SPECIFICATIONS FOR NONDESTRUCTIVE TESTING, SURVEYING, IMAGING AND DIAGNOSIS FOR UNDERGROUND UTILITIES

2,3 FLOW MONITORING FOR DRAINS/SEWERS (VERSION.1)

[NDTSID-UU-2,3]

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SPECIFICATIONS FOR NONDESTRUCTIVE TESTING, SURVEYING, IMAGING AND DIAGNOSIS FOR UNDERGROUND UTILITIES

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Foreword

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FLOW MONITORING FOR DRAINS/SEWERS

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A – Acknowledgement to Steering, Technical Workgroup 2,3

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B - Background

B1 – History

Flow monitoring of gravity drains/sewers is a specialized area of expertise with origins in pipe hydraulics as a branch of modern science. Over the last few decades, the requirements and technologies of flow monitoring were introduced by Rouse and Ince (1963), Biswas (1970), Bos (1976), WRc (1987, 2017), Levi (1995), Miller (1996), IBR (1997), Hager (1999), Mays (1999), Baker (2003), CIWEM (2009), WMO (2010), EPA (2020). The literature and ongoing development of this specialized discipline have provided essential information for understanding flow characteristics with reference to design models and engineering design. Since 1983, a technical committee in ISO (International Organization for Standardization) for streamflow measurement, known as ISO/TC113 Hydrometry, has been producing a wide range of international standards for flow monitoring in various man-made structures and natural streams. WRc (1987) produced one of the very first useful field guides for short-term flow survey in sewers. These standards, studies and guidelines, and many others besides, classify two categories of modern flow monitoring of gravity drains/sewers (Herschy, 2009). The first is for the planning and design of new gravity drains/sewers, and the second is required for current use and future upgrade in operational management. Planning and design data are valuable in the long term for civil engineering works of various types, such as flood control and forecasting, and for projecting long term trends in order to combat the impacts of climate change. Large amounts of data for operational management are increasingly collected for statistical analysis. Whereas various methodologies of flow monitoring have been developed, the use of which methodology of flow monitoring to address specific problems and meet the needs shall be subject to the discretion of engineers with hydraulic background and relevant experience. Whereas non-destructive methods by radar/sound/pressure are concerned, the significance and applications of the types of flow monitoring are further elaborated in Section B2.

B2 – Significance, Applications and Scope of Specification

B2,1 Significance and application

Underground utilities are the veins of any city. The discussion of flow monitoring methods in gravity water drainage and sewer systems in this specification covers the history, theories and principles, equipment, field procedures with respect to the use of non-destructive methods by radar/sound/pressure sensors. The approach suggested for conducting investigations is the most commonly used, widely accepted, and well proven. It examines two modes of survey: (a) flow depth survey, and (b) flow velocity survey in any gravity water drainage and sewer systems. However, other approaches or modifications, which are technically sound, may be substituted if technically verified, validated and documented.

The context of flow monitoring can be considered in terms of several different scales as follows: (a) from a global scale as in the case of climate change; to (b) a regional/catchment scale as used in regular reviews of runoff, drainage/sewage capacity and discharge capability in cities; and (c) even on a local scale, such as the influence of drainage on slope stability (ETWB, 2006). For climate change, an increase in greenhouse gases in the atmosphere might increase runoff significantly. Careful flow monitoring and associated modification of the design and upgrade of water-related structures, including flood control and conveyance capacity, is very much in need (Herschy, 2009). For (b), short- or long-term drainage/sewage improvement measures are always required to meet changing flood protection needs due to changes in land use and migration/growth of population (DSD, 2013; DSD, 2018), while parameters like catchment inflow are factors in sewage flow management that require regular updating (EPD, 2005). For (c), local-scale discharge rates can be evaluated by comparing flow monitor data, model curves (e.g. Manning's equation), and rainfall data via rain gauges plotted in the form of hydrographs and scattergraphs, so that the characteristic self-cleansing/non-self-cleansing long-term/short-term capability can be quantified and continuously monitored through Internet of Things (IoTs).

The monitored **flow depth** and **flow velocity** within clients' specified time periods are the major deliverables of surveys aimed at assessing hydraulic performance of gravity drainage and sewer structures. Using flow depth and flow velocity data, the flow capacity/discharge rate 'Q' (m^3/hr) can be computed within a known pipe/open channel's geometry. The data can then be used to plot hydrographs (Q as a function of time) and scattergraphs (flow depth vs flow velocity) for correlation with rain gauge data for I/I (Inflow and Infiltration) analysis in order to understand changes of hydraulic parameters after rehabilitation and/or revitalization. However, the ways these records are produced based on proper test/survey/diagnostic procedures vary significantly between companies and individuals. Erroneous or incomplete information concerning the flow measurement can mislead users, causing unnecessary damage and exposing the public and workers to danger. Experience and knowledge of the subject area greatly enhance the credibility of the flow monitoring results and, most importantly, help clarify when the test/survey/diagnostic results are uncertain due to site, materials and equipment limitations rather than the Signatory/Survey Officers' abilities. The successful management of the above factors can be summarized in a **4M1E** framework, namely **M**an/woman, **M**achine, **M**aterials, **M**ethods and **E**nvironment, which can be applied within an accreditation framework following 'ISO/IEC 17025: 2017: General requirements for the competence of testing and calibration laboratories'. In view of the above needs, this document provides a unified specification and standard for flow monitoring of gravity drainage and sewer systems based on 4M1E, which aims to help utility companies, laboratories/survey companies, developers, estate managers, contractors and consultants to maintain consistent standards of UU testing, surveying, imaging and diagnosis.

B2,2 Scope

1. This specification covers the history, theories/principles, equipment, field procedures with respect to use of non-destructive testing methods by radar/sound/pressure sensors, and associated flow monitoring in man-made gravity water-carrying utilities, such as, but not limited to urban drains/sewers, box culverts, and nullahs. It focuses on the measurement side of flow monitoring but not the hydraulics theories and computations. The planning and design for the flow monitoring plan shall be subject to the discretion of engineers with hydraulic background and relevant experience.

2. The suggested approach to conducting flow monitoring by radar/sound/pressure methods is the most commonly used, widely accepted, and well proven. However, other approaches or modifications to these methods, which are technically sound, may be substituted if technically verified, validated and documented. The flow monitoring plan shall be continuously reviewed and fine-tuned by engineers with hydraulic background and relevant experience throughout the course of flow monitoring exercise.

3. This method does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the method's user to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to its use.

Method A: Flow Depth measurement by downward-looking radar (A1-1), downward-looking ultrasonic (A1-2) ultrasonic (A2) and pressure transducer (A3)

Method A1-1 downward-looking radar and *Method A1-2* downward-looking ultrasonic can be adopted in large open channels, nullahs, box culverts, conduits and tunnels where flow depth can be as much as 10-20m (A1-1) and 5-10m (A1-2). Both methods require a free field of view, remote from and above the water flow.

Method A2 or A3 is used for closed drains/sewers, medium-sized open channels and natural streams where flow depth is up to few metres. These sensors are installed at the bottom of the pipe/channel (i.e. 6 o'clock) and in contact with the water flow. The readings for A1 to A3 shall be verified by adequate direct and independent depth measurements where the physical depth reading is taken from the surface of the flow to the invert of the pipe/top of silt at the deepest point, as described in Section E1.

Method B: Flow Velocity measurement by Doppler radar (B1), acoustic Doppler current profiler (ADCP) (B2) and ultrasonic area velocity sensor (B3)

In any types of drainage/sewer systems, there are three types of measurement of flow velocity: surface velocity, profile velocity and mean velocity, which can be measured by Doppler radar (B1), acoustic Doppler current profiler (ADCP) (B2), and ultrasonic area velocity sensor (B3), respectively.

Method B1 makes use of the measurements of frequency changes of non-contact radio signals (e.g. 24 GHz) above water level after computation by spectral analysis, then prediction of mean velocity by use of conversion factors and models suggested by the manufacturer. It requires a free field of view remote from and above the water flow and it usually works along with Method A1.

Method B2 makes use of a Doppler ultrasonic continuous wave in the range of hundreds of kHz, and the contact-type measurement of sound waves (e.g. 300 kHz to 1.5 MHz) scattered back from particles within the flow of the water column. It is ideal for large to medium pipes, open channels, tidal rivers, and nullahs, and is capable of identifying opposing stratified flows. Side-looking installation may be required for rivers and channels with wide, deep water flows.

Method B3 uses a Doppler ultrasonic continuous wave in the range of hundreds of kHz and is similar in principle to Method B2 but operates using a single cell only. Instead of the velocity profiling used in B2, this method measures a mean velocity of the flow. Together with the flow depth measurement in Method A1-A3 and known pipe/channel geometry, the velocity measurements in both B1 and B2 are converted to mean velocity by mathematical formulae suggested in flow processing software provided by manufacturers. It works best in closed pipes, box culverts, large-medium-small sized open channels and natural streams.

B3 – Theories and Principles

B3,1 Method A: Flow Depth measurement by downward-looking radar (A1-1), downward-looking ultrasonic (A1-2), upward-looking ultrasonic (A2), and pressure transducer (A3) in Figure 1 and 2

A1-1 Travel time type (downward-looking radar): A radar device mounted on bridges and the superstructure of open channels sends short radio pulses at an oblique angle to the water surface. The time between the transmission and reception of the pulses is recorded and multiplied by the speed of light in free space (0.3m/ns) in order to calculate the gap distance between the device and water level. Subtracting this gap distance from the known input distance between the device and invert provides the flow depth data. Depending on the site situation, the device can be installed at a height ranging from 0.5 to 35m.

A1-2 Travel time type (downward-looking ultrasonic): The ultrasonic device mounted on bridges and the superstructure of open channels sends short ultrasonic pulses at the water surface. The time between the transmission and reception of the pulses is recorded and multiplied by the speed of sound in air in order to calculate the gap distance between the device and water level. Subtracting this gap distance from the known input distance between the device and invert provides the flow depth data. Depending on the site situation, the device can be installed at a height ranging from 5 to 10m.

A2 Travel time type (contact-type ultrasonic): These sensors are installed at the bottom of the pipe/channel (i.e. 6 o'clock) and in direct contact with the water flow. The time between the transmission and reception of the pulses is recorded and multiplied by the speed of sound in order to calculate the flow depth.

A3 Pressure type transducer: the water head in terms of pressure is measured to calculate the water depth using a known gravitational constant and input density of the water and the particles.

B3,2 Method B: Surface flow velocity measurement by Doppler radar (B1), acoustic Doppler current profiler (ADCP) (B2) and ultrasonic mean velocity sensor (B3) in Figure 1 and 2

B1 Doppler effect (non-contact radar): The flow velocity is measured by using the radar's Doppler effect. A radar signal with a frequency in tens of GHz (e.g. 24GHz) is transmitted towards the water surface. The signal is partially reflected and the moving water causes a frequency change due to the Doppler effect. A spectral analysis of the peak frequency of the emitted and reflected waves is performed in order to calculate the flow velocity. The signal is required to be transmitted at a perpendicular angle to the surface.

B2 and B3 Doppler effect (contact-type ADCP): The ultrasonic device mounted at the bottom (6 o'clock) of the water flow emits ultrasonic waves. The waves scatter back from particles within the flow of the water column and the frequency shift of the echo is proportional to the water velocity along the acoustic path. Method B2 uses multi-cell Doppler ultrasonic continuous wave sensors for measuring the frequency shift of pulses reflected by air bubbles and flow particles, which profiles the velocity along the cross section of flow. Method B3 uses the same sensor but with a single-cell only, so the velocity value obtained is a mean of the flow.

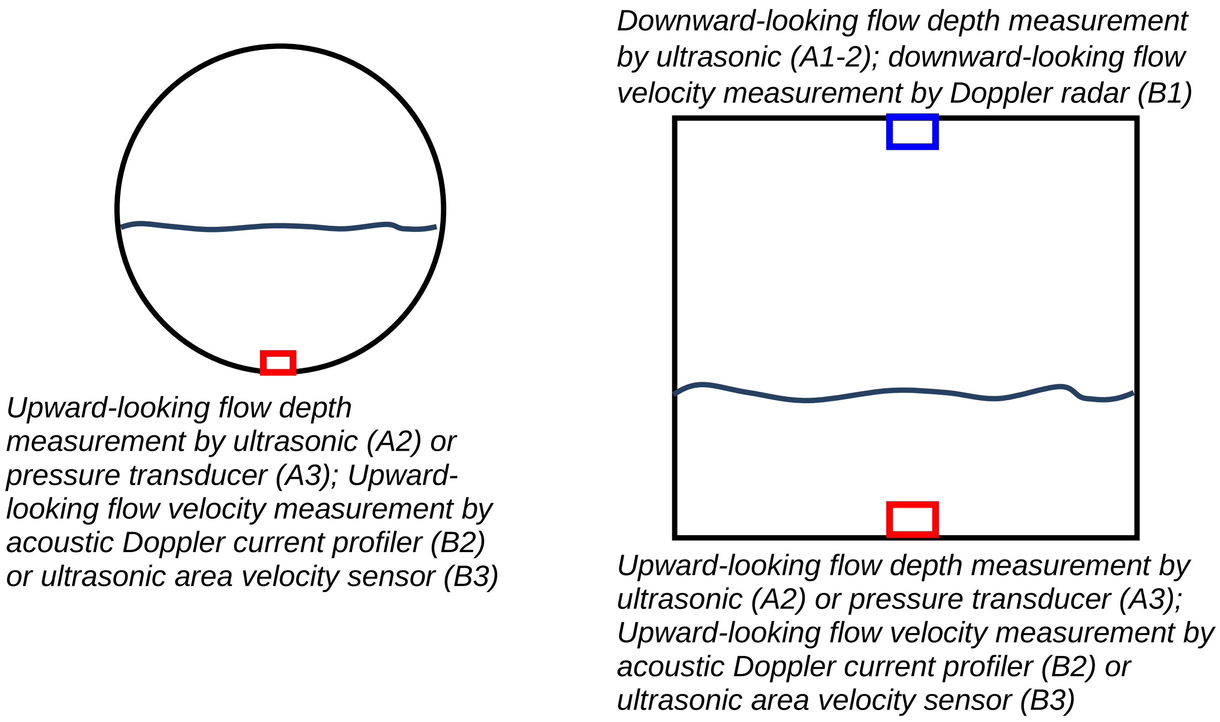

Figure 1 Flow monitoring sensor types in closed drain/sewer and box culvert

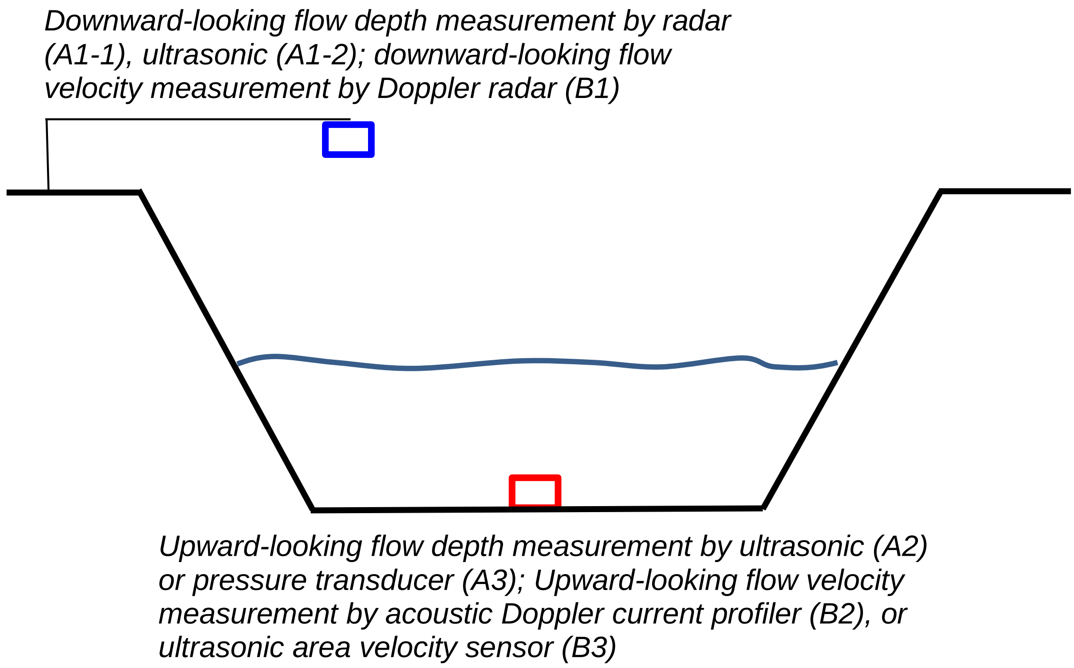

Figure 2 Flow monitoring sensor types in open channel/natural streams

C – Qualified Personnel

C1 – Personnel

The Signatories and Survey Officers for flow monitoring methods for gravity water-carrying utilities shall meet the personal requirements stated in Sections C2 and C3 below, respectively.

C2 – Signatory

C2,1 A **Signatory** of a report shall either have:

(i) a Bachelor of Science (e.g. Geomatics/Land Surveying) or Engineering (e.g. Civil/Electrical/Materials/Mechanical/Gas/Industrial) degree with specialization in underground-utility (UU) survey or a Bachelor of Science (e.g. Geomatics/Land Surveying) degree with not at less than 200 contact hours of BSc/BEng's UU training plus final year project, provided by a recognized tertiary institution plus at least ***three*** years of technical and managerial experience of underground utilities, within which a period of two years is substantially[1] related to the subject matter in this specification, or

(ii) a valid certificate or diploma[2] with sufficient flow monitoring aspects issued by a recognized organization operating under international standards or qualifications framework level 4 plus at least ***five*** years of technical and managerial experience of underground utilities, within which three years are substantially[1] related to the subject matter in this specification, or

(iii) at least a higher certificate or diploma issued by a recognized technical institute or an equivalent qualification in a relevant discipline with at least ***seven*** years of direct technical and managerial experience, within which five years are directly related to the subject matter in this specification, plus relevant training courses[2] covering the content in this specification.

[1] Direct technical and managerial involvement in 10 survey projects for either method A or B.
[2] A typical training course shall include all aspects covered in this specification.

C3 – Survey Officer

C3,1 A **Survey Officer** shall normally be supervised by a Signatory having the necessary qualifications, experience and technical knowledge. A Survey Officer shall either have:

(i) a higher diploma or above (e.g. Geomatics/Land Surveying) or an engineering higher diploma or above (e.g. Civil/Electrical/Materials/Mechanical/Gas/Industrial) with not less than 75 contact hours of UU training provided by a recognized tertiary institution, plus at least ***three*** year of on-the-job experience substantially[3] related to the subject matter in this specification, or

(ii) a valid certificate or diploma[4] with sufficient flow monitoring aspects issued by a recognized organization operating under international standards or qualifications framework level 3 plus at least ***three*** years of substantial on-the-job experience[3] related to the subject matter in this specification, or

(iii) at least a higher certificate or diploma issued by a recognized technical institute or an equivalent qualification in a relevant discipline, plus at least ***three*** years of substantial on-the-job experience[3] related to the subject matter in this specification, plus relevant training courses covering the content in this specification[4], or

(iv) at least ***eight*** years of substantial on-the-job experience[3] related to the subject matter in this specification.

[3] On-the-job direct involvement in 10 survey projects for either method A or B.
[4] A typical training course shall include all hands-on aspects covered in this specification.

D – Instrumentation

D1 – Flow depth sensors

For type A1-1 downward-looking radar sensors, they shall be weather-proof and dust-proof. The flow depth is measured by a nominal frequency of 20-30 GHz and the opening angle is about 10^0. The standard range of measurement shall be 0 to 15m for open channels, nullahs and tunnels, and 0 to 6m for box culverts. The measurement shall give an accuracy better than or equal to +/-2mm and a resolution of 1mm.

For type A1-2 downward-looking ultrasonic sensors, they shall be weather-proof and dust-proof. The flow depth is measured by a nominal frequency of 40 kHz and opening angle is about 10^0. The standard range of measurement shall in general be 5 to 10m. The measurement shall give an accuracy better than or equal to 1% of the full scale of the measured depth and a resolution of 1mm.

For type A2 ultrasonic sensors, they shall be water-proof and dust-proof. The flow depth is measured by an ultrasonic sensor with a nominal frequency ranging from 500 kHz to 3 GHz. The standard range of measurement shall be from about 300mm (including the sensor thickness and blanking distance) up to 6m. The measurement shall give an accuracy better than or equal to +/-0.5% of the reading or 0.3cm, whichever is greater (up to 3m flow depth), and +/-0.5% of the reading or 0.5mm, whichever is greater (up to 6m flow depth).

For type A3 pressure sensors, they shall be water-proof and dust-proof. The flow depth is measured by a hydrostatic pressure transducer. The standard range of measurement shall be up to 6m at an accuracy better than or equal to +/-1% of the full scale of measurement.

D2 – Flow velocity sensors

For type B1 surface flow velocity sensors, they shall be weather-proof and dust-proof. The surface flow velocity is measured using the Doppler effect. A radar signal with a frequency of about 24 GHz is transmitted towards the moving water surface, partially reflected and causes a frequency change due to the Doppler effects. At a distance to water surface from 0.5 to 35m, the nominal measurement range shall be 0.1 to 15m/s at a resolution better or equal to 1mm/s.

For type B2 flow velocity profiling, in a typical set-up four water-proof and dust-proof piezoelectric ceramics operating at a frequency of about 1 MHz in the sensors emit short pulses pointing in different directions to measure velocities at different locations, which are also known as bins, within the water column. This distribution of velocity measurements is then used to determine the flow patterns over the entire cross-section of flow. The nominal measurement range shall be about +/- 5m/s and the accuracy shall better than or equal to 0.5% of reading +/-3mm/s, at a water depth up to about 6m.

Since the flow pattern and velocity distribution are dependent on each other, the flow algorithms shall be designed to adapt to changing hydraulic conditions within the pipe.

For type B3 mean flow velocity measurement, in a typical set-up twin water-proof and dust-proof piezoelectric ceramics operating at a frequency range of hundreds of kHz in the sensors emit short pulses pointing towards the water column. The accuracy shall be better than or equal to +/-1.5mm/s or 2% of the measurement velocity, whichever is the greater. The measurement shall be better than or equal to a resolution of +/-0.03m/s.

D3 – Equipment Calibration/Verification

The requirements for equipment calibration/verification intervals are provided in Table 1.

Table 1 Specific Calibration / Verification Requirements

Type of equipment	Maximum period between successive verifications	Calibration / verification procedure or guidance documents and equipment requirements
Flow depth sensors (method A)	1 year (verification)	Carry out verification in a controlled environment with five measurements of three reference flow depths with a difference of not less than 150mm. The amplitude of the flow waves shall be controlled to be within +/-5mm. For shallow flow, use a steel ruler and take a direct measurement. For wading flow, conduct physical measurement of water flow. For example, fasten a 1mm cable tie around a levelling staff or steel ruler above the highest position that the flow reaches. Insert the levelling staff into the flow and slide the cable tie until it just touches the water surface. Remove the levelling staff or steel ruler from the flow and read the depth from the scale just below the cable tie. The curve of reference flow depth against measured flow depth shall be plotted. All deviations of the measured values from the known values shall be within the manufacturer's recommended tolerance level. If a controlled environment is not available (i.e. sensors installed on-site for long term monitoring), then on-site verification under different flow conditions and manufacturer's recommendation shall be followed.
Flow velocity sensors (method B)	1 year (verification)	Carry out verification in a flume with four measurements of five reference mean flow velocities. The first measurement is in air. The second to the fourth measurements are in water with a difference in reference velocities of not less than 0.1 m/s. The reference mean flow velocity shall be obtained by a life-time calibrated instantaneous and single measurement sensor (e.g. a radar gun) and converted to the mean velocity via appropriate algorithm(s), or other developed and validated means of measurement.

	The curve of reference flow velocity against measured flow velocity shall be plotted. All deviations of the measured values from the known values shall be within the manufacturer's recommended tolerance level. If a controlled environment is not available (i.e. sensors installed on-site for long term monitoring), then on-site verification under different flow conditions and manufacturer's recommendation shall be followed.

E – General Testing and Survey Procedure

The site selection, the general testing and survey procedure shall be confirmed and agreed with the client's engineer with relevant hydraulic background and relevant experience and be marked to provide on-site limits for the field crew led by the Survey Officer. The geo-referencing by topographic survey shall make use of well-established control points. A comprehensive desktop search of the available and 'best-known' utility maps shall be completed to provide the potential layout of utilities before the test/survey. Temporary traffic arrangements (TTA) shall be prepared in advance and implemented by the crew for the sake of safety. The instrumentation detailed in Section D shall be used. The following general procedures shall be followed by the crew led by the Survey Officer.

Table 2 Survey procedures for flow depth, flow velocity or both

Procedures	Actions
(a) On-site observation	An on-site inspection shall be carried out to record all visible ground level surface features potentially related to gravity water-carrying utilities, such as manholes, draw pits, inspection/valve chambers and gullies, street furniture connected to pipes and cables such as lamp posts, illuminated road signs and bollards.
(b) Visual inspection of the internal condition	If required; visual inspection shall be carried out according to Method A: Manhole survey of vertical shafts of the NDTSID specification 2,1 Visual Inspection (LSGI, 2021a) and/or 1,3 Laser Scanning Survey (LSGI, 2021b). A visual inspection and/or test using laser scanner shall be conducted by a testing laboratory accredited by HKAS or its MRA partners, and the results shall be reported in an endorsed test report. If required; visual inspection of the flow conditions in the manhole or the structures shall be conducted where the flow sensors are requested to be installed.
(c) Selection of location(s) of flow monitor	The accuracy of the measurements will be affected if the sensor(s) is/are installed at/close to noisy facilities, such as pumping stations. It is preferable to select a site with a straight and uniform cross section, avoiding junctions, weirs, orifices, vortex drops, backdrops, drop shafts and other significant hydraulic features. Abnormal and/or skewed flow conditions should be avoided as much as possible. Among others, a few recommendations are as follows: 1. select a flow monitor location with at least 2-4 times the pipe diameter of the upstream manhole (WRc,1987 Guide to short-term flow surveys of sewer system Section 2.3.2.2d.) or

	2. select a flow monitor location with at least 10 times pipe diameter downstream and at least 5 times pipe diameters upstream of the manhole (UTI, 2011 Guide to short term flow surveys of closed conduits in Hong Kong Section 4.4), or 3. when the length of the channel is restricted, the straight length upstream should be at least twice that of the downstream length (EN ISO 748:2007 Hydrometry - Measurement of liquid flow in open channels using current-meters or floats, Section 5.1a).
(d) Flow and silt condition	1. Observe and record the flow condition as either 'static', 'turbulent' or 'steady'. 2. Measure flow velocity and record as 'fast' (more than 1m/s), 'medium' (between 0.4 and 1 m/s), or 'slow' (< 0.4 m/s). 3. Measure silt sectional profile, if present.
(e) Risk assessment and safety measures	This specification does not purport to address risk assessment and safety measures, if any, associated with its use. It is the responsibility of the method's user to establish appropriate health and safety practices and determine the applicability of regulatory limitations prior to its use.
(f) Mounting the sensors in open channel	1. Install the sensors in the downward-looking position for flow depth method A1 (radar) and flow velocity method B1 (Doppler radar), following the minimum and maximum distance requirement between the expected flow surface and the sensor according to the manufacturer's recommendations. 2. Install the sensors always at the invert of the utilities, if practicable. If silt is present, offset the sensors to a height above the silt level. Record the actual offset distance and apply necessary corrections in the logger setup program before continuous measurements are made. For method A2, align the sensor transducer perpendicular to the flow direction and not tilted from the vertical axis. 3. Install other necessary equipment, cable and protection devices (e.g. base plate sensor shield, metal trunk)
(g) Mounting the sensors in conduit	1. Install the sensors at the invert of the conduits and attach the sensors as securely as possible using spring ring/bracket plate/iron beam. If silt is present, offset the sensors to a height above the silt level. Record the actual offset distance and apply necessary corrections in the logger setup program before continuous measurements are made. For method A2, align the sensor transducer perpendicular to the flow direction and not tilted from the vertical axis. 2. Take precautionary measures not to leave any extra sensor cable length dangling in the flow stream where it could trap debris or become tangled. 3. In pipes and culverts that are always full, the sensor may be installed at the top of the pipe in a downward-looking position, so installation is more secure with reduced risk of the system becoming buried by sediment.
(d) Measurement/on-site checking	1. Test the installed systems including the sensors and data loggers according to the manufacturer's suggested procedures. 2. After mounting and testing the sensors, re-visit the site, check, photograph & record the working conditions of the entire system and download flow

	data at a time interval agreed with the client. During the download, conduct and record in-situ measurement of flow depth and/or flow velocity. 3. Give reasons if, despite the best efforts of the site crew, the survey of any particular utility unreliable or not successful. One or more of the reasons in Section G 'Limitations' shall be listed. 4. Give reasons if, despite the best efforts of the site crew, the survey of any particular utility is declared as 'survey not successful (SNS)'. One or more of the reasons in Section G 'Limitations' shall be listed.
(e) Maintenance	1. Conduct periodic checking to ensure the sensors are operational and in good condition by use of a telemetry data system, if necessary. 2. Identify and record any limitations listed in Table 3 and possible cause of deterioration of instruments, and issues of vermin and noise. 3. Verify, repair, rectify any fault/malfunction of the sensor during the survey, report to the client and explain in the survey report.

F – Reporting

The report shall include, but not be limited to the following sections:

- Introduction and background
- Site areas, boundary and conditions
- Instrumentation (Section D)
- General test/survey procedures (Section E) and site-specific procedures
- Collected flow monitoring data, can be presented in the form of hydrographs of depth, velocity and discharge and the tabulated data in digital format.
- Collected flow monitoring data, can be presented in the form of scattergraphs for specific storm events/discharge period if required.
- Limitations (Section G)
- Conclusion
- Site photos in an appendix
- Record drawing (reference utility plans provided by utility companies and clients)

a. In the drawing, the location(s) of feature(s), if any, shall be connected to the identified utility alignment, ground features like valves, roads and buildings contained in the location plan. All reported coordinates and levels should be represented in HK 1980 Grid coordinates based on HK80 Datum (The coordinates for N,E are presented as 8*****.***, 8*****.***, relative to the HK80 Datum. Normally, "All levels are referred to HKPD" and must be present in the survey plan).
b. For submission of other materials in CAD and GIS format, requirements in Computer-Aided-Drafting Standard for Works Projects (CSWP) Version 1.03.00 (2007) and Geographic Information System (GIS) Specifications for Engineering Surveys of Highway Department (2015) shall be followed, respectively.

G – Limitations

When the results of a flow monitoring survey is regarded unreliable or not successful (SNS)', the following limitation(s) shall be reported. The lab/survey company shall expand the list as an in-house procedure, as necessary.

Table 3 Limitations of flow monitoring

Method	Limitations	Examples
All	Loss of reading due to fouling of sensors	Ragging in foul sewer, floating/suspended debris/vegetation in storm drainage, siltation in both.
	Hydraulic conditions	(1) Low flow, e.g. minimum recordable water depth dependent on the combined sensor thickness and blanking distance of the sensors, in the scale of hundred(s) of milli-metres; (2) High flow: it might be dangerous for person entry if the flow volume is too large; (3) Low velocity: silt deposits in the invert; (4) High velocity and shallow flow depth associated with steep gradient (WRc, 1987 Section 3.3.2 (ii)).
A1, A2	Undulating wave conditions	The flow exhibits a large undulating wave and surface ripple wave.
	Angular surface	During dry or low flow conditions, an angular surface at or close to the invert causes scattering/echoes.
A2	Temperature and humidity	Large difference of temperature and relative humidity levels between the sensors and the water surface
	Noise	Interference by other ultrasonic sensors, external noise such as road traffic, excavation, and over-pumping, and internal noise such as high-level falling flow, orifice, and weirs.
A3	Tidal effects and surge	Stratified and/or opposing flows and instantaneous spikes (e.g. vessel wakes)
	Temperature	Large temperature differential leading to thermal expansion/contraction along the exposed cable in the water and outside.
	Moisture condensation within the vent tube	Rapid changes in temperature with highly humid environment
B1	Negative flow direction	Negative flow direction for only positive velocity readings for standalone sensors, i.e. negative flow shown as positive.
	Complex modelling	Tidal effects and stratified flow requiring extensive and complex flow modelling that cannot be handled by standard models
B2, B3	Blanking distance limit	Flow depths too shallow at blanking distance limit of the sensor towards the water surface. The blanking distance is frequency-dependent.
	Absence of suspended particles	Clean water with absence of suspended particles.

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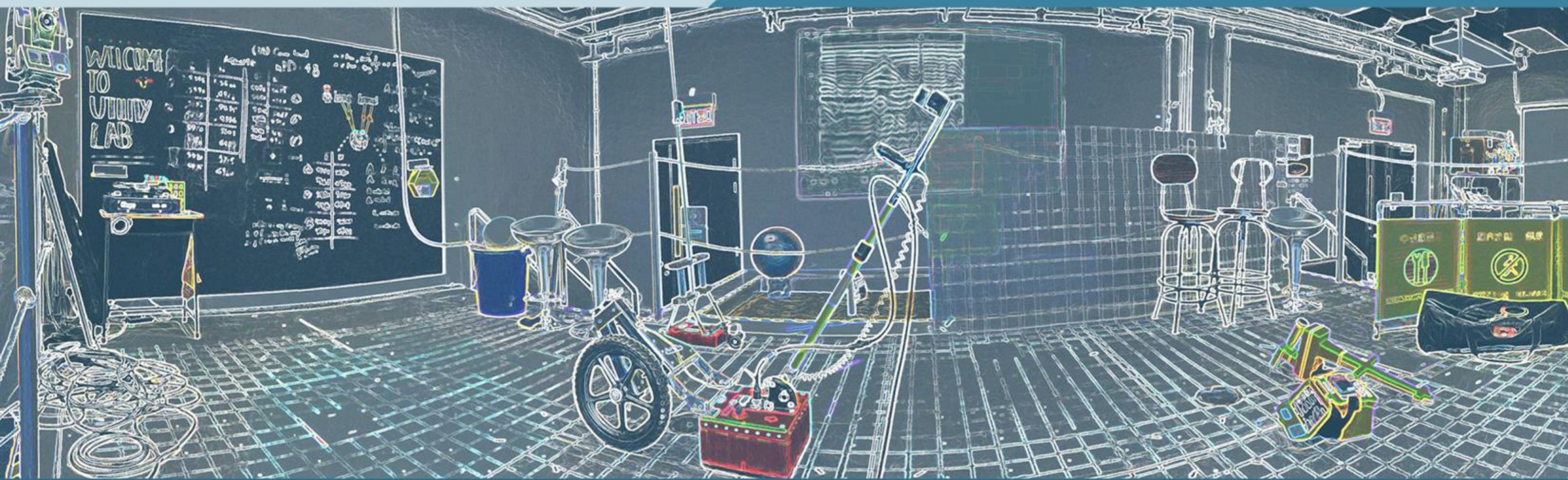

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