Guide to Short-term Flow Surveys of Closed Conduits in Hong Kong

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FOREWORD

After the disastrous landslip of 1994 occurred in Kwun Lung Lau on Hong Kong Island, the Government has paid more attention on utility maintenance with particular emphasis on leakage detection of buried water carrying services on both slopes and roads. The Government has increased resources and imposed additional legislation on the detection of underground utilities. As a direct result, the utility profession has been developing rapidly, and over the last decade, the number of "Utility Specialists" (管綫專業監理師) has grown as the Government's requirements for Competent Persons to carry out the investigations has been implemented, in addition, Recognized Professional Utility Specialist (RPUS) (管綫專業監察師) has been recognized in recent years. However, lack of standard surveying methods, centralized monitoring systems and organized management, have lead to unsatisfactory investigation results.

In order to address these issues, Hong Kong Institute of Utility Specialists (HKIUS) (香港管綫專業學會), targeting the promotion of knowledge and good practice in the utility profession, collaborated with Hong Kong Utility Research Centre (HKURC) and supported by the funding from the Professional Services Development Assistance Scheme (PSDAS) of HKSAR, published a series of guide books and pamphlets in 12 disciplines of the utility profession in order to set standards for the practitioners to follow. As part of HKIUS continual effort to enhance the professionalism of the utility profession, it is the intention of the series that the quality of the survey can be raised and that utility related incidents can be avoided by performing high quality utility practices. Hopefully, the resulting benefits can extend to the general public.

As one of the 12 guidebooks, this issue provides good practices of conducting short-term flow surveys on closed conduits(管道流量測量) with the employment of flowmeters in Hong Kong. It states the whole process and specification of conducting a short-term flow survey on closed conduits from planning to finishing stages and intends to be used by all personnel involved in the works.

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April, 2011

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1. INTRODUCTION

1.1 Objective

For a modern city, stormwater drainage and sewerage are part of the essential infrastructure which can affect the daily life of the million. In Hong Kong, the collection and disposal of sewage and that of stormwater are provided by two separate systems. The systems, however, are built in early years, their efficiency and reliability decline due to the numerous defects accumulated as time passes. To assess the performance and sustainability of these systems, various close studies have to be carried out. One of these studies is flow survey.

In this guide, we attempt to provide recommendations on the practices for most aspects of conducting a short-term flow survey on closed conduits of Hong Kong's stormwater drainage system and sewerage system, with a hope to make flow inspection more time and cost effective as well as to reduce pipe incidents. Hence, social resources can be saved and, more importantly, properties and life injuries can be avoided or minimized.

1.2 Scope

For the stormwater drainage system, both open channels and closed conduits appear and open channels predominate in the system. Meanwhile, the sewerage system has only closed conduits. In this guide, we solely focus on the short-term flow survey of closed conduits.

Figure 1.1 Closed Conduit

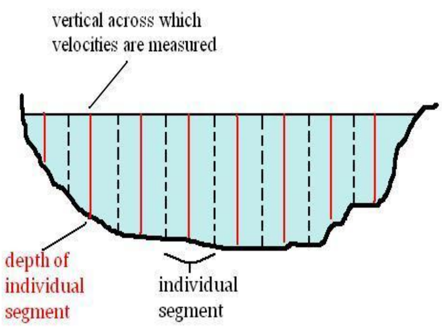


Figure 1.2 Open Nullah

We will have a general introduction on how to deduce the total flow discharge rate and the flowmeters, especially, the specific flowmeters that are mostly applied. We will also cover distinct stages of a flow survey from planning to data processing.

Nevertheless, it shall be noted that this guide does not include every detail of a flow survey. For the reason, the users of this guide shall refer to other relevant documents for the further information which is not included or detailed enough in this guide. Moreover, it must be stressed that the guidelines given in this guide are in no way exhaustive and professional judgment must be employed in all cases.

1.3 Hong Kong's Situation

Since Hong Kong locates in the tropical zone, she experiences heavy rainstorms every year, especially during the typhoon seasons, achieving an annual average rainfall of 2200 millimeters. These various spatially and temporally distributed rainfalls plus the blockage of the drainage conduits by human activities can cause flooding, threatening the life and property of Hong Kong people.

Figure 1.3 Flooding in Urban Area (Provided by Andrew Newman, taken in 2008, available at www.thenewmans.id.au/blog/)

Figure 1.4 Flooding in Central (Provided by Andrew Newman, taken in 2008, available at www.thenewmans.id.au/blog/)

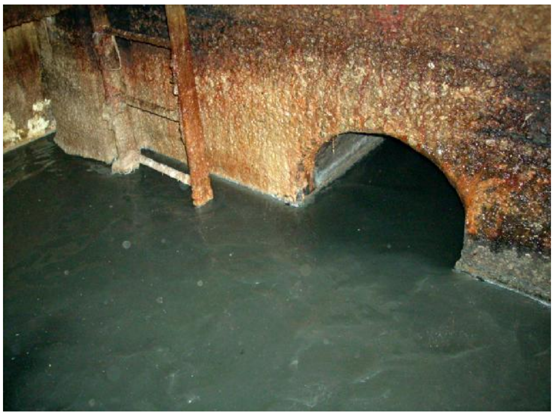


Figure 1.5 Surging Sewer of the City

Figure 1.6 Surging Sewer of the City

Meanwhile, under the rapid urbanization of the past 40 years, the population of Hong Kong has significantly increased up to more than 7 million in 2009. Commercial and industrial activities also surge dramatically with population's increase. As a consequence, the daily wastewater generated has gone beyond 2.5 million cubic meters, putting a heavy burden on the shaller of the declining sewage system.

To tackle the problems generated by Hong Kong's stormwater drainage and sewerage, various studies have been conducted by the Government since early 90s in last century and appropriate remedial and replacement measures are carried out. For example, DSD commenced seven Stormwater Drainage Master Plan Studies in 1996 to review the performance and conditions of the existing drainage system all over Hong Kong. Obviously, flow survey essentially takes an important role in the studies.

1.4 Simple Theory

Flow survey is a key step of a hydraulic investigation as shown in Figure 1.7. Flow survey assists the study on the performance of a hydraulic system by providing data on actual flows of the system during both dry and wet weather conditions. The data are then used to verify the computer hydraulic model which is the basis for the assessment of the hydraulic system.

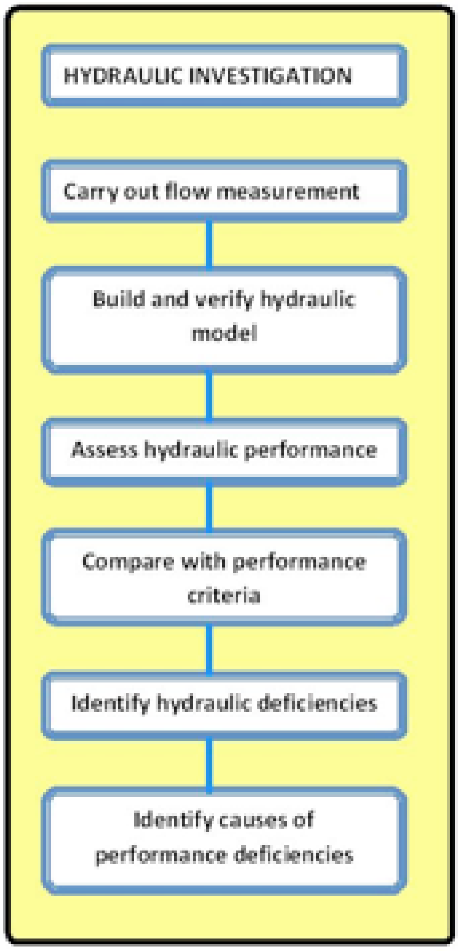


Figure 1.7 Chart of Hydraulic Investigation Stages (Picture adapted from "Sewage Rehabilitation Manual", 2001, published by WRc)

For most cases in Hong Kong, only part of a hydraulic system rather than the whole system undergoes investigation in a single project. Also, the hydraulic model has normally built already and most of the flow surveys are short-term surveys from one week to three months.

A flow survey usually measures three quantities: rainfall, cross-sectional area and velocity. Flow rate can be deduced from the cross-sectional and velocity data and studied along with the rainfall data. Yet, rainfall investigation is not often included in a flow survey project in Hong Kong. More often, rainfall records as well as tidal data are purchased and collected from Hong Kong Observatory and Geotechnical Engineering Office of Civil Engineering Development Department. As a result, rain gauges are only occasionally mentioned in this guide. One can always refer to "A Guide to Short-term Flow Surveys of Sewer Systems" published by WRc or other materials for details of rain gauges.

Flow can be divided into open channel flow and closed conduit flow. Open channel flow is a flowing stream with a free or unconstrained surface open to the atmosphere. The presence of the free surface prevents transmission of pressure from one end of the conveyance channel to another as in fully flowing pipes. Therefore, the only force that can cause flow in an open channel is the force of gravity on the fluid.

Meanwhile, for closed conduit flows, there are two sorts: fully filled and partially filled. Fully filled flow in a closed conduit is usually driven by pressure. If flow in a conduit does not completely fill it, the flow is driven by gravity and considered as an open channel flow.

Basically, the discharge rate or volume flow rate can be calculated through the simplest form of Continuity Equation as

$$\mathbf{Q = A\ v}$$

where
Q = volume flow rate (m^3/s)
A = cross-sectional area of the flow (m^2)
v = cross-sectional average velocity (m/s)

From the equation, we know that the accuracy of the volume flow rate depends on the accuracy of A and v. A cross section of flow is chosen for measurement in a flow survey. Cross-sectional dimensions are measured and a relationship between the dimensions, especially the depth (or another term, stage, which means flow level relative to a fixed datum) and cross-sectional area A is deduced and A can be obtained. Point velocities across the chosen cross-sectional area are measured by flow monitors and a relationship between them and the cross-sectional average velocity v is deduced and v can be obtained. Hence, the accuracy of Q highly relies on the sampling density and distribution of the dimension measurements and point velocity measurements.

The surveying principle for volume flow rate for surveys of different conduits and channels is the same but the measuring and deduction methods can vary from case to case depending on the accuracy requirements. In certain circumstances, to achieve a higher accuracy, an integrating principle is applied rather than directly using the above continuity equation.

For a chosen flow cross section, its width is measured by means of graduated steel tape or other surveying methods. Across the width, points are chosen and the flow vertical depth or stage at each point are measured by either physically graduated device like sounding rod or flow monitors. The number of points taken shall be sufficient to determine the shape and area of the cross-section. The location of each point, i.e. each measured vertical stage, is determined by suitable method so the cross section can be divided into segments as shown in Figure 1.8, such that each segment contains at least one vertical. The vertical or mean value of the verticals within a segment can then be the corresponding stage for that segment. With segment width obtained, the segment cross-sectional area can be calculated.

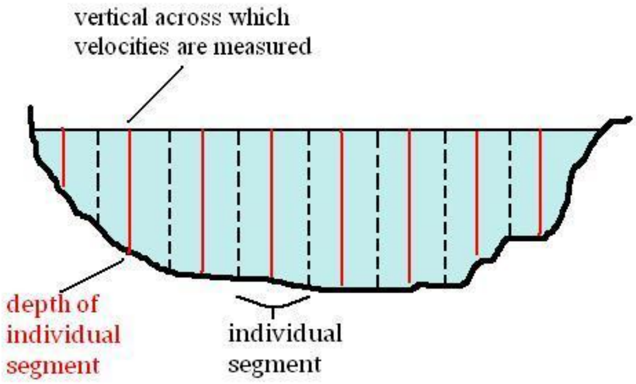


Figure 1.8 Cross-sectional segments

Along each vertical crossing the chosen flow cross section, points are selected for velocity measurement by employing flow monitors. The density of the selected points depends on the method decided for mean velocity measurement in a vertical. The point velocities from each vertical are averaged to be a mean vertical velocity. The product of the mean vertical velocity and the segment cross-sectional area gives the segment volume discharge rate. Integrating the segment volume discharge rate across the chosen flow cross section, we have the total volume discharge rate.

The accuracy of the total volume discharge rate increases with an increase in the number of verticals across the cross section. Table 1.1 gives suggestions on the number of verticals corresponding to the channel or conduit width.

Channel or conduit width, w	Number of verticals for stage measurement
$0m < w \le 0.5m$	3 to 4
$0.5m < w \le 1m$	4 to 5
$1m < w \le 3m$	5 to 8
$3m < w \le 5m$	8 to 10
$5m < w \le 10m$	10 to 20
Above 20m	Not less than 20
Measurements of depth or velocity at the flow’s edge are additional to the above	

Table 1.1 The specific number of verticals

For closed conduits, when the pipe is in full flow condition, simple continuity equation is applied. A is equal to the cross-sectional area of the conduit and can be calculated after measuring the cross-sectional dimensions of the conduit. For example, for circular conduit,

$$A = \pi r^2$$

where r is the conduit radius (Radius can be known by measuring the pipe diameter and dividing it by 2). The average velocity v is commonly deduced from the sensor velocities which are measured by flowmeter at chosen points along verticals of the flow cross section. This time all points on the cross section are averaged to give the cross sectional average velocity v.

For partially full flow in a closed conduit, when the conduit is large, around 3000mm, the integrating principle applies. When the conduit is not large, flow depth can be determined by flow monitors. With a clear investigation and understand on the cross-sectional geometry of the conduit,

$$\mathbf{A} = \left(\frac{\pi \mathbf{r}^2}{180}\right) \times \left\{\cos^{-1}\left[\frac{(\mathbf{r}-\mathbf{h})}{\mathbf{r}}\right]\right\} - (\mathbf{r}-\mathbf{h})\sqrt{(2\mathbf{hr}-\mathbf{h}^2)}$$

flow depth is used to calculate the flow cross-sectional area, A. For example, for circular conduit,

where r is the conduit radius and h is the flow depth (Details of finding A for different conduit shapes can be found on http://www.engineeringtoolbox.com/). Again, the cross-sectional average velocity v is deduced from sensor velocities.

2. FLOWMETERS

2.1 General

In many flow surveys, a flowmeter is employed. Flowmeter is a device that measures the physical quantity of a moving fluid in an open or closed conduit. A flowmeter usually consists of a primary and a secondary device. The primary device is mounted internally or externally to the fluid conduit and interacts with the fluid to generate a signal to the secondary device. The secondary device converts the signal to a display or to an output signal that can be translated relatively to flow rate or quantity.

Figure 2.1 An Inline Ultrasonic Flowmeter (Adapted from http://www.controlengeurope.com/)

Figure 2.2 A Clamped-on Handheld Ultrasonic Flowmeter (Adapted from http://theultrasonicflowmeters.com/)

There are different ways to categorize the flowmeters. Table 2.1 shows flowmeters being categorized by the technology employed. Different types of flowmeters can be applied to different liquids owing to their technology employed. Table 2.2 lists the recommendation of flowmeters for various liquid flows. Apart from the type of liquid flow, many other factors need to be considered in selecting a right flowmeter, including conduit size, ability, head loss, accuracy, repeatability, installation method, cost, etc. Table 2.3 lists the applicable line size range, ability, relative head loss and straight-run requirement of different sorts of flowmeters. For other particular characteristics of a flowmeter, one can always find them on the manual of the flowmeter from the manufacturer. The decision of using a specific flowmeter is usually based on the practitioner's experience and knowledge and limited to the choices provided by the Contractor.

	Technology employed		Parameter Measured	Result output
1	Coriolis		Acceleration	Mass
2	Differential Pressure	Dall Tube	Pressure	Volume
3		Elbow	Pressure	Volume
4		Flow Nozzle	Pressure	Volume
5		Orifice	Pressure	Volume
6		Pitot Tube	Pressure	Volume
7		Averaging Pitot Tube	Pressure	Volume
8		V-Cone	Pressure	Volume
9		Venturi	Pressure	Volume
10		Segmental Wedge	Pressure	Volume
11	Magnetic Induction	Magnetic	Induced Voltage	Velocity
12	Positive Displacement	Rotating Disc	Volume	Volume
13		Oscillating Piston	Volume	Volume
14		Oval Gear	Volume	Volume
15		Roots (Rotating Lobe)	Volume	Volume
16		Rotating Valve	Volume	Volume
17		Birotor	Volume	Volume
18		Rotating Impeller	Volume	Volume
19	Target		Force	Velocity
20	Turbine		Volume	Volume
21	Ultrasonic	Doppler Utrasonic	Acoustic Waves	Velocity
22		Transit-time Ultrasonic	Acoustic Waves	Velocity
23	Variable Area	Movable Vane	Pressure	Volume
24		Rotameter	Pressure	Volume
25		Weir, Flume	Pressure	Volume
26	Vortex		Frequency	Velocity

Table2.1: Flowmeters Being Categorized by Technology (Table partly adapted from www.efunda.com)

	Clean Liquid	Dirty Liquid	Direct Mass Liquid	Non-Newtonian Liquid	Viscous Liquid	Abrasive Slurry	Fibrous Slurry	Corrosive Liquid
Coriolis	R	R	R	R	R	R	L	L
Differential Pressure	R	R			R	L		L
Magnetic	R	R		L	R	R	R	R
Positive Displacement	R	L			R			L
Target	R	R			R			L
Turbine	R							L
Doppler Ultrasonic	L	R			L			R
Transit-time Ultrasonic	R	R			L			R
Variable Area	R	L						L
Vortex	R	L						L

Table 2.2: Flowmeters for Various Liquid Flows

Index: R Recommended
L Limited application

Type of Flowmeter	Applicable Line Size Range	Rangeability / Turn-down Ratio	Relative Head Loss	Straight-run Requirement (in pipe diameter)	
Upstream	Downstream				
Coriolis	6 ~ 200 mm	20:1	Low	5	3
Differential Pressure	6 ~ 2000 mm	3:1	Medium to high	15	10
Magnetic	In-line model: 10 ~ 3000 mm	10:1	Low	3	2

Insertion model: 75 mm and up

10	5				
Positive Displacement	6 ~ 300 mm	5 ~10 : 1	High	1	1
Target	In-line model: 15 ~ 150 mm	7:1	Medium	15	10

Insertion model: 100 ~ 1500 mm

20	15				
Turbine	In-line model: 6 ~ 100 mm	20 : 1	Low to medium	20	10

Insertion model: 64 ~ 1500 mm

25	20				
Transit-time Ultrasonic	Inline model: 20 ~ 6000 mm	20:1	No head loss	10	5

Clamped-on model: 75 ~6000 mm

10	5				
Doppler Ultrasonic	Inline model: 10 ~ 2000 mm	20:1	No head loss	10	5

Clamped-on model: 75 mm and up

10	5				
Variable Area	Mostly used in lines size 100 mm and below, but may go up to 2000 mm in line size.	10 ~ 20 : 1	Low	20	10
Vortex	In-line model: 10 ~ 1200 mm	5:1	Low to medium	15	10

Clamped-on model: 75 mm and up

20	10

Table 2.3: Characteristics of Flowmeters

2.2 Specific Flowmeters

Magnetic induction flowmeters and ultrasonic flowmeters are suggested for the closed conduit flow surveys of stormwater and sewage in Hong Kong since pipe size of the systems varies from 150mm to 4500mm. There are three sorts of installation methods depending on the flowmeter type: inline, insertion and clamped-on. Clamped-on transit-time ultrasonic flowmeter or insertion magnetic flowmeter is suggested for full pipe condition while insertion Doppler ultrasonic/ sonic flowmeter with depth sensor is suggested for partially full condition. The Doppler ultrasonic/ sonic flowmeter with depth sensor suggested here and mentioned in the later text refers to the bed-mounted type.

Transit-time Ultrasonic Flowmeter

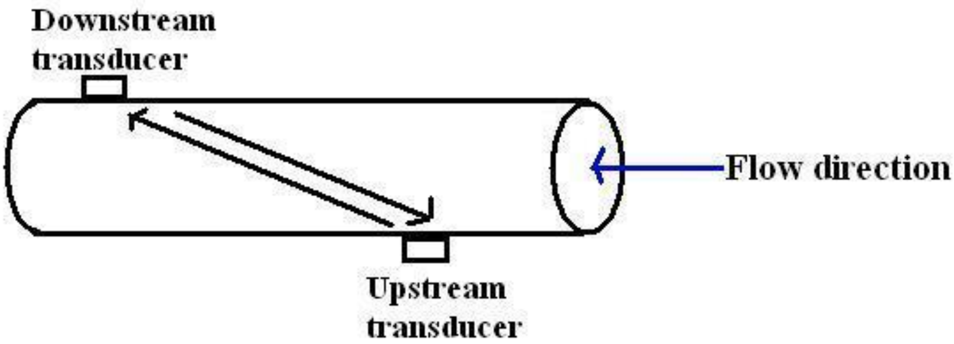


Figure 2.3 Transit-time Ultrasonic Flowmeter

A transit-time ultrasonic flowmeter is also named as time-of-flight or through-transmission meter. A transit-time ultrasonic flowmeter has a pair or pairs of transducers, each containing its own transmitter and receiver. The transducers are placed diagonally across the flow, as shown in Figure 2.3. The transducers transmit and receive an ultrasonic pulse in the direction of flow, followed by a return pulse against the direction of the flow. The speed of the pulse directed downstream is increased by the speed of the stream; when directed upstream, the speed of the pulse is slowed by the stream flow. The time difference between the two pulse transmissions is a function of fluid velocity. Hence, with pipe diameter entered into the meter and by manipulation, the rate of flow can be found.

Doppler Ultrasonic/ Sonic Flowmeter

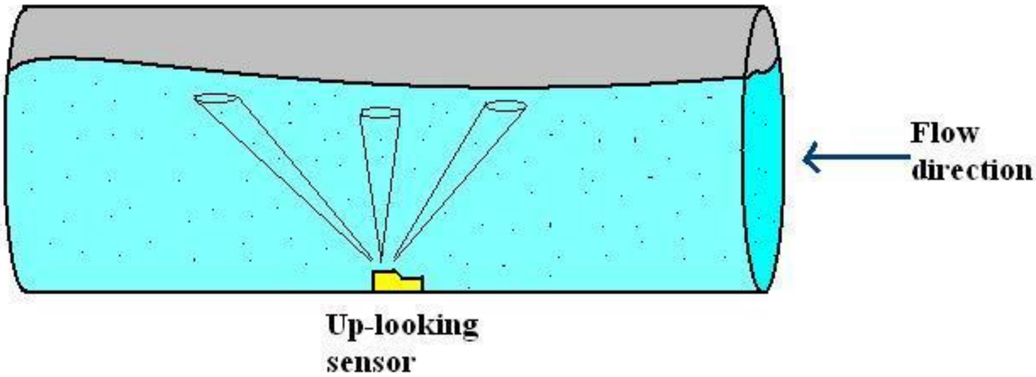


Figure 2.4 Up-looking Doppler Sonic Sensor

Doppler ultrasonic/ sonic flowmeters make use of the Doppler Effect to relate the frequency shifts of acoustic waves to the flow velocity. The Doppler Effect is the change in frequency of a wave for an observer moving relative to the source of the waves (Details of Doppler Effect can found on http://en.wikipedia.org/wiki/Doppler_effect). The flowmeters usually require some particles in the flow to reflect the acoustic waves. As the particles are moving with the flow, the waves reflected by the particles will have a frequency shifts so that flow velocity can be determined. The rule of thumb is 25 ppm (parts per million) suspended solid or bubbles with diameters of 30 µm or larger for 1 MHz or higher frequency transducers. Denser fluid conditions will be needed for lower frequency transducers. Sewage and stormwater commonly have enough air bubbles, minerals and other suspensions to act as reflectors.

An illustration of a typical Doppler sonic flowmeter employed in flow surveys in Hong Kong is shown in Figure 2.4. This type of sonic flowmeters also measure flow depths apart from measuring flow velocities. As the figure shown, three acoustic wave beams are generated. One points upstream and one points downstream for velocity measurement while one points vertically up to measure the flow depth based on timing the reflection from the flow surface. On the other hand, some depth sensors of these flowmeters apply the principle of the hydrostatic pressure rather than reflection of wave to determine the flow depth.

Insertion Magnetic Flowmeter

Since sewage and stormwater are conductive and have a conductivity of 3 μScm-1 or higher, magnetic flowmeters can be used for flow surveys. Magnetic flowmeters apply Faraday's law of electromagnetic induction. With a magnetic field applied across a flow, i.e. perpendicular to the flow direction, electric charges will be induced in the flow. The induced voltage is proportional to the flow speed. Hence, flow velocity and also flow rate can be deduced by measuring the induced voltage as shown in Figure 2.5.

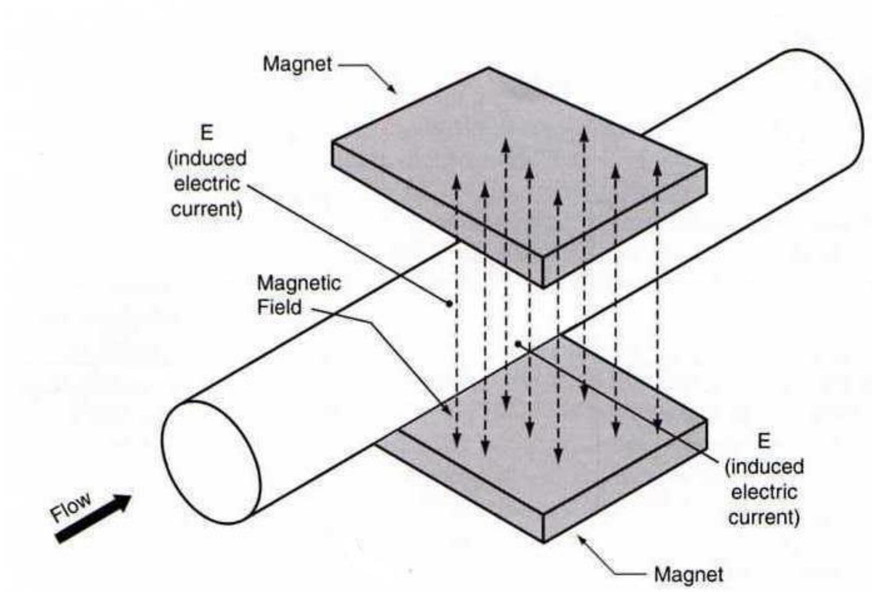


Figure 2.5 Magnetic Field across a Flow (Picture adapted from "Flowmeters in Water Supply", 2006, published by AWWA)

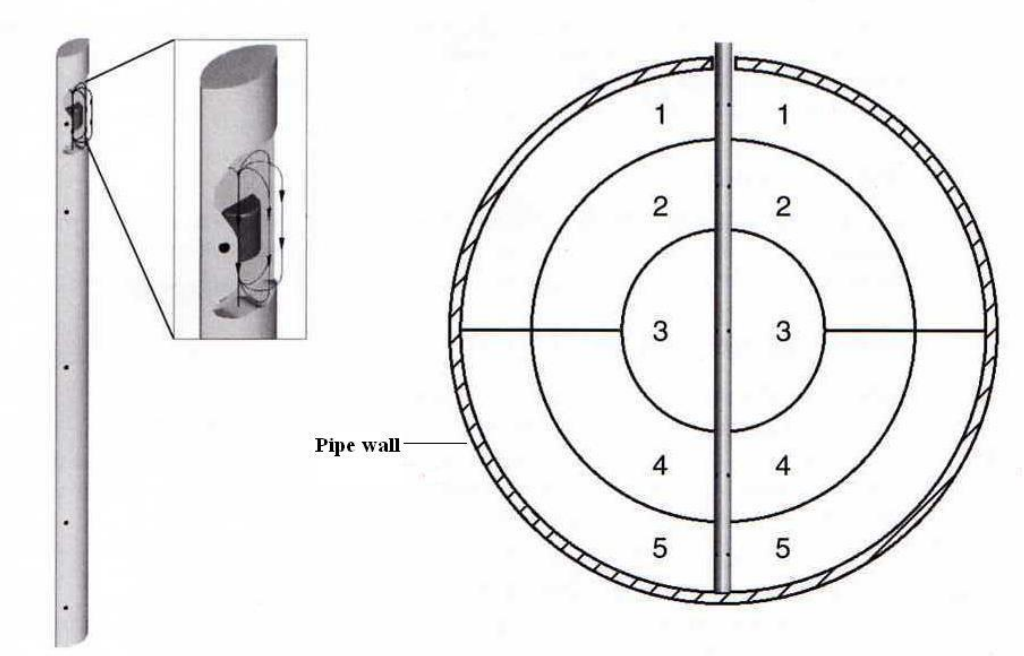


Figure 2.6 The Sensor of an Insertion Magnetic Flowmeter (Picture adapted from "Flowmeters in Water Supply", 2006, published by AWWA)

The sensor of an insertion magnetic flowmeter is shown in Figure 2.6. It has electromagnetic coils within its streamlined sensor to generate multiple magnetic fields at points along the sensor as shown. The sensor will normally be inserted into a pipe section through a tap connection on the pipe. When a conductive fluid passes through each magnet, a small electric charge that is proportional to the fluid speed is induced and can be sensed by multiple pairs of electrodes adjacent to the electromagnets. Each coil and associated pair of electrodes becomes a velocity sensing point. These sensing points are evenly distributed across the sensor; hence measure the various velocities of the fluid across the pipe are measured and the result is averaged to a mean velocity continuously.

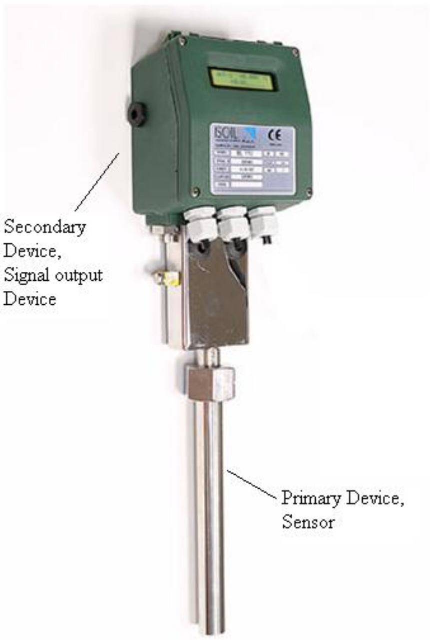


Figure 2.7 An Insertion Magnetic Flowmeter (Adapted from www.isoil.com)

3. GENERAL REQUIRMENTS

3.1 General

With proper flowmeters selected, we can then introduce various flow survey stages. Before commencing a flow survey, one has to understand the various requirements of the survey, including statutory requirements, safety requirement, personnel requirement, equipment requirement, etc. One shall also prepare a comprehensive plan to ensure a smooth and safe inspection process.

3.2 Statutory Requirements

There are different statutory requirements on different areas, such as health and safety, noise, traffic, excavation, site etc. For the details, one may refer to contractual documents and other guides. Information can also be obtained from the Hong Kong Institute of Utility Specialists (HKIUS). The following is a brief introduce on some common statutory requirements.

Health and safety: the Workplace Health and Safety Regulations of Hong Kong specify several requirements for personnel involved in works; some of the requirements are stated in relevant ordinance or regulations such as working in a confined space, road traffic control, excavation safety, dangerous substance, noise at work, etc. It is important to follow relevant ordinances stated on the Occupational Safety and Health Council (http://www.oshc.org.hk).

Noise: the Noise Control Ordinance (Cap400) shall be complied with and Construction Noise Permits shall be obtained.

Traffic: the Code of Practice for Lighting, signing and Guarding of Road Works published by the Highways Department shall be complied with and the Road Liaison Officer of the Hong Kong Police Force shall be liaised.

Excavation: For the installation of flow monitors, excavation may sometimes be required. The access around the excavation area has to be properly supervised by a Competent Person (CP) (合資格人士), under Cap. 406H, the Electricity Supply Lines (Protection) Regulation, at all times. Excavation Permits from the Highways Department shall also be applied. Completing excavations, no dirt, excess spoil or any other materials shall be left in the conduit or water channel and polluting the system. Sediment control procedures can be referred to the Environmental Protection Department (http://www.epd.gov.hk).

Figure 3.1 Memorandum on Noise of EPD (Adapted from www.epd.gov.hk/)

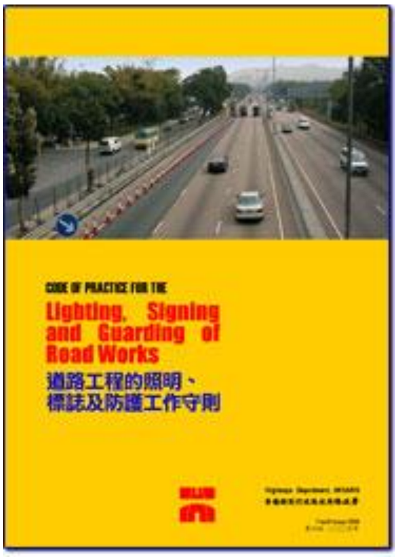


Figure 3.2 COP for Road Works (Adapted from www.hyd.gov.hk/)

3.3 Safety Requirements

Both employers and employees shall comply with relevant occupational health and safety legislations and obligations to ensure a safe working environment and minimize disturbance to the public caused by the work. As mentioned, it is important to follow relevant ordinances stated on the Occupational Safety and Health Council (http://www.oshc.org.hk).

Generally, the employer or the contractor has to prepare a safety plan and has risk assessment carried out by trained safety personnel before the commencement of work. The safety plan shall have regard to the Government's Construction Site Safety Manual and to UK's Water Industry's National Joint Health and Safety Committee's publications. The details of a safety plan can be found in the appendix part of the contractual document. Apart from risk assessment, the effect on the public shall also be evaluated. Appropriate steps shall be taken to minimize or even eliminate any potential risks for injuring the public.

Moreover, all staff working on the Site has to be given general safety and health training as well as Personal Protective Equipment (PPE) and shall have sufficient knowledge in both usage and maintenance of that equipment. PPE shall include:

Steel toe cap, rubber safety boots
Safety helmet
Safety vest (reflective at night)
Safety goggles/Anti-glare glasses
Breathing apparatus/Disposable respirator
Harness and Fall arrester
Gloves
Ear muffs / ear plugs
Handy gas detector
Audio-visual alarm
Resuscitator

Figure 3.3 Personal Protective Equipments (PPE)

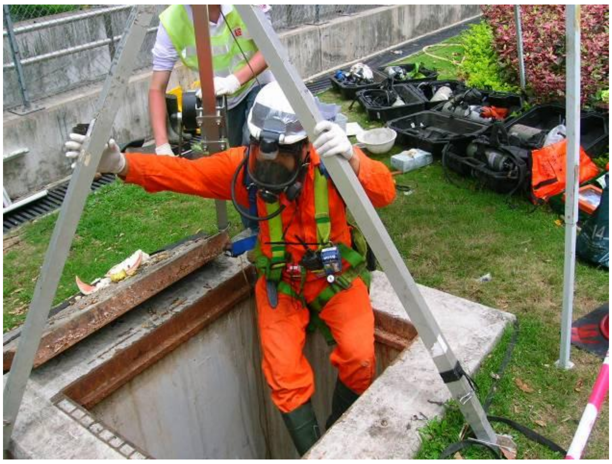


Figure 3.4 Protective Equipment for Entering a Confined Space

Especially, the installation of flow monitors is usually at manhole or through manhole. Hence, the Code of Practice: Safety and Health at Work in Confined Spaces and DSD's Practice Note No. 1/2007 for working in confined space shall be strictly followed. A "Permit and Enter" system in accordance with the Factories and Industrial Undertaking (Confined spaces) Regulations shall be operated. Besides, the, electrical equipment shall meet certain standard, such as BS 5345, in order to operate under potentially explosive atmospheres.

3.4 Personnel Requirements

In order to maintain the Utility Profession's requirements for the consistency, reliability and accuracy of reports, flow inspection shall be performed by properly trained and accredited personnel. Accredited personnel shall hold a certified qualification issued by a Registered Training Organisation (RTO), such as Utility Training Institute (UTI) or The Hong Kong Polytechnic University or equivalent. Table 3.1 states indicative guidelines on the training and experience requirements. Besides, qualified personnel are required to attend refreshment course in every 3 years to refresh and enhance their knowledge.

Figure 3.5 Training Course of UTI

Figure 3.6 Safety Training on Site

Figure 3.7 Training for Confined Space Works

Figure 3.8 Training Course of UTI

Type of Personnel	Role	Minimum Training Requirement	Minimum Years of Experience
Project Leader (M/ FHKIUS + RPUS)	Contractual arrangement, check and certify reports.	Training courses for utility survey/detection methods and data management.	10 years in contract administration, preferably in utility survey.
Team Leader (M/FHKIUS)	Works arrangement, check data quality and consistency.	Training courses for utility survey/detection methods and data management.	5 years in works of utility survey.
Crew Leader (O/MHKIUS)	Supervision of field works and site safety.	Training course and valid training certificate for utility survey.	3 years in works of utility survey.
Operator (AMHKIUS)	On-site inspection and operation of equipment.	Training course and valid training certificate for utility survey.	2 years in works of utility survey.

Table 3.1 Training and Experience Requirements for Personnel Carrying Out Utility Survey using PCL. (Reference to the Code of Practice on Monitoring and Maintenance of Water-carrying Services, Work Branch, 2006 and HKIUS constitution, 2010)

3.5 Equipment Requirements

There are three types of flow monitors: permanent flowmeters, temporary flowmeters and handheld meters. Our concern will be the temporary type which is for short-term flow surveys.

The following specifications are suggested for the flow monitors so that requirements of conducting both drainage and sewerage surveys can be met. However, what stated here are not necessarily the only appropriate requirements; one shall always refer to the contractual documents of the project on the specifications.

- The depth sensor shall meet the following requirements:

- Being capable of measure flow depth above the invert of a conduit over a certain range which can be a range within 20mm and 5000mm or covering the whole 20mm to 5000mm range. Thus, the depth sensor has to meet most of the situations of stormwater and sewage conduits

- Having an accuracy of the depth readings within 2% of the reading determined by controlled factory measurements for factory testing

- Having minimum instrument resolution of 2mm or less

- The velocity sensor, which is of ultrasonic flowmeter or magnetic flowmeter as suggestion, shall meet the following requirements:

- Being capable of measuring a velocity of flow from -1.50 ms-1 up to and including 5 ms-1 for sewage measurement and at least from -1.50 ms-1 up to and including 10 ms-1 for stormwater measurement

- Having an accuracy within ±2% for flow speed ≥ 1ms-1 and when there are suitable site hydraulic characteristics

- Having minimum resolution of 0.01 ms-1 or less

- Having a recording and storing interval of 2 minutes or shorter

- Being synchronized to within ±15 seconds with other velocity sensors of other locations

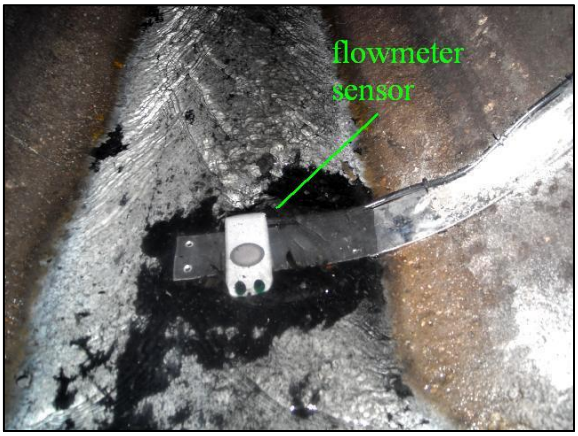


Figure 3.9 Flowmeter in Shallow Flow

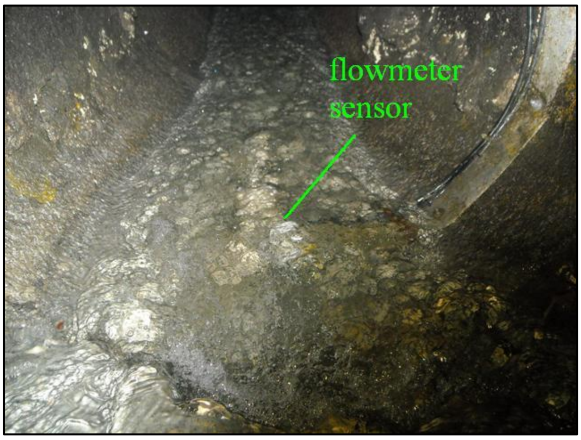


Figure 3.10 Flowmeter in Deeper Flow

Figure 3.11 Sonic Flowmeter in Silt

Figure 3.12 Sonic Flowmeter in Shallow Flow

4. PRE-SURVEY PLANNING

4.1 General

For a project, an estimated survey period and the general locations of the survey are normally specified in the Contract Documents. The determination of the duration and locations is purpose-oriented and pre-tender steps. Yet, the determination of specific monitoring sites within the ranges of the general locations is upon the pre-site visit before the commencement of the survey. Specific installation sites are carefully chosen as the sites' situation affects data accuracy. Another measure to keep data accuracy is to have pre-installation calibration and functional test of the instruments. Basically, a comprehensive plan is always needed to ensure a smooth and safe inspection process.

Figure 4.1 Site Visit

Figure 4.2 Site Visit

Figure 4.3 Chosen Site is Marked

Figure 4.4 Chosen Site is Marked

4.2 Survey Duration

A flow survey needs to last as long as it takes adequate data for the survey's purpose. A survey for model verifying purpose, 3 peak flow situations and 3 dry periods are generally required. A flow survey of 5 weeks is common in Hong Kong and usually long enough. It will virtually depend on seasonal conditions when it is a stormwater survey. When a survey is carried out to investigate a specific problem, the occurrence of the problem is essential before the survey can be withdrawn.

A scheduled survey period is an experiential estimation. Whether a survey can be completed adhering to the schedule is dependent on the catchment response and engineering judgment is required when assessing catchment response. The scheduled survey period may be extended when the catchment response is inadequate. One week before the survey's anticipated site completion, the data collected shall be reviewed to decide whether an extension is needed or not.

4.3 General Monitoring Locations

The choice of monitoring sites is a two stage process. General locations in compatibility with the survey's objectives are initially selected before tender is out. The selection of monitors' installation sites via pre-site visit is the second stage.

For model verifying purpose, the following general monitoring locations are suggested:

- At system outfall that the outcome data can be for checking on the overall accuracy of simulation
- At the middle of the main trunks that the main trunk flow components can be obtained
- In large subcatchment pipes with monitors placing near the junctions with the main trunk that the effects of major subcatchments can be assessed
- At critical points in subcatchments experiencing problems
- At other upstream and downstream bifurcations, loops or specific problem points

4.4 Selection of Specific Monitoring Sites

With the survey duration and general locations determined in the Contractual Documents, one can instantly enter the pre-survey preparation when the Documents are accepted. Pre-site visits are taken to select the suitable installation sites of monitors. Two or three potential sites for each general location shall be investigated and the site with the most stable flow pattern shall be chosen.

The following points shall be noted when deciding which sites to be chosen for monitoring:

The site shall be straight and of uniform cross section so that abnormal velocity distribution can be avoided. Rapid and high variance in velocity distribution across the flow cross section will bring error to the flowmeter measurement.

Installation at points of straight through conduits is the best way to avoid skewed flow patterns. However, if it is inevitable to install at points close to elbow, tee or other junctions, the straight-run rule shall be followed. Straight-run requirement of different types of flowmeters is shown in Table 2.3. Whenever possible, installation in the upstream is suggested for better accuracy.

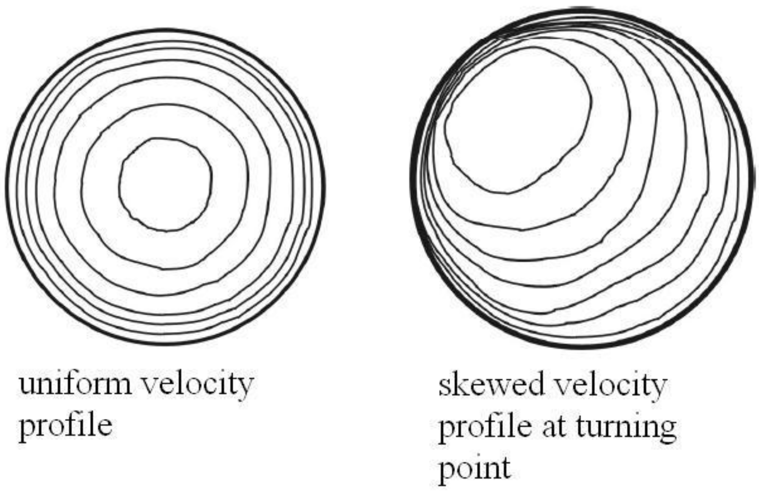


Figure 4.5 Velocity profile

The straight-run requirement for ultrasonic flowmeters is 10 pipe diameters downstream and 5 pipe diameters upstream. This, however, may not be practical owning to safety matters in large-pipe-size case. It is subjected to site conditions when considering straight-runs.

Sites at pump stations and active valves shall be avoided whenever possible. The straight- run for valves is at least 10 diameters upstream and 25 diameters downstream.

Sites displaying vortices, reverse flow and dead water shall also be avoided.

For the application of Doppler sonic flowmeters, the depth of the flow shall be within a range of 100mm to 5000mm. Out of the range, the data will be inaccurate. Also, the flow velocity shall be within ±5 ms-1 or the reflected wave will be carried away by the flow. For most other flowmeters, the effective operating range is 0.02 ms-1 to 5 ms-1.

Silt does not usually exist in the stormwater drainage system as heavy storm can flush away any sediment in the system. Silt can however exist in the sewerage system and sites prone to silting are usually unsuitable. The existence of silt can bring error to flow computation.

Sites close to strong noise sources, e.g. pump stations, transformer stations or other locations where heavy machinery exists, shall be eschewed. The data of a flowmeter is taken and stored in electrical form and so strong electromagnetic waves can affect flowmeters' operation accuracy.

4.5 Pre-commence Inspection and Preparation

Before survey commences, pre-site visit has to be carried out so that the accessibility and flow conditions of sites can be examined and right sites for equipment installation can be chosen. During the pre-site visit, it is also important to undertake reconnaissance velocity profile surveys of the chosen site, in a range of flows. The data collected can later be used to determine the best height or position for the instrument.

After the visit, a report on each designated manhole or position for survey shall be done. The report information shall include the flow depth and the estimated depth of silt if there is any. For certain situation, drain cleaning is required and the proposed method of drain cleaning for the connecting pipelines shall also be included in the report. The purpose of drain cleaning is to get rid of debris and silt but it is normally optional. The details of drain cleaning can be found in any tender files of flow survey. Apart from the above, Temporary Traffic Arrangements (TTA) shall be considered if the installation of equipment is located in a traffic road and there shall also be comprehensive risk assessment and safety plan.

4.6 Pre-installation Calibration and Functional Test

Often, calibration works are done by manufactories or labs and a certification of calibration is issued. The certification shall be of at least 3 points verification, including zero point, normal point and maximum point. If obtaining calibration certification is not possible, functional test shall be carried out by practitioners 14 days prior to the delivery of instrument to the site for installation.

Velocity function can be checked by immersing the sensor of the monitor in a flume or other suitable channel of running water. The result after continuous recording and logging for 15 minutes can be compared with that by the measurement of a handheld meter of accuracy range ±5% to check that the sensor velocity is within ±0.03 ms-1 or 15%, whichever is the lesser of the alternative instrumentation.

Depth function can be checked by immersing the sensor in a tank at various water depths, each for 15 minutes. The results at each depth are compared with that by a graduated ruler or alternative instrument. The difference between the instrument and ruler measurement shall also be recorded as the offset. The result shall be acceptable if neither of the offsets is more than 20mm and the arithmetical difference between the two is equal to or less than 5mm.

However, even the devices have been calibrated in the laboratory, in situ calibration or verification is still required. Laboratory calibration only ensures that the instrument is recoding the correct average velocity for the sample area. It does not verify that the sampled velocity is correctly converted to actual velocity or flow. This is a site-specific process and cannot be tested in the laboratory.

Due to insufficient conditions, in situ calibration is generally not easy. In situ calibration with conventional current meter, such as hand-held ultrasonic flowmeter is suggested. Calibration gauging shall be undertaken when the instrument is installed and subsequently over a range of flows. The velocity profiling taken during pre-site visit can also be used for assisting calibration but with a less weighting.

After data is retrieved, the computational calibration can further be applied on the data. Details of computation calibration can refer to “A Guide to Short-term Flow Surveys of Sewer Systems” published by WRc. For velocity data, velocity-index ratings are required. When the instrument has been installed, the calibration gauging shall be continued for a range of flows. The data coming from gauging shall be used to derive a relationship between the velocity recorded by the instrument and the actual velocity or flow. Details of velocity-index ratings can refer to the manual of this guidebook.

5. IN SITU FLOW INSPECTION

5.1 General

A proposed event sequence of a flow survey is stated as following:

1) Commencement of equipment installation

2) Completion of survey installation and commencement of the continuous recordings

3) Weekly site visits to retrieve recorded data, carrying out site calibration checks (quality assurance checks) and checking the operation of the instruments

4) Completion of the continuous recoding period

5) Commencement of equipment removal

6) Completion of equipment removal

7) Delivery of rainfall data to Employer or Client if rain gauges are included in the survey.

8) Delivery of fully processed velocity, depth and flow data

9) Delivery of the survey report

5.2 Site Installation

Whether a flow survey can be completed according to the scheduled period depends on the catchment responses. In most cases, the hydraulic network area covered by a short-term survey project is not very large and the instruments can be installed within one or two days. However, for a survey covering the whole or a large section of a hydraulic network, the installation order can affect the opportunities of obtaining suitable catchment responses. A proposed installation order is stated as following:

- Rain gauges shall be first installed whenever rain gauges are included in a flow survey. Rainfall data of days before the flow data obtained is needed if the survey is for model verifying purpose.

- Flow monitors in outfall and main trunk pipes shall secondly be installed as suitable flow responses in large pipes tend to occur less often than in small pipes.

- Flow monitors in trunk feeder conduits and then monitors in other minor conduits shall be installed lastly.

The installation of equipment shall follow the manufacturer's manual. A typical installation of an inline type sonic flowmeter is illustrated in Figure 5.1. When conduit flow is not full and Doppler sonic flowmeter is employed, the sensing head might have to be offset installed from the pipe's invert as illustrated in Figure 5.2:

- For some sewerage conduits where silt exists, the sensing head has to be offset above the silt for the reason that silt can impede Doppler signals.

- For some large pipes where flow is considerable that it is dangerous to enter the flow, the instrument‘s sensing head can usually be fixed offset to the pipe wall for safe installation. However, for other large closed pipes with full flow, clamped-on ultrasonic flowmeters are suggested.

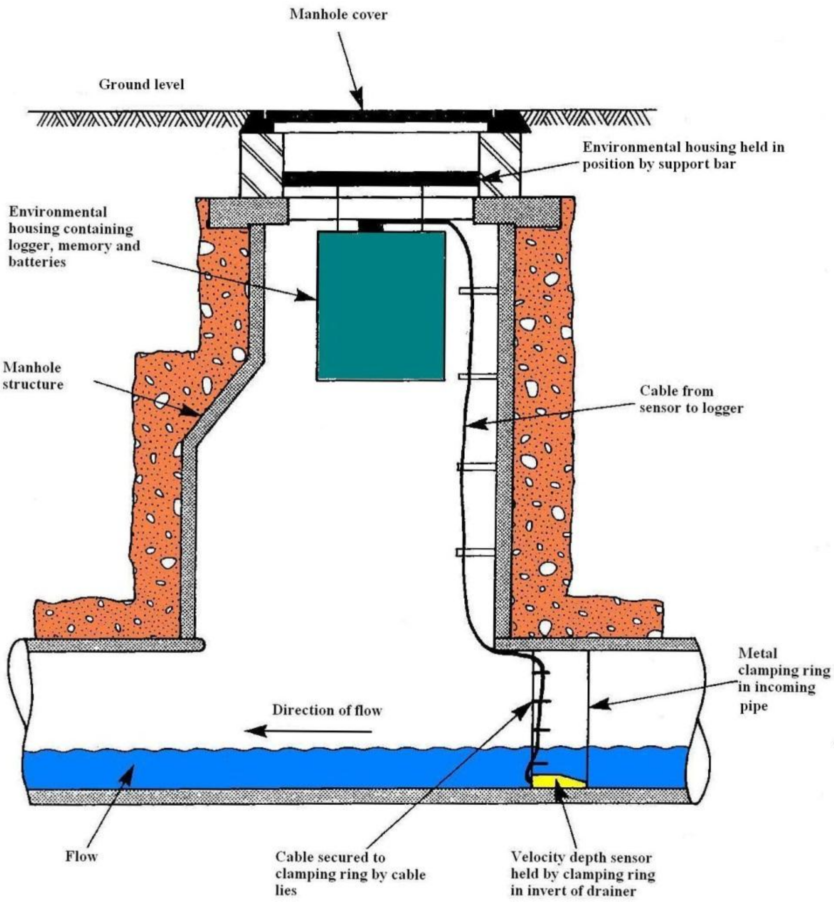


Figure 5.1 Installation of Doppler Sonic Flowmeter in a Manhole (Picture adapted from “A Guide to Short-term Flow Surveys of Sewer Systems”, 1987, published by WRc)

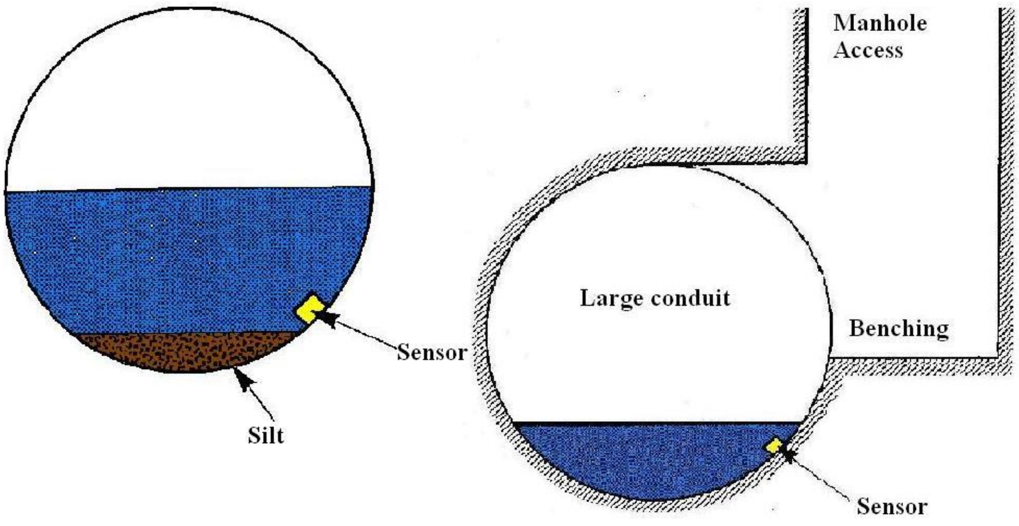


Figure 5.2 Senor Installed Offset (Picture adapted from “A Guide to Short-term Flow Surveys of Sewer Systems”, 1987, published by WRc)

5.3 Dimensional Measurement of Cross Sections

At the time of installation and removal or relocation, the dimensions of the conduits, in which the flow monitors are installed, shall be measured and recorded.

There are many conduit shapes apart from circular, including square, rectangular, egg shaped, etc. (For details on the conduit shapes, one may refer to "Hong Kong Conduit Condition Evaluation Codes" published by HKIUS)

In circular and rectangular shaped conduits, the major vertical and horizontal dimensions shall be measured and recorded. In other shapes, the width measurement shall be taken at depth increments of at least every 100mm up to one third conduit height. Above that, widths must be taken at depth increments of at least 200mm. Flow surface widths shall also be taken during each week's site visit.

5.4 Data Collection

Commonly, the retrieve of data to data processing centre is done by manual downloading. The survey area is visited to collect the data and for quality assurance checks on the instruments each week. The survey team shall be capable of interpreting the data so that faults or anomalies in the result can be checked on site and adjustment can be made.

Site visits are recommended to be arranged at different times each week because the hydraulic conditions will vary in accordance with the diurnal flow patterns. Visiting the site at different times enables the survey team to observe the site hydraulic suitability for measurement under different flow conditions and allows the quality assurance checks to be carried out under different flow patterns so that the instrument's linearity can be checked.

Apart from downloading the data manually, new technologies allow automatic measurement and transmission of data from remote sources to receiving base stations via wireless telemetry such as GPRS. This type of real-time reporting technology is especially useful for long-term surveys like flood monitoring. For instance, DSD has developed its own Flood Monitoring and Reporting System of more than 60 automated gauging stations to monitor the flooding situation and to collect the hydrological data for calibration of computer drainage models. The data transmitted can undergo analysis immediately and if flooding is over certain level, mobile phone SMS alarm and email alarm will be delivered out instantly as shown in Figure 5.3.

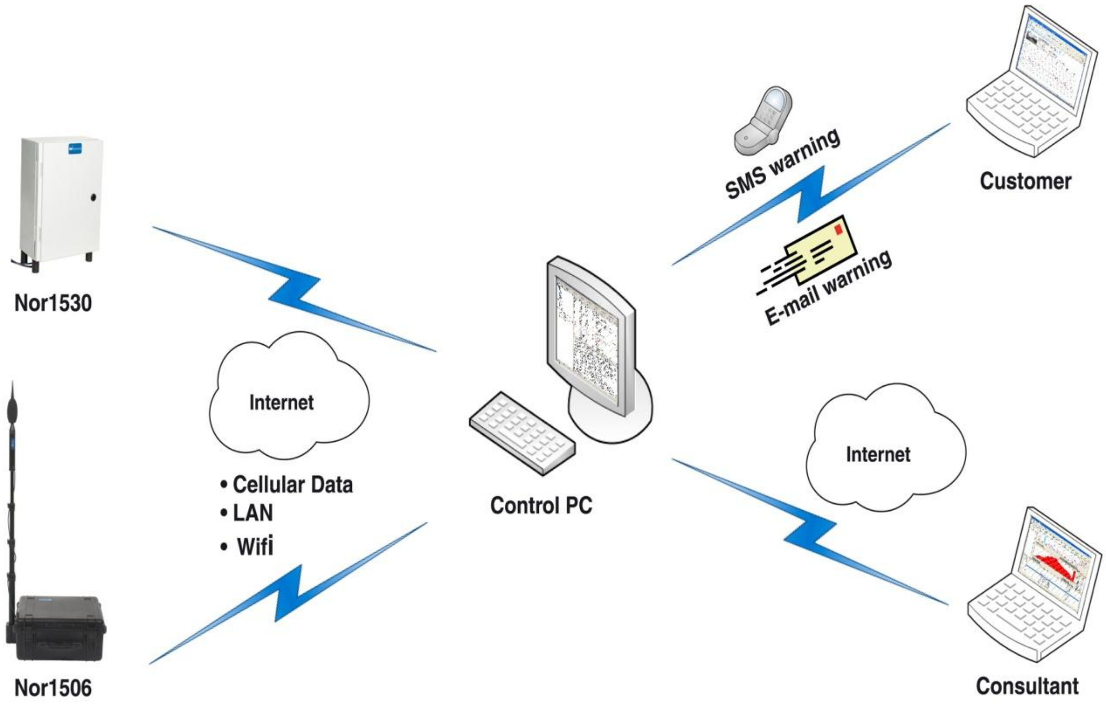


Figure 5.3 Real-time Reporting System (Picture provided by Greenspan Singapore PTE Limited)

5.5 Data Return Rate and Quality Coding

The data return rate is counted in terms of percentages of the site survey period, not proportions of data recorded, i.e. at least 90% of the monitors shall be operational at all times during the site survey period. Also, every instrument shall operate in accordance with the specification for at least 80% of the site survey period, i.e. an instrument shall not be faulty for more than 1/5 of the site survey period. If the above data return rates are not met, the site survey period may be extended.

Regarding the 90% operational clause, in case of less than 10 instruments are used, the fail of one instrument may be taken as being acceptable.

5.6 Quality Assurance Checks

Apart from pre-installation calibration, quality assurance checks are carried out during data retrieve to make sure the data obtained within an acceptable range. The recorded data alone without quality assurance checks can often be useless. Once a week, the accuracy of each flow monitor shall be checked by using alternative instruments. Site Check Sheets shall be filled while carrying out the checking procedure and shall be included in the reports. An example of Site Check Sheet is given in Figure 5.5.

The checks for velocity are done with an independent hand held meter to take a series of flow velocity readings corresponding to that measured by the site-installed monitor. The two are then compared to verifying the monitor's accuracy. Portable ultrasonic flowmeter may be applied as the hand held meter. It is recommended the velocities at different points of the flow are checked. The number of points chosen will be subjected to the practitioner's experience or contractual specification and a recommendation is shown in Figure 5.4. More points shall be taken or applies the integrating principle when the flow is found skewed. Besides, it is recommended that around 10 check velocity readings shall be recorded for each point.

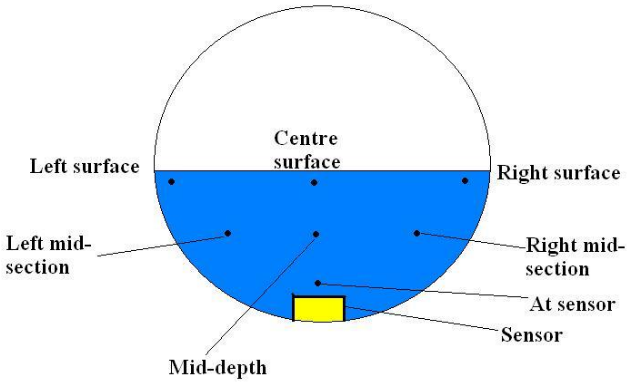


Figure 5.4 Flow Points Taken for Velocity Checks

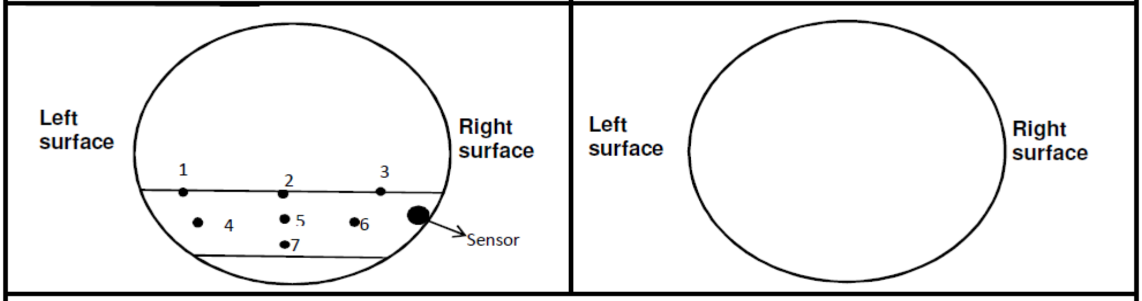
For the case of silt existing, which is common in sewerage system and occasional in stormwater drainage system, and when the pipe flow is partially full, the depth of the flow shall be checked by a graduated rule or other instruments and compared with the depth reading of site monitor. The depth of the silt shall also be measured and can be obtained by the depth of flow surface to pipe invert minus the depth of flow surface to silt surface.

Apart from the above measures, the in situ experience of the practitioners is also important and can even overwhelm the measures in determining the reliability and accuracy of the data under certain circumstances.

When quality assurance checks indicate that a monitoring site is unsuitable, the instrument may be relocated. Moreover, when the measurements are failed to meet the quality assurance checks, the scheduled survey period may be extended.

CALIBRATION AND PROFILE REPORT
HONG KONG SEWER FLOW GAUGING
Provision of services for sewage flow survey
for Kwun Tong sewerage system

STATION:	FM13 (Mace)		DATE / 日期	03-04-2009	
Pipe Size(mm)	750				
1st calibration / 第一次校準			2nd calibration / 第二次校準		
Start time / 開始時間:	22:49		Start time / 開始時間:		
Water Level (mm) 水深	360	Sensor Reading 0.356	Water Level (m) 水深		Sensor Reading
silt (mm) 泥深	140				
LEFTBANK/由左起	No of Revs	Velocity (m/s)	LEFTBANK/由左起	No of Revs	Velocity (m/s)
1	50/10Sec	0.306	1		
2	64/10Sec	0.381	2		
3	62/10Sec	0.371	3		
4	48/10Sec	0.295	4		
5	61/10Sec	0.365	5		
6	62/10Sec	0.371	6		
7	54/10Sec	0.328	7		
8			8		
9			9		
RIGHT BANK			RIGHT BANK		
Sensor Reading	0.350-0.390		Sensor Reading		
End Time / 完結時間:	22:51		End Time / 完結時間:		
Water Level (mm) 水深	460		Water Level (mm) 水深		
silt (mm) 泥深	140		silt (mm) 泥深		
Sensor Position	4 O'Clock		Distance of sensor from pipe bottom (mm)		



Comments/ remark:

- ☐ Site is pump affected / 受到泵的影響
- ☐ Lots of silt at site, measured at 140 mm / 很多泥
- ☐ Velocity is faster on right bank side. Due to upstream bend / 由於係轉彎位 (左 / 右), 左右的速度不一樣
- ☐ Site was pumping when gauging was conducted/做緊校準時有泵泵水
- ☐ Very Slow Flows / 水流很慢
- ☐ Surface of water is very wavy and turbulent / 水面很多波紋
- ☐ Water level changes rapidly during calibration / 做緊 calibration 時水位突然改變
- ☐ Rubish exist during in calibration porint / 做 calibration 個位有垃圾 (邊幾點)
- ☐ 其他 / others

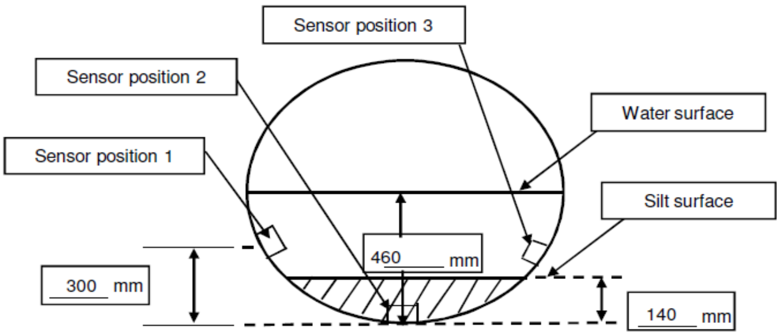


Figure 5.5 Filled Site Check Sheet/ Calibration Form (Provided by Buda Surveying Limited) POST-

6. SURVEY DATA PROCESSING

6.1 General

This part does not intend to dig deeply into the details of data processing but to give a basic impression of post-survey data processing to the readers.

The analysis of data can be divided into two stages:

1) Before a survey ends, initial data analysis shall be done. It shall include the examination on the data of site monitors and Site Check Sheets returned from site, checking the data consistence and ruling out the bad points. Interim reports are also presented to the Employer/ Client during the survey period.

2) After a survey ends, a whole assessment of accuracy on all the data collected and computational calibration on the depth and velocity data shall be done. The depth and velocity data will be analyzed along with rainfall data. Suitable storm and dry periods or periods with suitable catchment responses will be chosen for detailed analysis. Flow rates will be calculated and final report will be presented to the Employer/ Client.

6.2 Data Processing Before Survey Ends

After the raw data is obtained from the site monitors, data quality coding is often applied. Then examination of the data is done by plotting graphs of velocity versus time and depth versus time. Graph of flow rate is usually plotted as well. Examples of the plots are shown in Figure 6.1, 6.2 and 6.3. The produced graphical plots are compared with the information on the Site Check Sheets and also the previous raw data plots from the same site to check the consistency of flow characteristics. The diurnal flow pattern of a sewerage conduit repeats and certain flow characteristics of a stormwater conduit appear under a heavy storm.

If rain gauges are included in a flow survey, an examination of rainfall data shall be done by producing the graphical plot of rainfall versus time and weekly rainfall patterns to make a comparison with that of adjacent sites. The details can be found in “A Guide to Short-term Flow Survey for Sewer Systems”, published by WRc.

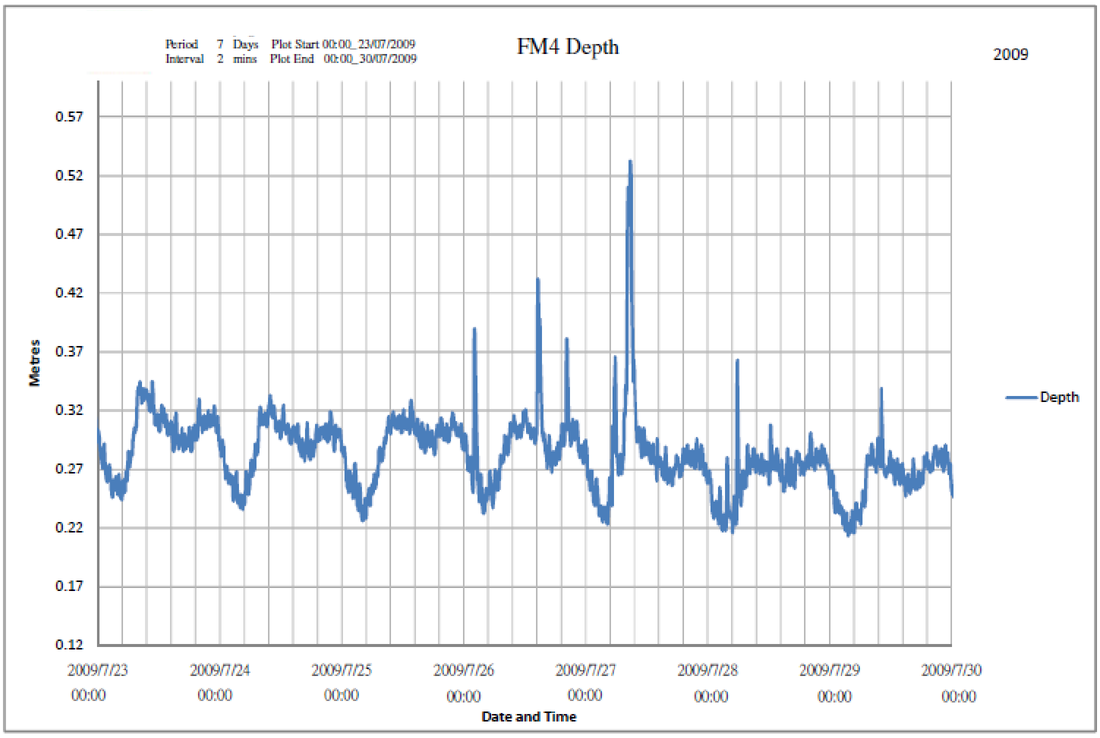


Figure 6.1 Depth versus Time (Data plot of monitor FM4 in the Flow Survey for Wan Chai East and North Point Sewerage Remaining Works provided by Buda Surveying Limited)

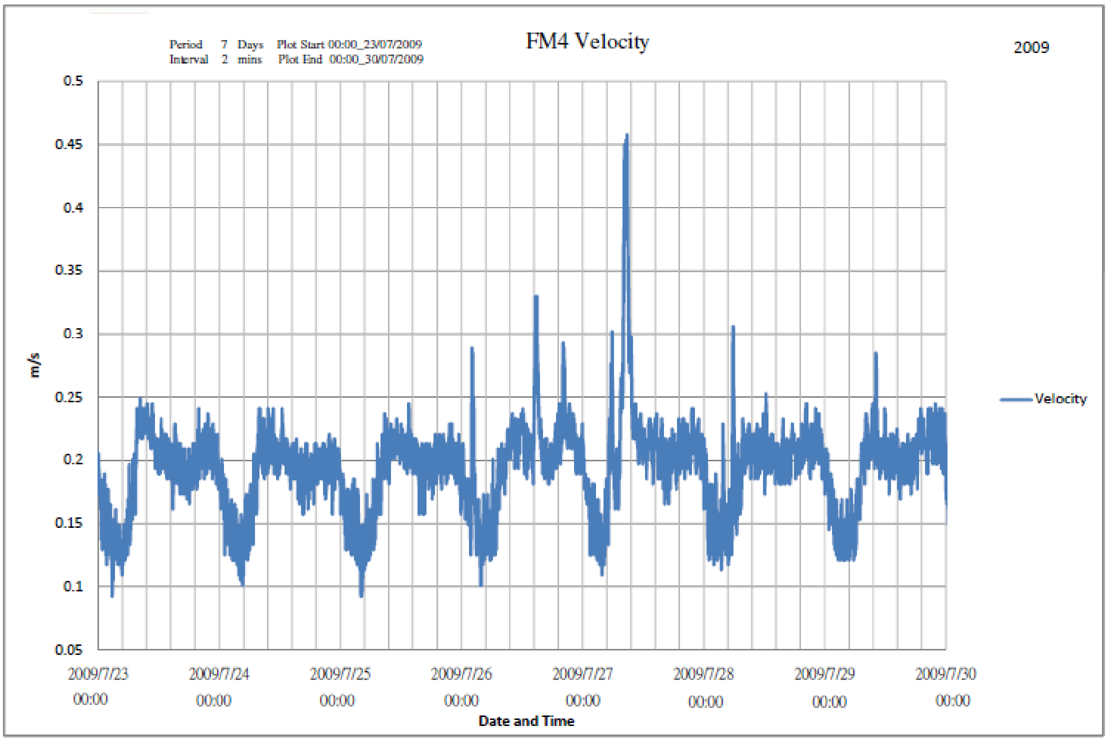


Figure 6.2 Velocity versus Time (Data plot of monitor FM4 in the Flow Survey for Wan Chai East and North Point Sewerage Remaining Works provided by Buda Surveying Limited)

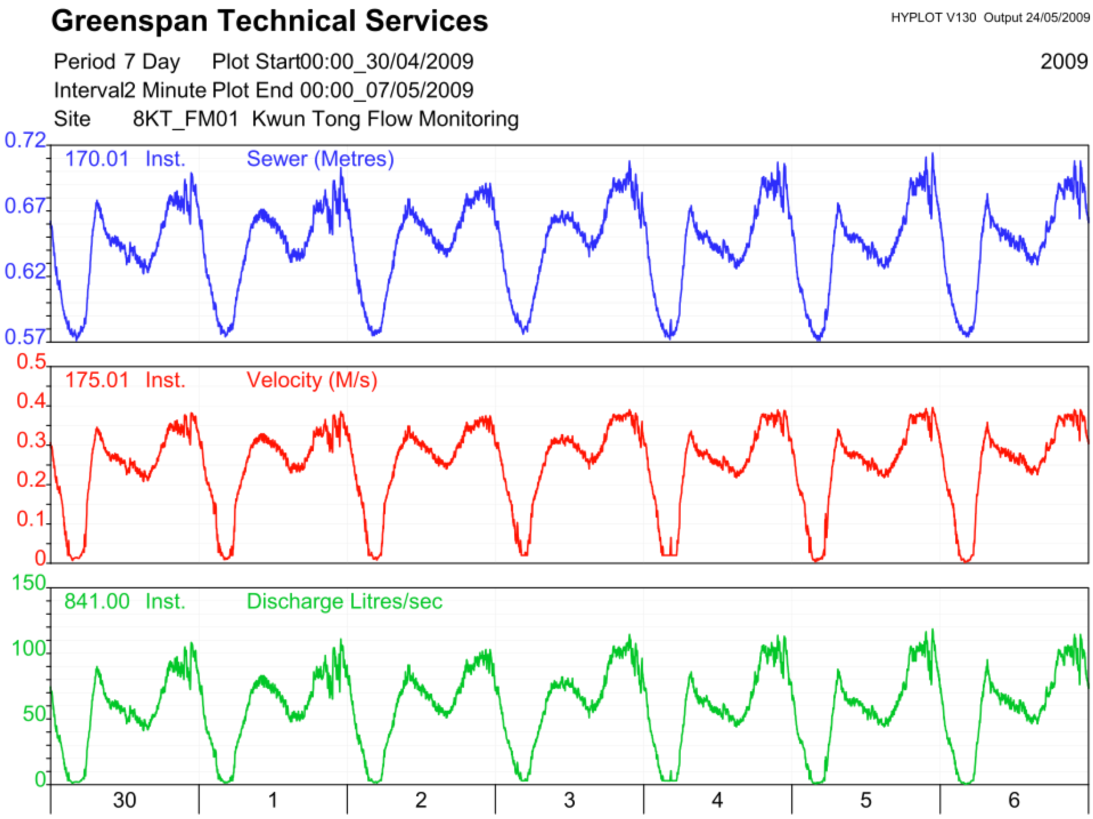


Figure 6.3 Depth versus Time (Blue), Velocity versus Time (Red), Flow Volume Rate (Green)(Data plot of monitor 8KT_FM01 in the Flow Survey for Kwun Tong Preliminary Treatment Works Upgrading Feasibility Study of Kwun Tong Sewerage System provided by Buda Surveying Limited)

The examination of the Site Check Sheets will compare the information on the Site Check Sheets of the same site but different visits. The information is also used for more detailed depth checks and velocity checks. The reason is that on site quality assurance checks are generally rough so it is necessary to have the checks when data are back to data processing centre. At the end of the survey, all the information shall be summarized so the constancy of a site's data can be assessed.

Depth checks shall compare the alternative manual measurement with the depth sensor readings. The depth offset is the difference between the manual measurement and the sensor readings. A depth offset within the range of ±15mm (or of other value specified in the Contractual Document) is acceptable. The manual measurement is assumed to be the accurate depth.

Velocity checks shall compare the hand held meter measurement at various points in the flow with the sensor readings. The velocity ratio (or velocity factor) is the ratio of the handheld reading to the sensor reading. It is calculated as an indication of accuracy.

Apart from the above examining measures, a weekly interim presentation of data aiming to let the Employer/ Client's Engineer keep informed of the survey's findings and progresses has to be prepared. Generally, a weekly interim report is with the following contents:

1) Graphical plots of the recorded velocity and depth data
2) Graphical plots and tabulated printout of rainfall data (if applicable)
3) Copies of the Site Check Sheets
4) A summary of the week's results, including details like instrument problems, rainfall events, etc.

6.3 Data Quality Coding

When data are collected from different monitoring sites, it is not of equal quality. Hence, quality coding, which assigns an individual code to each data point to indicate uncertainty ranges, will firstly be applied on the data. This can aid the modeling process by providing a better realization of the data accuracy for the hydraulic modelers. Nonetheless, there does not exist a standard coding system commonly applied and adopted for all project contractors. An example of data quality coding system is shown in Figure 6.4.

SEWER LEVEL DATA (170.01) metres

Quality Code Description	Quality Code	Application Criteria
GOOD/FAIR – Quality level data which satisfies the following criteria:	2	Record processed +/- 10%, time correct to (a) +/- 10 mins or (b) +/- 10 Logging periods.
POOR – Quality level data which satisfies the following criteria	76	Record processed +/- 20%, time correct to (a) +/- 20 mins or (b) +/- 20 Logging periods.
DATA NOT AVAILABLE	201	Data lost.

SEWER VELOCITY DATA (175.01) metres/sec

Quality Code Description	Quality Code	Application Criteria
GOOD/FAIR – Quality velocity data which satisfies the following criteria:	2	Record processed +/- 10%, time correct to (a) +/- 10 mins or (b) +/- 10 Logging periods.
POOR – Quality velocity data which satisfies the following criteria:	76	Record processed +/- 20%, time correct to (a) +/- 20 mins or (b) +/- 20 Logging periods.
DATA NOT AVAILABLE	201	Data lost.

DISCHARGE FLOW DATA (841.01) Litres/sec

Quality Code Description	Quality Code	Application Criteria
GOOD/FAIR – Quality level data which satisfies the following criteria:	2	Record processed +/- 20% of observed flow and time correct to (a) +/- 10 mins or (b) +/- 10 Logging periods.
POOR – Quality level data which satisfies the following criteria	76	Record processed +/- 30%, time correct to (a) +/- 20 mins or (b) +/- 20 Logging periods.
DATA NOT AVAILABLE	201	Data lost.

Figure 6.4 Data Quality Coding (Provided by Buda Surveying Limited)

6.4 Data Processing After Survey Ends

A whole assessment of all the data obtained is carried out when the flow survey has finished. This is done by combining all the data of the same monitor into one file for graphical plotting and checking the consistency. The processing procedures are similar to that before the survey ends. Since calibration on site is impractical due to poor site situation, computational calibration may be required when all the data are gathered. The details of computational calibration of depth and velocity can be referred to “A Guide to Short-term Flow Survey for Sewer Systems”, published by WRc.

Once site survey period comes to an end, there will probably be 4 to 8 periods of fitting catchment responses as the candidates chosen for detailed analysis. The number of periods to choose is stated in the Contract Document and which periods analyze are determined by the Engineer appointed by the Employer/ Client. In a detailed way, flow rates will be calculated and analyzed and final report will be presented to the Employer/ Client. For the analysis work, most of the time, scattergraphs are essentially employed and are introduced in the following section.

The final report is suggested to include the following items:

- Tabulated and graphical rainfall data
- Tabulated depth (mm) and discharge data (liters/second) for each selected period. Velocity data is an optional extra requirement
- Graphical plots of depth versus time for each selected period
- Graphical plots of discharge versus time and rainfall versus time for a comparison for each selected period
- Graphical plots of velocity versus time for each selected period is optional
- A series of hyetographs giving rainfall intensities for the selected storm period, if this required by the hydraulic modeler

6.5 Scattergraphs

Scattergraph evaluation techniques are essential for data analysis. The editing and graphing of data are done by comprehensive data management software, such as HYDSYS. An example graph of log flow versus log depth is shown in Figure 6.5. Though the flow/ depth relationship for an idealized flow is theoretically not a straight line on a log/log plot, the plot is a good way to check the hydraulic conditions practically. The scattergraphs are particularly useful in indicating the instrumental performance and the suitability of the flow monitoring locations.

A scattergraph shall include all the recorded data from a site. However, since the data is normally recorded at 2 minute interval, there will commonly be tens of thousands sets of velocity and depth readings for a survey period as short as a week and so it may cause problems or the outcome graph is too dense to read owing to the limitation of computer software abilities, printer resolution, etc. As a consequence, certain proportion of data is chosen for plotting in a graph or all data of the same site is plotted in several graphs.

A scattergraph consists of two essential pieces of information:

1) The 2-dimensional shape produced by data, i.e. the outline of the graph in the x-y plane

2) The number of readings associated with a point on the graph, i.e. height or the data's frequency

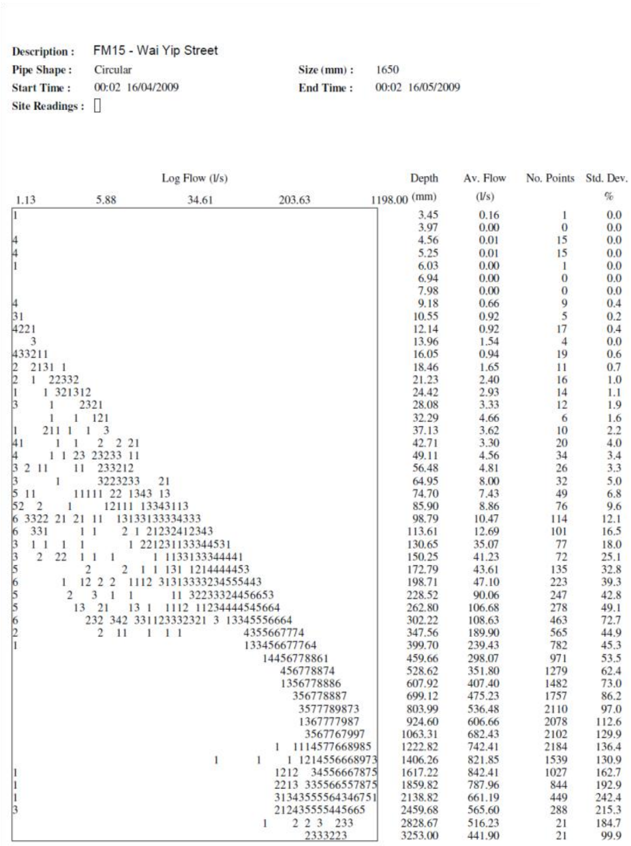


Figure 6.5 Log Flow Rate versus Log Depth (Provided by Buda Surveying Limited)

2-Dimensional Shape

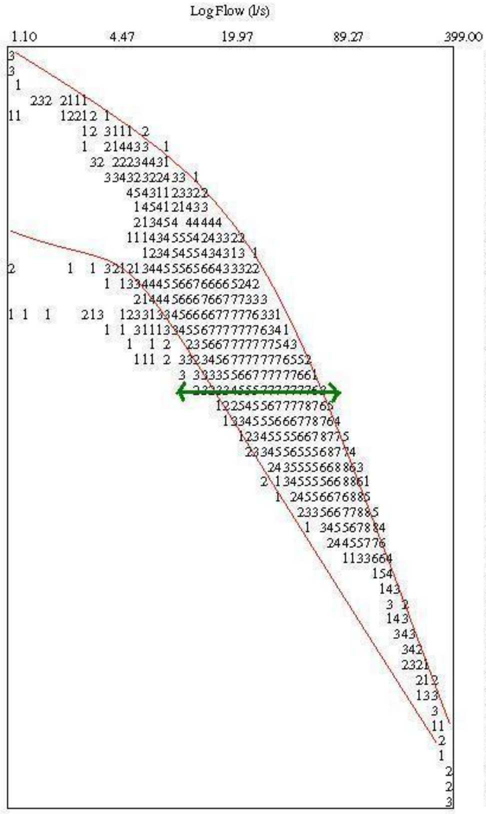
A scattergraph with a shape close to that of an ideal scattergraph is shown in Figure 6.6. The red line in the Figure shows the shape of an ideal scattergraph. The green arrow shows the scatter range, i.e. the uncertainty of flow rate, at a certain depth. When the flow level is too shallow, say below 20mm, certain monitor's sensor will hardly take any readings so there will not be many data points at a very low depth. As depth increases, more data points appear and the scatter range becomes bigger. The wider the scatter range is, the larger the uncertainty. A large scatter of data is expected at depth below 100mm or 10% of the pipe height because:

The flow-depth relationship will vary with the smallest changes in the hydraulic gradient which can be caused by moving silt and debris when at low depths

Slight pipe misalignments and settlements can induce unstable flow at low depths

Unstable flow will be induced by the sensing head at lower depth and transit to a relative stable condition at higher depths if the monitor used is an insertion type

Description :	Eastern Road - FM12		
Pipe Shape :	Circular	**Size (mm) :**	1350
Start Time :	00:02 16/04/2009	**End Time :**	00:02 16/05/2009
Site Readings :	☐		



Depth (mm)	Av. Flow (l/s)	No. Points	Std. Dev. %
134.28	0.00	3	0.0
139.77	0.28	3	0.1
145.49	1.20	1	0.0
151.44	1.91	13	0.4
157.64	2.47	11	0.9
164.09	4.36	11	1.2
170.80	5.16	25	1.1
177.79	5.91	37	1.4
185.07	6.59	56	2.3
192.64	7.15	70	2.5
200.52	8.60	58	2.4
208.73	10.97	84	3.1
217.27	11.61	120	3.6
226.16	12.44	147	3.3
235.41	12.37	362	4.0
245.04	13.73	700	3.9
255.07	16.98	923	4.7
265.50	19.71	1062	5.5
276.37	22.16	1273	5.8
287.67	25.42	1114	6.5
299.44	30.21	1233	8.1
311.70	36.34	1138	9.8
324.45	43.42	1376	10.4
337.72	51.05	1385	11.1
351.54	58.19	1293	12.3
365.93	66.83	1152	13.6
380.90	74.49	948	15.5
396.48	84.79	1002	13.4
412.71	93.22	1161	14.3
429.59	102.56	1488	15.5
447.17	113.01	1565	15.4
465.46	123.19	1016	15.2
484.51	132.52	478	15.0
504.33	147.79	162	10.9
524.97	158.50	33	6.1
546.45	175.29	12	9.9
568.81	185.81	5	12.8
592.08	192.68	14	13.0
616.30	208.90	17	12.8
641.52	231.83	12	16.2
667.77	236.95	9	21.9
695.09	278.67	5	24.8
723.53	289.01	8	15.0
753.13	318.80	3	5.2
783.95	327.97	2	12.6
816.03	344.14	2	14.7
849.41	351.66	1	0.0
884.17	368.79	2	10.8
920.34	378.52	2	20.3
958.00	384.00	4	13.0

Figure 6.6 Log Flow Rate versus Log Depth (Provided by Buda Surveying Limited)

As shown in the Figure, the scatter width will decrease as the depth increases. The reason is that the flow stability is higher with a higher flow level or a farther distance from the pipe wall.

Standard deviation is usually given on the graph for an estimation of the scatter. If standard deviation is not given, ratios of maximum to minimum flow for a number of depths can be calculated easily.

The ideal graph's shape will depend on what type of flowmeter is employed. Though Figure 6.6 has a shape close to that of an ideal graph, in many other cases, the graph shape is greatly affected by instrument related problems or hydraulic conditions and become very complex. For instance, Figure 6.5 shows a shape of surcharging condition. Studying those 2-dimensional shapes is especially useful in looking for specific instrument related failures and specific hydraulic characteristic at the monitoring site. Further details of the typical graph features can be found in "A guide to short term flow surveys of sewer systems" published by WRc.

Data Frequency

Obtaining the 2-dimensional shape is insufficient for analysis and indicating the data quality. Accordingly, the data's frequency, i.e. the scattergraph's height is also required. There are different methods to represent frequency distribution. The most commonly used one is frequency matrix which is as shown in Figure 6.5 and 6.6. The frequency of the recorded data is represented by a series of numbers within the graph which acts as a matrix. The numbers are based on a power-to-2.5 scale, representing the bands as given in Table 6.1. In most scattergraphs that represent a five week site survey period, the frequency matrix numbers shall reach 8 or 9.

Representing Number of Frequency Matrix	Frequency Band of Readings
1	1
2	2
3	3 – 6
4	7 – 15
5	16 – 39
6	40 – 97
7	98 – 244
8	245 – 610
9	611 and over

Table 6.1 Bands of Frequency Matrix (Table adapted from "A Guide to Short-term Flow Surveys of Sewer Systems", 1987, published by WRc)

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Appendix A: Abbreviations

Company/ Organization	
Code	Description
BD	Buildings Department, HKSARG
CEDD	Civil Engineering and Development, HKSARG
DSD	Drainage Services Department, HKSARG
EMSD	Electrical and Mechanical Services Department, HKSARG
EPD	Environmental Protection Department, HKSARG
HA	Hong Kong Housing Authority, HKSARG
HKIUS	Hong Kong Institute of Utility Specialists
HKURC	Hong Kong Utility Research Centre
HyD	Highways Department, HKSARG
LandsD	Lands Department, HKSARG
LD	Labour Department, HKSARG
PolyU	The Hong Kong Polytechnic University
UTI	Utility Training Institute
WRc	Water Research Centre
WSAA	Water Services Association Australia
WSD	Water Supplies Department, HKSARG
WTI	Water Training Institute
Others	
Code	Description
%	Percentage
BMP	Bitmap (Picture Format)
BWCS	Buried Water Carrying Service
CCE	Conduit Condition Evaluation
CCE(CCTV & ME)	Conduit Condition Evaluation(Closed Circuit Television & Man- Entry)

Company/ Organization	
CCES	Conduit Condition Evaluation Specialists
CCTV	Closed Circuit Television
CD	Compact Disc
CL	Cover Level
COP	Code of practice
CP	Competent Person
DN	Nominal Diameter
DP	Design Pressure
DVD	Digital Versatile Disc
e.g.	Exempli Gratia
GIS	Geo-Information System
EPR	Environmental Protection Requirements
etc.	et cetera
GL	Ground Level
H	Height
HKCCEC	Hong Kong Conduit Condition Evaluation Codes
HPWJ	High Pressure Water Jetting
hr	Hour
Hz	Hertz
ICG	Internal Condition Grade
ID	Internal Diameter
IDMS	Integrated Data Management System
IL	Invert Level
ISO	International Standards Organization
JPEG	Joint Photographic Experts Group (Picture Format)
kHz	Kilo- Hertz
kPa	Kilopascal

Company/ Organization	
m	Meter(s)
ME	Man Entry
MHICS	Manhole Internal Condition Survey
mm	Millimetre(s)
Mpa	Megapascal
MPEG	Motion Picture Experts Group (Video Format)
MS	Method Statement
MSCC	Manual of Sewer Condition Classification, UK
OHSAS	Occupational Health and Safety Assessment Series
PPE	Personal Protective Equipment
ppm	Parts per million
PS	Particular Specification
PSI	Pound Per Square Inch
QA/ QC	Quality Assurance/ Quality Control
Ref.	Reference
RMSE	Root Mean Square Error
RPUS	Recognized Professional Utility Specialist
RTO	Recognized Training Organization
SCG	Service Condition Grades
SOPs	Safe Operator Procedures
SPF	Sun Protection Factor
SPG	Structural Performance Grade
SRM	Sewer Rehabilitation Manual
STP	System Test Pressure
TTA	Temporary Traffic Arrangement
US	Utility Specialist
VHS	Video High Speed

Company/ Organization	
W	Width
WLD	Water Leakage Detection
WO	Works Order
WP	Work Procedure

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2-6 Kin Hong Street,
Kwai Chung, New Territories
HKSAR, China

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Guideline Amendment Form

Please fill in the following form if any error or mistake is found in this manual. We thank for your support and appreciate your continuous help in improving this manual.

Discipline*	Page No.	Description of Existing Content	Suggested Amendment

* A. Conduit Condition Evaluation (CCTV and ME Survey)
B. Manhole Internal Condition Survey
C. Utility Survey (Pipe Cable Locator Survey, PCL)
D. Water Leakage Detection and Control
E. Advanced Leakage Detection of Buried Water Carrying Services Affecting Slopes
F. Pipe Rehabilitation by Trenchless Technology
G. GPR(Ground Penetrating Radar) Survey
H. Flow Study in Drainage Conduit (流量監控)
I. Pipe Condition Surveys by other non-destructive methods
J. Data Management for Utility Records
K. Utility Management
L. Safety

Please fill in your contact information in case follow up is needed.

First Name: ______________ Second Name: ______________ Last Name: ______________

Title: ____________________

Organization:____

#Telephone No.: ____________________ #Email Adress:_________________________________

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Professional Service Development Assistance Scheme (PSDAS)
Professional Guide Notes and Pamphlet for utility professionals in Hong Kong
Project ref: Y09-HKIUS-P02-PSDAS