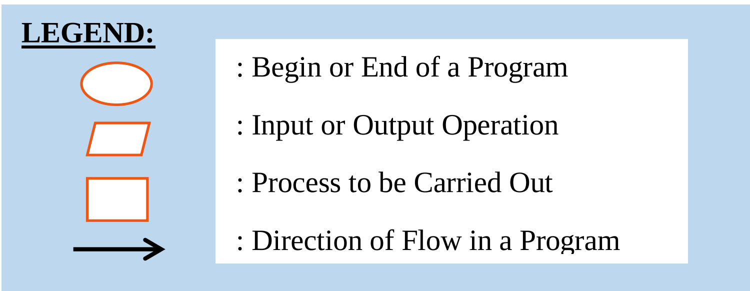


Figure 3.3: Inflow and Infiltration Methodology Flow Chart



3.2 PRELIMINARY AND FEASIBILITY STUDY

Before starting the research in the field, it is required to study and collect information about the topic of inflow and infiltration from previous theses and books to have a proper understanding on the topic given. Arrangement for meeting and site visit with Jabatan Pembangunan and Pengurusan Harta (JPPH) mechanical unit staffs, hydrology lecturers, laboratory assistance and manhole contractors are also required and conducted to ease the works afterwards and to assess the situation of the selected places.

3.3 COLLECTION OF RELEVANT INFORMATION

The sources of information and case studies on the topic of inflow and infiltration in sewerage systems can be widely found from abroad compared to local case studies in Malaysia. This is due to the fact that the study of inflow and infiltration is still new in Malaysia and very few researches have been conducted on this aspect. Therefore the journals, articles as well as books that were referred to are mostly from abroad.

3.4 LIST OF EQUIPMENT AND MATERIALS

Several equipment and materials are required when conducting the research and they are listed as follows shows:

1. Area Velocity Flow-meter Isco 4250
2. Area Velocity Flow-meter Isco 2150
3. Batteries of Flow-meter Isco 4250 & Isco 2150
4. Sensors of Flow-meter Isco 4250 & Isco 2150
5. Rain Gauge
6. Digital Multimeter
7. Mounting Rings
8. Flow-meter Isco 4250 & Isco 2150 Adaptor

9. Gloves
10. Masks
11. Manhole opener

3.5 SITE VISIT

Site visit had been conducted twice. The first site visit was a demonstration of the installation of newly arrived flow-meter (model 2150) using mounting ring at the manhole near to Kolej Kediaman (KK3) area.

The second site visit was conducted to determine a suitable sewer and manhole location based on the sewer reticulation layout plans obtained from UMP Holdings Berhad before beginning the field work. There are three sites that were proposed for the research. Finally, manholes nearby the sport complex and library were selected as the location to undergo the research due to its suitability. Based on the sewer reticulation layout plan, the sewage transport area covered is wide and the sewage is collected at manhole 6 before flowing to manhole 7 and after that to the localized wastewater treatment plant. (Refer to Figure 3.4 and Figure 3.5)

Figure3.4: Manhole 6 Site Visit

Figure 3.5: Manhole 7 Site Visit

3.6 FLOW-METER CALIBRATION

There is a need to have calibration on both area velocity flow-meters before the start of the field work. Calibration of the two area velocity flow-meter was carried out at the hydrology laboratory's open channel. Both flow-meters are different in model series, but still have a similar duty in performance. Since area velocity flow-meter Isco 2150 is new, it didn't have any error after the calibration as well as battery issue. While for area velocity flow-meter Isco C4250, there were some reading errors during the high rate of water flow. After adjustment, the error was fixed and the calibration of Isco C4250 was good. Unfortunately, Isco C4250 faced another problem which is the battery issue since Isco C4250 is old equipment. After a series of tests on the batteries A, B, C and X, a result was attained by using digital multimeter to measure the voltage of batteries which showed that Battery A and X can perform well among the four batteries tested. Battery B is damaged and cannot be used while battery C can just sustain for a short period of time (about 5 hours). Hence, Battery A and X are used. (Refer to Figure 3.6 to Figure 3.9) After run about 2 sets of data. Battery X is damaged and there are six batteries from UTM are used and replaced for the damaged of battery X.

Figure 3.6: Battery of Flow-meter C4250

Figure 3.7: Digital Multimeter

Figure 3.8: Isco Flow-meter C4250

Figure 3.9: Isco Flow-meter 2150

Figure 3.10: Lead Acid Battery from UTM

Figure 3.11: Isco Flow-meter Sensor

3.6.1 CONDITION OF BATTERIES FOR ISCO 4250

At below shown, there are 6 batteries with label:

- UTM a (Ni-Cd) – not available
- UTM b (Ni-Cd) – not available
- UTM c (Lead-Acid) - available
- UTM d (Lead-Acid) - available
- UTM e (Ni-Cd) – available

- UTM X (Ni-Cd) - not available
- UMP A (Ni-Cd) - available

Based on the second battery calibration, Battery UTM e and both Lead Acid batteries for area velocity flow-meter ISCO 4250 can only last for maximum 3 days. But it still needs to observe by time to ensure the performance. UMP A after several times used, it can also last for maximum 4 days. To ensure the flow data are recorded smoothly without any halt, battery normally should change after every 3 days. At last, there are four batteries (UTM & UMP) can be used after the calibration.

3.6.2 FLOW-METER AND BATTERIES EQUIPMENT

The table below shows the summary of the area velocity flow-meter ISCO 4250 and others equipment that in good condition.

Adscription	UMP	UTM
a. <u>Batteries:</u> **1.** Nickel-Cadium Battery **2.** Lead-Acid Battery	1 nos (with Label A) - 	4 nos (with Label UTM a, b, e & X) 2 nos (with Label UTM c & d)
b. Flow-meter (Isco 4250)	2 nos (at laboratory)	2 nos (with UTM label) -1 nos (using) -1 nos (at laboratory)
c. Sensor	2 nos (1 nos using)	3 nos (at Laboratory box)
d. Battery charges	2 nos	2 nos

Table 3.1 Flow-Meter and Batteries Equipment

3.6.3 BATTERIES CALIBRATION FOR ISCO 2150

Date		Time	Batteries			
			A	% of batte	B	% of battery
17 Nov 20	Mon	4pm	6.41	83.3	6.41	83.3
19 Nov 20	Wed	4pm	6.226	55.1	6.226	55.1
21 Nov 20	Fri	10am	6.182	48.7	6.182	48.7
24 Nov 20	Mon	4pm	17.2	22	6.095	17.2

Date		Time	Batteries			
			C	% of batte	D	% of battery
24 Nov 20	Mon	4pm	6.5	90	6.5	90
26 Nov 20	Wed	4pm	6.289	64.8	6.289	64.8
28 Nov 20	Fri	10am	6.201	51.6	6.201	51.6
1 Dec 201	Mon	4pm	6.058	29.7	6.058	29.7

Table 3.2: Batteries Calibration for Isco 2150

3.7 SITE WORK

3.7.1 POPULATION EQUIVALENT (PE) DETERMINATION

According to the sewer reticulation layout plan, the location of the research is within the area of sewer reticulation that covers faculty office, FKASA laboratory building, library, curriculum center building and sports complex with 1473 PE. There are different types of population in the area covered. Therefore, PE needs to be estimated and calculated based on the PE table by Indah Water Konsortium. The PE table also same with the PE table in Malaysia Standard MS 1229:1991 code of practice for design and installation of sewerage systems. (Refer Appendix E)

3.7.2 WORK SCHEDULE FOR MANHOLE CONTRACTOR

After the second site visit, a work schedule is needed for the manhole contractor to assist in manhole opening, installation of area velocity flow-meter and batteries checking. This work schedule will also be given to the hydrology laboratory assistant.

This is because in a few months, the hydrology laboratory assistant will be the one to assist in the manhole opening work instead of the contractor. (Refer to Appendix C)

3.7.3 INSTALLATION OF FLOW-METER

The two area velocity flow-meters with sensors were installed after all equipment calibrations were done. The two flow-meters' sensors were fixed by the mounting ring as shown in Figure 3.10 and Figure 3.11.

Figure 3.12: Mounting ring

Figure 3.13: Mounting ring that fixed the sensor

3.7.4 INFLOW AND INFILTRATION MEASUREMENT

At the early stage, a suitable section of the sewerage system in between two manholes that do not have lateral flow was determined. Each manhole will be installed with an area velocity flow-meter with sensor inside it. The area velocity flow-meters will record the flow every ten minutes. The data are obtained from the area velocity flow-meters and downloaded into a laptop that has the Flowlink software to analyze the data. The two selected manholes are manholes 6 and 7, with manhole 6 as upstream manhole while manhole 7 is downstream manhole. Therefore flow in manhole 6 will be indicated as Q_1while Q_2 will be indicated as flow in manhole 7. Normally when $Q_1 = Q_2$ this shows that there is not any infiltration or leakage occurring in the sewer pipe.

If $Q_1 > Q_2$, the sewer pipe has leaked while $Q_1 < Q_2$, means that inflow and infiltration exist in the sewer pipe.

3.7.5 RAINFALL MEASUREMENT

Rainfall data are collected from the rain gauge located at KK2. Rainfall data are obtained by downloading the data from a laptop that receives the data remotely from the rain gauge as shown in Figure 3.13.

Figure 3.14: Rain Gauge at KK2

3.7.6 DATA COLLECTION

Data is collected once after every two weeks from the area velocity flow-meters. There are eight sets of flow data are obtained for the inflow and infiltration of the study area. Rainfall data will is also collected concurrently. The inspection will be done after each interval of three days to check on the battery life and if needed, change of battery will be done.

CHAPTER 4

RESULTS ANALYSIS AND DISCUSSION

4.1 RESULTS AND ANALYSIS

There are eight sets of data was collected on the selected sewer line which connecting the two manholes, which are manhole 6 (M6) and manhole 7 (M7) respectively. The collection of data can be divided into two series, which are series 1 and series 2. Series 1 data was collected at first semester from 1st December 2014 to 24th January 2015, while for series 2 data was collected at second semester from 7th March 2015 to 16th May 2015. In series 1, there are three sets of data were collected and for series 2, there are five sets of data were collected. Each set of data was collected for every two weeks in liter per day with every ten minutes time interval. In addition, rainfall also collected with every ten minutes interval in millimeter (mm) per day. Basically, at the Malaysia east coast area, the rain season usually occurs within the month of December to February. Therefore, series 1 was denoted as wet period while series 2 was denoted as dry period due to the rainfall in the months that do not occur as frequently as rainy season period.

Below are the eight sets of data that collected from 1st December 2014 to 16th May 2015. The period for each data set is as shown in the Table 4.1 and Table 4.2.

Set	Periods (Semester 1: 2014/2015)
1	1/12/2014 (Monday 12.00 am) - 15/12/2014 (Monday 12.00 am)
2	15/12/2014 (Monday 12.00 am) - 1/1/2015 (Monday 12.00 am)
3	1/1/2015 (Monday 12.00 am) - 24/1/2015 (Wednesday 10.20 am)

Table 4.1: Series 1 Data Collection

Set	Periods (Semester 2: 2015)
4	7/3/2015 (Saturday 10.20 am) - 21/3/2015 (Saturday 12.00 am)
5	21/3/2015 (Saturday 12.00 am) - 4/4/2015 (Saturday 12.00 am)
6	4/4/2015 (Saturday 12.00 am) -18/4/2015 (Saturday 12.00 am)
7	18/4/2015 (Saturday 12.00 am) - 2/5/2015 (Saturday 12.00 am)
8	2/5/2015 (Saturday 12.00 am) – 16/5/2015 (Saturday 12.00 am)

Table 4.2: Series 2 Data Collection

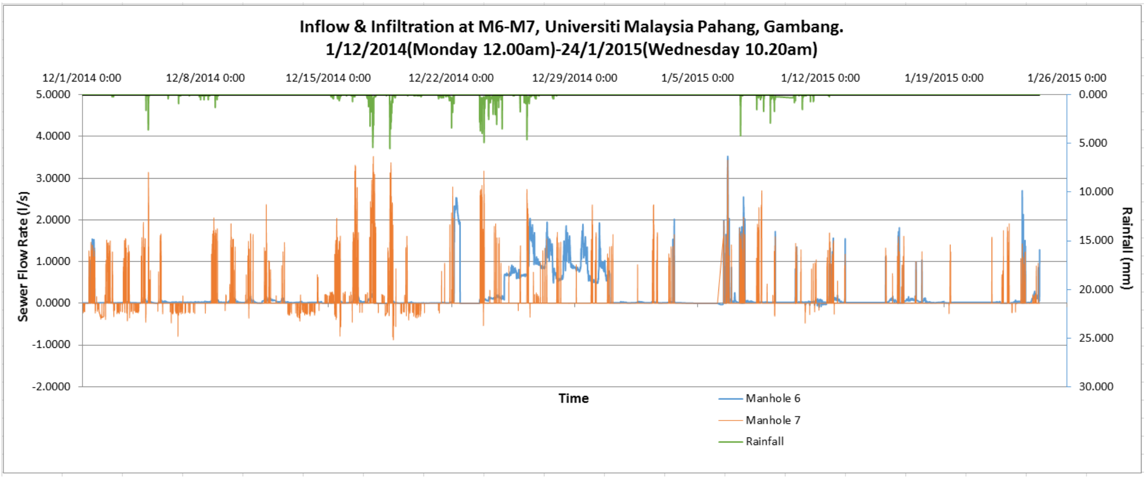


Figure 4.1: Series 1 Rainfall against Inflow and Infiltration

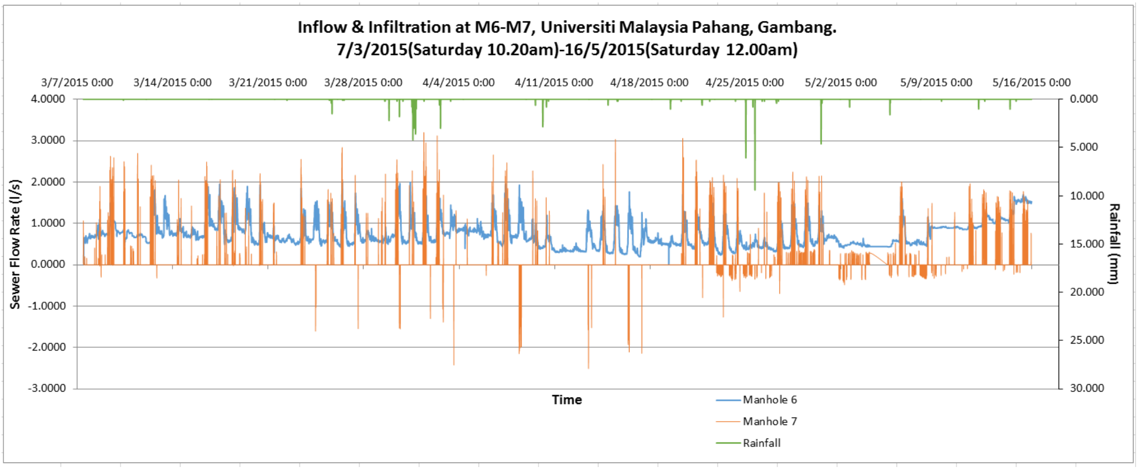


Figure 4.2: Series 2 Rainfall against Inflow and Infiltration

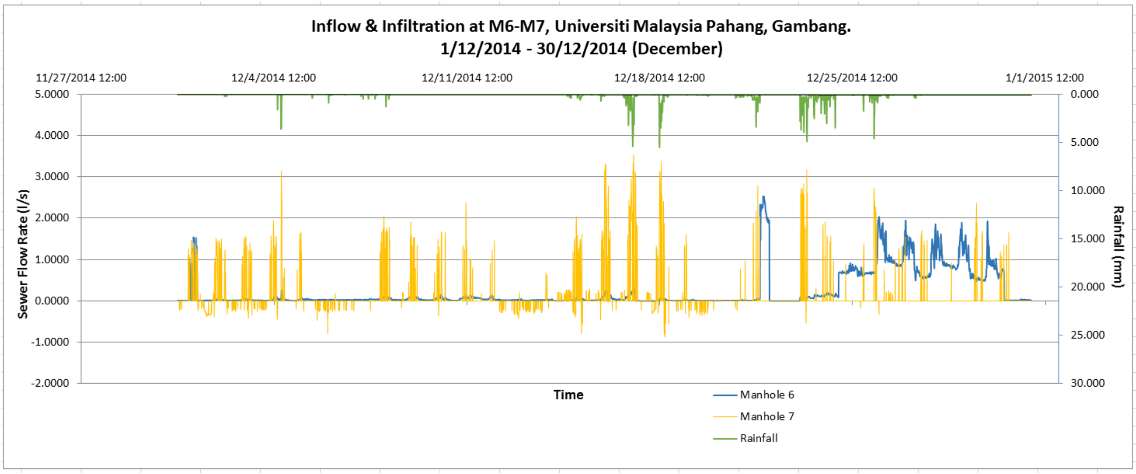


Figure 4.3: Inflow and Infiltration versus Rainfall in December (Wet Period)

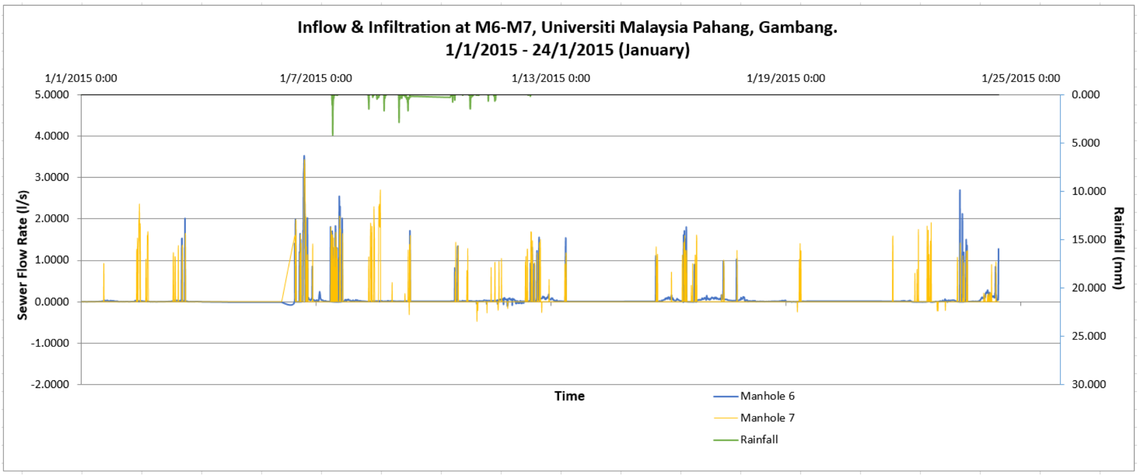


Figure 4.4: Inflow and Infiltration versus Rainfall in January (Wet Period)

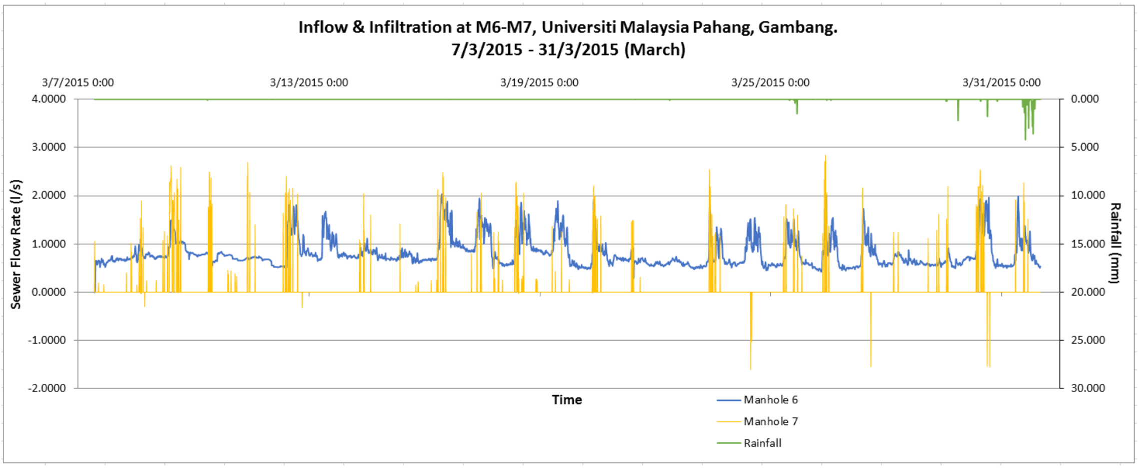


Figure 4.5: Inflow and Infiltration versus Rainfall in March (Dry Period)

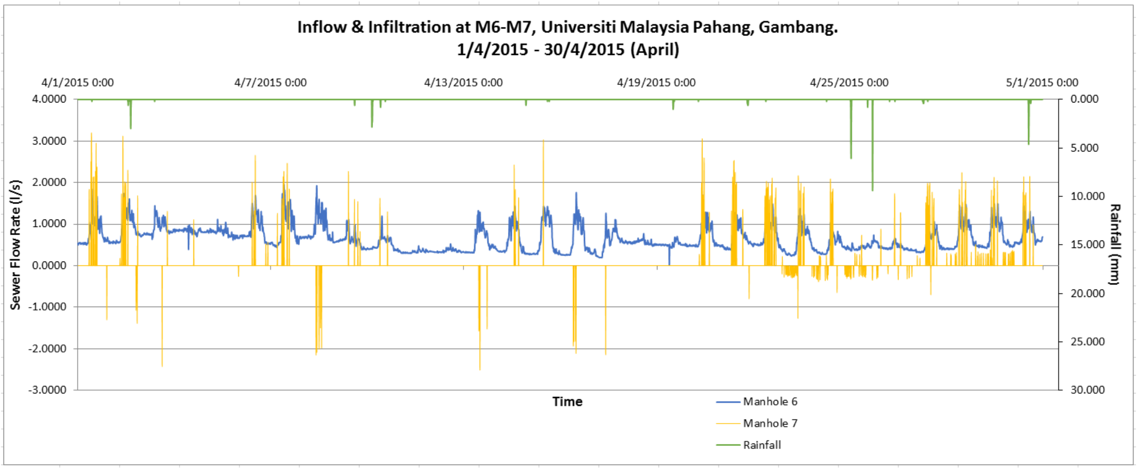


Figure 4.6: Inflow and Infiltration versus Rainfall in April (Dry Period)

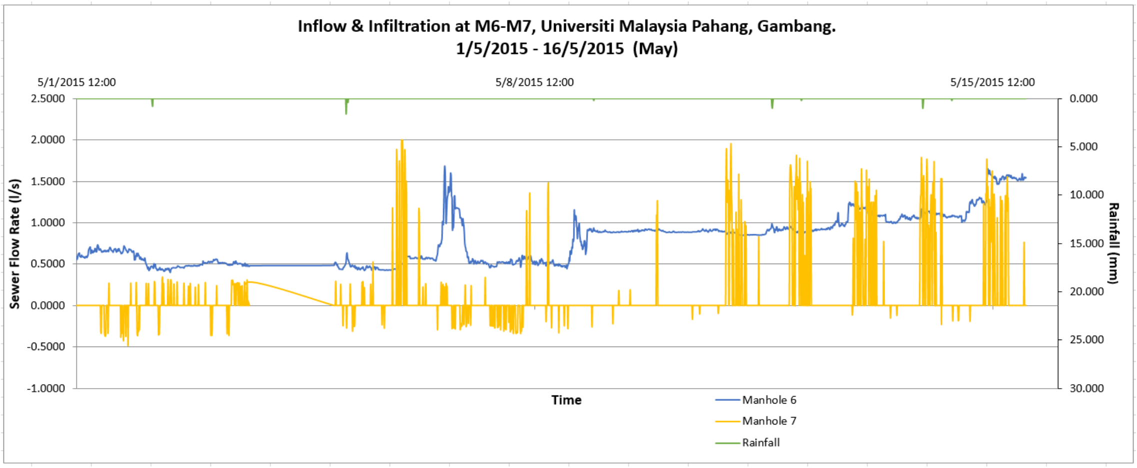


Figure 4.7: Inflow and Infiltration versus Rainfall in May (Dry Period)

4.2 DISCUSSION

In Figure 4.1, there is Manholes M6-M7 Flow Rate Graph from 1st December 2014 to 24th January 2015. In Figure 1, it shows the sewer flow rate at downstream manhole 7 is higher compared to the sewer flow rate at upstream manhole 6. This is due to the rainfall, which act as an influence factor in contributing the infiltration rate into sewer. Therefore, there is the rapid rise of infiltration rate after rain. In addition, there are numerous backflow occurs in manhole 7 flow rates. This can be explained the flow sometimes in manhole 7 is very small until the backflow of sewage. There may have the leakage or blockage in between the sewer line or nearby the sewer at downstream manhole 7.

In Figure 4.2 shows Manholes M6-M7 Flow Rate Graph from 7th March 2015 to 16th May 2015. In this Figure 4.2, it can be clearly seen that the sewer flow rate at downstream manhole 7 is smaller than the sewer flow rate at upstream manhole 6. There are numerous negative flow rate, which denoted backflow does occur in manhole 7. This can be explained the flow in manhole 7 is very small until the backflow of sewage.

There may have the leakage or blockage in between the sewer line or nearby the sewer at downstream manhole 7 which cause the backflow of sewer flow.

After comparing both of the flow rates from manhole 6 and manhole 7, the result from graph shows that leakage happens during dry periods. This occurs is due to the inflow of sewage in upstream manhole mostly is higher than the sewage outflow in downstream manhole. There might also have some crack within the old pipe due to the lack of inspection or time established. Besides, it also might have blockage occur in the sewer, which have improper act in toilet usage by flush away not flushable things into the sewerage system.

Figure 4.3 to figure 4.7 are the inflow and infiltration versus rainfall in about five months. Figure 4.3 and 4.4 are indicated as the sewer flow rate in the wet period from December to January while the figure 4.5 to figure 4.7 are the sewer flow rate in dry periods from March to May.

In Figure 4.3, a clear infiltration can be seen in the middle month of December, especially during the rainy period. This can be explained the rain act as influence factor which distribute the infiltration in the sewer pipe. In Figure 4.4, the infiltration also exists, but sometimes the sewer flow rate in upstream manhole also greater than the sewer flow rate in downstream. This can be predicted as there was somewhere leakage or blockage exist in between the pipe even there still have infiltration within the sewer pipe line.

In the dry period, there are almost three months of sewer flow rate were collected. From the figure 4.5, mostly the sewer flow rate in upstream manhole is greater than the sewer flow rate in downstream manhole but infiltration still exists even though the rain does not occur as frequent as the rain during the wet period shown. In figure 4.6, the infiltration rate can be see clearly at the end of the April which there was rain occur at that period. While in figure 4.7, the data was collected about half month.

Therefore, the half month of sewer flow rate can be concluded as mostly the sewer flow rate in upstream manhole is greater than the sewer flow rate in downstream manhole but there are still have infiltration among the period. Hence, during dry period the infiltration rate does exist but is not as high as infiltration rate that showed in wet period.

While in dry period, there might have some leakage or blockage in sewer pipe since the upstream sewer flow rate is higher than the sewer flow rate in downstream. During weekdays and weekend, the sewage has a different flow rate, included the flow rate during rain period. The selected sewer line is within the area of sewer reticulation that covers mostly offices and community complex, with 1473 population equivalent (PE). Therefore, during weekdays, the sewage flow rate is high compared to the sewage flow rate as weekends due to the working day at weekdays. The flow rate during the day and night also have tremendous different due to the operation time of office and community complex. The flow rate during day time is higher than the flow rate in night time, sometimes the flow rate at night time will be approximately zero; mean very small flow rate that's hard to detect by flow meter due to few of people consume within the selected area during the night.

Based on the discussion, flow in manhole 6 indicate as Q_1 and Q_2 as flow in manhole 7. From the results shown, most of the sewer flow rate was $Q_1 > Q_2$, the sewer pipe have leakage in between, but sometimes $Q_1 < Q_2$ also occur when rainy; it shows that inflow and infiltration does exist in the sewer pipe during the rainy period. In addition, the highest infiltration rate occurs during wet periods and dry period obtained which are 19.17 liter/day/km/mm-dia. and 11.96 liter/day/km/mm-dia. respectively. According to Malaysia Standard MS1228:1991 (code of practice for design and installation of sewerage systems) section 3: design flow and organic loadings clause 3.7: Infiltration. The sewerage system shall be designed cater for unavoidable amount of infiltration, which arises from faulty joints, cracked sewer pipes and manholes, it is absolutely important that the infiltration into the sewerage system be minimized through the proper selection of construction technology and materials, proper supervision of construction and field testing of the components of system for water-tightness. For guidance, the sewerage system may be designed to cater for a maximum infiltration rate of 50 liter per millimeter diameter per km of sewer per day.

Formula at below are used in obtaining infiltration rate for measuring wastewater flow at 2 manholes as below shown.

Infiltration rate (two manholes flow measurement)

$$= \frac{\textbf{Downstream Flow } (\boldsymbol{Q\ Out}) - \textbf{Upstream Flow } (\boldsymbol{Q\ In})}{(\textbf{Pipe Length x Pipe diameter})}$$

Based on the sewer reticulation plan, the details of manhole 6 and manhole 7 (refer Appendix B). The High Density Polyethylene (HDPE) pipe length is 56 mm with pipe diameter 225 mm. Basically 1 liter per second is equal to 86400 liter per day. From the Figure 4.1 and Figure 4.2 graphs shown, the peak flow for both wet and dry periods that occurred on 17^{th} December 2014 and 1^{st} April 2015 respectively. For a wet period in 17^{th} December 2014 at 13.10 pm, the sewer flow rate in manhole 6 is 0.6430 liter/second, which is smaller than the sewer flow rate in manhole 7 is 3.518 liter/second and the rainfall occurs in that period also give the highest rainfall with 5.4 mm. Therefore, the highest infiltration rate in the wet period is 19.17 liter/day/km/mm-dia. From, the Figure 4.1 shown, rainfall is act as contributing factors to the infiltration in a sewer pipe.

While for a dry period in 1^{st} April 2015 at 10.00 am, the peak sewer flow rate in manhole 6 is 1.4310 liter/second, which is smaller than the sewer flow rate in manhole 7 is 3.1760 liter/second and the rainfall was occurred on 31^{st} December 2015 is 4.2 mm. The infiltration rate in the dry period is 11.96 liter/day/km/mm-dia. From, the Figure 4.2 shown, infiltration rate will exist after rain even though it happened in dry period, which rain did not occur as frequent as rainy season.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSIONS

From the results that obtained, there was either leakage or blockage present in between the sewer line in which the flow rate in upstream manhole 6 is larger than the downstream manhole 7 due to the backflow in the downstream manhole 7 sometimes.

It also showed that the rainfall does contributes the infiltration rates at set periods flow rates that undergo wet weather compare to dry period. The highest infiltration rate in wet period and dry period are 19.71 liter/day/km/mm-dia and 11.96 liter/day/km/mm-dia respectively, which are within the limits that prescribed by Malaysian Standard MS 1228: 1991 with 50 liter/day/km/mm-dia and it also within infiltration estimation range which is 18 to 46 liter/day/km/mm-dia that mentioned by Hammer & Hammer as well. The infiltration rate also lower than the infiltration that obtained from Taman Sri Pulai, Skudai, Johor which is showed 310 liter/day/km/mm-dia. Therefore, the design of sewer pipe line is within the design range to cater for unavoidable amount of infiltration that arises from faulty joints and cracked pipes Result feedback will send to the relevant authority for their further reference and maintenance as well.

5.2 RECOMMENDATIONS

There are several recommendations are recommended to provide a more comprehensive study for the inflow and infiltration in a sewer line. The study should be carried out in various places which in at least two different places, thus a comparison can be made at both locations of study due to the different population equivalent (PE) in the locations.

In addition, the data collection from field test should continue to at least half to one full year. So a clear picture and pattern may be seen regarding the infiltration in the sewers. A laboratory test can be conducted. Therefore, a comparison with field work can be made. Smoke testing can be conducted on sewer lines that suspected of leaking to detect the exact location of leakage. Smoke testing is a time saving step before the more through regression, integration and acceptance tests. This provides a time and cost effective way in sewer pipe leakage detection.

Besides that, infiltration into the soil and determination of groundwater level that surrounding or nearby the sewer pipes also can be accompanied within the studies as well. This is to improve the inflow and infiltration study by predicting and measuring the infiltration rate via soil in selected areas since the local climate and soil conditions play a big role in sewer infiltration. Infiltration rates also sensitive to the vicinity of surface condition and to antecedent water content as well.

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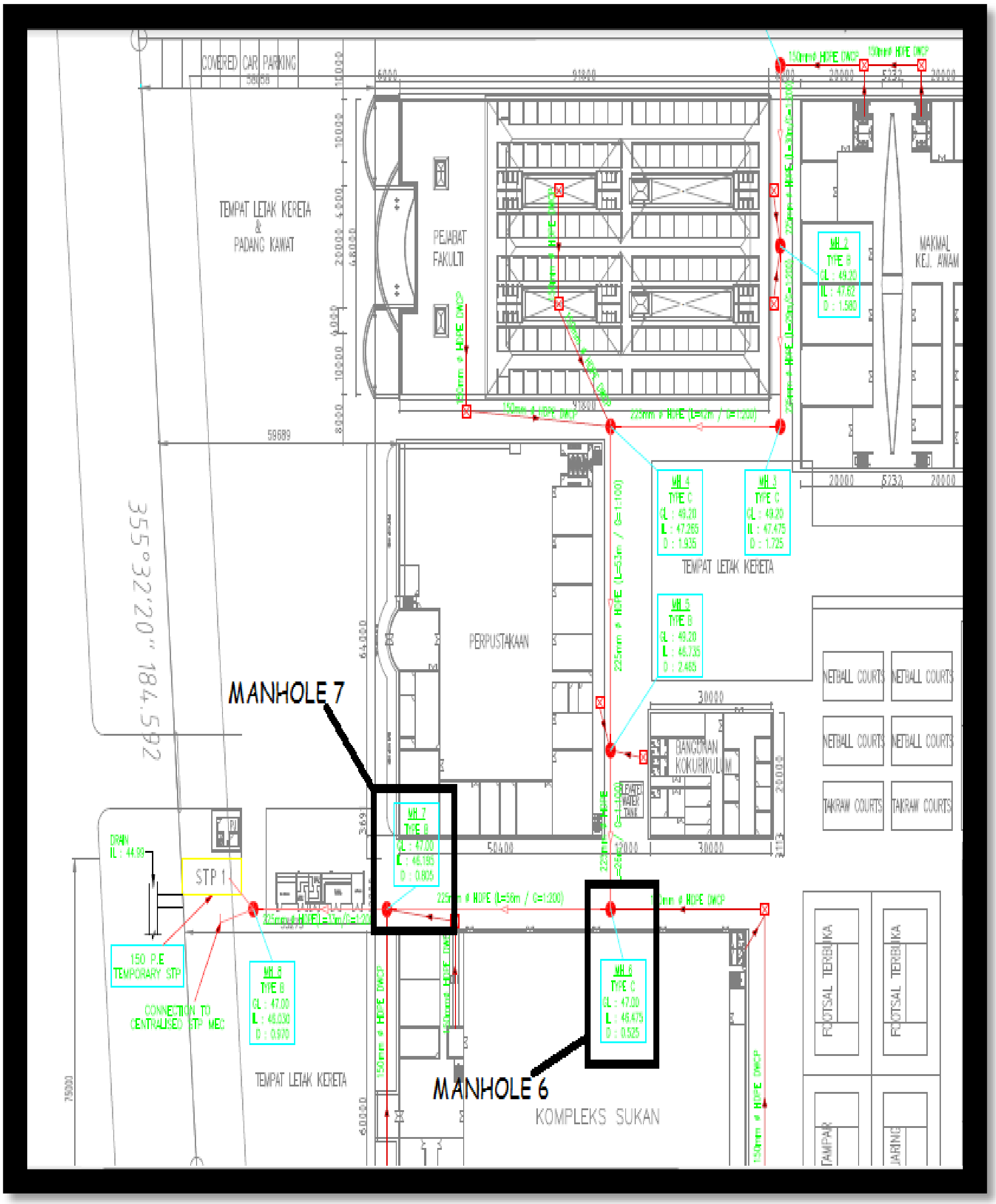
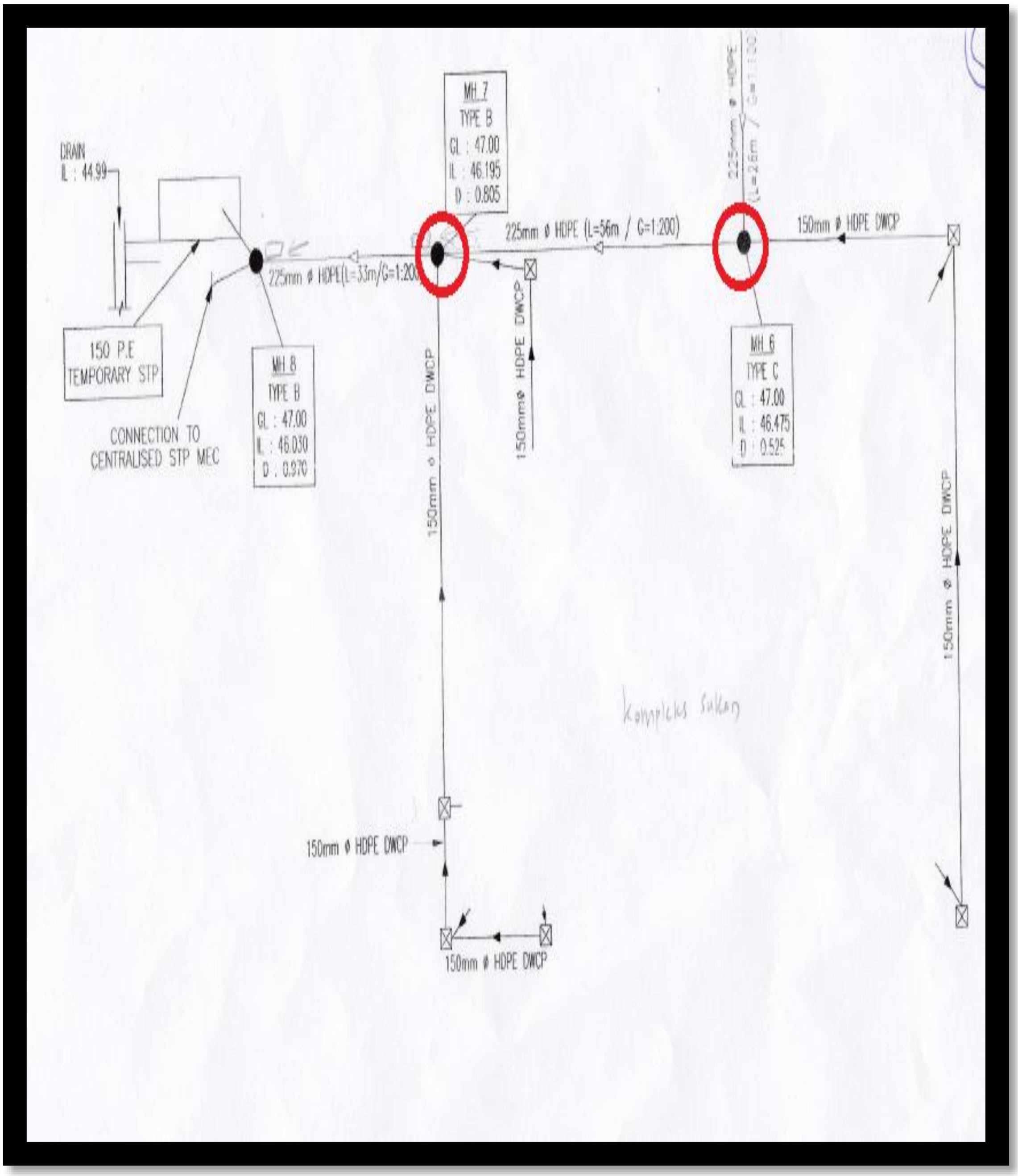
APPENDIX A

Sewer Reticulation Layout Plan



APPENDIX B

Sewer Reticulation Layout Plan (Details of Manholes 6 &7)



APPENDIX C

Work Schedule for Manhole Contractor

(light peach)	Get information from JPPH about the manhole
(pink)	demo installation
(light blue)	installation the equipment/ download data [4pm]
(purple)	check battery [10am (time is not consistent, it depends on staff)]

NOV 2014

MON	TUE	WED	THU	FRI	SAT	SUN
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

DEC 2014

MON	TUE	WED	THU	FRI	SAT	SUN
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

JAN 2015

MON	TUE	WED	THU	FRI	SAT	SUN
			1	2	3	4
5	EXAM	7	EXAM	9	10	11
12	EXAM	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

FEB 2015

MON	TUE	WED	THU	FRI	SAT	SUN
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	NEW YEAR		21	22
23	24	25	26	27	28	

MAR 2015

MON	TUE	WED	THU	FRI	SAT	SUN
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

APPENDIX D

Gantt Charts for Project Schedules

Research Methodology and Pre-Project Activities Schedule

Week (Date) / Task / Activity	Week 1 8/9-12/9	Week 2 15/9-19/9	Week 3 22/9-26/9	Week 4 29/9-3/10	Week 5 6/10-10/10	Week 6 13/10-17/10	Week 7 27/10-31/10	Week 8 3/11-7/11	Week 9 10/11-14/11	Week 10 17/11-21/11	Week 11 24/11-28/11	Week 12 1/12-5/12	Week 13 8/12-12/12	Week 14 15/12-19/12	Week 15 22/12-26/12
1. Briefing	■														
2.Preliminary Study & Literature Review	■	■													
3.Meeting with JPPH Mechanical Unit Staff		■													
4.Site Visit for Suitable Location				■	■										
5. Test Load on Steel Plate (Hang Equipment)						■	■								
6.Flow-meter & Batteries Callibration									■	■					
7.Flow-meter Installation										■	■				
8.Inflow & Infiltration Measurement												■	■	■	■
9. Rainfall Data Collection														■	■
10. Draft of PSM 1 Chapters			■	■	■	■	■	■	■	■	■	■	■	■	■
11. Presentation															■

PSM 2 Scehdule :

Week / Task/Activity	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
1. Inflow & Infiltration Measurement		■	■	■	■	■	■	■	■	■	■	■	■		
2. Rainfall Data Collection		■	■	■	■	■	■	■	■	■	■	■	■		
3. Results Analysis					■	■	■	■	■	■	■	■	■	■	
4. Discussions									■	■	■	■	■	■	
5. Conclusions													■	■	
6. Presentation															■

APPENDIX E

Table 1 is obtained from MS 1228:1991 Section 3 Clause 3.8

Table 1. Equivalent population

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

*1 peak flow is equivalent to 225 l/cap

APPENDIX F

Photo taken during the Project

Installation of hanger steel plate in manhole by contractor

Installation of Flow Meter Sensor in mounting ring by lab assistant

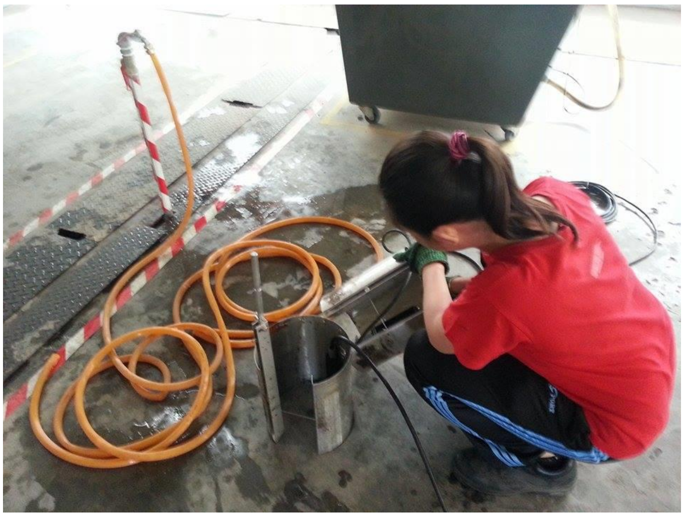
Install the sensor into manhole by using mounting ring

Set up the Flow-meter by using laptop

Using multimeter to check the battery voltage

Tipping bucket rain gauge

Lab assistant hangs the Flow-meter in a manhole



Clean the sensor and mounting ring after completed the test