# EVALUATION OF SEWERAGE INFLOW AND INFILTRATION IN RESIDENTIAL AREAS WITHIN KUANTAN, PAHANG

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B. ENG (HONS.) CIVIL ENGINEERING

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# EVALUATION OF SEWERAGE INFLOW AND INFILTRATION IN RESIDENTIAL AREAS WITHIN KUANTAN, PAHANG

CHAN SHIAO TING

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor Eng (Hons) Civil Engineering

Faculty of Civil Engineering and Earth Resources
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JUNE 2016

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**Dedicated to my parents,**

**Who always support and encourage me in my life**

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## ABSTRACT

Infiltration rate acts as important aspect in the design of sewerage system. The extraneous water that enters the sewer pipe system through leakage or improper connections will affect the flow rate and flow capacity of wastewater in the sewer pipe. This thesis deals with the inflow and infiltration that is occurring in the current sewerage system and the appropriateness of the sewer pipes design criteria through collection of data from field runs in three different residential areas which are Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas. Besides that, this research also studies the effects of rainfall on inflow and infiltration in the sewerage system, which was found to be large. The data used in this research was obtained by using two area velocity flow-meters to measure the flow rate in the sewers as well as a rain gauge to collect the rainfall data at every location with an average duration of a month per location. This research was done on selected sewer lines connecting two manholes with no lateral branches in between each location. The data obtained was converted into graph form. Thus, inflow and infiltration of the sewerage system and its relationship with rainfall can be clearly seen. The results of inflow and infiltration are compared with the design infiltration rate prescribed in MS1228:1991 and Hammer & Hammer. The highest infiltration rate obtained at Taman Lepar Hilir Saujana (7756.36 liter/day/km/mm-dia); Bandar Putra (9213.53 liter/day/km/mm-dia) are much higher than the design limits mentioned in MS 1228:1991 (50 liter/day/km/mm-dia) and Hammer & Hammer (46 liter/day/km/mm-dia). There was leakage or blockage that occurred at Kota Sas where the infiltration rate was in the negative sign.

**ABSTRAK**

Kadar penyusupan bertindak sebagai aspek penting dalam reka bentuk sistem pembetungan. Air luaran yang memasuki sistem paip pembetung melalui sambungan kebocoran atau tidak betul akan memberi kesan kepada kadar aliran dan aliran kapasiti air sisa dalam paip pembetung. Ini tawaran tesis dengan aliran masuk dan penyusupan yang berlaku dalam sistem pembetungan semasa dan kesesuaian kriteria paip pembetung reka bentuk melalui pengumpulan data dari berjalan lapangan di tiga kawasan perumahan yang berbeza yang Taman Lepar Hilir Saujana, Bandar Putra dan Kota Sas. Selain itu, kajian ini juga mengkaji kesan hujan pada aliran masuk dan penyusupan dalam sistem pembetungan, yang didapati tidak besar. Data yang digunakan dalam kajian ini telah diperolehi dengan menggunakan dua halaju kawasan aliran meter untuk mengukur kadar aliran dalam pembetung serta tolok hujan untuk mengumpul data hujan di setiap lokasi dengan tempoh purata sebulan bagi setiap lokasi. Kajian ini telah dilakukan pada garis pembetung dipilih menghubungkan dua lurang pembetungan tanpa cawangan sisi di antara setiap lokasi. Data yang diperolehi telah ditukar ke dalam bentuk graf. Oleh itu, aliran masuk dan penyusupan dalam sistem pembetungan dan hubungannya dengan hujan yang dapat dilihat dengan jelas. Keputusan aliran masuk dan penyusupan dibandingkan dengan kadar reka penyusupan ditetapkan dalam MS1228: 1991 dan Hammer & Hammer. Kadar penyusupan tertinggi diperoleh di Taman Lepar Hilir Saujana (7756,36 liter / hari / km / mm-dia); Bandar Putra (9213,53 liter / hari / km / mm-dia) adalah lebih tinggi daripada had reka bentuk yang dinyatakan dalam MS 1228: 1991 (50 liter / hari / km / mm-dia) dan Hammer & Hammer (46 liter / hari / km / mm-dia). Terdapat kebocoran atau halangan yang berlaku di Kota Sas mana kadar penyusupan adalah tanda negatif.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| BCE | Before the Common Era |
| CCTV | Closed-Circuit Television |
| HDPE | High Density Polyethylene |
| IWK | Indah Water Konsortium |
| MH84 | Manhole 84 |
| MH85 | Manhole 85 |
| MH92a | Manhole 92a |
| MH92b | Manhole 92b |
| MH219 | Manhole 219 |
| MH220 | Manhole 220 |
| MS | Malaysia Standard |
| PE | Population Equivalent |
| Q | Flow Rate |
| $Q_{84}$ | Flow Rate in Manhole 84 |
| $Q_{85}$ | Flow Rate in Manhole 85 |
| $Q_{in}$ | Upstream Flow |
| $Q_{out}$ | Downstream Flow |
| $Q_{new}$ | New Flow Rate |
| $R^2$ | Accuracy of Calibration Results |
| RDII | Rainfall Derived Inflow and Infiltration |
| UMP | Universiti Malaysia Pahang |
| VCP | Vitrified Clay Pipe |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

A sewerage system is an infrastructure or system consisting of a pipes network and pumps to collect, treat and dispose of wastewater or sewage. It is one of the significant considerations for any industrial or residential construction projects since this system will be used often for various activities in everyday life. This research is focused on the residential areas sewerage system and is working together with Indah Water Konsortium (IWK) as well as Universiti Malaysia Pahang (UMP).

Sewerage system is very important. The elements in the sanitary sewer system include ditches, gravity pipelines, pump stations, screening chambers, manholes and other devices that are used to collect and transport the sewage to wastewater treatment plants. The sources of sewage include water that leaves the sink or shower, and toilet flushing from residential, industrial or commercial area. An effective sanitary sewerage system is essential for the health and safety of the citizen, which if not managed properly will cause pollution and environmental problem.

According to the USEPA (2014), base sanitary flow, rainfall derived infiltration and inflow and groundwater infiltration are the three main components of wastewater flow in a sewerage system. Inflow and infiltration have a large extent to influence the effectiveness of sanitary sewer system. Normally, every sewer line will have some inflow and infiltration.

A small amount of inflow and infiltration can be tolerated since it may not cause overflows or increase the cost to transport and treat the sewage. Based on Donohue & Associates (2012), infiltration occurs when the sewer lines are poorly designed and constructed as well as the existing sewer lines undergo deterioration and degradation of the material and joint. For inflow, it will occur when rainfall or storm water enters the sewerage system at points of direct connection of the system such as manhole covers, roof leaders, foundation drains, drains from driveway and other indirect connections to the storm sewer.

In Malaysia, sewerage systems are designed based on the Malaysian Standard Code of Practice MS1228:1991. Normally sewerage systems do indeed include an acceptable amount for inflow and infiltration. Due to a different geographical area, every sewerage system may experience a different amount of rainfall and infiltration. Therefore, suitable adjustment for special conditions of inflow and infiltration is needed to include in the MS1228:1991.

## 1.2 Problem Statement

In order to design a sewerage system, the designer will base on the population equivalent (PE) of that area to design a specific amount of capacity and include some allowance for inflow and infiltration. As stated in MS1228:1991, the maximum infiltration rate for a sewerage system is 50 litre/day/km/mm-dia. Meanwhile, Hammer & Hammer (2004) proposed that 46 litre/day/km/mm-dia is the maximum infiltration rate of a sewerage system. The sewerage system is considered adequate if the infiltration rate does not exceed 50 litre/day/km/mm-dia and 46 litre/day/km/mm-dia as stated in MS1228:1991 and Hammer & Hammer (2004) respectively. Once the infiltration rate of a sewerage system exceeds the designed amount, the system will overload and negative impacts will occur. The negative impacts will be discussed further in the literature review part. From the negative impacts stated, research is definitely required to study on the suitability of the current sewerage system to accommodate the amount of inflow and infiltration.

## 1.3 Objectives of Study

i. To measure the rate of inflow/infiltration of the sewerage system at Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas.
ii. To compare the infiltration rate of the sewerage system at Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas with Malaysia Standard MS1228:1991 and Hammer & Hammer (2004).
iii. To study the effects of rainfall on inflow and infiltration patterns in the sewerage system.

## 1.4 Scope of Work

In this research, Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas were chosen to measure the inflow and infiltration pattern with population equivalent (PE) 1290, 4723 and 10000 respectively. A survey to analyse the population equivalent of Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas was carried to check on the population given by IWK. Two manholes located near the sewerage treatment plant were selected at each site. For Taman Lepar Hilir Saujana, Manhole 84 (MH84) and Manhole 85 (MH85) were chosen to carry out this research; Manhole 92a (MH92a) and Manhole 92b (MH92b) were chosen at Bandar Putra; Manhole 219 (MH219) and Manhole 220 (MH220) were chosen at Kota Sas. In order to measure the inflow and infiltration pattern, area-velocity flow-meter and sensor was installed in both upstream and downstream manholes. Rain gauge that was used to measure the rainfall intensity was set-up at each site. 5 sets of data were required to increase the accuracy of the data collected. The average duration for each set of data is 2 weeks. From the data collected, graphs used to determine the relationship of flow rate with rainfall intensity was produced. Malaysia Standard Code of Practice MS1228:1991, Hammer & Hammer (2004) and Indah Water Konsortium Population Equivalent Table were used as a guide in this research.

## 1.5 Importance of Study

This research was carried out to evaluate the inflow and infiltration in the sewerage systems of Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas. Inflow and infiltration is one of the critical considerations for the design criteria of a sewerage system. If it is not properly included, the effectiveness of a sewerage system as well as the sewerage treatment facilities can be affected. Therefore, this research is important to convey the information of inflow and infiltration in a sewerage system, factors and impacts of inflow and infiltration in a sewerage system. Moreover, the reduction in infiltration may decrease the treatment cost and also the burden of a sewerage system. Besides, the result from this research can be a basis for corrective measures to be carried out in problem areas and also as a basis for future studies.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 History of Sewage Disposal

Virtually, raw sewage was conveyed to the place that can dilute and dissipate it, such as natural water sources like river or ocean. By New World Encyclopedia (2014), the world's first sanitation systems started in the Indus Valley Civilization (3000-2000BCE) at Harappa, Mohenjo-daro. During the Indus Empire, the wastewater was directed to the drainage system like covered drain or rectangular x-section masonry which belongs to the major streets. For bathroom and latrine in the house, it was also connected with the sewers in the streets. Around 2600 BCE, Indus Valley Civilization constructed complex networks of brick-lined sewage drains and also had outdoor flush toilets which connected to this network in the cities of Harappa and Mohenjo-daro. Within the cities, the wastewater that entered the brick-lined cesspools (soak-pits) will be discharged in the local river outside the cities. The drainage and sewerage systems that were developed and used in the cities during the Indus Empire were more efficient than some modern areas in Pakistan and India today and even more advanced than other contemporary urban cities in the Middle East.

In the middle ages, the progress of the sewer systems slowed down during 100 BCE through the early 19$^{th}$ century. By Schladweiler (2004), 25% of the ancient European population died of diseases such as cholera and plague. In the early year, the open-air style sewer systems in Europe raised the hygiene and uncleanliness problems which cause the diseases spread across Europe cities such as Paris and London. In order to sustain the growing of population and rise in civilization, the better sewerage systems were developed and even a law was passed to make sure the sanitary systems work well into $19^{th}$ century. After years of development, the ‘Sewerman’ Eugéne Belguard from Paris was created combined sewers which collect both sanitary sewage and storm water which was used instead of sewers for transport storm water runoff only. The sludge in the sewers was removed by the manholes and some of the sludge transported via boats to various places for disposal or reuse. By 1930, the hygiene and odour problems were slowly minimized and the diseases under controlled.

As stated by New World Encyclopedia (2015), most of the sewage was disposed into the natural water sources and some of the sewage used for farming in Western countries, in the early 1600s. As the steep rise in population and urbanization of the nation, the water sources like river, stream and ocean could no longer bear the burden of all the sanitary sewage. The huge quantities of urban sewage were discharged into water sources which cause considerable pollutions eventually the sewage disposal locations were getting too close to the area of drinking water supplies. In order to solve the problems, sewage treatment process such as broad irrigation, sewage farming and land treatment was needed before discharged into the river. In England, septic tank and trickling filters were used instead of sewage farming or filtration basins due to not sufficient in acreage.

In the view of inadequate clean water supply and failure in removal of sewage in the cesspools, Edwin Chadwick had proposed the idea about removing contaminated sewage underground by constant water supply throughout the cities which also called sewage flow. Chadwick also proposed some other methods to increase the effectiveness of the sewage systems such as the velocity-augmenting pipes can be used for sewers, arranged the network layout and outfall locations to convenient the farmers, effective flushing should be ensured to avoid stagnated sewage underground and many more. The solution suggested by Chadwick was become normative practice up till this day (Hamlin, 1992).

## 2.2 Sewerage System

Sewerage system acts as a significant role in every civilization. It developed throughout history with changes in the structure layout of the cities, socioeconomic condition and also the environment of the cities. Nowadays, sewerage systems are well-developed and operated to support city sanitation and also other related activities. Sewerage systems consist of several components such as drains, manholes, pumping station which used to discharge the sewage in a sewerage system and storm water outflows and screening chamber which to avoid rubbish enter and obstruct the system.

The type of sewer used in every city varies due to the location, population and layout of the city. There are two main types of sewer exist in the town which are combined sewer system and separate sewer system. According to Ohio EPA (2006), combined sewer system is designed to collect both domestic wastewater and storm water runoff, and transport to the treatment facility pipe systems. This combined sewer system may lead to severe water pollution problems when Combined Sewer Overflows (CSOs) occur during the water flow overwhelm the capacity of the treatment plant. This type of sewer usually serves the older cities. Figure 2.1 shows the flows of sewage and storm water in the combined sewer system during dry weather and wet weather.

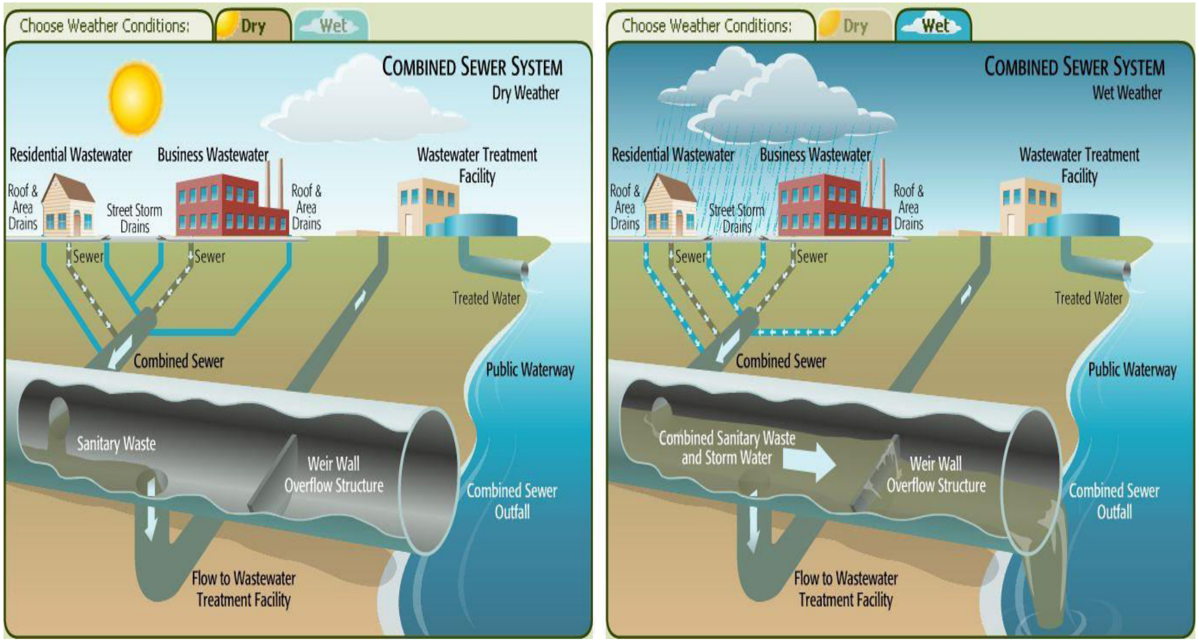


**Figure 2.1:** Combined Sewer System

The separate sewer system is the system that sanitary sewage is separated from the storm water, and conveyed with the separated pipe network. This separate system's principle was developed by Edwin Chadwick in 1842 and England was the first country implemented this type of system (Schladweiler, 2004). Sanitary sewer and storm water drain were considered as separate sewer system. The role of sanitary sewers is to direct the domestic sewage into the connected main sewer and transport the sewage to the nearest sewage treatment plant. Meanwhile, storm water drain is designed to collect and drain the excess rain from the streets into the river or stream. Separate sewer is more efficient compared with combined sewer as the storm water is excluded from the treatment plant and the flexibility of plant operation increase, as well as combined sewer overflow can be prevented which lead to water pollution. Due to the cities evolved and treatment process of sewage is provided, separate sewer system is widely practiced in most of the country including Malaysia. Figure 2.2 shows the sewage and storm water flow in the separate sewer system.

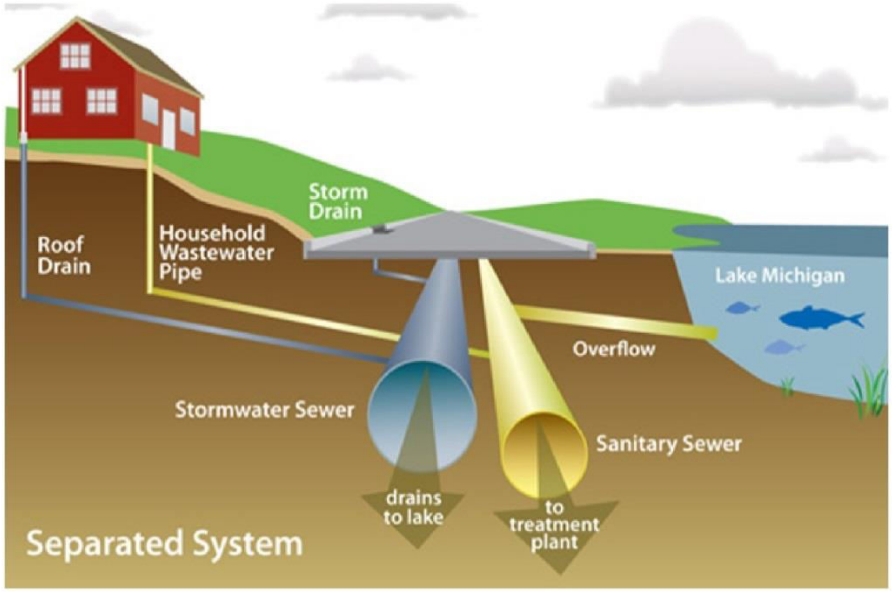


**Figure 2.2:** Separate Sewer System

According to UNEP (2003), sewerage system is important for improving the living environment through appropriate sewage drainage and sewage disposal, maintain the quality of receiving waters and also to avoid floods occur during removal of rainwater. Besides, the additional roles of the sewerage systems are converting sludge into numerous beneficial products, advanced the wastewater treatment, nutrient recycling and extract the thermal energy from the sewage and wastewater.

## 2.3 Inflow and Infiltration in Sewerage System

According to Donohue & Associates (2012), inflow and infiltration are used to describe the ways groundwater and storm water enters the sewerage system. Virtually, higher rainfall country like Malaysia has the highest possibilities of the occurrence of inflow and infiltration in the sewerage system (FCM, 2003). Since the sanitary sewerage system and sewerage treatment plant were designed to collect and treat the sewage, the intrusion of wastewater into the sewerage system reduced the effectiveness and capacity of the sewerage system as well as treatment facilities. The extraneous water or inflow and infiltration water should be conveyed by the storm sewers which have larger dimension and designed to convey large amounts of water.

Basically, inflow and infiltration occurs when the existing sewer pipe leak and crack or misconnected the joints. According to Xylem Inc (2011), the excessive water decreased the effectiveness of sanitary sewerage system and disturbed the treatment facility's processes in a result poorly treated wastewater discharged to the environment. Other than that, the operating cost of treatment processes increased because all water inflowing the wastewater treatment plant must be treated including the unnecessary inflow and infiltration water. The backward flow of the wastewater through the sanitary sewers occurred once the sanitary systems have overloaded. The overflows of the sanitary sewer manhole results in environmental and water pollution as well as public health hazards since potential pathogens and wastewater overflows into water bodies and polluted the water. Figure 2.3 shows the occurrence of inflow and infiltration.

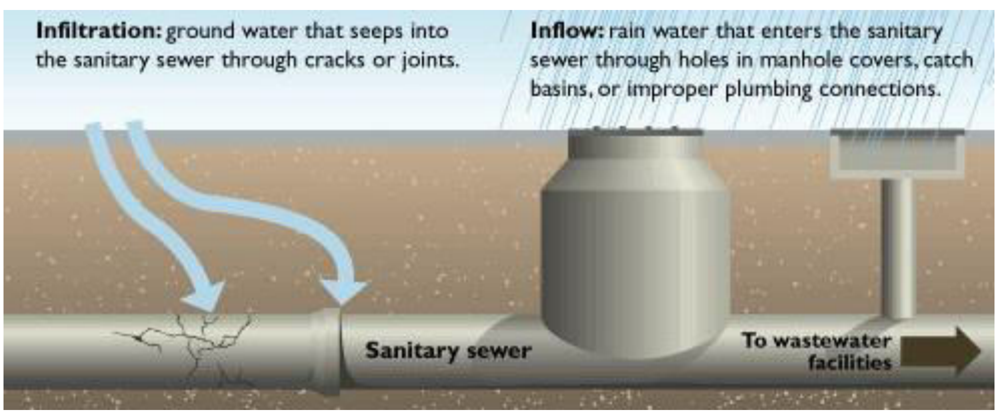


**Figure 2.3:** The occurrence of inflow and infiltration

In past years, the inflow and infiltration problem was not much concern to the engineer or the government even though it did bring about harassment to the cities (American Consulting Services, 1973). Due to the major reasons as stated above, the intrusion of sewerage system should be solved. According to American Consulting Services (1973), in order to solve the problem, a systematic evaluation or analysis of sewerage system should be carried out so that the engineer enables to identify the source of inflow and infiltration, the sewer systems that occurred inflow and infiltration and the amount of inflow and infiltration water can be removed.

## 2.4 Factors Contributing to Inflow and Infiltration in Sewerage Systems

### 2.4.1 Sewer Pipes

According to Feeney et al. (2009), most of the infiltration occurs in sewerage system is from defected pipes, faulty joints, damaged house lateral connections or manhole. The situations stated above occur during construction of sewerage system as well as after the construction.

During the construction of a sewerage system, the poor supervision of the site supervisor and poor workmanship of the workers which lead to the cracked pipes and faulty joints happen from rough handling and unskillful fitting and concreting. The used of defective material to construct the sewerage system which may shorten the lifetime of the structure and causing cracks, holes and fissures that contributes to infiltration occur.

Alternatively, settlement of the structure and the sewer pipes would happen and in different level after the construction of the sewerage system. This may result in pipe joints dislocated and creates openings which allow water to seep through and cause infiltration. Besides, the unpredicted chemical reaction between the inflow water and sewer pipes may lead to pipe weakening eventually cracking of the pipe which contributes to infiltration.

### 2.4.2 Population Increase

According to MS1228:1991, sewerage systems were designed based on the population of the area. As the sewerage systems are not spared for the growing of the population, when the population is far more than the population equivalent initial, the additional sewage is overloaded the sewerage system ultimately lead to leakage or cracks in the sewer. Sewerage system break down may occur if the overburden sewerage system does not solve instantly. The leakages or cracks of sewer may cause infiltration happened.

### 2.4.3 Rainfall

The occurrence of inflow and infiltration in sewerage system can be by natural phenomenon like rainfall. In a tropical country like Malaysia, the inflow and infiltration rate have a huge difference between dry season and wet season. During high rainfall intensity, the inflow and infiltration rate is increasing. Meanwhile, the inflow and infiltration rate is low when the intensity of rainfall decreases. This circumstance can be clearly seen in the combined sewerage system. Other than rainfall intensity, rainfall duration and the volume of rainfall may affect the rate of inflow and infiltration too. The longer the duration of rainfall, the higher the infiltration rate because the time for rainwater to seep into soil is longer and the surface runoff is less. It is the same goes to the high volume of rainfall. The infiltration rate increase when the rainfall volume increases.

### 2.4.4 Soil Surface Cover

The soil surface cover that consists of grass and tree which located near the sewerage system may contribute infiltration into the sewerage system occurs. The vegetation reduced the rate of surface runoff simultaneously increases the infiltration rate though the soil. Besides, vegetation’s nature was searching for the water resources to prolong their life. Due to this natural phenomenon, the trees that located near the sewerage system have a high tendency to cause leakage and pipe cracked which contribute the infiltration of sewerage system.

### 2.4.5 Ground Water Table

The level of ground water table may affect the infiltration rate (FCM, 2003). Soil that has the characteristic of high permeability will experience higher infiltration rate when then ground water table is far below the ground surface. This is because the soil is dry and have ample of voids for water particles to pass through it. Other than soil characteristic, the existing ground water table level either above or at the same level with the sewer pipes may cause infiltration problem to occur. Since the sewer pipes are surrounded partially or wholly by the water table, the rate of infiltration is high once leakages or cracks of pipes happen. Figure 2.4 shows the typical factors that causing inflow and infiltration occur in the sewerage system.

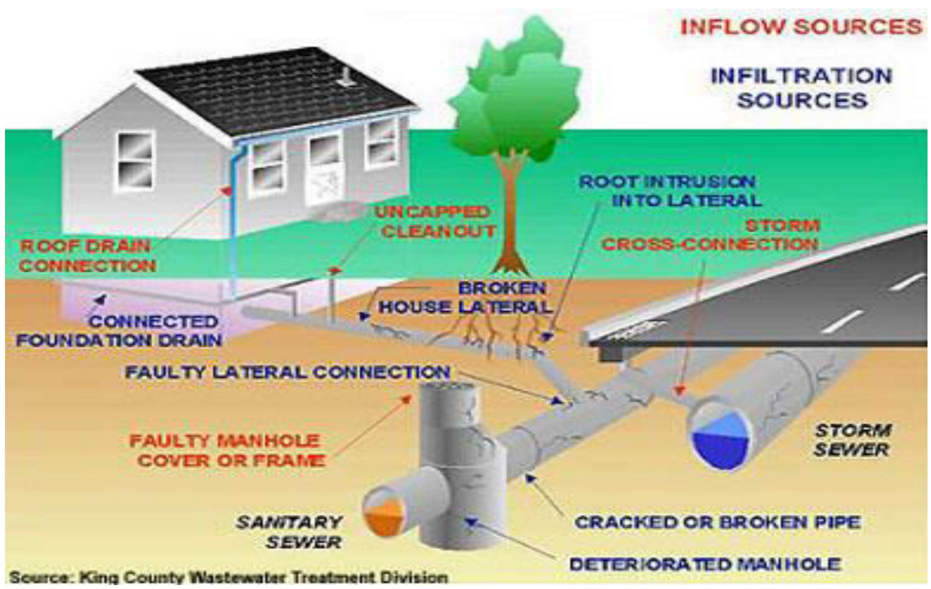


**Figure 2.4:** Typical sources of inflow and infiltration

## 2.5 Impacts of Inflow and Infiltration

In past years, the engineers believed that the designed sewerage system is the best economical design choice and sufficient to support the capacity of the sewage (American Consulting Services, 2013). However, inflow and infiltration into sewerage system are getting serious nowadays, so the corrective measures are required to solve the excess water flow problem. The following are the major trigger reasons why desperate solving methods are required and also the adverse effects brought up by the extraneous water of inflow and infiltration in the sewerage system.

a) Backflow of wastewater in the sanitary sewer pipes during the rainfall season causing flooded basement.
b) Reduced the sewage capacity that supposed to be conveyed by designing sewers.
c) Surcharging of pump stations which lead to excessive used on equipment and higher power cost.
d) Overloading of treatment facilities, causing untreated sewage overflow and pollute the water bodies.
e) Higher treatment operating costs due to treatment also done on the excessive water that entered the treatment plant facilities.
f) Higher maintenance costs caused by failure of structural in the sewers and entrance of soil in the sewer.
g) Air pollution and health hazard resulting from sewage overflow and potential pathogens released.

## 2.6 Previous Case Studies

Inflow and infiltration analysis is always needed to investigate and identify the existence of excessive inflow and infiltration in a sewerage system. The Village of Whitefish Bay, Wisconsin experiences the worst inflow and infiltration problem which the inflow and infiltration contribution for each community is approximately proportional to its population. Therefore, a systematic investigation of the sewerage system is carried out to identify the presence, flow rate and type of inflow and infiltration which exist in the sewerage system. This research proved that the flow in the sanitary sewerage system is excessive during wet weather which leads to basement backups. Besides, the sewerage system reached its capacity and the infiltration rate is generally high during rainfall intensity increase also proven in this study. Therefore, removal of extraneous water in the sewerage system is essential with the aim of improved the service level and reduced basement backup problem (Donohue & Associates, 2012).

Based on Karpf and Krebs (2011), discharge and uncertainty of typical wastewater sources in urban catchment information are undeniably vital requirements for the sewerage system management. Moreover, surface water inflow and ground water infiltration are significant for decision making process for the rehabilitation and operation of sewer networks. The objectives of this study are to identify inflow and infiltration in the sewerage system of the City of Dresden, Germany as well as estimate the quantity of inflow and infiltration. Sewer pipes are grouped according to the attributes construction year and influence of ground water so that the infiltration characteristic and behaviour can be recognized. Furthermore, the condition from the CCTV-data can be used to predict the sewer pipes infiltration potential. In this test, the relationship of pipe condition and potential of infiltration was detected and its results were valid based on the pipe condition. Besides, the ground water influence and attribute construction year were identified as dependable indicators to predict the sewer pipe infiltration potential.

Rainfall is the major factor that raised the inflow and infiltration in the sewerage system. The rainfall enters the system in the form of inflow or infiltration and increase the flow in the sewerage system which also called as Rainfall Derived Inflow and Infiltration (RDII). RDII may increase the operating cost and also required greater capacity of sewerage systems to prevent overflow occurred. With different rain duration and intensity, the RDII characteristic could be different. Therefore, this research is carried to produce more reliable estimates for RDII characteristic in a sanitary sewer basin. A diligent modeling technique is required to produce a good forecast such as provide a natural platform for flow forecast under hypothetical storm condition. Yet, there are some modeling details need to be improved and upgrade to support the working model and further research is required for practical need for flow forecast (Zhang, 2007).

According to Xylem Inc (2011), inflow and infiltration may affect the effectiveness of sewerage system. The inflow and infiltration in the sewerage system in Hampden

Township (Township), Pennsylvania is getting critical ultimately causing the difficulties in operating the wastewater collection, conveyance and treatment. In order to solve the problem, removal of excessive water in sewerage system is definitely required. Sewage rehabilitation is one of methods to reduce the inflow and infiltration even though it is costly. After identifying the sources and area of inflow and infiltration by using television inspection trucks, there are two major rehabilitation projects is required in the Township. There are several methods of rehabilitation such as cured-in-place lining of sewer mains and laterals, fold-arm-form lining of manholes and cured-in-place manhole lining. In this study, the rehabilitation is estimated successfully removed 180000 gallons per day, which is approximately 5 percent of inflow and infiltration on average daily flow basis from Township's sewer system (Strauch et al, 2008).

In 2002, around 95 percent of the Village's sewer videos were inspected by the staff. From the observation, structural defects such as cracks, holes in pipes, defective connections, collapsed and broken pipes, manhole defects, and defects in direct and lateral connections are the main reason that causing inflow and infiltration in the sewerage system. Besides, from the hydraulic analysis, there are at least six of the Village's bypasses which between the storm and sanitary sewer have a high tendency of backflow which may result in storm runoff flow into the sewerage system. Therefore, Village's 2002 Sanitary Sewer Facilities Plan was developed to reduce inflow and infiltration and increase the capacity of sanitary systems. In this plan, the combination of manhole rehabilitation, replacement of storm and sanitary sewer, repairing in private lateral and sanitary sewer lining are recommended to solve the intrusion of sewerage system. After the plan elements implemented, there are approximately 25 percent of the sanitary sewer have been replaced or rehabilitated since 2004 (Donohue & Associates, 2012).

Other than abroad case studies, there is some local case study that provided useful information for the inflow and infiltration in the sewerage system. By Kamran (2005), an evaluation of inflow/infiltration and flow characteristic was carried out at Skudai, Johor which provides the suitability of some design parameters that used by the local engineers. In the research of Kamran, the aspect of variation of inflow and infiltration with respect to the rainfall occurrence was having much more attention. The data is obtained by using flow-meters for measuring the flow in the running sewer line in two different residential areas, collecting and measuring the amount of water trapped in the abandoned sewer line continuously for approximately eight months, which include dry and wet periods and infiltration tests is performed on a laboratory model under saturated and unsaturated conditions to get the results in a controlled environment. The rainfall is also measured as well and the results show that during wet periods, the infiltration into sewers is higher than allowable that stated in the Malaysia Standard MS 1228:1991. The results from laboratory tests show that the infiltration is within limits.

# CHAPTER 3

# METHODOLOGY

## 3.1 Research Methodology

As stated by Rahman et al (2007), methodology is the statement or steps to complete the proposed research. In this chapter, the techniques to obtain the flow rate and rainfall intensity data will be shown and stated. In this research, fieldwork method will be utilized throughout the study and sewer line that connecting two manholes with no lateral branches in between is required. This study was carried out at 3 different residential areas which are Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas. The two manholes located nearest to the sewerage treatment plant were chosen to conduct this study. Besides, the sewer line that has steady sewer flow, no backflow and turbulence occur and little head loss is suitable for this study. For Taman Lepar Hilir Saujana, the two selected manholes were Manhole 84 (MH84) and Manhole 85 (MH85) which shown in Appendix A; Manhole 92a (MH92a) and Manhole 92b (MH92b) shown in Appendix B were chosen at Bandar Putra; Manhole 219 (MH219) and Manhole 220 (MH220) shown in Appendix C were chosen at Kota Sas. There are in total 5 sets of data collected in this research and the average duration for each set of the sewerage flow rate and rainfall intensity data collected is two weeks. Figure 3.1 shows the methodology flow of this research.

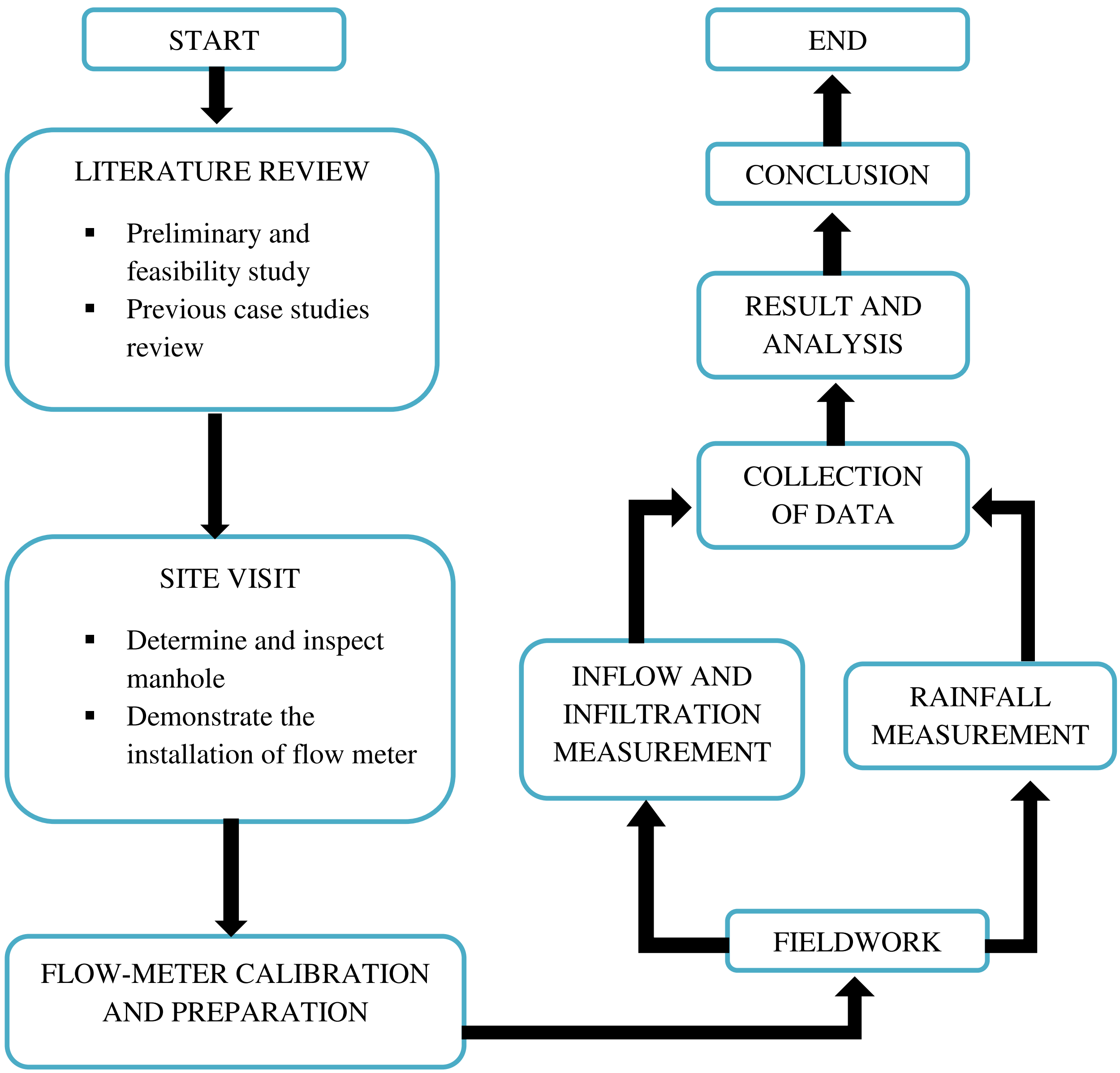


**Figure 3.1:** Methodology Flow Chart of Inflow and Infiltration

## 3.2 Preliminary Works

Before conducting the research at the field, information gathering on the topic of inflow and infiltration, review of previous thesis and also relevant books is required in order to have a proper understanding on the topic given. In order to assess the situation and decide the best way for data collection, a site visit was conducted together with the authorities.

### 3.2.1 Information Gathering

In order to gain more information on the topic of inflow and infiltration, a wide array of books, journals and article has to be read. The information and case studies sources on inflow and infiltration in the sewerage system are mostly from foreign countries rather than Malaysia. This is because the study on inflow and infiltration is relatively new in Malaysia and only few researches have been done in this aspect.

### 3.2.2 Site Visit

A site visit have been conducted to Taman Lepar Hilir Saujana (MH84 and MH85), Bandar Putra (MH92a and MH92b) and Kota Sas (MH219 and MH220) together with the supervisor, IWK's officer and Hydrology and Hydraulic Laboratory assistant before the installation process. Site visits are necessary to determine suitability sewer and manhole location based on the sewer reticulation layout plans provided by IWK, to know the actual location of the site, manhole conditions and ground conditions.

## 3.3 Equipment and Software

The software that was used in this research is Flowlink 5.1 which was used to analyse the depth of water, velocity and flow rate. The equipment required for this research are shown in Figure 3.2 to Figure 3.13.


**Figure 3.2:** Battery of Flow-meter ISCO4250

**Figure 3.3:** Charger of the Battery ISCO4250


**Figure 3.4:** Multimeter


**Figure 3.5:** Area Velocity Flow-meter ISCO4250


**Figure 3.6:** Area Velocity Flow-meter ISCO 2150

**Figure 3.7:** Batteries of ISCO 2150

**Figure 3.8:** Charger of the Batteries ISCO 2150

**Figure 3.9:** ISCO Flow-meter Sensor

**Figure 3.10:** Adapter of Flow-meter ISCO 4250

**Figure 3.11:** Manhole Opener



**Figure 3.12:** Mask

**Figure 3.13:** ISCO 674 Rain Gauge

## 3.4 Calibration of Flow-meter

In order to ensure the data collected was precise and accurate, calibration of both areas velocity flow-meters were essential before the installation. For this research, calibration for both flow-meters was carried out at the Hydrology and Hydraulic Laboratory's open channel at UMP Gambang. The flow-meter was calibrated and compared with the results from the open channel. The main purpose of checking the flow-meters is to make sure the flow-meters are ready to use and its batteries are working. The calibration results of both flow-meter ISCO 4250 and flow-meter ISCO 2150 are shown in Chapter 4. The function of both flow-meters is the same even though they are from different series. For the area velocity flow-meter ISCO 4250, battery problem is the main issues since the equipment is old. There are a total of six batteries available at the laboratory. After series of tests on each battery, Battery A, B and C can perform well among the six batteries which is around 3 to 4 days while the other three batteries can only sustain for a short period of time. Therefore, Battery A and B were selected to conduct this research. For the area velocity flow-meter ISCO 2150, there were no error on it after calibration as well as a battery issue since it is new. The batteries for this flow-meter can sustain for 3 to 4 weeks.

## 3.5 Field Work

### 3.5.1 Population Equivalent (PE) Determination

As stated in Section 2.4.2, the population of the area is important which can influence the effectiveness of the sewerage system and also may cause leakage and infiltration happen. According to the PE obtained from the IWK, the designed PE at the Taman Lepar Hilir Saujana for the section of the sewerage pipe where the study takes place is 1290, Bandar Putra is 4723 and Kota Sas is 10000. In order to check for the accuracy of the PE provided as well as increase or decrease from the initial PE value, a recount of PE is scheduled and the results obtained is the PE of Taman Lepar Hilir Saujana decreased to

1253, Bandar Putra decreased to 1694 and Kota Sas decreased to 3950. The detail calculation of the PE will be shown in section 4.1.

### 3.5.2 Installation of Flow-meter

After the calibration of flow-meters and batteries checking, the installation of flow-meters with sensors is carried out. The sensors for both flow-meters were fixed by the mounting ring as shown in Figure 3.14 and Figure 3.15. In this research, manhole contractor is needed to assist in manhole opening, batteries checking and installation of area velocity flow-meter. Since the batteries of area velocity flow-meter ISCO 4250 can only sustain for 3 to 4 days, the batteries need to change twice a week which is more frequent compare with the batteries of area velocity flow-meter ISCO 2150. Therefore, work schedule is needed for the manhole contractor and also hydrology laboratory assistant. The schedule has to be matched with the hydrology laboratory assistant. This is because in a few months, the hydrology laboratory assistant will be the one assist in the manhole opening work instead of manhole contractor. Figure 3.16 and Figure 3.17 shows the instrument used and selected manhole which is Manhole 84 and Manhole 85 at Taman Lepar Hilir Saujana.

**Figure 3.14:** Mounting ring with sensor

**Figure 3.15:** Mounting ring ready to install

**Figure 3.16:** Manhole 84 (Upstream)

**Figure 3.17:** Manhole 85 (Downstream)

For Bandar Putra and Kota Sas, the instrument used was slightly different from Taman Lepar Hilir Saujana. This is because the pipe size at both Bandar Putra and Kota Sas are bigger and there are no suitable mounting rings available in Hydrology and Hydraulic Laboratory. Therefore, special made steel plates were used at both Bandar Putra and Kota Sas to fix the sensor on it. Figure 3.18 shows the special made steel plates with the sensor.

**Figure 3.18:** Special made steel plate with sensor

### 3.5.3 Inflow and Infiltration Measurement

After the selection of suitable sewer line and manholes, the area velocity flow-meter is installed in each manhole together with the sensor. The depth of water, velocity and flow rate was recorded every 5 minutes through the sensor of the area velocity flow-meter. The data recorded will be retrieved by connecting the Flow-meter Cable Adaptor to the laptop that has Flowlink 5.1 software. Flowlink 5.1 software is used to analyse and determine the depth of water, velocity and flow rate. As stated in subtopic 3.1 previously, Manhole 84 and Manhole 85 were selected at Taman Lepar Hilir Saujana. The upstream manhole would be Manhole 84 and downstream manhole would be Manhole 85. In order to investigate the presence of inflow and infiltration, the data of flow rate, Q for each manhole is important. Let the flow rate in Manhole 84 be $Q_{84}$ and the flow rate in Manhole 85 be $Q_{85}$. In normal sewer pipeline which leakage, inflow and infiltration do not occur, the flow rate in both manholes should be the same which can also be indicated as $Q_{84}=Q_{85}$. If the flow rate in the downstream manhole is bigger than the upstream manhole which means $Q_{85}>Q_{84}$, inflow and infiltration is said to occur in the sewer pipe. On the contrary, if the flow rate in the upstream manhole is larger than the downstream manhole which means $Q_{84}>Q_{85}$, leakage of sewer pipe occurred. The same method was also used to investigate the presence of inflow and infiltration at both Bandar Putra and Kota Sas.

### 3.5.4 Rainfall Measurement

Rainfall measurement is very significant in this research. As stated in literature review, rainfall can influence the infiltration greatly. For this study, ISCO 674 Rain Gauge was used to record the rainfall intensity. ISCO 674 Rain Gauge is a tipping-bucket rain gauge which stores the rainfall data in internal memory. Since the battery can sustain for long periods and change of battery is not required, rainfall data will be retrieved monthly and analysed by using the Flowlink 5.1 software. The rain gauge is set-up at the location of study so that the effect of rainfall can be analysed. The rain gauge data is retrieved using Flowlink 5.1 with Flow-meter 4250 Cable Adaptor. Figure 3.19 shows the rain gauge used in this study.

**Figure 3.19:** ISCO 674 Rain Gauge at Taman Lepar Hilir Saujana

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Population Equivalent Survey

As stated in Section 3.5.1, survey to calculate the population equivalent of each location was conducted in order to have the correct current population in that area. The result of PE from the survey for each location is shown in Table 4.1.

**Table 4.1:** PE from survey at each location

| | | | |
|---|---|---|---|
| i) **Location :** Taman Lepar Hilir Saujana | | | |
| **Type of premise** | **Unit/ Area** | **Requirement** | **PE** |
| Commercial | 819.47m$^2$ | 3 per 100 m$^2$ gross area | 24 |
| Residential | 250 unit | PE from survey | 1229 |
| | | **Total PE** | 1253 |
| | | | |
| ii) **Location :** Bandar Putra | | | |
| **Type of premise** | **Unit/ Area** | **Requirement** | **PE** |
| Business centre | 800m$^2$ | 3 per 100 m$^2$ gross area | 24 |
| Residential | 334 unit | PE from survey | 1663 |
| Kindergarten | 20 person | 0.2 per non-residential student | 4 |
| | 3 person | 1 per residential student | 3 |
| | | **Total PE** | 1694 |

| iii) **Location :** Kota Sas | | | |
|---|---|---|---|
| **Type of premise** | **Unit/ Area** | **Requirement** | **PE** |
| Shoplot | 3160m$^2$ | 3 per 100 m$^2$ gross area | 96 |
| Residential | 733 unit | PE from survey | 3690 |
| Kindergarten | 130 person | 0.2 per non-residential student | 27 |
| | 17 person | 1 per residential student | 17 |
| Mosque | 600 person | 0.2 per person | 120 |
| | | **Total PE** | 3950 |

## 4.2 Area Velocity Flow-meter Calibration

In this research, calibration of area velocity flow-meter is important to increase the precision and accuracy of the data collected. In order to minimize the systematic error, calibration is required and carried out before the installation process for both Area Velocity Flow-meter ISCO 2150 and Area Velocity Flow-meter ISCO 4250. The results of the calibration of both area velocity flow-meters for each location were analysed by using the calibration graph method and the results are shown in the followed section. The results of the calibration graph method are in equation form and the standard accuracy, $R^2$ is 1.

### 4.2.1 Taman Lepar Hilir Saujana

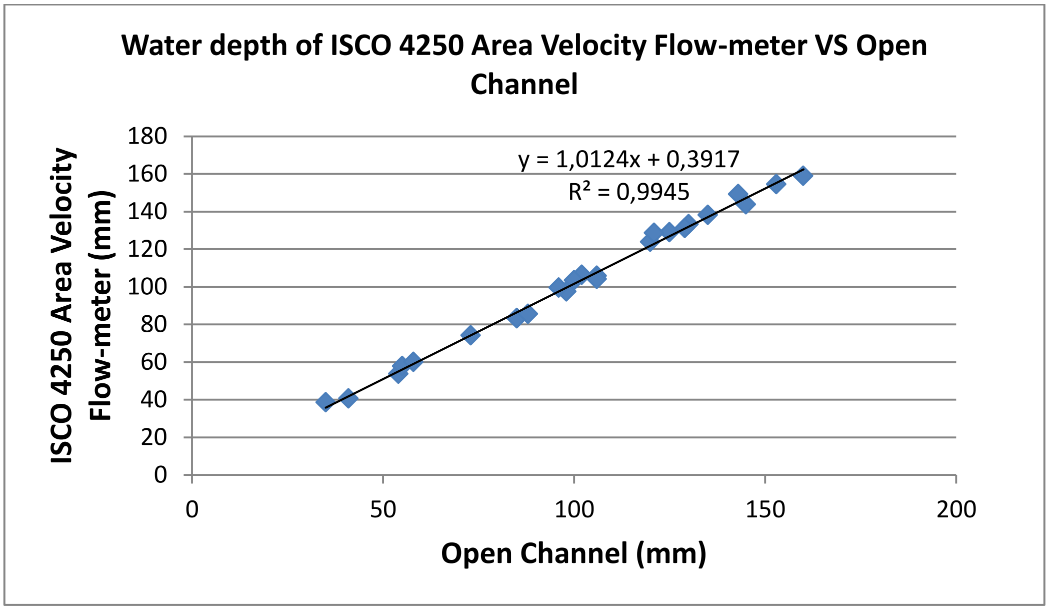


**Figure 4.1:** Taman Lepar Hilir Saujana ISCO 4250 water depth calibration results with accuracy, $R^2$

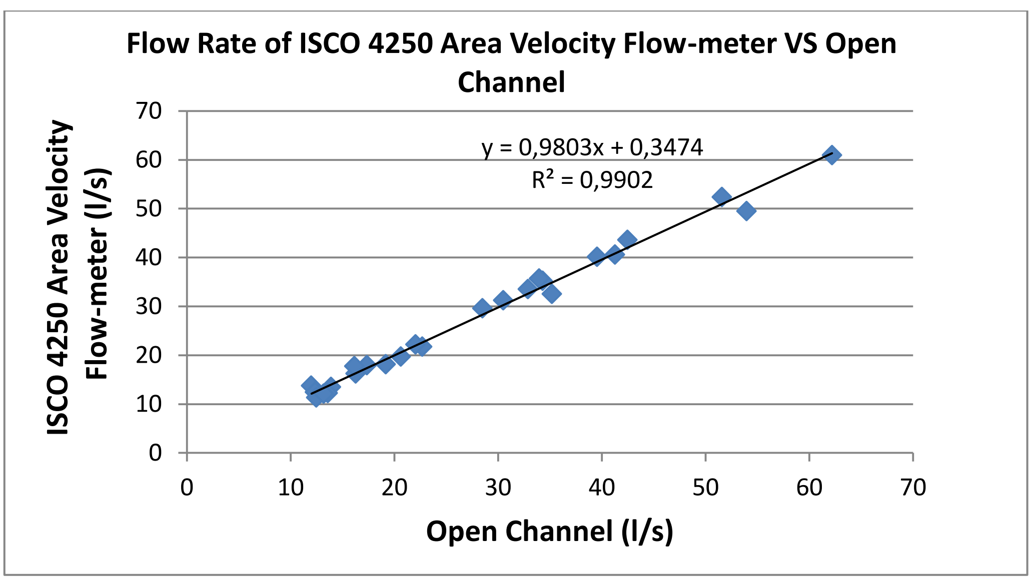


**Figure 4.2:** Taman Lepar Hilir Saujana ISCO 4250 flow rate calibration results with accuracy, $R^2$

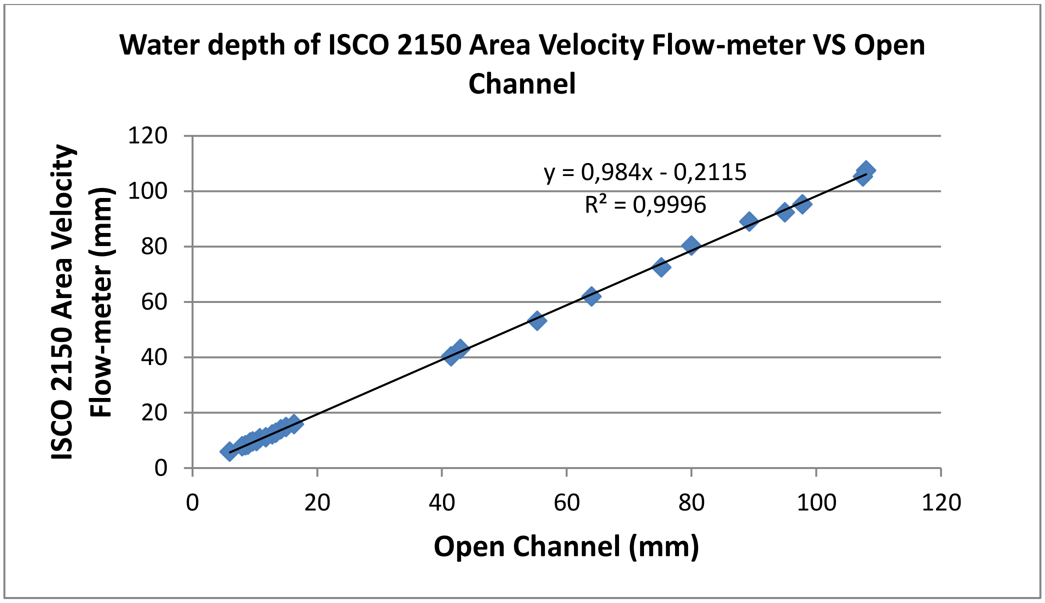


**Figure 4.3:** Taman Lepar Hilir Saujana ISCO 2150 water depth calibration results with accuracy, $R^2$

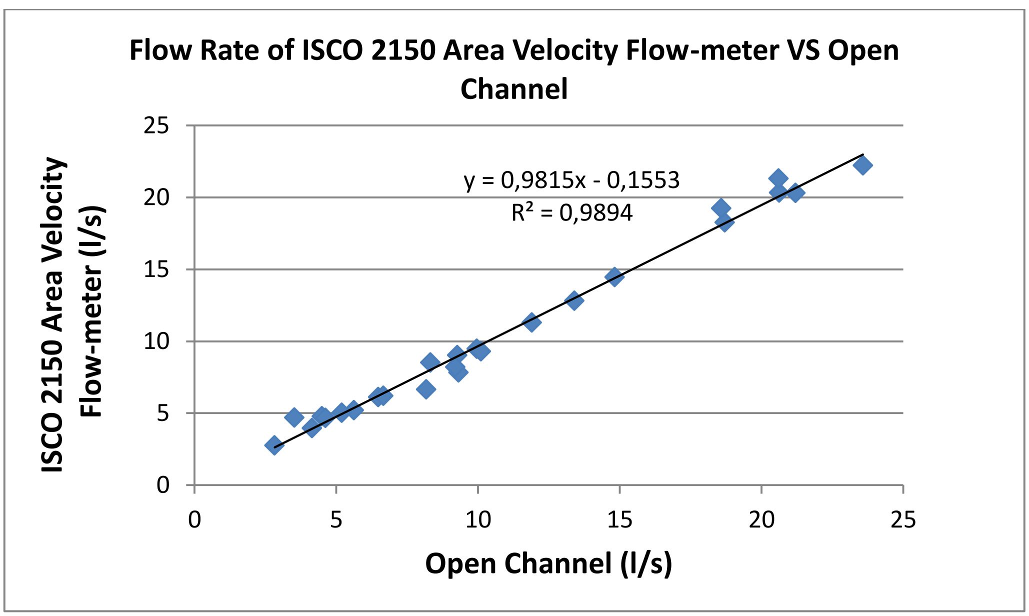


**Figure 4.4:** Taman Lepar Hilir Saujana ISCO 2150 flow rate calibration results with accuracy, $R^2$

### 4.2.2 Bandar Putra

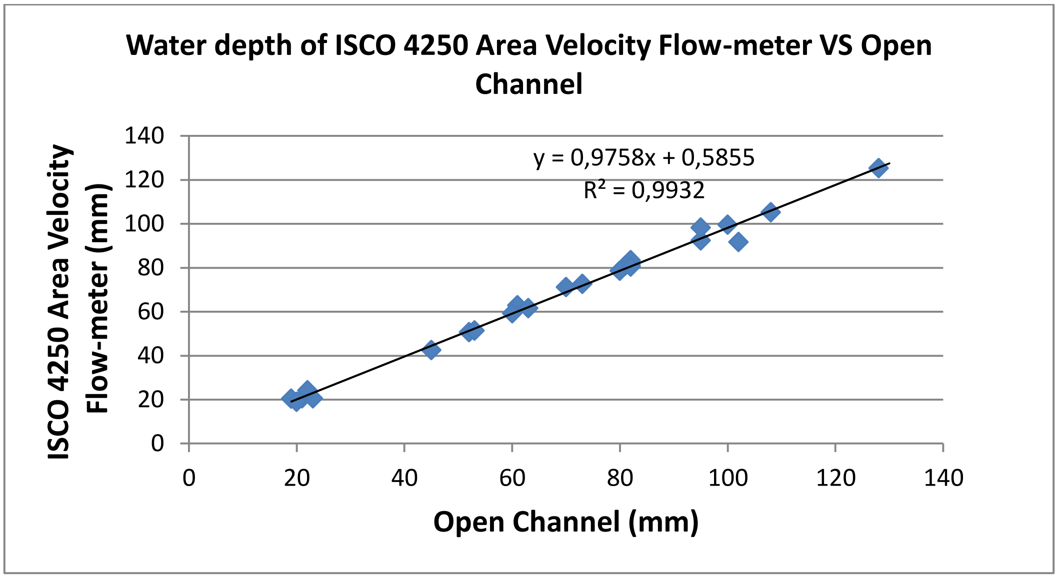


**Figure 4.5:** Bandar Putra ISCO 4250 water depth calibration results with accuracy, $R^2$

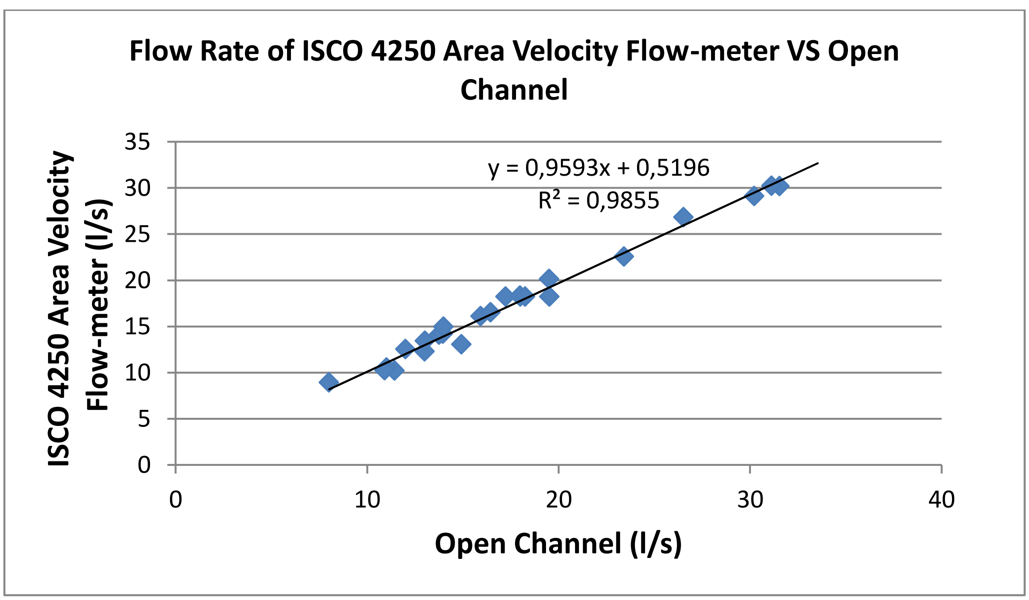


**Figure 4.6:** Bandar Putra ISCO 4250 flow rate calibration results with accuracy, $R^2$

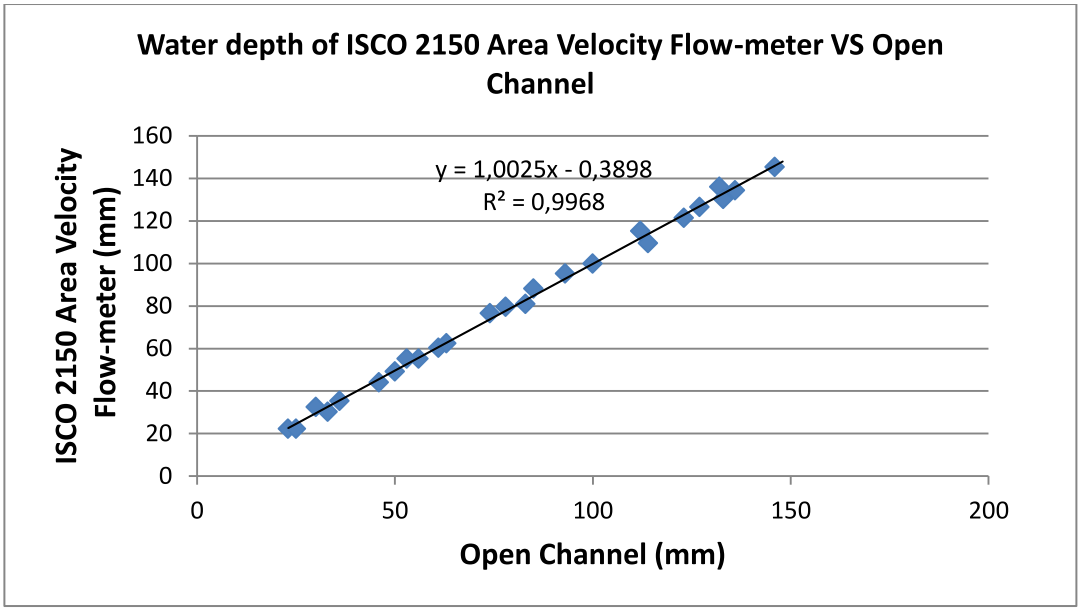


**Figure 4.7:** Bandar Putra ISCO 2150 water depth calibration results with accuracy, $R^2$

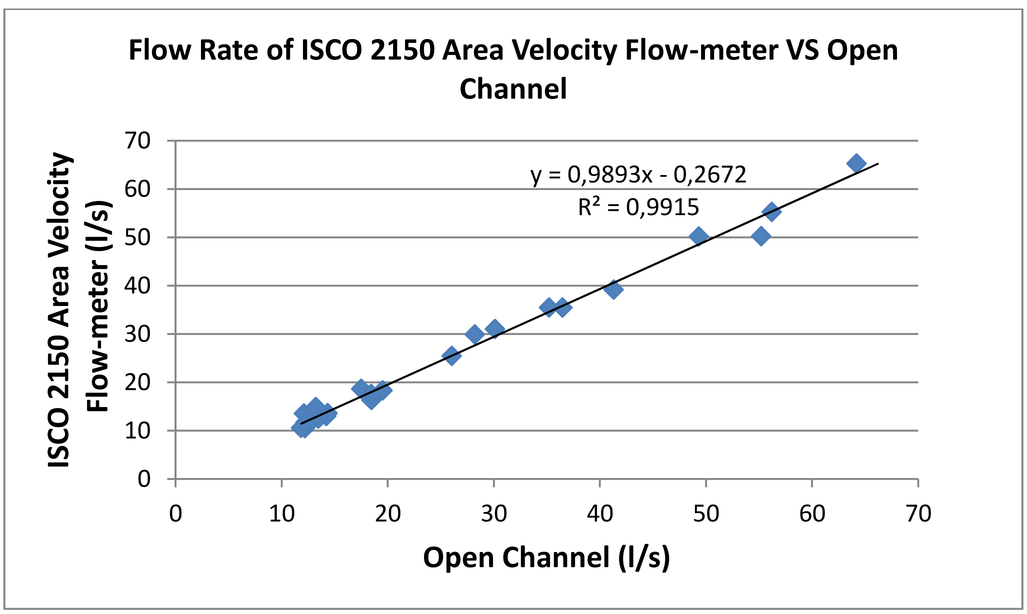


**Figure 4.8:** Bandar Putra ISCO 2150 flow rate calibration results with accuracy, $R^2$

### 4.2.3 Kota Sas

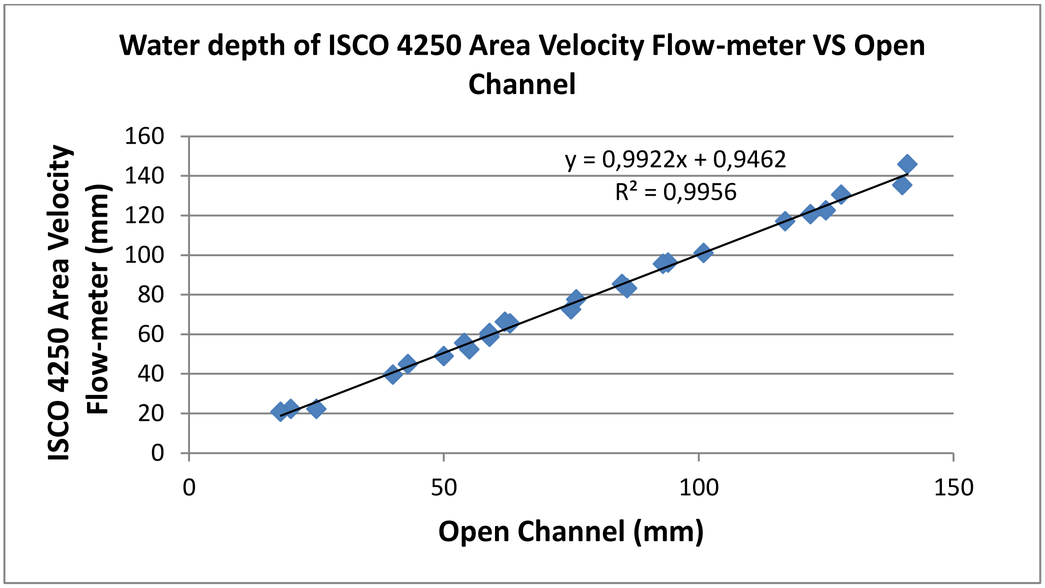


**Figure 4.9:** Kota Sas ISCO 4250 water depth calibration results with accuracy, $R^2$

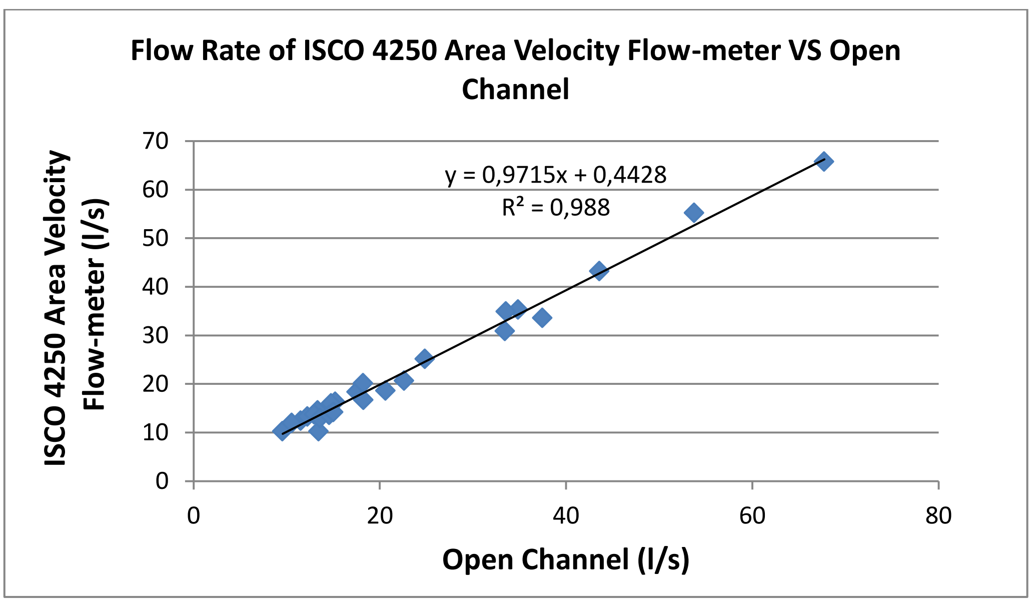


**Figure 4.10:** Kota Sas ISCO 4250 flow rate calibration results with accuracy, $R^2$

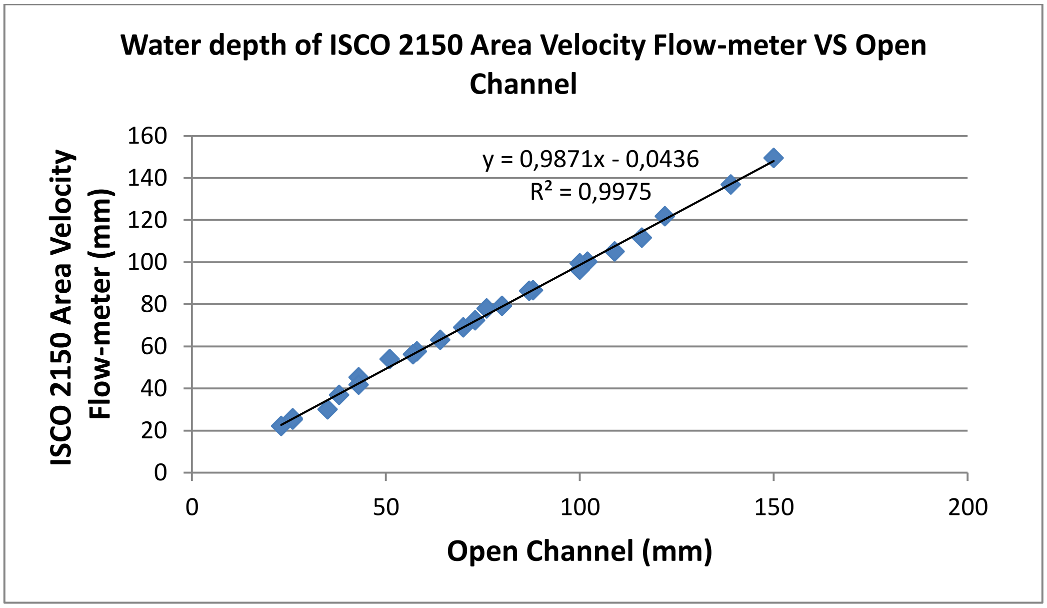


**Figure 4.11:** Kota Sas ISCO 2150 water depth calibration results with accuracy, $R^2$

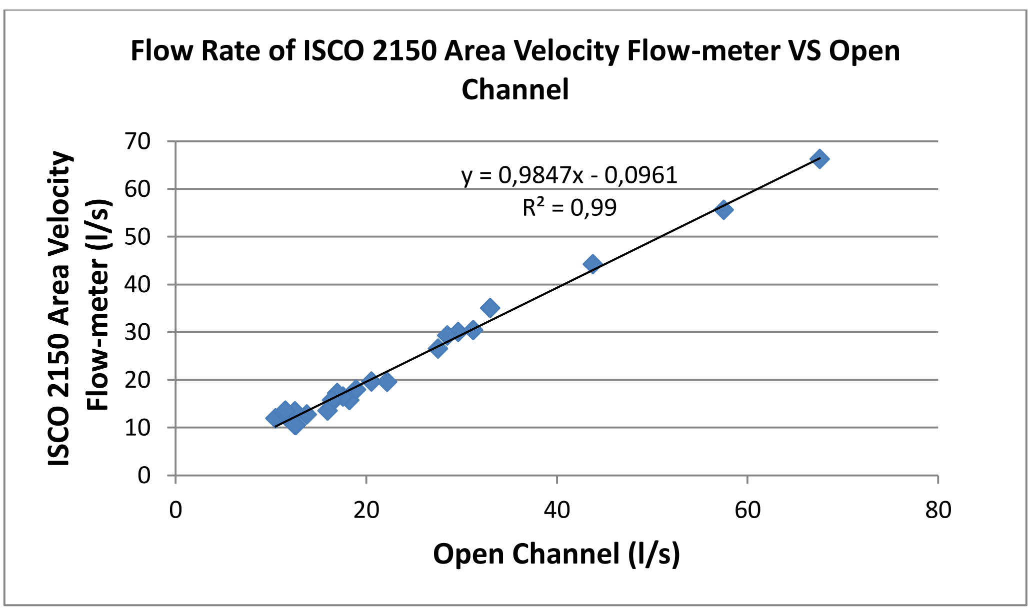


**Figure 4.12:** Kota Sas ISCO 2150 flow rate calibration results with accuracy, $R^2$

### 4.2.4 Summary of Calibration Results

According to the results shown in Section 4.2.1 to Section 4.2.3, a summary table of the equations and accuracy, $R^2$ of both Area Velocity Flow-meter ISCO 4250 and ISCO 2150 at each location is shown in Table 4.2. From Table 4.2, the accuracy for both area velocity flow-meters at each location is approximately to 1 which is high enough to be considered as accurate.

**Table 4.2:** Equations and accuracy, $R^2$ of both area velocity flow-meters at each location

| Location | Flow-meter Type | | Water Depth | Flow Rate |
|---|---|---|---|---|
| Taman Lepar Hilir Saujana | ISCO 4250 | Equation | y = 1.0124x + 0.3917 | y = 0.9803x + 0.3474 |
| | | Accuracy | $R^2 = 0.9945$ | $R^2 = 0.9902$ |
| | ISCO 2150 | Equation | y = 0.984x - 0.2115 | y = 0.9815x - 0.1553 |
| | | Accuracy | $R^2 = 0.9996$ | $R^2 = 0.9894$ |
| Bandar Putra | ISCO 4250 | Equation | y = 0.9758x + 0.5855 | y = 0.9593x + 0.5196 |
| | | Accuracy | $R^2 = 0.9932$ | $R^2 = 0.9855$ |
| | ISCO 2150 | Equation | y = 1.0025x - 0.3898 | y = 0.9893x - 0.2672 |
| | | Accuracy | $R^2 = 0.9968$ | $R^2 = 0.9915$ |
| Kota Sas | ISCO 4250 | Equation | y = 0.9922x + 0.9462 | y = 0.9715x + 0.4428 |
| | | Accuracy | $R^2 = 0.9956$ | $R^2 = 0.988$ |
| | ISCO 2150 | Equation | y = 0.9871x - 0.0436 | y = 0.9847x - 0.0961 |
| | | Accuracy | $R^2 = 0.9975$ | $R^2 = 0.99$ |

## 4.3 Inflow and Infiltration Results, Analysis and Discussion

There are in total 5 sets of data collected from 3 different locations which is from Taman Lepar Hilir Saujana, Bandar Putra and Kota Sas. For Set 1, the data were collected on the selected sewer line connecting MH84 and MH85 at Taman Lepar Hilir Saujana from 5$^{th}$ October 2015 to 15$^{th}$ October 2015 in the first semester. Set 2, 3 and 4 were collected from 26$^{th}$ February 2016 until 8$^{th}$ April 2016 at Bandar Putra where the selected sewer line is connecting MH92a and MH92b. For Set 5, the data was collected at Kota Sas from 15$^{th}$ April 2016 to 29$^{th}$ April 2016 on the chosen sewer line connecting MH219 and MH220. Each set of data was collected for two weeks in litre per day at 5 minutes time interval. Besides, rainfall at each location was also collected at every 5 minutes interval in millimeter (mm) per day. The period and location for each set of data is shown in Table 4.3.

**Table 4.3:** The period and location for each data set

| Set | Location | Period |
|---|---|---|
| 1 | Taman Lepar Hilir Saujana | 6/10/2015(Monday 12.00am)-15/10/2015(Thursday 9.25am) |
| 2 | Bandar Putra | 26/2/2016(Friday 11.35pm)-9/3/2016(Friday 7.00pm) |
| 3 | Bandar Putra | 11/3/2016(Friday 9.40am)-25/3/2016(Friday 9.40am) |
| 4 | Bandar Putra | 25/3/2016(Friday 9.45am)-8/4/2016(Friday 9.45am) |
| 5 | Kota Sas | 13/4/2016(Wednesday 11.10am)-27/4/2016(Wednesday 10.10am) |

In order to increase the precision and accuracy of the data, the flow rate, Q that was collected from the area velocity flow-meter was substituted based on the location in the equations as ‘x’ as shown in Table 4.2. The graphs of Time versus Flow Rate versus Rainfall were produced based on the new flow rate, $Q_{new}$. Moreover, based on Malaysia Standard MS12228:1991 (Code of Practice for Design and Installation of Sewerage Systems) Clause 3.7: Infiltration, the sewerage system shall be designed to 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 proper selection of construction technology and materials, proper supervision of construction and field testing of components of system for water tightness. For guidance, the maximum infiltration rate that the sewerage system is designed cater for is 50 litre/day/km/mm-dia. The formula below was used to calculate the infiltration rate of wastewater flow at 2 manholes.

$$Infiltration\ rate = \frac{Downstream\ Flow\ (Q_{out}) - Upstream\ Flow\ (Q_{in})}{Pipe\ Length\ x\ Pipe\ Diameter} \quad \text{--- Equation 1}$$

### 4.3.1 Taman Lepar Hilir Saujana

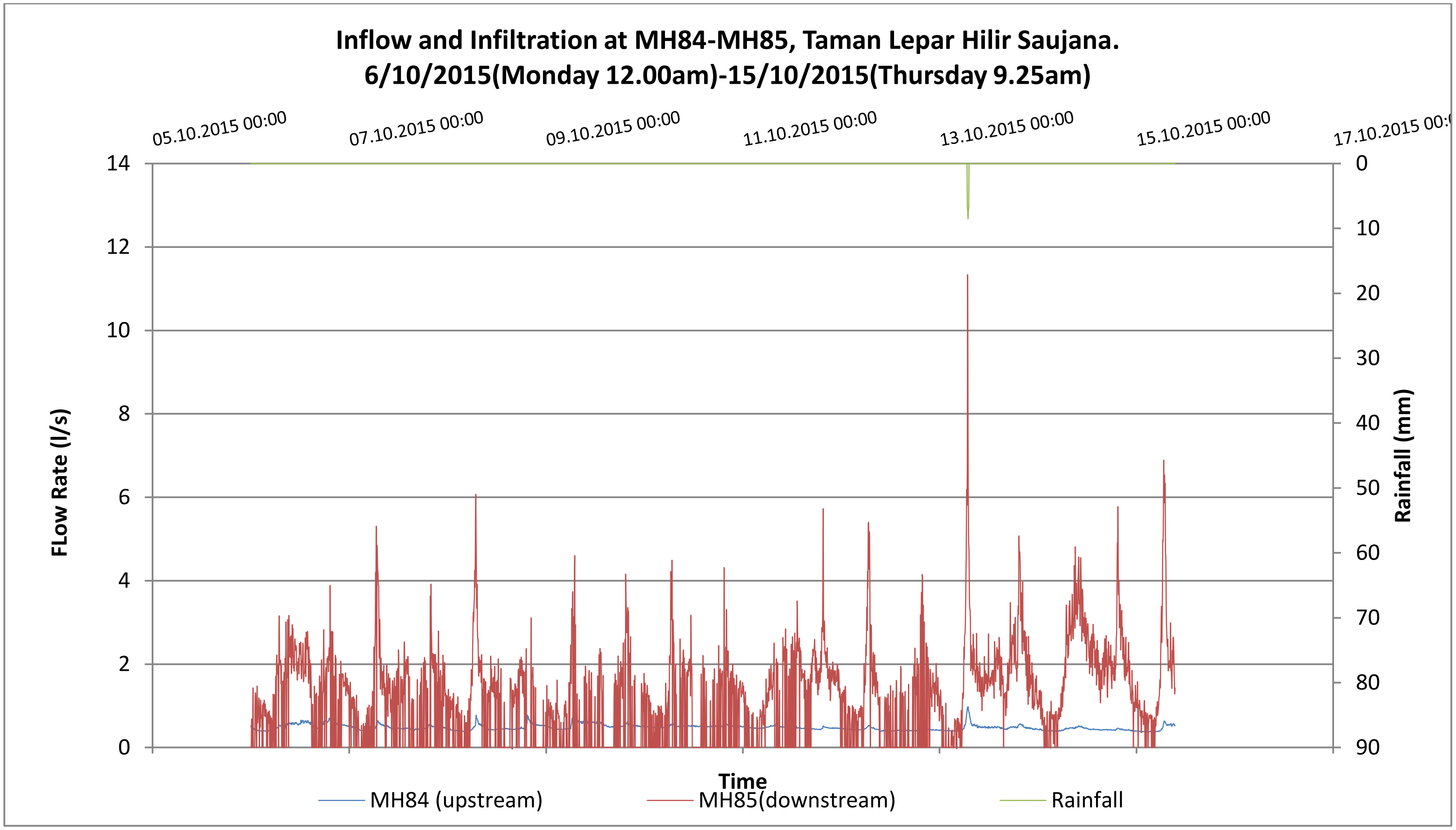


**Figure 4.13:** Set 1 Rainfall against Inflow and Infiltration

Figure 4.13 shows the manholes MH84-MH85 Flow Rate Graph from 6th October 2015 to 15th October 2015. In Figure 4.13, the sewer flow rate, $Q_{85}$ of Manhole 85 which is the downstream manhole is higher than the sewer flow rate, $Q_{84}$ at the upstream manhole which is Manhole 84. This situation is considered as inflow and infiltration occurred in this sewer line since $Q_{85}>Q_{84}$. From Figure 4.13, it shows that the flow rate increases rapidly after rain. As stated in Section 2.4, rainfall is one of the significant influence factors that contributing the infiltration rate into the sewer. Besides, there are numerous zero flow rate that occurred at the downstream Manhole 85 which could be due to the sewer flow being too small or there was blockage of the sewer pipeline that occurred somewhere between Manhole 84 and Manhole 85 even when there was infiltration between the sewer pipeline. Since the main population equivalent of the selected sewer line at Taman Lepar Hilir Saujana is mostly contributed by housing residences, the sewer flow rate during working hours is lower compared to non-working hours.

According to IWK officer, the pipes in Manhole 84 and Manhole 85 are made from Vitrified Clay Pipe (VCP) with pipe length 35.2m and 225mm in diameter. From Figure 4.13, the peak flow of the sewer line occurred on 13th October 2015 at 6.50am. The sewer flow rate in Manhole 1 is 0.9189 litre/second, which is smaller compared with the sewer flow rate in Manhole 2, 11.3351 litre/second. In addition, rainfall occurred in that period with a total of 7.2mm rainfall. Theoretically, 1 litre per second is equal to 86400 litre per day. In order to determine the infiltration rate in this period, the average flow rate of downstream Manhole 85 and upstream Manhole 84 calculated which is 1.1913 litre/second and 0.4803 litre/second respectively. The infiltration rate was calculated by using the formula stated in the previous section as shown in below.

$$Infiltration\ rate = \frac{Downstream\ Flow\ (Q_{out}) - Upstream\ Flow\ (Q_{in})}{Pipe\ Length\ x\ Pipe\ Diameter}$$

$$= \frac{(1.1913x\ 86400) - (0.4803x86400)}{0.0352\ x\ 225}$$

$$= 7756.36\ litre/day/km/mm - dia$$

From the calculation, the infiltration rate is 7756.36 litre/day/km/mm-dia which is higher than the maximum infiltration rate stated in the MS12228:1991 which is 50 litre/day/km/mm-dia and also Hammer & Hammer (2004) which is 46 litre/day/km/mm-dia. The infiltration rate in Taman Lepar Hilir Saujana is 15412.782% and 16761.65% greater than the maximum infiltration rate stated in MS12228:1991 and Hammer & Hammer (2004) respectively. The main reason for infiltration in sewer pipe is because of rainfall which can be clearly seen from Figure 4.13. Besides, there may be some cracks in the sewer pipes because of the vegetation located near to the pipeline.

### 4.3.2 Bandar Putra

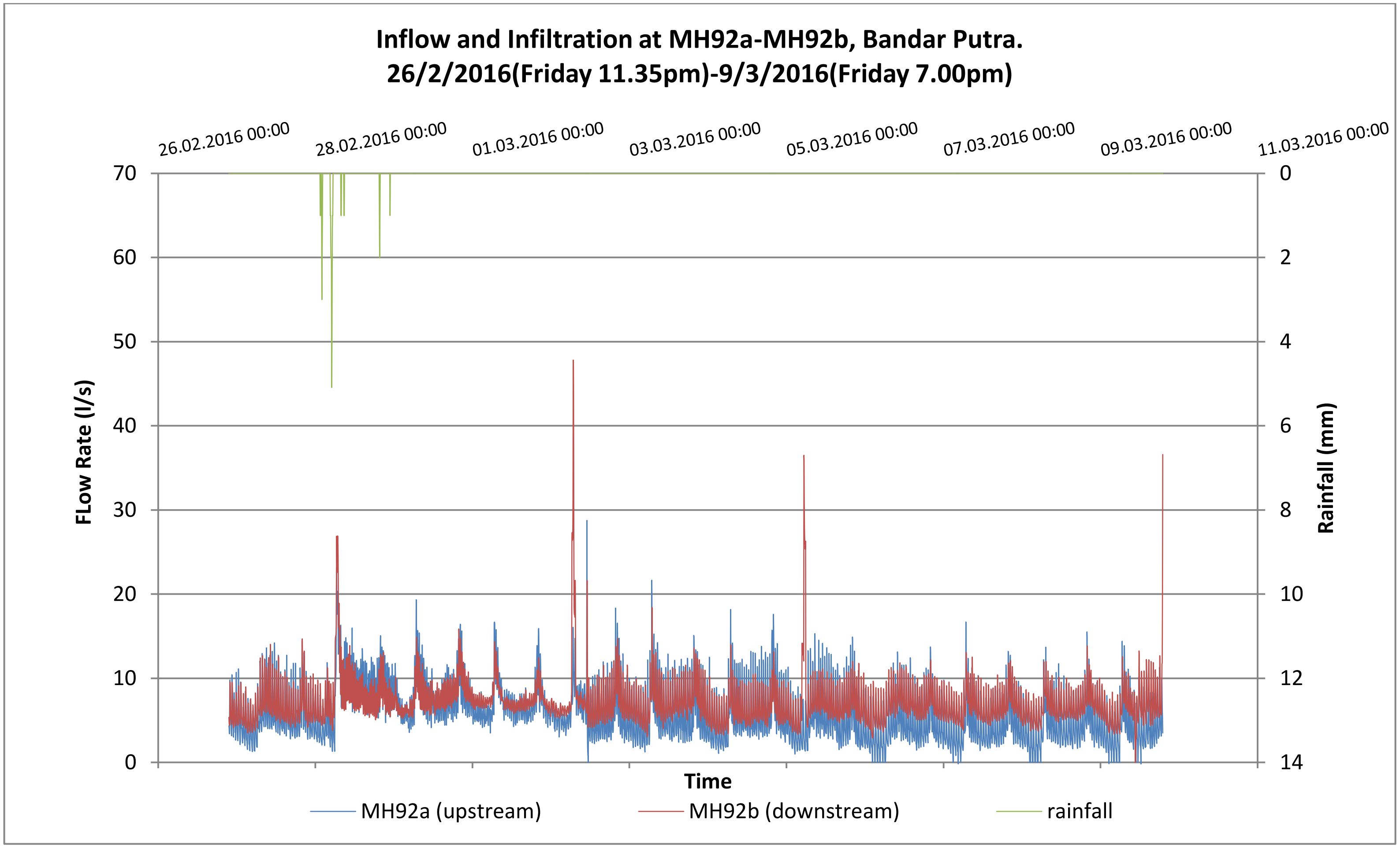


**Figure 4.14:** Set 2 Rainfall against Inflow and Infiltration

The Flow Rate Graph of the manholes MH92a-MH92b from 26th February 2016 to 11th March 2016 is shown in Figure 4.14. Refer to Figure 4.14, it can be clearly seen that the sewer flow rate, $Q_{92b}$ at the downstream Manhole 92b is higher compared to the sewer flow rate, $Q_{92a}$ at the upstream Manhole 92a. What can be noticed is the rapid increase in flow rate after rainfall occurred. Besides, there are numerous zero flow rate that occurred at the downstream Manhole 92b which could be due to there was blockage of the sewer pipeline that occurred somewhere between Manhole 92a and Manhole 92b even when there was infiltration between the sewer pipeline.

The details of Manhole 92a and Manhole 92b are shown clearly in the sewer reticulation plan that provided by IWK (refer to Appendix B). The sewer pipes are made from High Density Polyethylene (HDPE) and the pipe length between Manhole 92a and Manhole 92b is 25.7m with pipe diameter 500mm. Refer to Figure 4.14, the highest flow rate occurred on 2nd March 2016 6.50am which is 47.8083 litre/second at downstream Manhole 92b. While, the highest flow rate at the upstream Manhole 92a is 28.7579 litre/second which happened on 2nd March 2016 11.00am. In order to determine the infiltration rate, the average flow rate of both upstream and downstream manholes calculated which is 5.8536 litre/second and 7.2239 litre/second respectively. The calculation of infiltration rate of this period is shown below.

$$Infiltration\ rate = \frac{Downstream\ Flow\ (Q_{out}) - Upstream\ Flow\ (Q_{in})}{Pipe\ Length\ x\ Pipe\ Diameter}$$

$$= \frac{(7.2239x\ 86400) - (5.8536x86400)}{0.0257\ x\ 500}$$

$$= 9213.53\ liter/day/km/mm - dia$$

From the calculation, the infiltration rate is 9213.53 litre/day/km/mm-dia which is 18327.06% and 19929.41% greater than the maximum infiltration rate stated in the MS12228:1991 which is 50 litre/day/km/mm-dia and also Hammer & Hammer (2004) which is 46 litre/day/km/mm-dia respectively. From Figure 4.14, rainfall acts as contributing factors to infiltrate in a sewer pipe.

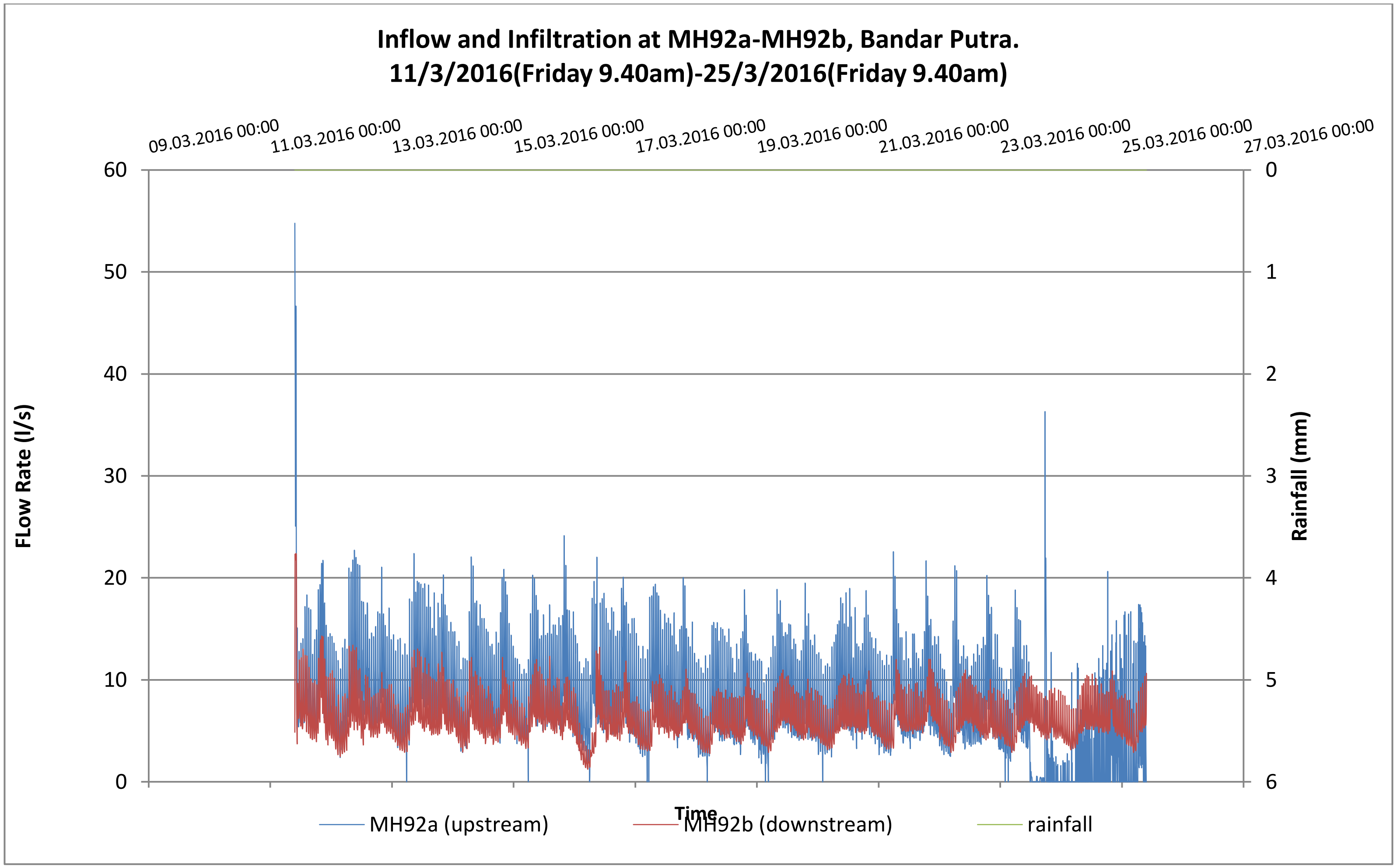


**Figure 4.15:** Set 3 Rainfall against Inflow and Infiltration

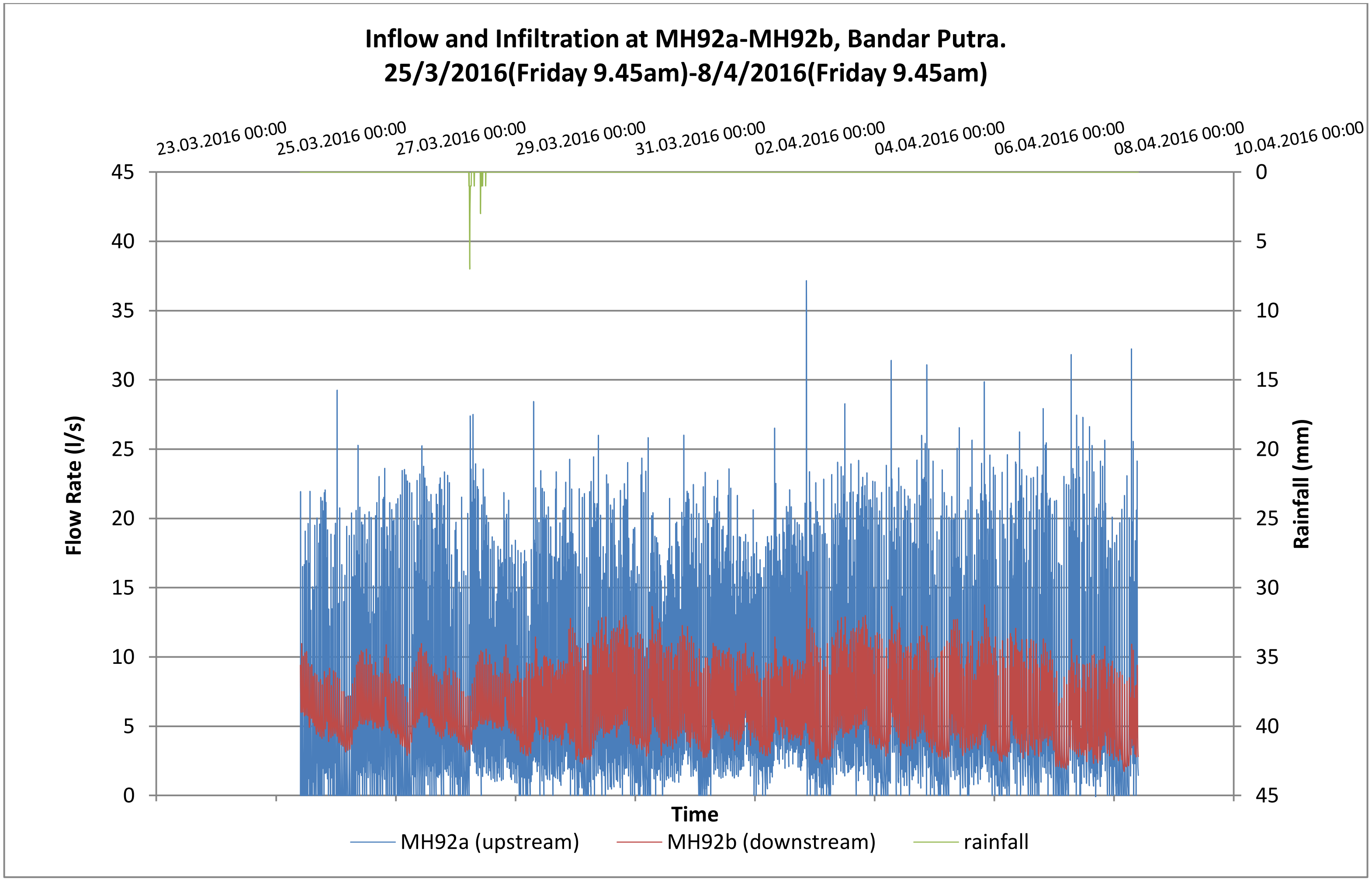


**Figure 4.16:** Set 4 Rainfall against Inflow and Infiltration

On the other hand, Figure 4.15 and Figure 4.16 show that the upstream flow rate, $Q_{92a}$ is higher than the downstream flow rate $Q_{92b}$. What can be noticed is the flow rate in the sewer line increase after rainfall occurred. Refer to Figure 4.15 and Figure 4.16, the flow rate during rainfall period (Figure 4.16) is much higher than no rainfall period (Figure 4.15). Even though rainfall does exist on 28$^{th}$ March 2016, the infiltration rate is much smaller than the leakage or blockage occurred in the sewer pipes.

Moreover, there are numerous zero flow rate that occurred at the upstream Manhole 92a which could be due to leakage or blockage of sewer pipeline that occurred somewhere nearby Manhole 92a even when there was infiltration between the sewer pipeline. Refer to Figure 4.14 to Figure 4.16, the differences of flow rate between the upstream and downstream manholes were getting bigger in other words the leakage or blockage of sewer pipeline was getting serious started from 11$^{th}$ March 2016. The leakage or blockage of sewer pipeline could happen due to the inappropriate connection of the pipe joints which cause by improper supervision during construction. Besides, vegetation nearby can also cause the leakage or blockage of sewer pipeline. This is because most of the sewerage treatment plant was constructed in isolated form and surrounded by grasses and trees. Therefore, the roots of the vegetation can cause the leakage of sewer pipeline. Furthermore, Bandar Putra is still under construction which has various heavy machinery passes through or moving over the selected sewer line. This can cause surface depression if the soil at that area was not compacted during construction even broken of sewer pipeline may occur.

For Figure 4.15 which is conducted during 11$^{th}$ March 2016 to 25$^{th}$ March 2016, the highest flow rate at the upstream Manhole 92a is 54.7725 litre/second which happened on 11$^{th}$ March 2016 at 9.40am. While the downstream highest flow rate occurred on 11$^{th}$ March 2016 at 9.50am with 22.30907 litre/second. The infiltration rate was calculated by using the average flow rate of both upstream and downstream manhole. The average flow rate of upstream Manhole 92a is 7.5060 litre/second and downstream Manhole 92b is 6.1072 litre/second. The calculation of infiltration rate for Figure 4.15 is shown below.

$$Infiltration\ rate = \frac{Downstream\ Flow\ (Q_{out}) - Upstream\ Flow\ (Q_{in})}{Pipe\ Length\ x\ Pipe\ Diameter}$$

$$= \frac{(6.1072x\ 86400) - (7.5060x86400)}{0.0257\ x\ 500}$$

$$= -9405.16\ liter/day/km/mm - dia$$

According to the calculation, the infiltration rate of Figure 4.15 that period is in negative value which is -9405.16 litre/day/km/mm-dia. This means that there was either leakage or blockage occurred in the selected sewer pipeline in that period.

For Figure 4.16, the highest flow rate of downstream Manhole 92b occurred at 2nd April 2016 which is 16.1831 litre/second and upstream Manhole 93a is 37.1669 litre/second at 20.40pm on 2nd April 2016. To determine the infiltration rate of this period, the average flow rate of both upstream and downstream is required. The average flow rate of upstream is 6.8822 litre/second and downstream is 5.8717 litre/second. The infiltration rate of this period was calculated by using Equation 1 and the calculation shown below.

$$Infiltration\ rate = \frac{Downstream\ Flow\ (Q_{out}) - Upstream\ Flow\ (Q_{in})}{Pipe\ Length\ x\ Pipe\ Diameter}$$

$$= \frac{(5.8717x\ 86400) - (6.8822x86400)}{0.0257\ x\ 500}$$

$$= -6794.33\ liter/day/km/mm - dia$$

Based on the calculation, the infiltration rate of Figure 4.16 that period is in negative value which is -6794.33 litre/day/km/mm-dia. This means that there was either leakage or blockage occurred in the selected sewer pipeline in that period.

### 4.3.3 Kota Sas

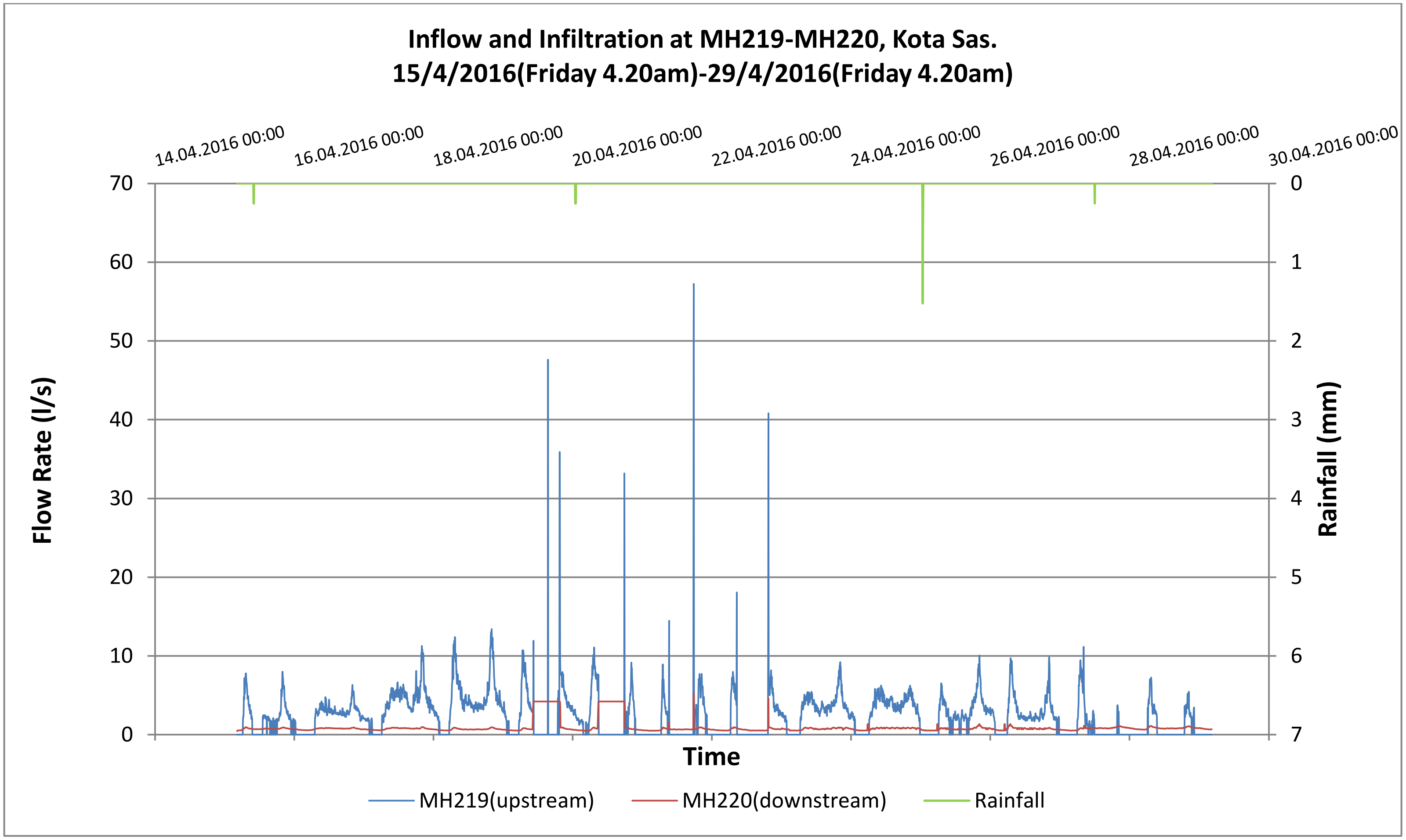


**Figure 4.17:** Set 5 Rainfall against Inflow and Infiltration

Figure 4.17 shows the manholes MH219-MH220 Flow Rate Graph from 15th April 2016 to 29th April 2016. From Figure 4.17, it can be clearly seen that the sewer flow rate, $Q_{219}$ of Manhole 219 which is upstream manhole is higher than the sewer flow rate, $Q_{220}$ at downstream manhole which is Manhole 220. This situation is considered as leakage or blockage in between the sewer line occurred since $Q_{219}>Q_{220}$. What can be noticed is rainfall does affect the flow rate in the sewer line. Besides, there are numerous zero flow rates and constant flow rate occurred. Zero flow rates that occurred at the upstream Manhole 219 which could be due to leakage or blockage of sewer pipeline somewhere nearby Manhole 219. Meanwhile, constant flow rate occurred is because of the maintenance of the pumping system of sewerage treatment plant was conducted at Kota Sas for twice which is on 19th April 2016 and 20th April 2016. The maintenance of pumping system caused the flow of the selected sewer line stopped and the water depth in both Manhole 219 and Manhole 220 increase rapidly.

According to IWK officer, the pipes in Manhole 219 and Manhole 220 are made from High Density Polyethylene (HDPE) with pipe length 89m and 450mm in diameter. From Figure 4.17, the peak flow of the upstream Manhole 219 happened on 21st April 2016 at 17.45pm sewer flow rate in Manhole 219 is 57.2410 litre/second, which is greater compared with the sewer flow rate in Manhole 220 is 5.3188 litre/second. In order to determine the infiltration rate of this sewer line, the average flow rate of the upstream and downstream manhole calculated which is 2.3227 litre/second and 0.9226 litre/second respectively. The calculation of infiltration rate is shown below.

$$Infiltration\ rate = \frac{Downstream\ Flow\ (Q_{out}) - Upstream\ Flow\ (Q_{in})}{Pipe\ Length\ x\ Pipe\ Diamater}$$

$$= \frac{(0.9226x\ 86400) - (2.3227x86400)}{0.089\ x\ 450}$$

$$= -3020.44\ liter/day/km/mm - dia$$

From the calculation, the infiltration rate of Figure 4.17 that period is in negative value which is -3020.44 litre/day/km/mm-dia. This means that there was either leakage or blockage occurred in this sewer pipeline during this period. The main reason of leakage or blockage occurred in Kota Sas is currently this residential area still under construction and there may be some construction wastes blocked in between the selected sewer line. Besides, the heavy machinery that passes through or moving over the selected sewer line may cause leakage of sewer pipe due to surface depression if the soil at that area was not compacted accurately during construction.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Based on the results obtained from the previous chapter, inflow and infiltration had occurred at Taman Lepar Hilir Saujana while leakage or blockage occurred at Bandar Putra and Kota Sas within the period from $6^{th}$ October 2015 to $29^{th}$ April 2016.

It also showed that rainfall does affect the flow rate of the sewer line and also infiltration rate. The infiltration rate at Taman Lepar Hilir Saujana and first set data at Bandar Putra is 7756.36 litre/day/km/mm-dia and 9213.53 litre/day/km/mm-dia respectively. The infiltration rate of these two sets of data is much higher than the maximum infiltration rate prescribed by Malaysia Standard MS1228:1991 which is 50 litre/day/km/mm-dia and 46 litre/day/km/mm-dia stated in Hammer & Hammer (2004). For Set 3 and Set 4 data from Bandar Putra, leakage or blockage occurred where the upstream Manhole 92a flow rate is higher than the downstream Manhole 92b flow rate. The same goes to Set 5 data collected at Kota Sas, where leakage or blockage happened during the research period. For Set 3, Set 4 and Set 5 data, the infiltration rate is shown in negative sign which stands for leakage or blockage of sewer pipe. The results feedback will be sent to the authority for further reference and maintenance.

## 5.2 Recommendations

There are a few recommendations suggested to improve the study and also to provide a more comprehensive analysis for the inflow and infiltration in a sewer line. First of all, the data collection for each location should be at least half to a year. This is because the pattern of the graph and the infiltration of the sewer pipe will be clearer once the number of data collected increases. Besides, laboratory test should be conducted so that the comparison of infiltration rate with field work can be made.

Moreover, sewer pipe leakage detection should be conducted on the suspected sewer line so that can provide clearer information for relevant authority. Smoking test is one of the leakage tests that are suitable for low budget researcher. Smoking test can also give results in short period accurately.

Furthermore, the characteristic of soil and groundwater level surrounding the sewer pipes can be also accompany the studies as well. This can improve the accuracy of inflow and infiltration study by measuring the infiltration rate through the soil in selected areas. This is because the infiltration rate can be affected by the surrounding surface condition and also the previous water content of the soil.

In addition, the area velocity flow-meter used to carry out the research must be up-to-dated so that the equipment required can be standardized. The equipment required to conduct the research must be sufficient instead of taking turns or waiting previous researchers to complete their research. The increase in the number of the equipment can help researcher to collect more data and increase the accuracy of the results.

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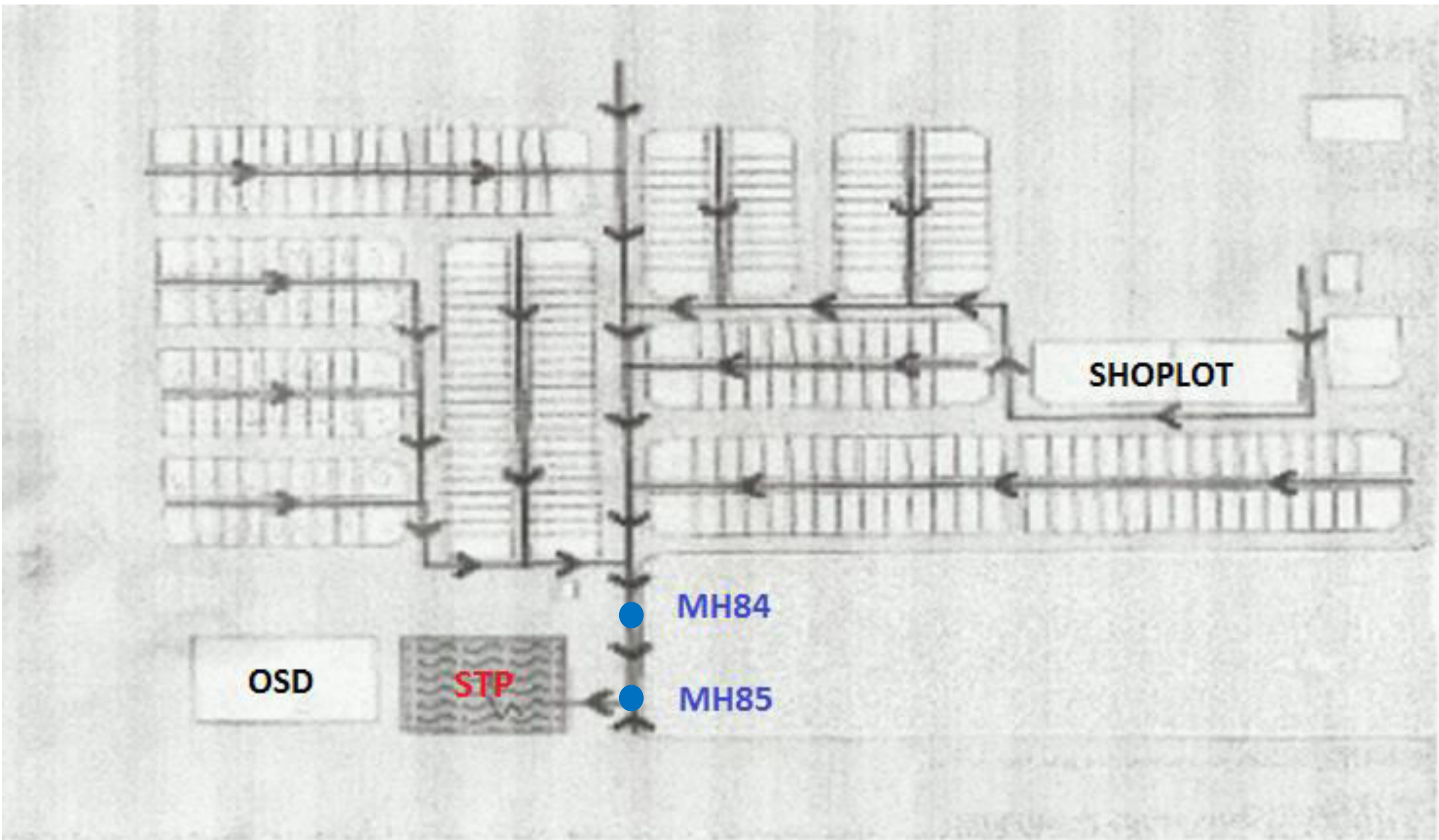
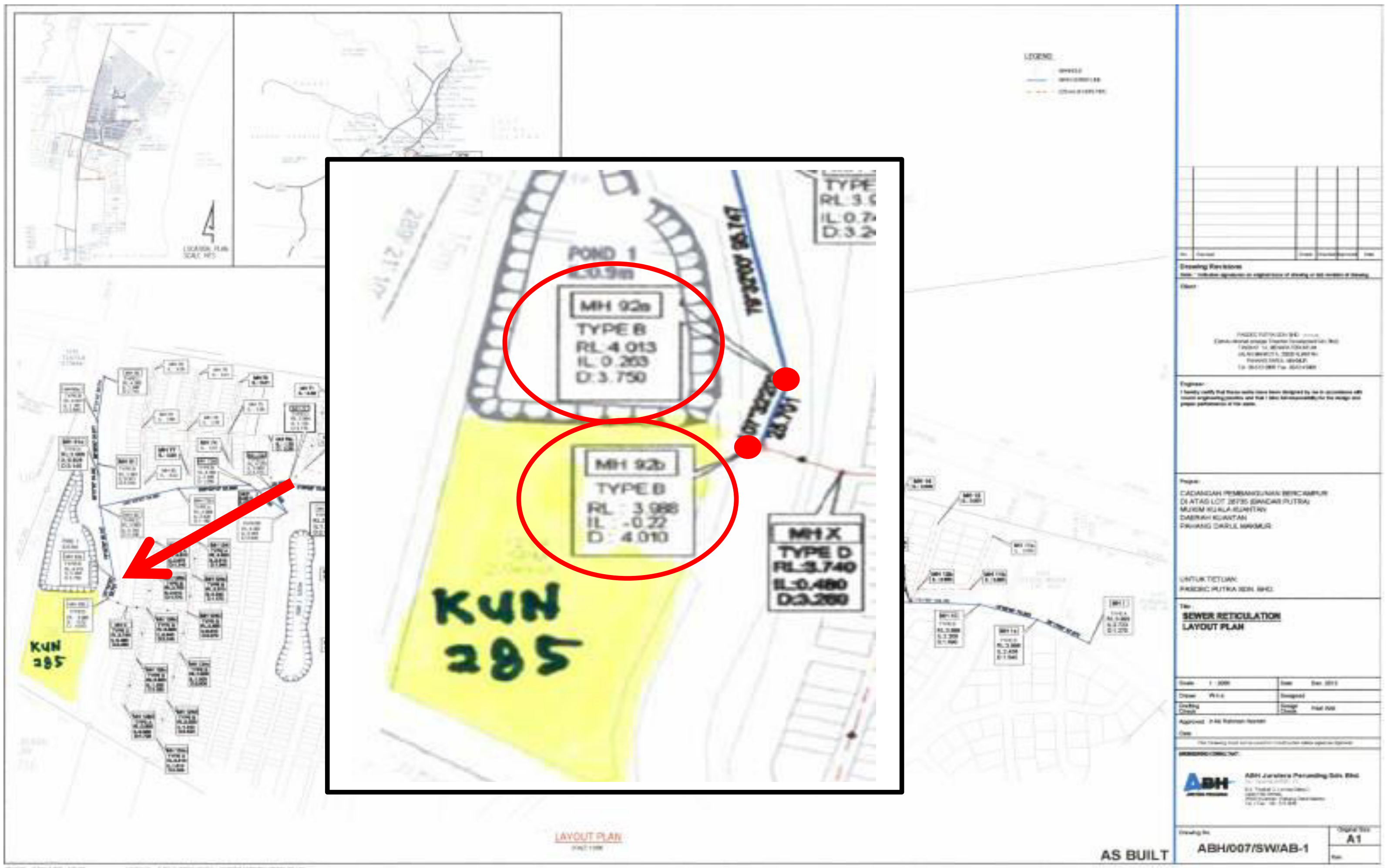
**APPENDIX A**

**Taman Lepar Hilir Saujana Sewer Reticulation Layout Plan**



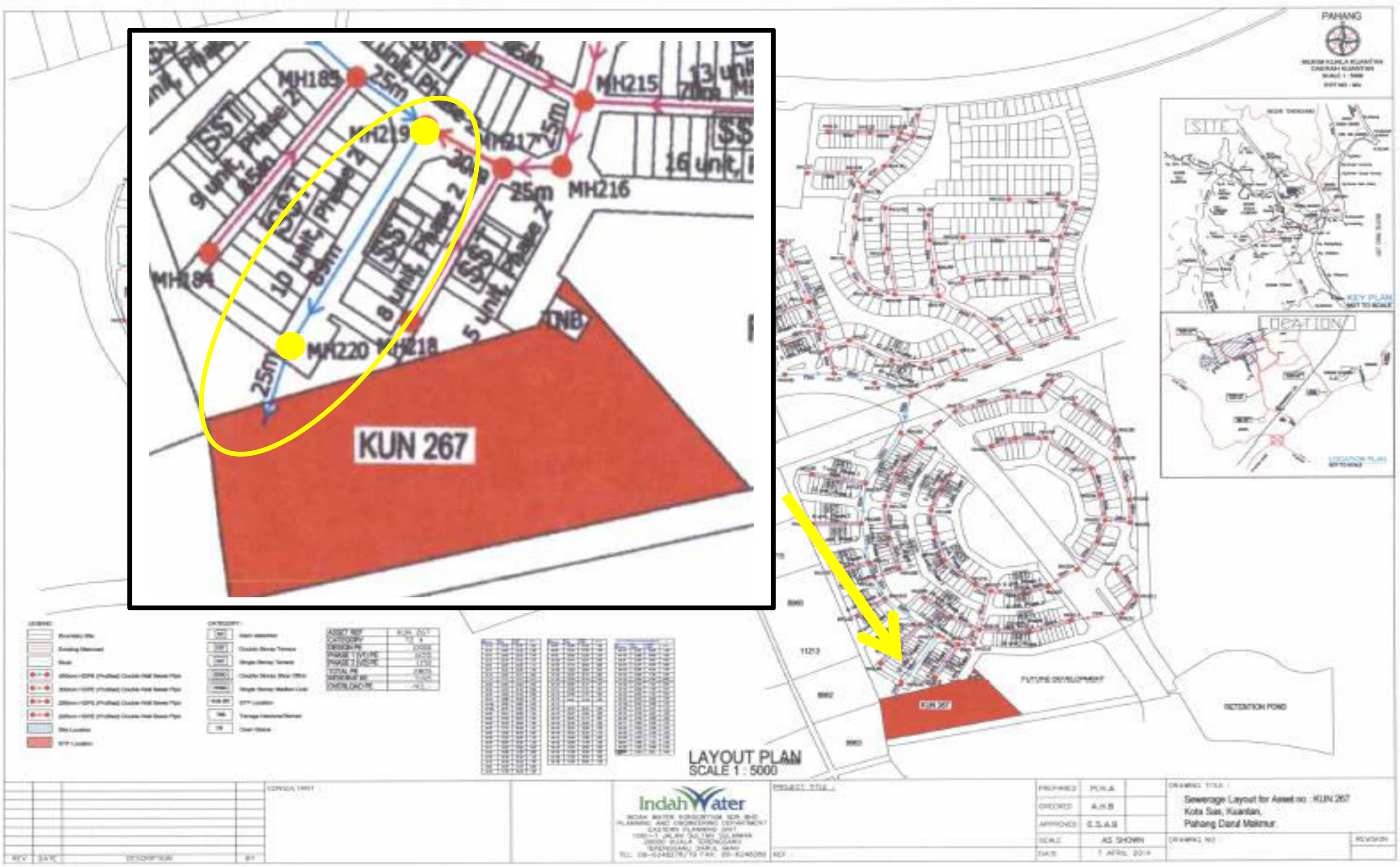
**APPENDIX B**

**Bandar Putra Sewer Reticulation Layout Plan**



**APPENDIX C**

**Kota Sas Sewer Reticulation Layout Plan**



## APPENDIX D1

## Taman Lepar Hilir Saujana Population Equivalent from Survey

| Type of Premise | Unit/Area | Requirement | PE |
|---|---|---|---|
| Commercial | 819.47 $m^2$ | 3 per 100 $m^2$ gross area | 24 |
| Residential | 15 units | OSS : 0 PE | 0 |
| Residential | 1 units | OSS : 1 PE | 1 |
| Residential | 11 units | OSS : 2 PE | 22 |
| Residential | 23 units | OSS : 3 PE | 69 |
| Residential | 37 units | OSS : 4 PE | 148 |
| Residential | 45 units | OSS : 5 PE | 225 |
| Residential | 86 units | OSS : 6 PE | 516 |
| Residential | 16 units | OSS : 7 PE | 112 |
| Residential | 13 units | OSS : 8 PE | 104 |
| Residential | 2 units | OSS : 10 PE | 20 |
| Residential | 1 units | OSS : 12 PE | 12 |
| | | **Total PE** | 1253 |

**APPENDIX D2**

**Bandar Putra Population Equivalent from Survey**

| Type of Premise | Unit/Area | Requirement | PE |
|---|---|---|---|
| Business centre | 800 $m^2$ | 3 per 100 $m^2$ gross area | 24 |
| Kindergarten | 20 person | 0.2 per non-residential student | 4 |
| | 3 person | 1 per residential | 3 |
| Residential | 5 units | OSS : 0 PE | 0 |
| Residential | 9 units | OSS : 2 PE | 18 |
| Residential | 82 units | OSS : 3 PE | 246 |
| Residential | 21 units | OSS : 4 PE | 84 |
| Residential | 102 units | OSS : 5 PE | 510 |
| Residential | 52 units | OSS : 6 PE | 312 |
| Residential | 21 units | OSS : 7 PE | 147 |
| Residential | 32 units | OSS : 8 PE | 256 |
| Residential | 10 units | OSS : 9 PE | 90 |
| | | **Total PE** | 1694 |

**APPENDIX D3**

**Kota Sas Population Equivalent from Survey**

| Type of Premise | Unit/Area | Requirement | PE |
|---|---|---|---|
| Shoplot | 3160 $m^2$ | 3 per 100 $m^2$ gross area | 96 |
| Mosque | 600 person | 0.2 per person | 120 |
| Kindergarten | 18 person | 0.2 per non-residential student | 4 |
| | 2 person | 1 per residential | 2 |
| Kindergarten | 27 person | 0.2 per non-residential student | 5 |
| | 4 person | 1 per residential | 4 |
| Kindergarten | 19 person | 0.2 per non-residential student | 4 |
| | 3 person | 1 per residential | 3 |
| Kindergarten | 28 person | 0.2 per non-residential student | 6 |
| | 3 person | 1 per residential | 3 |
| Kindergarten | 13 person | 0.2 per non-residential student | 3 |
| | 2 person | 1 per residential | 2 |
| Kindergarten | 25 person | 0.2 per non-residential student | 5 |
| | 3 person | 1 per residential | 3 |
| Residential | 17 units | OSS : 0 PE | 0 |
| Residential | 2 units | OSS : 1 PE | 2 |
| Residential | 21 units | OSS : 2 PE | 42 |
| Residential | 251 units | OSS : 5 PE | 1255 |
| Residential | 43 units | OSS : 6 PE | 258 |
| Residential | 85 units | OSS : 7 PE | 595 |
| Residential | 33 units | OSS : 8 PE | 264 |
| Residential | 41 units | OSS : 9 PE | 369 |
| | | **Total PE** | 3045 |

# APPENDIX E1

## Calibration Results of Taman Lepar Hilir Saujana (ISCO 4250)

| No. | Water Depth in Flow-meter ISCO 4250, $H_{4250}$ (mm) | Water Depth in Open Channel, $H_{OC}$ (mm) | Flow Rate in Flow-meter ISCO 4250, $Q_{4250}$ (l/s) | Flow Rate in Open Channel, $Q_{OC}$ (l/s) |
|---|---|---|---|---|
| 1 | 40.6 | 41 | 13.75 | 12 |
| 2 | 53.8 | 54 | 17.9 | 17.35 |
| 3 | 83.2 | 85 | 16.2 | 16.3 |
| 4 | 97.5 | 98 | 19.7 | 20.64 |
| 5 | 105.9 | 106 | 21.7 | 22.72 |
| 6 | 106.4 | 102 | 22.2 | 22.07 |
| 7 | 57.9 | 55 | 12.4 | 12.35 |
| 8 | 154.5 | 153 | 35.2 | 34.3 |
| 9 | 133.3 | 130 | 33.5 | 32.9 |
| 10 | 99.6 | 96 | 29.6 | 28.5 |
| 11 | 74.2 | 73 | 17.7 | 16.15 |
| 12 | 103.4 | 100 | 32.5 | 35.21 |
| 13 | 123.8 | 120 | 31.2 | 30.5 |
| 14 | 149.2 | 143 | 49.5 | 53.96 |
| 15 | 131.1 | 129 | 43.6 | 42.5 |
| 16 | 128.9 | 125 | 40.1 | 39.56 |
| 17 | 38.6 | 35 | 11.3 | 12.5 |
| 18 | 60.1 | 58 | 13.5 | 13.9 |
| 19 | 83.3 | 85 | 12.2 | 13.6 |
| 20 | 85.6 | 88 | 18.1 | 19.2 |
| 21 | 104.1 | 106 | 12.1 | 13.2 |
| 22 | 128.6 | 121 | 35.65 | 33.96 |
| 23 | 138.1 | 135 | 40.56 | 41.3 |
| 24 | 143.8 | 145 | 52.35 | 51.6 |
| 25 | 158.9 | 160 | 60.9 | 62.2 |

# APPENDIX E2

## Calibration Results of Taman Lepar Hilir Saujana (ISCO 2150)

| No. | Water Depth in Flow-meter ISCO 2150, $H_{2150}$ (mm) | Water Depth in Open Channel, $H_{OC}$ (mm) | Flow Rate in Flow-meter ISCO 2150, $Q_{2150}$ (l/s) | Flow Rate in Open Channel, $Q_{OC}$ (l/s) |
|---|---|---|---|---|
| 1 | 9.27 | 9.3 | 4.69 | 3.52 |
| 2 | 10.78 | 10.8 | 6.1 | 6.48 |
| 3 | 12.1 | 12.8 | 6.64 | 8.18 |
| 4 | 8.2 | 8.5 | 4.77 | 4.5 |
| 5 | 14.02 | 14.2 | 9.03 | 9.27 |
| 6 | 14.78 | 15 | 9.46 | 9.96 |
| 7 | 11.1 | 11.8 | 6.2 | 6.66 |
| 8 | 9.73 | 10.3 | 5.2 | 5.62 |
| 9 | 8.41 | 8.9 | 4.66 | 4.62 |
| 10 | 5.88 | 6 | 2.76 | 2.83 |
| 11 | 7.8 | 8 | 3.95 | 4.15 |
| 12 | 42.967 | 43 | 5.009 | 5.2 |
| 13 | 61.916 | 64 | 9.283 | 10.11 |
| 14 | 80.3 | 80 | 14.451 | 14.83 |
| 15 | 92.335 | 95 | 18.267 | 18.71 |
| 16 | 107.41 | 108 | 22.212 | 23.58 |
| 17 | 9.52 | 9.7 | 7.82 | 9.32 |
| 18 | 15.8 | 16.3 | 8.52 | 8.32 |
| 19 | 95.2 | 97.8 | 20.32 | 20.63 |
| 20 | 88.9 | 89.3 | 19.23 | 18.59 |
| 21 | 105.2 | 107.5 | 21.3 | 20.6 |
| 22 | 53.1 | 55.3 | 11.3 | 11.9 |
| 23 | 72.4 | 75.2 | 20.3 | 21.2 |
| 24 | 40.3 | 41.5 | 12.8 | 13.4 |
| 25 | 12.7 | 13.4 | 8.2 | 9.2 |

# APPENDIX E3

## Calibration Results of Bandar Putra (ISCO 4250)

| No. | Water Depth in Flow-meter ISCO 4250, $H_{4250}$ (mm) | Water Depth in Open Channel, $H_{OC}$ (mm) | Flow Rate in Flow-meter ISCO 4250, $Q_{4250}$ (l/s) | Flow Rate in Open Channel, $Q_{OC}$ (l/s) |
|---|---|---|---|---|
| 1 | 20.5 | 21 | 10.52 | 11.02 |
| 2 | 42.5 | 45 | 12.31 | 13.01 |
| 3 | 50.6 | 52 | 13.06 | 14.93 |
| 4 | 80.9 | 81 | 18.23 | 19.52 |
| 5 | 91.6 | 102 | 20.13 | 19.51 |
| 6 | 20.5 | 23 | 10.23 | 11.43 |
| 7 | 62.8 | 61 | 14.12 | 13.75 |
| 8 | 51.3 | 53 | 13.46 | 13.02 |
| 9 | 24.2 | 22 | 10.52 | 11.02 |
| 10 | 20.3 | 19 | 10.25 | 10.92 |
| 11 | 71.2 | 70 | 16.11 | 15.93 |
| 12 | 92.4 | 95 | 22.56 | 23.41 |
| 13 | 105.2 | 108 | 30.21 | 31.54 |
| 14 | 81.2 | 82 | 18.25 | 17.23 |
| 15 | 78.6 | 80 | 26.85 | 26.52 |
| 16 | 51.3 | 53 | 12.56 | 12.01 |
| 17 | 61.5 | 63 | 14.21 | 13.96 |
| 18 | 83.4 | 82 | 18.23 | 18.01 |
| 19 | 18.9 | 20 | 8.93 | 8.01 |
| 20 | 59.23 | 60 | 14.96 | 13.99 |
| 21 | 72.61 | 73 | 16.52 | 16.45 |
| 22 | 80.51 | 82 | 18.33 | 17.99 |
| 23 | 99.5 | 100 | 30.25 | 31.13 |
| 24 | 125.23 | 128 | 18.23 | 18.26 |
| 25 | 98.2 | 95 | 29.13 | 30.22 |

# APPENDIX E4

## Calibration Results of Bandar Putra (ISCO 2150)

| No. | Water Depth in Flow-meter ISCO 2150, $H_{2150}$ (mm) | Water Depth in Open Channel, $H_{OC}$ (mm) | Flow Rate in Flow-meter ISCO 2150, $Q_{2150}$ (l/s) | Flow Rate in Open Channel, $Q_{OC}$ (l/s) |
|---|---|---|---|---|
| 1 | 134.25 | 136 | 50.23 | 55.21 |
| 2 | 126.42 | 127 | 39.16 | 41.32 |
| 3 | 109.52 | 114 | 29.86 | 28.21 |
| 4 | 80.88 | 83 | 18.3 | 19.52 |
| 5 | 76.52 | 74 | 16.32 | 18.46 |
| 6 | 55.23 | 56 | 13.58 | 14.33 |
| 7 | 32.51 | 30 | 11.52 | 12.58 |
| 8 | 22.23 | 23 | 10.46 | 12.21 |
| 9 | 49.24 | 50 | 12.99 | 14.23 |
| 10 | 60.31 | 61 | 14.18 | 13.52 |
| 11 | 99.85 | 100 | 31.02 | 30.11 |
| 12 | 115.23 | 112 | 35.46 | 35.22 |
| 13 | 135.98 | 132 | 55.22 | 56.21 |
| 14 | 145.33 | 146 | 65.21 | 64.21 |
| 15 | 130.25 | 133 | 50.12 | 49.32 |
| 16 | 121.31 | 123 | 35.47 | 36.47 |
| 17 | 95.23 | 93 | 25.46 | 26.05 |
| 18 | 88.13 | 85 | 18.65 | 17.51 |
| 19 | 79.52 | 78 | 17.55 | 18.45 |
| 20 | 62.45 | 63 | 14.86 | 13.22 |
| 21 | 55.12 | 53 | 13.52 | 12.11 |
| 22 | 30.21 | 33 | 11.25 | 12.51 |
| 23 | 22.25 | 25 | 10.56 | 11.85 |
| 24 | 35.26 | 36 | 11.58 | 12.22 |
| 25 | 44.12 | 46 | 12.46 | 13.47 |

# APPENDIX E5

## Calibration Results of Kota Sas (ISCO 4250)

| No. | Water Depth in Flow-meter ISCO 4250, $H_{4250}$ (mm) | Water Depth in Open Channel, $H_{oc}$ (mm) | Flow Rate in Flow-meter ISCO 4250, $Q_{4250}$ (l/s) | Flow Rate in Open Channel, $Q_{oc}$ (l/s) |
|---|---|---|---|---|
| 1 | 22.23 | 25 | 10.25 | 9.56 |
| 2 | 44.85 | 43 | 12.43 | 11.52 |
| 3 | 52.23 | 55 | 13.26 | 12.22 |
| 4 | 65.42 | 63 | 14.52 | 13.32 |
| 5 | 72.56 | 75 | 16.28 | 15.21 |
| 6 | 83.25 | 86 | 18.33 | 17.52 |
| 7 | 96.1 | 94 | 20.66 | 22.63 |
| 8 | 122.48 | 125 | 35.26 | 34.87 |
| 9 | 135.26 | 140 | 55.21 | 53.78 |
| 10 | 145.78 | 141 | 65.78 | 67.74 |
| 11 | 120.56 | 122 | 34.89 | 33.54 |
| 12 | 95.47 | 93 | 25.11 | 24.85 |
| 13 | 85.23 | 85 | 18.59 | 20.63 |
| 14 | 66.21 | 62 | 15.96 | 14.78 |
| 15 | 58.56 | 59 | 13.73 | 12.96 |
| 16 | 39.56 | 40 | 11.97 | 10.56 |
| 17 | 22.18 | 20 | 10.24 | 13.42 |
| 18 | 20.78 | 18 | 20.11 | 18.21 |
| 19 | 48.89 | 50 | 12.96 | 13.56 |
| 20 | 55.56 | 54 | 13.58 | 14.57 |
| 21 | 77.58 | 76 | 16.71 | 18.25 |
| 22 | 100.99 | 101 | 30.89 | 33.46 |
| 23 | 130.47 | 128 | 43.21 | 43.59 |
| 24 | 116.96 | 117 | 33.56 | 37.48 |
| 25 | 60.52 | 59 | 14.21 | 15.02 |

# APPENDIX E6

## Calibration Results of Kota Sas (ISCO 2150)

| No. | Water Depth in Flow-meter ISCO 2150, $H_{2150}$ (mm) | Water Depth in Open Channel, $H_{OC}$ (mm) | Flow Rate in Flow-meter ISCO 2150, $Q_{2150}$ (l/s) | Flow Rate in Open Channel, $Q_{OC}$ (l/s) |
|---|---|---|---|---|
| 1 | 25.23 | 26 | 10.53 | 12.63 |
| 2 | 36.89 | 38 | 15.69 | 16.59 |
| 3 | 45.22 | 43 | 12.71 | 13.78 |
| 4 | 68.96 | 70 | 15.76 | 18.24 |
| 5 | 72.41 | 73 | 16.52 | 17.56 |
| 6 | 86.6 | 88 | 19.56 | 22.21 |
| 7 | 53.96 | 51 | 13.41 | 12.53 |
| 8 | 100.25 | 102 | 30.01 | 29.67 |
| 9 | 121.78 | 122 | 35.05 | 33.02 |
| 10 | 136.96 | 139 | 55.63 | 57.52 |
| 11 | 149.56 | 150 | 66.23 | 67.58 |
| 12 | 105.12 | 109 | 30.41 | 31.22 |
| 13 | 99.52 | 100 | 29.31 | 28.51 |
| 14 | 86.43 | 87 | 19.63 | 20.56 |
| 15 | 77.96 | 76 | 17.22 | 16.96 |
| 16 | 63.12 | 64 | 15.74 | 16.42 |
| 17 | 57.52 | 58 | 13.55 | 15.96 |
| 18 | 41.76 | 43 | 12.46 | 11.52 |
| 19 | 30.12 | 35 | 11.96 | 10.48 |
| 20 | 25.86 | 26 | 10.52 | 12.52 |
| 21 | 22.12 | 23 | 13.22 | 11.36 |
| 22 | 56.17 | 57 | 13.52 | 11.52 |
| 23 | 79.23 | 80 | 17.99 | 18.96 |
| 24 | 96.45 | 100 | 26.51 | 27.53 |
| 25 | 111.56 | 116 | 44.23 | 43.78 |

# APPENDIX F

## Table 1 is obtained from MS1228:1991 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 G

## Photo taken during the Project


**Calibration of Area Velocity Flow-meter at Hydraulic laboratory**


**Charging batteries of ISCO 2150**

**Installation of steel plate hanger in manhole by contractor**

**Installation of Flow-meter Sensor in mounting ring by lab assistant**

**Installation of Flow-meter in manhole**

**Retrieve data by using laptop**