Draft 4.0 - Generic Verification Protocol

Flowmeters for Wet Weather Flow Applications in Small- and Medium-Sized Sewers

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Environmental Technology Verification Program
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1 Introduction

1.1 Purpose

The purpose of this Verification Protocol is to establish the requirements for verifying the performance of flowmeters suitable for use in measuring wet weather flows. This Protocol was established under Wet Weather Flow Technologies Pilot of the Environmental Technology Verification Program of the United States Environmental Protection Agency (EPA). This protocol describes the steps to be followed to ensure that verification is carried out in a consistent and objective manner that assesses the relevant performance characteristics of stormwater treatment technologies. It describes the process of selecting the appropriate verification tests and establishes requirements for the methods to be used in conducting those tests. The Protocol provides guidelines for the preparation and approval of a Verification Test Plan for a specific flowmeter and test location. Guidance is also provided on the execution of testing and data reduction, analysis and reporting.

Verification requires that flowmeters be tested in a laboratory setting and in a field installation. This Protocol contains a Laboratory Protocol and a Field Protocol. The Laboratory Protocol (Section 2) defines the conditions and procedures for assessing performance and operational characteristics of area/velocity flowmeter in a hydraulic laboratory setting. The laboratory provides an environment where flow conditions may be controlled as desired; it is also conducive to frequent calibration of laboratory instrumentation for accuracy. The Field Protocol (Section 3) defines conditions and procedures necessary for evaluating the performance and operating characteristics of open-channel flowmeters installed in a combined sewer system. The Field and Laboratory Protocols establish requirements for conducting verification testing and provide guidelines for the preparation of Laboratory and Field Verification Test Plans for each flowmeter. Each Test Plan will be specific to the test site and the organization conducting the test. Guidance is also provided on the execution of testing and data reduction, analysis and reporting.

1.2 Scope

This Verification Protocol applies to flowmeters that are suitable for use in pipes used to convey wet weather flows such as storm sewers, combined sewers, and some separate sanitary sewers. The tests described herein are intended to verify the ability of the flowmeter to provide accurate, reliable real-time flow data over a range of flows representative of wet weather flow conditions. The Protocol calls for testing in pipes of ranging from 10 inches to 42 inches in diameter and is therefore most suitable for testing flowmeters having this range of application. Testing flowmeters at the lower end of the range of pipe diameters may be waived if a flowmeter is not designed nor intended for use in small diameter sewers.

It is not the intent of the ETV Program to restrict verification to specific types of flowmeters. However, in order to provide sufficient guidance on how testing is to be conducted and to ensure adequate data quality, this Verification Protocol primarily focuses on technologies commonly referred to as area/velocity flowmeters. With some modification, the principles and procedures described in this Protocol may be applied to other types of flowmeters, as well.

Area/Velocity flowmeters are frequently used to monitoring open-channel flows in place of the traditional fixed structures such as weirs and flumes. In addition to open channel flow monitoring, area/velocity meters can be used to measure flow under periodic full-pipe, submerged, surcharged, and reverse flow conditions and are available as portable systems. Area/velocity flowmeters generally contain a level sensor, a velocity sensor and an electronics module. The electronics module converts the level measurement (ft) to a fluid area (ft^2) estimate based on the pipe/channel geometry at the point of level measurement. The electronics module converts velocity to mean velocity, and calculates the flow based on the following equation:

$$Q \text{ (Flow, } ft^3/sec) = V \text{ (Velocity, ft/sec) x A (Area, } ft^2)$$

1.3 Verification Process

The process of verification of area/velocity flowmeters under the ETV Program consists of three primary phases as described below:

Planning – The planning phase involves establishing and documenting the procedures to be followed during the laboratory and field verification of an open-channel flowmeter, including identifying the personnel responsible for performance and oversight of the testing. The planning phase culminates in the preparation of a product-specific Verification Test Plan by a designated testing organization with input from the technology vendor. Test Plans shall be approved by the USEPA and NSF International before the start of testing.

Verification Testing – This phase involves establishing the required test conditions, conducting the required tests, and the collection of the relevant data. This will occur in both the laboratory and the field.

Data Assessment and Reporting – This phase includes all data analysis and the preparation of a Verification Report and Verification Statement. USEPA and NSF will issue a single Verification Report and Verification Statement for each flowmeter verified. The Verification Report and Verification Statement will describe the performance in both the field and laboratory testing.

1.4 Development of a Verification Test Plan

The requirements in this section apply to the preparation of both the Laboratory and Field Test Plan for each flowmeter being verified. Separate testing organizations will likely be responsible for the lab and field testing and thus two separate Test Plans are needed. Some of the information required in a Test Plan, especially information about a specific flowmeter, will be the same for the Laboratory and Field components. For the sake of consistency and prevention of duplicate effort, Testing Organizations are encouraged to cooperate on the development of their respective Test Plans.

1.4.1 Purpose of a Test Plan

Prior to the start of verification testing of an area/velocity flowmeter technology under the ETV Program, the testing organization shall prepare a Verification Test Plan that clearly describes how and by whom testing is to be conducted. An adequate Test Plan will help to ensure that testing is conducted in accordance with the requirements specified in this Protocol. A good Test Plan also ensures that information about a vendor's product is available for incorporation into a Verification Report upon the completion of testing. A Test Plan should be developed for each technology undergoing verification testing. If multiple flowmeters are to be verified simultaneously at a single test site, a single Test Plan that addresses each individual flowmeter may be suitable.

At a minimum a Test Plan shall include:

- An introduction that briefly describes the objectives of verification testing and an overview of the approach taken in this study;
- Roles and responsibilities of participants in the verification testing of the technology;
- A complete description of the technology and its intended functions and capabilities;
- A description of the field site(s) or laboratory where verification testing is to take place;
- A description of the experimental design that includes the specific test procedures to be followed and identifies any necessary deviations from the requirements established in this Protocol;
- A description of the Quality Assurance/Quality Control procedures to be employed to ensure data quality objectives are met;
- A description of how data is to be analyzed, managed, and reported
- Health and safety procedures

The following sections establish guidelines and requirements for the content and scope of each section required in a test plan.

1.4.2 Roles and Responsibilities of Participants

The Test Plan shall specify the names and addresses of each organization having a role in the verification of a treatment technology. Where possible, the Test Plan should include the names, titles, and contact information, for specific individuals with designated roles in the verification of the technology. General guidelines on the roles and responsibilities for the primary participants are listed below. A flow chart may be used to demonstrate the relationship among the various participants.

1.4.2.1 NSF International

NSF International (NSF) is the US EPA's verification partner on the Wet Weather Flow Technologies Pilot. In the context of this Verification Protocol, NSF will select a qualified Testing Organization to develop and implement a Test Plan. In addition, NSF has the following responsibilities:

- Review and approval of the site-specific Test Plans;

- Oversight of Quality Assurance, including the performance of technical system and data quality audits, as prescribed in the Quality Management Plan for the Wet Weather Flow Technologies ETV Pilot;
- Coordination of Verification Report peer reviews, including review by the Stakeholder Advisory Group and Technology Panel;
- Review and approval of Verification Report; and
- Preparation and dissemination of Verification Statement.

1.4.2.2 US Environmental Protection Agency (USEPA)

The USEPA's National Risk Management Research Laboratory provides administrative, technical, and quality assurance guidance and oversight on all WWF Pilot activities. EPA personnel are responsible for the following:

- Review and approval of Verification Test Plans;
- Review and approval of Verification Reports;
- Review and approval of Verification Statements; and
- Posting of Verification Report and Statement on EPA Website.

1.4.2.3 Testing Organization (Field or Laboratory)

The test plan shall identify personnel from the Testing Organization who will have important roles in the testing. The Testing Organization personnel shall have experience with using and evaluating flow monitoring equipment. The Testing Organization will be in charge of developing and implementing the Test Plan. The Test Plan shall describe how the following responsibilities will be met:

- Developing the Test Plan, including its revision in response to comments made during the review period;
- Coordinating testing with the vendor;
- Contracting with the analytical laboratories, contractors, and any other sub-consultants necessary for implementation of the approved Test Plan;
- Providing needed logistical support to the sub-consultants, as well as establishing a communication network, and scheduling and coordinating the activities for the verification testing;
- Overseeing or conducting the verification testing as per the approved Test Plan;
- Managing, evaluating, interpreting and reporting on data generated during the verification testing;
- Preparation and review of a Draft Verification Report.

1.4.2.4 Vendor

The Test Plan shall identify the vendor of the technology being verified, the main point of contact and the roles that vendor personnel will have in the testing. In general, the vendor's responsibilities include:

- Providing, and possibly installing, the technology and ancillary equipment required for the verification testing,

- Providing technical support for the installation, pre-calibration, and operation of the flowmeter; including the designation of at least one staff person as the point of contact;
- Providing descriptive details about the capabilities and intended function of the technology;
- Review and approval of the Verification Test Plan prior to the start of testing;
- Review and comment on the Draft Verification Report and Draft Verification Statement.

The Laboratory and Field Protocols specify additional responsibilities for participating vendors.

1.4.2.5 Contractors

The test plan shall identify any contractors to be used, a statement of their qualifications, and their responsibilities. This may include organizations hired to conduct tracer/dye dilutions for accurate flow determinations.

1.4.2.6 Site Owner

The owner of the site and facility where the equipment is being tested (if different from the Testing Organization) may have particular responsibilities during testing or site set-up and breakdown. Any special requirements established by the site owner that may affect the test shall be fully described including those related to site access, safety, and equipment needs.

1.4.2.7 Technology Panel on Flow Monitoring Equipment

The ETV Technology Panel on Flow Monitoring Equipment will serve as a technical and professional resource during all phases of the verification of a technology, including the review of test plans and the issuance of verification reports.

1.4.3 Technology Description

The Test Plan shall provide a complete description of the technology being tested. The purpose of this section is to provide the reader with a clear understanding of the technology. At a minimum, this section shall describe

- Components of the technology
- Manufacturer's claims as to technology performance
- System maintenance requirements
- Summary of existing evaluation data
- Special considerations for operations of the technology
- Graphics/Drawings

1.4.3.1 Description of the flowmeter and its capabilities

The Test Plan shall describe the engineering and scientific principles upon which operation of the equipment is based. A description of the physical construction/ components of the equipment, including footprint, weight, power requirements, and transportability shall also be included. The following information shall be included in the Test Plan:

- Manufacturer's name and address
- Flowmeter product name
- Flowmeter type (description)
- Flow monitoring equipment model # and serial #. (Include both sensor and readout instrumentation numbers if they are different.)
- Electrical requirements
- Readout type or style
- Design flow range for the meter
- Meter output range

1.4.3.2 Intended applications and limitations of use

The Test Plan shall describe the intended applications and limitations of the flowmeter, as represented by the vendor and as indicated in the product literature. This information shall include:

- Applications for which the flowmeter has been designed;
- Type and size of pipes for which installation is intended;
- Flow characteristics with which flowmeter is compatible:
  - Range
  - Pattern

1.4.3.3 Unique capabilities and innovative features

The Test Plan shall describe unique capabilities of the flowmeter and its innovative features, as represented by the vendor and as indicated in the product literature. This may include a capability to account for silt deposition, to measure reverse velocity, to send data to isolated outputs, and other similar features. In the Field Protocol, Test A – Flowmeter Software Evaluation (see Section 3.3) requires that specific information about the software capabilities be provided and includes a checklist for documenting available features.

1.4.3.4 Installation, operation and maintenance procedures

The Test Plan shall describe all relevant procedures for the installation, operation and maintenance of the flowmeter. These procedures shall be consistent with those described in product literature and the operator's manuals.

The vendor shall provide estimates of the number of person-hours required to perform all phases from installation to maintenance. The vendor shall also provide the time required to service different parts of the flowmeter. A blank table is provided in appendix to help the vendor provide correct information.

1.4.4 Description and Requirements for Laboratory/Test Facility

The Test Plan shall provide a complete description of the testing facilities where any verification testing is to occur. The Laboratory and Field Protocols establish minimum requirements for the test facilities. The Test Plan shall provide enough detail allow NSF and EPA to assess the suitability of the site for testing. The Test Plan shall include a schematic of the test facilities including pipes, instrumentation, flow controls, valves and equipment, test flowmeter location and other relevant equipment. The description of the Test Facilities will be incorporated into the Verification Report.

1.4.5 Experimental Design/Test Procedures

Field and Laboratory Test Plans shall completely describe the test procedures to be followed during the course of verification testing. The procedures established in the Test Plan shall be consistent with the requirements and guidelines established in this Protocol. Sections 2 and 3 of this Protocol establishes requirements and guidelines for laboratory and field testing, respectively. The Test Plan shall reference the relevant requirements in this Protocol. The Test Plan shall clearly identify which tests are to be conducted and the relevant test conditions. The Test Plan shall clearly state if one or more of the tests prescribed in Section 2 or 3 of this Protocol is not to be conducted or is to be conducted in a manner that deviates from the Protocol. The Test Plan shall provide justification for excluding or deviating from a test or test condition prescribed in this Protocol.

1.4.6 Quality Assurance/Quality Control

Quality assurance and quality control of the equipment calibration, equipment operation, process maintenance, and the measured water quality parameters shall be maintained throughout the verification testing program. The Testing Organization shall prepare a Quality Assurance Project Plan (QAPP) for the Verification Testing, to be included in the Test Plan, that specifies procedures to be followed to ensure the validity of test results and their use as the basis for equipment performance verification.

The QAPP applies to all organizations involved in the verification testing including Testing Organizations and any subcontract laboratories that may be used. The Testing Organization will be responsible for ensuring that all individuals involved in the verification testing comply with QA/QC procedures during the course of verification testing.

The objective of QA/QC is to ensure strict methods and procedures are followed during testing so that the data obtained are valid for use in the verification of a technology. In addition, QA/QC ensures that the conditions under which data is obtained will be properly recorded so as to be directly linked to the data, should a question arise as to its validity.

The following QA/QC measures shall be addressed in the QAPP:

- Description of methodology for measurement of accuracy;
- Description of methodology for measurement of precision;
- Description of the procedures used to assure that the data are correct;
- Definition of data to be reported during the verification testing;

- Outline of the frequency, format, and content of self-assessments of the Testing Organization's technical systems;
- Outline of the frequency, format, and content of assessment reports to the Verification Organization;
- Development of a corrective action plan responding to audit findings;
- Requirement to provide all QC information, such as calibrations, blanks and reference samples, in an appendix to the report. All raw data shall also be reported in an appendix.

The Test Plan shall explain the methods used to check the accuracy of equipment operating parameters and the frequency at which these checks will be performed. All sampling and analytical instruments to be used at the laboratory/test site shall be maintained and calibrated by trained test site personnel in accordance with manufacturer's instructions.

1.4.7 Data Management and Analysis

A variety of data will be generated during verification testing. Each piece of data or information identified for collection in the Test Plan shall be submitted by Testing Organization along with the draft Verification Report. The data handling section of the Test Plan shall describe what types of data and information need to be collected and managed, and shall also describe how the data will be reported. The Laboratory and Field Protocols each contain requirements and guidelines for data management and analysis.

All raw data and validated data shall be reported. These data shall be provided in hard copy and in electronic format. As with the data generated by the innovative equipment, the electronic copy of the data shall be provided in a spreadsheet. In addition to the sample results, all QA/QC summary forms shall be provided.

1.4.8 Safety Measures

The Laboratory and Field Test Plans shall address safety considerations that are appropriate testing situations and the equipment being tested. The safety procedures shall address safety considerations, including the following as applicable:

- Storage, handling, and disposal of dye or tracer chemical
- Conformance with electrical code
- Confined space entry

1.5 Verification Report and Verification Statement

1.5.1 Verification Report

Upon completion of flowmeter testing in accordance with relevant Test Plan, the testing organization shall prepare a draft report describing the verification testing and the results. The flowmeter vendor shall be provided the opportunity for input on the content of the report. At a minimum, the report shall include the following items:

- Introduction
- Executive Summary
- Description and Identification of Product Tested

- Procedures and Methods Used in Testing
- Results and Discussion
- References
- Appendices, which should include raw test data.

NSF International will combine the draft reports submitted by the field testing organization and the laboratory testing organization into a single Draft Verification Report. The Draft Verification Report shall undergo a complete review by NSF International, the US EPA, and the Technology Panel on Flow Monitoring Equipment. The final Verification Report shall be made available to the public by way of posting to the Internet websites of USEPA and NSF International.

1.5.2 Verification Statement

NSF and EPA shall prepare a Verification Statement that summarizes the Verification Report. The Verification Statement shall provide a brief description of the testing conducted and a synopsis of the performance results. The Statement is intended to provide verified vendors a tool by which to promote the strengths and benefits of their product.

2 Laboratory Protocol

2.1 Objectives of Laboratory Verification

The hydraulic laboratory tests shall verify the flowmeter being tested in a quantitative manner, and shall produce results in a manner that displays the precision and bias of the meter's measurable components. For area-velocity meters, the measurable components are depth of flow and velocity of flow. For other meters, the measurable component is flow rate only. If depth and velocity are not considered measurable components of the flowmeter, only the flow rate shall be logged and compared to the actual for the verification.

The laboratory tests shall serve two purposes during the flow monitoring equipment verification. The first is to provide a controlled environment for the tests where flow conditions remain constant and are near ideal. Specific variables can be incrementally changed to verify a range of flow conditions on individual instruments. Flow conditions can be identically duplicated for each verification test for each participating vendor. Repeating each test series in the same manner for the laboratory tests provides a standard by which all flowmeters are verified. On the other hand, repeating each test identically shall not be a primary objective of the field tests.

Accuracy is the second purpose of the hydraulic laboratory tests. N.I.S.T. traceable instrumentation shall be used to make measurements of flow rate, time, temperature, etc. Laboratory instrumentation is regularly calibrated for accuracy. Determining the ability of a flowmeter to precisely and accurately measure flow is the primary objective of the laboratory tests.

The laboratory tests are designed to provide potential users of flow monitoring equipment, for sewer and combined sewer applications, with information about the effect of the following variables on a meter's ability to perform accurately:

- Pipe size. Tests shall be performed in three different pipe sizes. The effect of pipe size on meter accuracy shall be determined.
- Pipe slope. Tests shall be performed at several pipe slopes. The effect of pipe slope on meter accuracy shall be determined.
- Backwater. Tests shall be performed with and without backwater (downstream control). The effect of backwater on meter accuracy shall be determined.
- Silt buildup. The ability of a meter to accommodate reduction in cross sectional area due to buildup of silt and debris shall be tested.
- Grease buildup. The ability of a meter to continue functioning accurately with a buildup of grease on all wetted components shall be tested. The tendency that the greased components have to remain greased shall also be observed.
- Reverse flow. Simulations of reverse flow, where downstream surcharge conditions reverse the flow direction, shall be tested. The meters' ability to measure reverse flow shall be determined.

2.2 Testing Roles and Responsibilities

As indicated in Section 1.5, several parties may have responsibilities in the verification testing. The following sections define specific responsibilities of the testing organization and the participating vendor.

2.2.1 Testing Organization Responsibilities

2.2.1.1 Model Construction and Setup

Testing organization (laboratory) personnel shall be responsible for the design and construction of the simulated sewer pipe models (test pipe). The test pipe models shall be constructed and operational before the start of testing. The Testing Organization shall be responsible for ensuring all equipment and materials required for testing are available, whether supplied by the laboratory, the vendor or an outside contractor.

2.2.1.2 Data Collection and Reporting

Testing Organization personnel shall be responsible for all data collection, evaluation and reporting of each verification test of flow monitoring technology. Data shall be electronically recorded. Average flow, depth and velocity measurements shall be electronically logged and recorded from the vendors output device. The vendor shall provide necessary hardware components for logging and downloading data. The laboratory shall provide a desktop computer to retrieve the logged data.

2.2.2 Vendor Responsibilities

2.2.2.1 Personnel/Technical Support

Each vendor shall provide technical support to the testing organization for its own product being verified. Vendor support shall be provided for the installation of the flow monitoring equipment, electronic setup, and ensuring correct operational procedures are followed.

Each vendor shall provide at least one individual for technical support (defined as the vendor technician in this document). This individual shall be responsible for installing the flow monitoring equipment in the simulated sewer for each test series. Laboratory shop personnel shall provide assistance only if the vendor desires changes to the laboratory pipe setup.

The vendor technician shall also connect and setup all pertinent electronics for the test, and shall be responsible for any pre-calibrations of vendor equipment. One short series of runs shall be provided in order that the vendor may ensure that his own equipment is operating properly. The time that the vendor takes to setup his instrument shall be recorded as part of the verification.

The vendor technician shall provide instructions and a brief written procedure for operation of the flow monitoring equipment. For subsequent tests, the vendor may witness but not participate in the data collection. This will ensure that vendor bias does not become a part of the verification. The vendor may be asked to assist during the tests in the case of unforeseen circumstances, such as; power outage, broken accessories, operational failures and readout interpretation.

2.2.3 Vendor supplied equipment and accessories

Each vendor participating in the laboratory verification tests shall be responsible for providing the following equipment.

2.2.3.1 Flow Monitoring Equipment

The vendor shall supply the complete metering system, including the flow sensor and all applicable electronics and software.

2.2.3.2 Installation Hardware

The vendor shall supply the accessories needed to install the flow sensor. The laboratory shall inform the vendor with the exact pipe layout and geometry before flowmeter is supplied. The vendor may be required to supply any special tools or equipment needed to install their device.

2.2.3.3 Power Supply

The vendor may be required to supply power cords (110V) or battery packs for flow monitoring electronics. Either a second battery or a means to recharge the battery may be necessary if a battery pack is used.

2.2.3.4 Calibration Equipment

Each vendor shall be prepared with necessary equipment for pre-test calibration and setup. This includes zero and temperature compensation of the instrument. Pre-test calibrations of flow monitoring equipment shall be the vendor's responsibility.

2.3 Test Facility Requirements

The Test Plan shall provide details of the test setup, including drawings showing dimensions of each significant portion of the simulated sewer setup. This information shall also be made available to the participating vendor before the verification tests.

2.3.1 Test Pipe

Flowmeters shall be shall be tested in each of the following sizes of pipe (nominal pipe diameter):

- 10-inch;
- 20-inch;
- 42-inch.

The pipe shall be constructed of either PVC or steel and shall be standard wall pipe.

NOTE: These pipe materials are commonly used in laboratory settings, because they are readily available and easy to manage. While not a common size sewer pipe, testing shall be conducted in a 20-inch pipe to provide an indication of a flowmeter's performance in non-standard pipe sizes.

2.3.2 Water Supply

Water shall be supplied by a constant-head source capable of maintaining constant and steady water depth in the test pipe for the duration of each test run. A supply reservoir or a constant head tank may be used. Pumps shall not be used to generate flow.

2.3.3 Reflectors

Many flowmeters require that water flowing past its sensors contain at least a small amounts of reflective material (approximately 100mg/l of suspended solids) in order to maintain sufficient signal strength. If the water supplied to the laboratory does not contain sufficient levels of suspended solids, a reflective material shall be added to the supply of water. If it is not practical to introduce suspended solids to the water supply (a single verification test may take many days thus may require tons of reflective material to be continuously added to the flow), pressurized air shall be used for those tests requiring reflectors.

Air has been demonstrated effective in providing required reflectors for laboratory tests. An emitter shall be mounted in the test pipe near the supply riser. A pressure regulator shall be available to control the flow of air into the test flow. The emitter shall be designed to emit air bubbles of as small a diameter as possible. The micro-air bubbles shall act as reflective particles without negatively affecting the fluid-flow conditions. For those vendors requiring reflectors, the supply of air shall be tuned to the instrument prior to actual testing.

2.3.4 Pipe Access Opening

An opening in the top of the pipe shall be provided near where the vendor test sensor is installed. The opening shall be sufficient to: (1) provide access to a location to mount a precision point gauge for the accurate measurement of flow depths; (2) allow test participants to view the installation from above and observe flow conditions around and/or through the flowmeter. The access opening shall have a watertight cover that may be closed during pressurized (full pipe) tests.

2.3.5 Manhole

A manhole shall be constructed in each test pipe at or near the location of the test flowmeter. The size and location of manhole shall be sufficient to (1) provide access for the installation of the flowmeter under test, and (2) provide a suitable location for monitoring surcharge flow conditions.

In the 10-inch and 20-inch test pipes, the length of straight pipe installed upstream of the manhole/ flowmeter test location shall be equal to at least 40 times the pipe diameter. This length of straight pipe upstream of the manhole is necessary to provide near-uniform flow to the flow monitoring equipment during tests with no backwater effects. In the 42-inch test pipe, the length of straight pipe upstream of the manhole/flowmeter test location shall be at least 22 times the pipe diameter. This shorter length should be sufficient to provide near-uniform flow at the single pipe slope (0.2%) given that the flow will be sub-critical.

The manhole shall consist of a cylindrical steel tank with a watertight bottom. The manhole shall be constructed at a diameter between two and four times the test-pipe diameter. The manhole shall be constructed at a height between three and five times the pipe diameter. The pipe for each sewer model shall enter and exit the manhole at a height of 0.2 to 0.5 pipe diameters from the bottom of the manhole to the invert of the test pipe. A minimum of 10 diameters of straight pipe shall be installed downstream of the manhole location. The downstream pipe is necessary to simulate the flow conditions exiting the manhole.

2.3.6 Slope

Each test line shall lie at a constant slope along the full length of the pipe. The test setup shall allow for the adjustment of pipe slope. The supports for each test line shall be capable of supporting the pipe from a slightly negative slope condition to a maximum slope of 2.0 percent.

2.3.7 Pipe Supports

Vertical pipe supports shall be sufficient to prevent the pipe form sagging under the weight of the water. If PVC pipe is used:

- the spacing between vertical pipe supports shall be no greater than three pipe diameters; or
- each pipe segment shall be uniformly supported by a rigid beam along its entire length with a rigid beam.

The spacing between vertical pipe supports for steel pipe shall be no greater than ten pipe diameters.

Horizontal supports shall be added to the test pipe, as needed, to minimize vibration and unexpected movement.

2.3.8 Flowmeter Installation

The test flowmeter shall be installed in the pipe adjacent to the manhole. The precise location of the meter in the test pipe shall depend on the vendor's specifications for the meter and its installation requirements. The crown of the pipe shall be removable near the installation location for access to the installed flowmeter. This access location may or may not be used to install the flowmeter. The cover to the access hole shall be replaced in a sealed condition for tests requiring surcharged flow conditions. All cables and wires to the sensor shall be directed into the test pipe from the manhole.

2.3.9 Flow Control

A control valve shall be placed both upstream and downstream of the model piping. The valves shall be used to control the rate of flow through the simulated sewer. The upstream valve shall be used to control the rate of flow entering the test line. The downstream valve shall be used to impose a downstream control to the test line, providing backwater during surcharge test conditions.

2.3.10 Supply Riser

A vertical riser shall be installed upstream of each test pipe to: (1) help dissipate the energy of the incoming flow, (2) provide a smooth pour-over into the model pipe for open channel tests, and (3) provide a surcharge reservoir during full-pipe tests.

The cross-sectional area of the riser shall beat least twice that of the test pipe. A baffle or grate shall be installed in the supply riser to dissipate incoming flow energy. The test pipe shall be connected to the vertical supply riser with a flexible coupling that allows for the required adjustment of pipe slope. The point of connection shall be high enough on the riser to allow the test pipe to be set at a maximum slope of 2.0% along its entire length. The riser shall extend above the test pipe connection to an elevation exceeding the top of the manhole when the test pipe is set horizontally.

2.3.11 Instrumentation

The laboratory shall be equipped with the following instrumentation:

- **Flow measurement tanks and calibrated flowmeters.** Laboratory weigh and/or volumetric tanks and/or master primary flowmeters (e.g. Venturi meter) shall be used to determine the reference flow rate for each test run. The measurement tanks should be directly traceable to the National Institute of Standards and Technology (NIST) by weight. The master flowmeters shall be calibrated in place by a NIST-traceable weigh and/or volumetric tanks. Uncertainty for the tanks and flowmeters shall be less than 0.25%.

- **Precision point gauges.** A precision point gauge shall be used as the reference depth measurement to measure the depth of flow at the same location (same focal point) that the test flowmeter measures depth. When applicable, the actual depth measurement shall be compared to the indicated depth measurement from the meter. The precision point gauge shall be readable to the nearest thousandth of a foot. A precision rule may also be used to supplement the point gauge measurements.

- **DP transmitters.** A calibrated DP transmitter (pressure transducer) shall be used to measure the pressure in the pipe during a surcharged condition. The actual pressure measurement shall be compared to the indicated pressure/depth reading from the meter. The DP transmitter shall be calibrated for accuracy before the verification tests.

- **Thermometer.** A calibrated thermometer shall be used to measure the temperature of the water flowing through the test pipe. The temperature measurement shall be used for meter setup calibrations and for spreadsheet calculations requiring temperature. The thermometer shall be calibrated for accuracy before the verification tests.

- **Timer.** A calibrated stopwatch/timer shall be used to measure the collection time of the water entering the weigh and/or volumetric tanks. The time measurement shall be used with the weigh and/or volumetric reading to calculate the actual flow rate for each test. The timer shall be calibrated for accuracy before the verification tests.

- **Precision calipers.** Precision calipers shall be used to measure the inside diameter of the model piping and to verify the roundness of the pipe. An accurate measurement of each pipe diameter is necessary for correct calculations.

All laboratory equipment used to make physical measurements shall be calibrated, and where applicable, traceable to the National Institute of Standards and Technology. Valid calibration certificates shall be available for laboratory instrumentation and equipment.

2.4 Testing Requirements and Guidelines

The Test Plan shall include a detailed set of test procedures to be followed during testing. These procedures shall be consistent with the requirements established in this section. The Test Plan shall clearly identify and provide justification for any planned deviations or modifications of the procedures outlined in this Protocol. This Protocol establishes requirements for testing flowmeters in three different nominal pipe sizes: 10 –inch, 20-inch, and 42-inch. The Test Plan may propose the exclusion of testing in 10-inch pipe if the minimum nominal pipe size for which a flowmeter is intended is 12-inches or larger. The Test Plan may propose the exclusion of testing in 10-inch and 20-inch pipe if the minimum nominal pipe size for which a flowmeter is intended is 24-inches or larger. These exclusions shall be acceptable only if the vendors product literature, the operation/installation manual, and the production description section of the Verification Test Plan clearly that the flowmeter is not intended for use in pipes less than 24 inch diameter.

2.4.1 Pre-Test Procedures

Laboratory personnel shall perform the following tasks before beginning the verification test on a specific pipe setup.

- Measure and document the geometry of the test pipe and location of the vendor instrument within the pipe. An accurate measurement of the inside diameter of the pipe shall be made using precision calipers. The location of the sensor in the pipe shall be measured and documented.
- A digital photograph shall be taken of the installed flowmeter in each pipe setup. This will document the installation technique and provide an illustration of each pipe setup for the verification report.
- Record the time required for flowmeter installation and setup by the vendor.

2.4.2 General Test Procedures

Flow, depth, and velocity data from the test flowmeter shall be logged electronically as recorded from the vendor-supplied electronics. Average recorded values shall be inputted into a computer spreadsheet.

Tables 2-1, 2-2, and 2-3 specify the set of test conditions required for each test run. Table 2-1, Table 2-2, and Table 2-3 define the required conditions for each run with a 10-inch pipe, 20-inch pipe, and 42-inch pipe, respectively. For each run, the following variables shall be controlled to achieve the required test condition:

- Pipe slope
- Water depth;
- Approximate flow velocity;
- Near-uniform (no backwater) or non-uniform (backwater) flow;
- Surcharged or non-surcharged conditions
- Silt build-up (simulated);
- Grease build-up;
- Reverse flow conditions

The procedures described in this section shall be conducted for each set of test conditions established in Tables 2-1, 2-2, and 2-3. The procedures shall be repeated each time that flow conditions are changed.

2.4.2.1 Water depth

Both the upstream and downstream control valves shall be used to set the flow. Uniform flow tests shall have no downstream control. Conversely, the downstream control valve shall be throttled for submerged and backwater tests. The three Tables list desired uniform water depths and corresponding estimated flow velocities with and without backwater.

2.4.2.2 Flow stabilization

Test measurements shall not be made until the water has stabilized in the pipe. The flow is stabilized when the depth in the pipe does not change with time. The precision point gauge, mounted on the centerline of the flow path shall act as a gauge for setting and stabilizing the flow. The flow depth shall be set within .02 D (D= diameter of the pipe) of the flow depths specified in the Tables 2-1, 2-2, and 2-3.

2.4.2.3 Water temperature

The temperature of the water in the test pipe shall be measured using a calibrated mercury thermometer. This manual reading shall be recorded once the mercury has stabilized.

2.4.2.4 Logging of meter data

With the flow stabilized, laboratory personnel shall begin logging data from the flow monitoring equipment. Data shall be recorded in accordance with the operational procedures provided by the vendor except that average flow rate, depth and velocity readings shall be logged and recorded at one-minute intervals over a 5-minute period. Data shall be reported for each one-minute interval. The instrument shall be reset following each one-minute sample, so those subsequent one-minute samples are independent and are not averaged with prior samples.

The vendor shall be responsible for setting up the instrument to perform this function. The data shall be downloaded from the meter by laboratory personnel and shared with the vendor if desired. The five flow rate, depth and velocity readings for each run shall be imported to a computer spreadsheet. The average of all five one-minute samples shall also be calculated and reported.

A means of capturing the logged data and transferring the values of flow rate, depth and velocity shall be provided by the vendor. If depth and velocity are not considered measurable components of the flowmeter, only the flow rate shall be logged and compared to the actual for verification. The verification report shall clearly define the typical data averaging method for the instrument in addition to the averaging method used during the verification tests.

2.4.2.5 Reference flow measurement

The actual flow rate shall be measured and recorded before and after each logging period. Laboratory personnel shall measure the actual flow rate using either the laboratory flow measurement tanks or laboratory master flowmeters. Calibrated master flowmeters shall be used for flow rates, which exceed the capacity of the laboratory measurement tanks. For all other flow measurements, the laboratory weight and /volumetric tanks shall be used at a minimum of every fifth run. This procedure provides an in-line calibration of the laboratory flow, while providing a primary flow measurement from the tanks.

2.4.2.6 Reference depth measurement

The actual depth shall be measured and recorded before and after the logging period of each run. Laboratory personnel shall measure the actual flow depth at the centerline of the pipe. This measurement shall be made directly above the focal point for the sensor depth measurement. The manufacturer of the flowmeter shall define the exact position of the flow depth measurement. If the water surface is mounded slightly at the measurement location, a measurement of the complete cross-sectional water surface profile may be necessary to generate the correct flow area for mean velocity calculation. An evaluation of each water surface profile shall be performed to decide if a single centerline depth or a complete cross-sectional water surface profile is necessary. The Test Plan shall describe how the water surface profile will be conducted. If the peak-to-peak difference in depth across the water surface profile is greater than 0.02D inches, a complete cross-sectional water surface profile (minimum of 5 points at equal spacing) shall be necessary.

If the style of the flowmeter being tested is enclosed within the pipe (such as a Venturi tube), no reference depth measurement is required since a direct depth to depth comparison cannot be made. In this case, only the flow will be compared, and an explanation for depth data omission shall be included.

2.4.2.7 Reference velocity calculation

Using the measured cross-sectional water surface profile, a flow area shall be calculated using a computer spreadsheet. The mean velocity for the test shall be calculated by dividing the flow area into the actual laboratory flow measurement.

2.4.2.8 Record observations

A note of flow conditions which are out of the ordinary or extreme, shall be recorded for each run. This record shall remain as part of the verification report and shall include notes about standing waves, hydraulic jumps, depth fluctuations, etc.

2.4.2.9 Record indicated meter data

After each test run, laboratory personnel shall download recorded data from the test flowmeter. These data will consist of depth, velocity and flow. The data shall be imported into a computer spreadsheet. The vendor technician may review these outputs, if desired.

2.4.2.10 On-site data review

Once all pertinent data for a single run has been imported to the computer, the results shall be reviewed before the flow conditions are changed for the next run. If flow conditions changed during a logging period, the test run shall be repeated. A run shall be repeated if the difference between the flow or depth measurements taken at the start of the logging period and the end of the logging period is greater than 1% of the lesser value. The vendor technician and laboratory personnel shall mutually agree that flow conditions have changed before a run is repeated.

2.4.3 Special Test Conditions

2.4.3.1 Full Pipe Tests (Manhole Surcharged)

For tests in which there is downstream control and the pipe is pressurized and runs full, the opening on the top of the pipe through which the sensor is accessed, and through which the point gauge readings are taken, shamble closed. The cover for the access opening shall be replaced with a watertight seal. During these tests, the depth of water (hydraulic grade line) shall be measured using a calibrated DP transmitter. The transmitter shall average the submerged water surface elevation in the manhole, providing an accurate measure of water depth over the sensor. Velocities shall be calculated based on the full pipe area and the measured flow rate.

2.4.3.2 Backwater Tests

Partial backwater conditions shall be simulated, by closing the downstream control valve in the pipe. Each backwater test (non-uniform flow condition) shall have a corresponding uncontrolled flow test (uniform flow condition). The flow rate for the backwater test shall be set to match the flow rate for the uncontrolled test by using the supply Venturi meter. No backwater tests shall be performed for slopes greater than 0.5%.

2.4.3.3 Silt Simulation Tests

A simulated deposit of silt or sediment in the bottom of the pipe shall be modeled during the 0.1% slope series on the 42-inch pipe tests. A rigid flat bed shall be installed in the bottom of the 42-inch pipe at a depth of 3 inches. The simulated fixed sediment bed shall be simulated using wood or plate steel. It shall extend at the 3-inch depth for five diameters. A 5:1 smooth sloped transition shall also be installed at the leading edge of the fixed bed to reduce turbulence. The vendor technician shall adjust the installation of the flow measurement device, so that it sits above the simulated fixed bed. The same fixed bed simulation shall be used for each vendor performing laboratory verification tests. Runs shall be made as indicated in Table 2-3. If a specific flowmeter cannot be used in the reduced-flow-area region of the pipe, it shall be noted in the verification report.

2.4.3.4 Grease Buildup Tests

Tests shall be performed with very thin layers of grease placed on all submerged components of the flow monitoring equipment. The ability that the meter has to continue functioning accurately when grease builds up on the wetted components shall be tested. The tendency that the greased components have to remain greased shall also be observed and noted. Both a 0.5-mm and 2.0-mm thick layer of grease shall be tested under three different flow conditions (6 runs). Runs shall be made as indicated in Table 2-3.

2.4.3.5 Reverse Flow Tests

A simulation of reversed pressure flow conditions shall be tested by elevating the test pipe to a slightly negative slope, installing the flowmeter in the test line backwards, submerging the manhole, and forcing water uphill. The sensor shall be installed on the downstream side of the manhole (uphill side). Runs shall be made as indicated in Tables 2-1and 2-2. Reverse flow tests are not required when testing in the 42-inch pipe.

2.4.4 Equipment Failure

Any failure or malfunction of the flow monitoring equipment during verification testing shall be documented. Data collected up to the time of failure shall be retained for inclusion in the verification report. If the vendor technician can repair the instrument, the tests may continue. Repair procedures and time required to repair the unit shall be documented. If the flowmeter cannot be repaired, it may be replaced with an identical model and the testing restarted at the first run for the pipe size being tested when the failure occurred. A description of the nature and suspected cause of the failure, and the corrective action taken shall be documented for inclusion in verification report.

Table 2-1 Test Conditions and Sequence – 10-inch Test Pipe

Run Number	Pipe Size (D)	Pipe Slope	Water Depth	Approx. Velocity (fps)	Uniform Flow (Downstream Uncontrolled)	Non-uniform (Downstream Controlled)
1	10-inch	0.1%	0.1 D	0.74	Yes	
2	10-inch	0.1%	0.3 D	1.43	Yes	
3	10-inch	0.1%	0.5 D	1.84	Yes	
4	10-inch	0.1%	0.8 D	2.10	Yes	
5	10-inch	0.1%	0.1 D	0.37		Yes
6	10-inch	0.1%	0.3 D	0.71		Yes
7	10-inch	0.1%	0.5D	0.92		Yes
8	10-inch	0.1%	0.8 D	1.05		Yes
*9	10-inch	0.1%	~1.5 D	~5.0		Yes
*10	10-inch	0.1%	~2.5 D	~5.0		Yes
11	10-inch	0.5%	0.1 D	1.65	Yes	
12	10-inch	0.5%	0.3 D	3.20	Yes	
13	10-inch	0.5%	0.5D	4.12	Yes	
14	10-inch	0.5%	0.8 D	4.70	Yes	
15	10-inch	0.5%	0.1 D	0.83		Yes
16	10-inch	0.5%	0.3 D	1.60		Yes
17	10-inch	0.5%	0.5D	2.06		Yes
18	10-inch	0.5%	0.8 D	2.35		Yes
*19	10-inch	0.5%	~1.5 D	~5.0		Yes
*20	10-inch	0.5%	~2.5 D	~5.0		Yes
21	10-inch	1.25%	0.1 D	2.61	Yes	
22	10-inch	1.25%	0.3 D	5.06	Yes	
23	10-inch	1.25%	0.5D	6.51	Yes	
24	10-inch	1.25%	0.8 D	7.42	Yes	
*25	10-inch	1.25%	~1.5 D	~5.0		Yes
*26	10-inch	1.25%	~2.5 D	~5.0		Yes
27	10-inch	2.0%	0.1 D	3.31	Yes	
28	10-inch	2.0%	0.3 D	6.39	Yes	
29	10-inch	2.0%	0.5D	8.24	Yes	
30	10-inch	2.0%	0.8 D	9.39	Yes	
*31	10-inch	2.0%	~1.5 D	~5.0		Yes
*32	10-inch	2.0%	~2.5 D	~5.0		Yes
***33	10-inch	-0.1%	~1.5 D	~0.5		Yes
***34	10-inch	-0.1%	~2.5 D	~1.0		Yes

*Manhole is surcharged
***Flowmeter installed backwards, pipe slope set negative, surcharged conditions

Table 2-2 Test Conditions and Sequence – 20-inch Test Pipe

Run Number	Pipe Size (D)	Pipe Slope	Water Depth	Approx. Velocity (fps)	Uniform Flow (Downstream Uncontrolled)	Non-uniform (Downstream Controlled)
1	20-inch	0.1%	0.1 D	0.86	Yes	
2	20-inch	0.1%	0.3 D	1.66	Yes	
3	20-inch	0.1%	0.5 D	2.14	Yes	
4	20-inch	0.1%	0.8 D	2.43	Yes	
5	20-inch	0.1%	0.1 D	0.43		Yes
6	20-inch	0.1%	0.3 D	0.83		Yes
7	20-inch	0.1%	0.5D	1.07		Yes
8	20-inch	0.1%	0.8 D	1.22		Yes
*9	20-inch	0.1%	~1.5 D	~5.0		Yes
*10	20-inch	0.1%	~2.5 D	~5.0		Yes
11	20-inch	0.5%	0.1 D	1.92	Yes	
12	20-inch	0.5%	0.3 D	3.71	Yes	
13	20-inch	0.5%	0.5D	4.77	Yes	
14	20-inch	0.5%	0.8 D	5.44	Yes	
15	20-inch	0.5%	0.1 D	0.96		Yes
16	20-inch	0.5%	0.3 D	1.85		Yes
17	20-inch	0.5%	0.5D	2.39		Yes
18	20-inch	0.5%	0.8 D	2.72		Yes
*19	20-inch	0.5%	~1.5 D	~5.0		Yes
*20	20-inch	0.5%	~2.5 D	~5.0		Yes
21	20-inch	1.25%	0.1 D	3.03	Yes	
22	20-inch	1.25%	0.3 D	5.86	Yes	
23	20-inch	1.25%	0.5D	7.55	Yes	
24	20-inch	1.25%	0.8 D	8.60	Yes	
*25	20-inch	1.25%	~1.5 D	~5.0		Yes
*26	20-inch	1.25%	~2.5 D	~5.0		Yes
27	20-inch	2.0%	0.1 D	3.83	Yes	
28	20-inch	2.0%	0.3 D	7.41	Yes	
29	20-inch	2.0%	0.5D	9.55	Yes	
30	20-inch	2.0%	0.8 D	10.88	Yes	
*31	20-inch	2.0%	~1.5 D	~5.0		Yes
*32	20-inch	2.0%	~2.5 D	~5.0		Yes
***33	20-inch	-0.1%	~1.5 D	~0.5		Yes
***34	20-inch	-0.1%	~2.5 D	~1.0		Yes

*Manhole is surcharged
***Flowmeter installed backwards, pipe slope set negative, surcharged conditions

Table 2-3 Test conditions and sequence - 42-Inch Test Pipe

Run Number	Pipe Size (D)	Pipe Slope	Water Depth	Approx. Velocity (fps)	Uniform Flow (Downstream Uncontrolled)	Non-uniform (Downstream Controlled)
1	42-inch	0.2%	0.1 D	2.01	Yes	
2	42-inch	0.2%	0.3 D	3.90	Yes	
3	42-inch	0.2%	0.5 D	5.02	Yes	
4	42-inch	0.2%	0.8 D	5.72	Yes	
5	42-inch	0.2%	0.1 D	1.00		Yes
6	42-inch	0.2%	0.3 D	1.95		Yes
7	42-inch	0.2%	0.5D	2.51		Yes
8	42-inch	0.2%	0.8 D	2.86		Yes
*9	42-inch	0.2%	~1.5 D	~5.0		Yes
*10	42-inch	0.2%	~2.5 D	~5.0		Yes
**11	42-inch	0.2%	0.1 D	~1.0		Yes
**12	42-inch	0.2%	0.7 D	~3.0		Yes
**13	42-inch	0.2%	~1.5 D	~5.0		Yes
****14	42-inch	0.2%	0.1D	2.01	Yes	
****15	42-inch	0.2%	0.3D	3.90	Yes	
****16	42-inch	0.2%	0.8D	5.02	Yes	
*****17	42-inch	0.2%	0.1D	2.01	Yes	
*****18	42-inch	0.2%	0.3D	3.90	Yes	
*****19	42-inch	0.2%	0.8D	5.02	Yes	

*Manhole is surcharged
** Silt simulation test
*** Flowmeter installed backwards, pipe slope set negative, surcharged conditions
**** Grease buildup test with 0.5 mm grease layer
***** Grease buildup test with 2.0 mm grease layer

2.5 Data management and analysis

All raw data, notes, observations and test descriptions shall be recorded using Microsoft Excel or similar spreadsheet software.

2.5.1 Reference values

Reference values for flow, depth, and velocity shall be calculated for each test run. These reference values shall provide the basis for determining the accuracy of the values from the flowmeter output.

The reference flow value for each run shall be the arithmetic average of the flow at the beginning and at the end of logging period, as determined using the volume/weigh tanks or calibrated Venturi meter (see 2.4.2.5).

The reference depth value for each run shall be the arithmetic average of the depth at the beginning and at the end of logging period, as determined using calibrated precision point gauges or pressure transducers (for surcharged conditions) (see 2.4.2.6).

The reference velocity value for each run shall be the arithmetic average of the velocity values calculated from the depth and flow measurements taken at the beginning and end of the logging period (see 2.4.2.7).

2.5.2 Accuracy calculations

Flowmeter accuracy shall be characterized by comparing the average flow, depth, and velocity values recorded from the electronic output of the test flowmeter for each of the five 1-minute intervals shall be compared to the reference values for each run. The average and standard deviation of the five 1-minute averages for flow, velocity and depth shall also be calculated. The average shall compared to the reference values for flow, depth, and velocity. For each, the difference between the reference values and metered values shall be calculated as a percent deviation as follows:

$$\text{Percent Deviation (\%D)} = 100 \cdot (X_M - X_R) / X_R$$

Where X_M= value recorded by test flowmeter (flow, velocity, or depth)
X_R = Reference value (flow, velocity, or depth)

Figure 2-1 provides an example for presenting data in tabular form.

Comparison between metered and reference flow data shall be all that is required for flowmeters that do not measure depth and velocity to determine the flow and instead rely on direct measurement of flow.

2.5.3 Flowmeter Precision and Bias

To provide an indication of the bias and precision associated with each measurement/output of a flowmeter, depth, velocity and flow data shall also be presented in graphical form. Test data from each run shall be used to generate the following graphs:

- A depth-velocity scattergraph showing the pipe curve for each pipe slope/pipe size configuration, including the depth-velocity condition for each run and all meter data and average meter data for each run for the slope and pipe size (see example in Figure 2-2);
- A plot of the percent deviation (average metered flow from the reference flow) versus the reference flow for each pipe slope/pipe size configuration (see example in Figure 2-3);
- A plot of the average metered flow versus the reference flow for each pipe slope/pipe size configuration (see example in Figure 2-4).

Figure 2-1 – Example Table of Results

Run 1	Indicated Meter Readings								
Date: 21-Dec-99	Flow (gpm)			Depth (inches)			Velocity (fps)		
Start Time: 12:30 PM	Indicated Flow	% dev. from actual	std. dev.	Indicated Depth	% dev. from actual	std. dev.	Indicated Velocity	% dev. from actual	std. dev.
Name of Laboratory									
1st one minute average	9.18	-2.75		0.972	-1.37		0.70	-7.44	
2nd one minute average	9.26	-1.91		0.970	-1.57		0.68	-10.08	
3rd one minute average	9.21	-2.44		0.974	-1.17		0.65	-14.05	
4th one minute average	9.29	-1.59		0.968	-1.78		0.69	-8.76	
5th one minute average	9.33	-1.17		0.971	-1.47		0.68	-10.08	
Average of 5 readings	9.25	-1.97	0.060	0.971	-1.47	0.002	0.68	-10.08	0.019
Test Conditions	Actual Measurements								
10-Inch Pipe / Uniform Flow	Flow (gpm)			Depth (inches)			Velocity (fps)		
Pipe I.D. (inches)= 10.019	Initial	Final	Average	Initial	Final	Average	Initial	Final	Average
Pipe Slope= 0.10%	9.41	9.47	**9.44**	0.987	0.984	**0.986**	0.75	0.76	**0.76**

Figure 2-2 Example of depth-velocity scattergraph

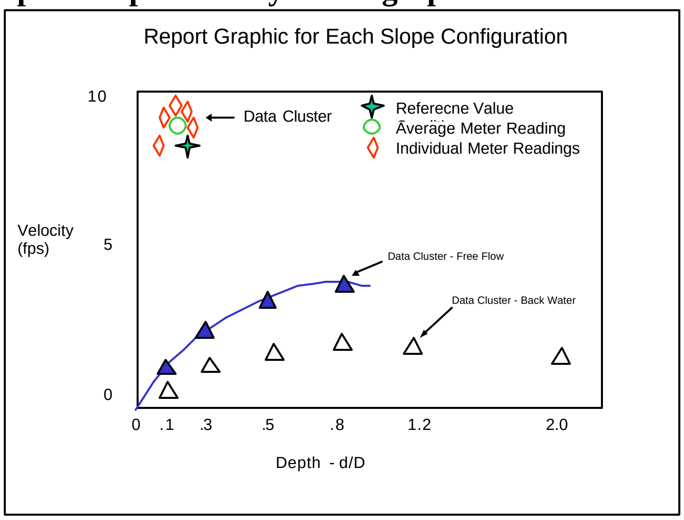


Figure 2-3 Example Plot of Percent Deviation vs. Reference Flow (single pipe configuration)

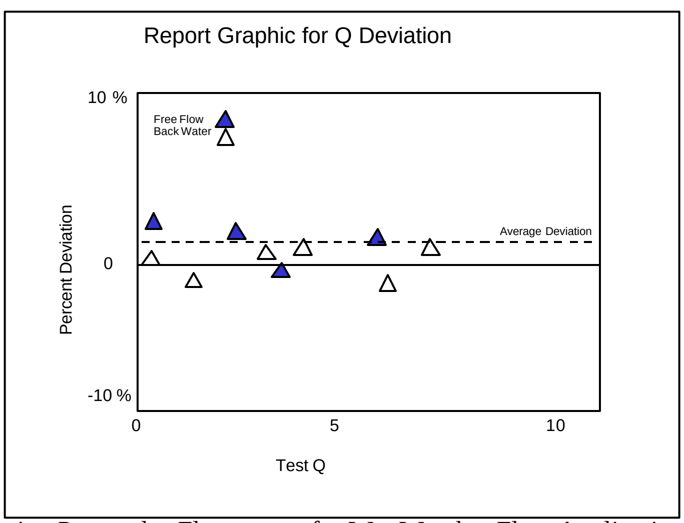
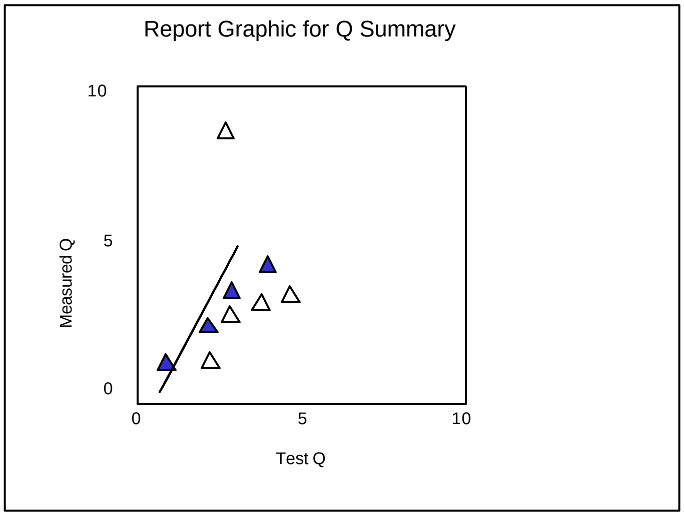


Figure 2-4 Example Plot of Average Metered Flow vs. Reference Flow (single pipe configuration)



3 Field Protocol

3.1 Objectives of field verification

The objectives of field verification of open-channel flowmeters under this Protocol include:

- Verification of meter performance relative to the manufacturer's stated range of equipment capabilities and intended applications;
- Verification of meter accuracy relative to accepted reference methods over a range of flow conditions and sewer configurations, including response to changes in flow;
- The characterization of the resources required for proper installation, operation, and maintenance of the equipment;
- The characterization of reliability, capacity, and usefulness of the meter and its support software for combined sewer and storm sewer applications.

This field protocol defines the in-situ test conditions and data collection requirements for the verifying the performance of open-channel flowmeters in an actual sewer. The protocol defines the procedures for verifying flowmeter accuracy in a combined sewer or storm sewer pipe using actual or simulated wet weather flows.

3.1.1 Performance verification

The field verification of flowmeters shall include a demonstration of the accuracy of depth and velocity sensors. It will also provide a quantitative demonstration of the accuracy with which they calculate the flow and measure the level (depth) and velocity in a combined sewer under defined dry and wet-weather conditions. This requires that each tested flowmeter have separate signal outputs for depth, velocity and flow. The verification of accuracy shall be based on a comparison to a reference method, as defined in this protocol.

This protocol describes the methods for verifying and reporting the performance of flowmeters under the following conditions:

- Dry weather flow (low flow and depth);
- Wet weather flow (high flow and depth);
- Backflow conditions, such as caused by downstream disturbance and;
- Surcharge conditions (transition from open channel to surcharge conditions);
- Multiple pipe and flow patterns.

3.1.2 Operational verification

The field verification of flowmeters shall include an evaluation of the installation, start-up, operation and maintenance activities. Qualitative and quantitative measurements will evaluate the time, labor, and equipment needed to effectively install, operate, and maintain the flowmeter in a combined sewer or storm water collection system. The physical integrity, the ease of operation, and the ability of a meter to measure properly in actual use shall be documented. Software applications provided by a flowmeter manufacturer shall also be verified for ease of application, flexibility, and compatibility with Windows-based operating systems.

3.2 Test Facility Requirements

Selection of an appropriate test facility is critical to the proper verification of open channel flowmeters. In keeping with the objectives of the flowmeter verification, field tests shall be conducted in a collection system designed for the conveyance of wet weather flows. A single facility may include multiple sites for flowmeter installation, each of which includes the sewer pipe and the necessary auxiliary equipment.

3.2.1 Physical description

The Test Plan shall describe the overall facility and individual test sites. The description shall include information relevant to the hydraulic and physical conditions in the collection system, which might affect flow, water quality characteristics, or the ability to measure flow, velocity or level accurately. This may include the following:

- Physical characteristics that might create backflow conditions during dry and/or wet weather flows and the nature of such a backflow;
- Surcharge conditions;
- The location of manholes, elbows, or other features that might cause changes in the direction or the area of flow;
- Locations of silt accumulations, including actual or potential silt levels;
- Nature and location of inputs to the sewer which might rapidly affect the concentration of suspended solids;
- Conditions that promote the formation of foam on the water surface;
- Rapid drops in elevation, upstream or downstream of a flowmeter location;
- The level of the overflow weir.

Diagrams and drawings of each site shall show the location(s) for the installation of the flowmeter, including the transmitter and probes. The diagrams shall also indicate important locations for the tracer dilution reference tests and for the installation of reference flow and level meters, as applicable. Table 2-1 identifies site characteristics that shall be defined in the Test Plan.

3.2.2 Minimum Requirements

Field verification of flowmeter performance for wet weather flow applications requires the ability to generate a wide range of flow conditions at the flowmeter installation. Several tests in this protocol require the ability to manually adjust and control flow upstream of the flowmeter installation in order to achieve the desired flow velocity and head for each test (Tests B, C, D). Alternative tests (Tests E, F) allow testing to be conducted using actual wet weather flows in a sewer pipe to achieve the required flows. It is expected however that testing will be most practicable in sewers that have upstream storage capacity and the ability to control the flows to simulate various wet weather flow conditions. Section 3.3 of this Protocol defines the site requirements for specific tests.

Table 3-1: SITE DESCRIPTION FORM

Site Characteristic	Value or comment
Type of Pipe (materials)	
Pipe diameter	
Length of pipe without input or disturbance	
Pipe slope	
Range of dry weather flow	
Range of dry weather depth	
Range of flow during 10-yr rainfall event	
Range of depth during 10-yr rainfall event	
Range of flow during 1-yr rainfall event	
Range of depth during 1-yr rainfall event	
Range of water temperatures	
Description of pipe accesses (building, manhole)	
Number of possible flowmeter installation locations	
Availability of an upstream gate to modify flow	
Availability of an upstream storage tank to simulate wet weather flows	
Availability of a downstream gate to create backflow conditions	
Availability of electrical connections	
Availability of a SCADA system (distance, # and type of I/O)	
Availability of lighting	
Availability of water	
Availability of air for instrumentation	

3.3 Testing Requirements and Guidelines

This section describes the tests to be conducted as part of the flowmeter verification. The Test Plan shall identify which of these tests are to be conducted, including the sequence and schedule for installing and maintaining the flowmeter and conducting the tests. The Test Plan shall provide a detailed rationale for deviating from or excluding one or more of the tests identified in this section.

3.3.1 Overview

Eight different tests (A through H) may be included in the field verification of a flowmeter. In this Protocol, tests are classified under the following categories:

- Test A: Flowmeter software evaluation
- Test B: Flowmeter accuracy under simulated dry weather flow with backflow
- Test C: Flowmeter accuracy under simulated wet weather flow without backflow
- Test D: Flowmeter accuracy under simulated wet weather flow with backflow
- Test E: Flowmeter accuracy under actual dry weather flow with backflow conditions
- Test F: Flowmeter accuracy under actual wet weather flow without backflow
- Test G: Accuracy / operation and maintenance over short term operation (21 days)
- Test H: Accuracy /Operation and maintenance over long term operation (180 days)

Tests B, C, and D are intended to be performed at test sites capable of simulating wet weather flows. Tests E and F are intended to be performed at sites where upstream storage and flow control facilities are not available and thus rely on actual dry and wet weather flows to verify flowmeter performance. Test G and H may be performed under simulated or actual wet weather flow conditions. It is not necessary to conduct tests under both sets of conditions. Test H is optional and is thus not required for verification under the ETV Program.

Table 3-1 presents which tests should be performed based on the type of flow available. The Test Plan shall indicate which tests are to be conducted.

Table 3-1: SELECTION OF TESTS

Test	Simulated flow	Actual flow
Flowmeter software evaluation	A	A
Accuracy under dry weather flow with backflow conditions	B	E
Accuracy under wet weather flow	C	F
Accuracy under wet weather flow with backflow conditions	D	not applicable
Accuracy under extended operations	G	G
Operation and maintenance under extended operations (optional)	H	H

3.3.2 Definitions

Terms used in this section of the Protocol that have special technical meaning are defined here.

3.3.2.1 Maximum dry weather flow:

Flow equal to approximately 0.07 times the maximum capacity of the sewer at the site of the flowmeter installation.

3.3.2.2 Maximum head:

The level that exceeds the crown of the pipe by approximately 33% of the diameter of the pipe, unless the accuracy of the reference measurement is adversely affected. In this case, it is the level that is equal to the crown of the pipe.

3.3.2.3 Normal head:

Level corresponding to the current flow without any downstream backflow.

3.3.3 Test A: Evaluation of flowmeter software

3.3.3.1 Objective

To evaluate the software provided by the flowmeter manufacturer for ease of use, functionality, innovation and compatibility. The elements verified under this test shall be based on the claims made by the vendor with respect to the features and capabilities of the flowmeter software. Appendix A contains a list of tests that may be applicable to a given flowmeter. Those features and capabilities claimed by the manufacturer shall be verified during this test.

3.3.3.2 Test Conditions

This is a qualitative evaluation, parts of which shall be performed in the field during configuration, calibration and data collection. Other parts shall be done before installation or following removal of the flowmeter from the sewer.

3.3.3.3 Measurements

3.3.3.3.1 Ease of use

The testing organization shall note the time and general level of effort associated with using the software to accomplish the following:

- Defining, managing, and modifying the configuration file of a site;
- Steps required to transfer data from the flowmeter;
- Collecting and saving data and generating time series graphs of level, velocity and flow;
- Generating and viewing hyetographs and scattergraphs;
- Zeroing of the level probe;
- Adjusting the level reading to match a reference level measurement;
- Adjusting velocity readings to match a reference velocity measurement;
- Configuring output signal parameters:
    - Span
    - 4 mA (lower limit)
    - 20 mA (higher limit)
    - Real time serial output (if available)

3.3.3.3.2 Functionality/flexibility

The testing organization shall verify the availability or functionality of all elements of the software, as indicated by the vendor in Appendix A. The elements observed in this test shall be rated as “possible” or “not possible”, according to the ability of the flowmeter software to process them. The testing organization shall document special conditions or limitations associated with the element.

3.3.4 Test B - Accuracy under simulated dry weather flow with backflow

3.3.4.1 Objective

To verify the accuracy of depth and velocity measurement and verify the accuracy with which an in-line flowmeter calculates flow during simulated dry weather flow (low flow) and when subject to backflow conditions caused by a downstream obstruction in a typical sewer pipe. This test shall be run at least three times for each flowmeter installation.

3.3.4.2 Site requirements

This test requires an upstream gate and upstream water storage of adequate volume to allow for the required flow adjustments. The upstream control point shall be located far enough upstream so that the flow at the flowmeter installation site can return to its normal depth, pattern, and aeration. The level in the pipe where the test flowmeter is installed should not exceed the crown of the pipe during the test as it might affect the accuracy of the reference measurement.

This test requires that a gate be available downstream from the flowmeter installation, which can be opened and closed to affect the head in the pipe to simulate a downstream obstruction.

This test requires a minimum pipe diameter of 36 inches at the location of the flowmeter installation.

3.3.4.3 Test Conditions

To create and maintain a range of flow conditions over the duration of the test, the following procedures should be followed in the sequence described here. The Test Plan shall describe planned deviations from these procedures which may be necessary due to constraints of the test site or the specific flowmeter under test.

a) Open the upstream gate and adjust the flow to the maximum dry weather flow.

b) Initiate the reference flow and velocity measurement in accordance with Section 3.4 of this Protocol. Verify the level measurement using the reference level meter and manual measurements in accordance with section 3.4 of this Protocol

c) If using tracer dilution flow reference measurement, allow at least 30 minutes of steady flow before starting the flowmeter test to ensure that the tracer concentration is constant.

d) Start the test and operate for at least 30 minutes under steady flow conditions.

e) Progressively close the downstream gate over a period of 10 minutes or less to establish a head at the flowmeter location equal to 3 $\pm$ 0.5 times the normal head of water. Adjust flow (i.e., open upstream gate) as necessary to maintain the specified head for at least 30 minutes.

f) Progressively close the downstream gate over a period of 10 minutes or less to establish the maximum head at the flowmeter location. Adjust flow (i.e., open upstream gate) as necessary to maintain the specified head for at least 30 minutes.

g) Note the time, terminate the reference flow measurement and end the test. Collect the flowmeter data.

3.3.4.4 Measurements

For every time increment the level, the velocity and the flow of the tested flowmeter and reference flowmeter shall be logged.

Each gate manipulation shall be logged with the corresponding time and level upstream and downstream from the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and corresponding time noted.

3.3.5 Test C – Accuracy under simulated wet weather flow

3.3.5.1 Objective

To verify the accuracy of depth and velocity measurement and verify the accuracy with which an in-line flowmeter calculates flow during simulated wet weather flow conditions (normal and high flow) in a typical sewer pipe. This test shall be run at least three times for each flowmeter installation.

3.3.5.2 Site requirements

This test requires an upstream gate and upstream water storage of adequate volume to allow for the required flow adjustments. The upstream control point shall be located far enough upstream so that the flow at the flowmeter installation site can return to its normal depth, pattern, and aeration. The level in the pipe where the test flowmeter is installed should not exceed the crown of the pipe during the test as it might affect the accuracy of the reference measurement.

This test requires a minimum pipe diameter of 36 inches at the location of the flowmeter installation.

3.3.5.3 Test Conditions

To create and maintain a range of flow conditions over the duration of the test, the following procedures should be followed in the sequence described here. The Test Plan shall describe planned deviations from these procedures which may be necessary due to constraints of the test site or the specific flowmeter under test.

a) Open the upstream gate and adjust the flow to the maximum dry weather flow.

b) Initiate reference flow and velocity measurement in accordance with Section 3.4 of this Protocol. Verify level measurement using the reference level meter and manual measurements in accordance with section 3.4 of this Protocol.

c) If using tracer dilution for flow reference measurement, allow at least 30 minutes of steady flow before starting the flowmeter test to ensure that the tracer concentration is constant.

d) Start the test and operate for at least 30 minutes under steady flow conditions.

e) Progressively open the upstream gate over a period of 10 minutes or less to establish a flow equal to 10 ± 0.5 times the maximum dry weather flow. Establish and maintain steady flow for at least 30 minutes.

f) Progressively close the upstream gate over a period of 10 minutes or less to establish a flow equal to 5 ± 0.5 times the maximum dry weather flow. Establish and maintain steady flow for at least15 minutes.

g) Progressively open the upstream gate over a period of 15 minutes or less to establish a flow equal to 20 ± 0.5 times the maximum dry weather flow. Establish and maintain steady flow for at least 30 minutes.

h) Progressively close the upstream gate over a period of 15 minutes or less to establish a flow equal to 5 ± 0.5 times the maximum dry weather flow. Establish and maintain steady flow for at least 15 minutes.

i) Progressively close the upstream gate over a period of 10 minutes or less the maximum dry weather flow. Establish and maintain steady flow for at least 30 minutes.

j) Note the time, stop the reference flow measurement and end the test. Collect the flowmeter data.

3.3.5.4 Measurements

For every time increment the level, the velocity and the flow of the tested flowmeter and reference flowmeter shall be logged.

Each gate manipulation shall be logged with the corresponding time and the upstream and downstream level of the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and the corresponding time noted.

3.3.6 Test D – Accuracy under simulated wet weather flow with backflow

3.3.6.1 Objective

To verify the accuracy of depth and velocity measurement and verify the accuracy with which an in-line flowmeter calculates flow during simulated wet weather flow (high flow) and when subject to backflow conditions caused by a downstream obstruction in a typical sewer pipe. This test shall be run at least three times for each flowmeter installation.

3.3.6.2 Site requirements

This test requires an upstream gate and upstream water storage of adequate volume to allow for the required flow adjustments. The upstream control point shall be located far enough upstream so that the flow at the flowmeter installation site can return to its normal depth, pattern, and aeration. The level in the pipe where the test flowmeter is installed should not exceed the crown of the pipe during the test as it might affect the accuracy of the reference measurement.

This test requires that a gate be available downstream from the flowmeter installation, which can be opened and closed to affect the head in the pipe to simulate a downstream obstruction.

This test requires a minimum pipe diameter of 36 inches at the location of flowmeter installation.

3.3.6.3 Test Conditions

To create and maintain a range of flow conditions over the duration of the test, the following procedures should be followed in the sequence described here. The Test Plan shall describe planned deviations from these procedures which may be necessary due to constraints of the test site or the specific flowmeter under test.

a) Open the upstream gate and adjust the flow to the maximum dry weather flow as described above.

b) Initiate reference flow and velocity measurement in accordance with reference flow measurement and reference velocity measurement requirements in Section 3.4 of this Protocol. Verify level measurement using the reference level meter and manual measurements in accordance with reference level measurement requirements in Section 3.4.

c) If using tracer dilution for flow reference, allow at least 30 minutes of steady flow before starting the flowmeter test to ensure that the tracer concentration is constant.

d) Start the test and operate for at least 30 minutes under steady flow conditions.

e) Progressively open the upstream gate over a period of 5 minutes or less to establish a flow at the flowmeter location equal to 5 ± 0.5 times the maximum dry weather flow. Establish and maintain steady flow for at least 30 minutes.

f) Progressively close the downstream gate over a period 10 minutes or less to establish the maximum head at the flowmeter location. Establish and maintain steady flow for at least 30 minutes.

g) Progressively open the upstream gate over a period of 5 minutes or less to establish a flow at the flowmeter location equal to 10 ± 0.5 times the maximum dry weather flow, while adjusting the downstream gate to maintain the maximum head. Establish and maintain steady flow for at least 30 minutes.

h) Progressively open the upstream gate over a period of 15 minutes or less to establish a flow at the flowmeter location equal to 20 ± 0.5 times the maximum dry weather flow, while adjusting the downstream gate to maintain the maximum head. Establish and maintain steady flow for at least 30 minutes.

i) Progressively close the upstream gate over a period of 15 minutes or less to establish the maximum dry weather flow. Establish and maintain steady flow for at least 30 minutes.

j) Note the time, stop the reference flow measurement and end the test. Collect the flowmeter data.

3.3.6.4 Measurements

For every time increment the level, the velocity and the flow of the tested flowmeter and reference flowmeter shall be logged.

Each gate manipulation shall be logged with the corresponding time and level upstream and downstream from the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and the corresponding time noted.

3.3.7 Test E - Accuracy under actual dry weather flow with backflow

3.3.7.1 Objective

To verify the accuracy of depth and velocity measurement and verify the accuracy with which an in-line flowmeter calculates flow during dry weather flow (low flow) and when subject to backflow conditions caused by a downstream obstruction in a typical sewer pipe. This test shall be run at least three times for each flowmeter installation.

3.3.7.2 Site requirements

This accuracy test under actual dry weather flow with backflow conditions may be performed at any desired location where the necessary reference flow, velocity and level measurements can be made in accordance with reference method requirements in 3.4. The level in the pipe where the test flowmeter is installed should not exceed the crown of the pipe during the test as it might affect the accuracy of the reference method measurement.

This test requires that a gate be available downstream from the flowmeter installation, which can be opened and closed to affect the head in the pipe to simulate a downstream obstruction.

This test requires a minimum pipe diameter of 36 inches at the location of flowmeter installation.

3.3.7.3 Test Conditions

To create and maintain a range of flow conditions over the duration of the test, the following procedures should be followed in the sequence described here. The Test Plan shall describe planned deviations from these procedures which may be necessary due to constraints of the test site or the specific flowmeter under test.

a) Open the upstream gate and adjust the flow to the maximum dry weather flow.

b) Initiate the reference flow and velocity measurement in accordance with the reference flow measurement and reference velocity measurement procedures described in the Test Plan. Verify the level measurement using the reference level meter and manual measurements.

c) If using tracer dilution flow reference measurement, allow at least 30 minutes of steady flow before starting the flowmeter test to ensure that the tracer concentration is constant.

d) Start the test and operate for at least 30 minutes under steady flow conditions.

e) Progressively close the downstream gate over a period of 10 minutes or less to establish a head at the flowmeter location equal to 3 ± 0.5 times the normal head of water. Establish and maintain steady flow for at least 30 minutes.

f) Progressively close the downstream gate over a period of 10 minutes or less to establish the maximum head at the flowmeter location. Establish and maintain a steady flow for at least 30 minutes.

g) Progressively open the downstream gate over a period of 10 minutes or less to establish the normal head of water at the flowmeter location. Establish and maintain a steady flow for at least 30 minutes.

h) If using tracer dilution flow reference measurement, stop injection and sampling.

i) Wait for the maximum dry weather flow period of the day. If using tracer dilution flow reference measurement, begin injection and sampling 75 minutes before the time of the maximum dry weather flow and allow at least 30 minutes of steady flow before starting the flowmeter test to ensure that the tracer concentration is constant.

j) Start the test and operate for at least 30 minutes under steady flow conditions.

k) Progressively close the downstream gate over a period of 10 minutes or less to establish a head at the flowmeter location equal to 3 ± 0.5 times the normal head of water. Establish and maintain a steady flow for at least 30 minutes.

l) Progressively close the downstream gate over period of 10 minutes or less to establish the maximum head at the flowmeter location. Establish and maintain steady flow for at least 30 minutes.

m) Progressively open the downstream gate over a period of 10 minutes or less to establish the normal head of water at the flowmeter location. Establish and maintain a steady flow for at least 30 minutes.

n) Note the time, stop the reference flow measurement and end the test. Collect the flowmeter data.

3.3.7.4 Measurements

For every time increment the level, the velocity and the flow of the tested flowmeter and reference flowmeter shall be logged.

Each gate manipulation shall be logged with the corresponding time and the upstream and downstream level of the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and the corresponding time noted.

3.3.8 Test F – Accuracy under actual wet weather flow

3.3.8.1 Objective

To verify the accuracy of depth and velocity measurements and verify the accuracy with which an in-line flowmeter calculates flow during actual wet weather flow (normal and high flow).. This test shall be conducted during at least three qualifying rain events for each flowmeter installation.

3.3.8.2 Site requirements

This test requires that the flowmeter under evaluation be installed in a pipe which the flow will likely be significantly impacted by a qualified rain event at least three times during a single month of testing.

In a collector pipe, a single qualified rain event is one having the following effect on the flow:

- Flow at/or exceeding 3 times the maximum dry weather flow for at least 60 minutes;
- Flow at/or exceeding 10 times the maximum dry weather flow for at least 15 minutes;
- Flow at/or exceeding 20 times the maximum dry weather flow for at least 5 minutes.

In an interceptor pipe, a single qualified rain event is one having the following effect on the flow:
- Flow at/or exceeding 2 times the maximum dry weather flow for at least 60 minutes;
- Flow at/or exceeding 3 times the maximum dry weather flow for at least 10 minutes.

This test requires the ability to conduct a tracer dilution flow measurement upon notification that a rainfall event of significant impact is imminent. At the beginning of a rain event, the tracer dilution flow measurement team starts the tracer injection to insure at least 15 minutes of steady flow at the collection site. If the pipe flow increases before this, samples should be taken and analyzed in the same manner. The decision to accept or reject the samples will be made during data analysis.

3.3.8.3 Test Conditions

It may be necessary to deviate from these procedures depending on the nature of the collection system and the intensity and duration of the rain events. Planned deviations shall be clearly identified in the Test Plan. Unplanned deviations shall be fully documented and reported in the draft Verification Report.

3.3.8.3.1 Collector installations

The monitoring steps and test conditions described in this section apply to the testing of flowmeters installed in a collector pipe. After starting the test, the sequence of steps may be changed depending on the nature of the rain event. The minimum duration is specified for each monitoring step. If possible, the duration of each monitoring step should be extended to twice the minimum duration specified or the monitoring step should be conducted twice during the single qualified rain event. To establish the desired head for a given monitoring step, the downstream gate should be opened or closed within a 10-minute period.

a) Initiate reference flow and velocity measurement in accordance with the reference flow measurement and reference velocity measurement requirements in 3.4. Verify level measurement using the reference level meter and manual measurements in accordance with the reference level measurement requirements in 3.4. If possible, initiate reference flow measurement at least 30 minutes before the start of the test.

b) Start the test. If possible, the test should be started early enough in the rain event to allow for at least 30 minutes of dry weather flow measurement.

c) Test for at least 30 minutes at a flow equal to at least 3 times the maximum dry weather flow without backflow.

d) Test for at least 30 minutes at a flow equal to at least 10 times the maximum dry weather flow.

e) Test for 5 minutes at a flow equal to at least 20 times the maximum dry weather flow.

f) Test for 30 minutes at the end of the rain event.

g) Note the time, stop the reference flow measurement and end the test. Collect the flowmeter data.

3.3.8.3.2 Interceptor installations

The monitoring steps and test conditions described in this section apply to the testing of flowmeters installed in an interceptor pipe. The sequence of steps may be changed depending on the nature of the rain event. The minimum duration is specified for each monitoring step. If possible, the duration of each monitoring steps should be extended to twice the duration specified or the monitoring step should be conducted twice during the single qualified rain event. To establish the desired head for a given monitoring step, the downstream gate should be opened or closed within a 10-minute period.

a) Initiate reference flow and velocity measurement in accordance with sections "Reference flow measurement" and "Reference velocity measurement". Verify level measurement using the reference level meter and manual measurements in accordance with section "Reference level measurement". If possible, initiate reference flow measurement at least 30 minutes before the start of the test.

b) Start the test. If possible, the test should be started early enough in the rain event to allow for at least 30 minutes of dry weather flow measurement.

c) Test for at least 30 minutes at a flow equal to at least 2 times the maximum dry weather flow

d) Test for 30 minutes at a flow equal to at least 3 times the maximum dry weather flow

e) Test for at least 30 minutes at the end of the rain event

f) Note the time, stop the reference flow measurement and end the test. Collect the flowmeter data.

3.3.8.4 Measurements

For every time increment the level, the velocity and the flow of the tested flowmeter and reference flowmeter shall be logged.

Each gate manipulation shall be logged with the corresponding time and the level upstream and downstream from the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and the corresponding time noted.

3.3.9 Test G - Accuracy under short-term continuous operation

3.3.9.1 Objective

To verify the accuracy of depth and velocity measurement and verify the accuracy with which an in-line flowmeter calculates flow over a 21-day period of continuous operation.

3.3.9.2 Site requirements

This test may be performed at any location where the necessary reference flow and level measurements can be made in accordance with reference method requirements in 3.4. It is likely that other tests required by this protocol will also be conducted during the 21-day test period and therefore the site requirements of those tests would also apply.

3.3.9.3 Test Conditions

There shall be at least one period, during which flow data is not retrieved (i.e., collected from the flowmeter transmitter)for seven consecutive days of data collection. This should follow the completion of Tests B, C, and D (or Test E and F, if applicable).

The Testing Organization shall be responsible for the proper operation and maintenance of the flowmeter in accordance with the operating instructions. Interventions required maintaining the proper operation of the flowmeter shall be authorized by the Testing Organization. Such interventions may be performed between tests B, C, D, E and F or during Test G. The testing organization shall record the nature and frequency of any operation and maintenance procedures required during a 21-day period of continuous operation.

The Testing Organization shall make note of any activity required to operate and maintain the flowmeter during the course of the test. The Testing Organization shall record the number of person-hours required for any field intervention to maintain the flowmeter in operating order, in accordance with the operation manual or the procedures recommended by the flowmeter manufacturer. The personnel required for operation and maintenance procedures shall be classified according to their qualifications, as follows:

- Engineer
- Technician
- General Laborer

The Testing Organization shall also note whether any specialized tool or equipment was required and whether the need for such tools or equipment was indicated by the operation and maintenance instructions.

3.3.9.4 Measurements

The verification report shall describe the nature and frequency of operation and maintenance procedures required during a 21-day period of continuous operation.

The number of person-hours (rounded to nearest whole hour) of each personnel classification shall be reported for any field intervention to maintain the flowmeter in operating order, in accordance with the operation manual or the procedures recommended by the flowmeter manufacturer.

The time, level, velocity, and flow shall be recorded by the test flowmeter and the reference flowmeter during all periods of normal operation, including the periods covered under tests B, C, D, E and F.

Manual level measurements shall be made at least once daily for comparison to values recorded by the reference level meter. For each comparison, at least five manual level measurements shall be made at intervals of 60 seconds.

The level and velocity probes shall be inspected daily for debris accumulation or other problems. The presence of accumulated debris on the probes shall be noted and documented by photograph or videotape.

After dismantling, the flowmeter and the probes shall be inspected for infiltration, broken, cracked or scratched components. The extent and nature of the damage, if any, shall be described. Evidence of water infiltration or broken components shall be noted and documented by photograph or videotape.

Each gate manipulation shall be logged with the corresponding time and the level upstream and downstream from the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and the corresponding time noted.

3.3.10 Test H - Operation and maintenance under extended operations - Optional

3.3.10.1 Objective

To characterize the time and labor resources required for the proper operation and maintenance of a flowmeter as installed in a sewer.

To evaluate the ability of a flowmeter to resist fouling and damage over an extended period of typical use conditions.

To verify the accuracy with which an in-line flowmeter calculates flow over a 6-month period of continuous operation.

3.3.10.2 Test Conditions

The Testing Organization shall be responsible for the proper operation and maintenance of the flowmeter in accordance with the operating instructions. The testing organization shall record the nature and frequency of operation and maintenance procedures required during a 180-day period of continuous operation.

The personnel required for operation and maintenance procedures shall also be classified according to their qualifications, as follows:

- Engineer
- Technician
- General Laborer

The testing organization shall also note whether any specialized tool or equipment was required and whether the need for such tools or equipment was indicated by the operation and maintenance instructions.

The testing organization shall periodically perform a visual inspection of the flowmeter, including probes and transmitters. The flowmeter shall be inspected for broken, cracked or scratched components. Probes shall be examined for debris accumulation.

3.3.10.3 Measurements

The verification report shall describe the nature and frequency of operation and maintenance procedures required during a 180-day period of continuous operation.

If any failure occurs, the Mean-Time-To-Failure (MTTF) and Mean-Time-To-Repair (MTTR) shall be determined. The total time that the flowmeter was in service (measuring flow) shall be computed as a percentage of the 180-day test period.

The number of person-hours (rounded to nearest whole hour) of each personnel classification shall be reported for any field intervention required to maintain operation of the flowmeter in accordance with the operation manual or the procedures recommended by the flowmeter manufacturer.

The time, level, velocity, and flow shall be recorded by the test flowmeter and the reference flowmeter.

Manual level measurements shall be made at least once monthly for comparison to values recorded by the reference level meter. For each comparison, at least five manual level measurements shall be made at intervals of 60 seconds.

The level and velocity probes shall be inspected at least once monthly for debris accumulation or other problems. The presence of accumulated debris on the probes shall be noted and documented by photograph or videotape.

After dismantling, the flowmeter and the probes shall be inspected for infiltration, broken, cracked or scratched components. The extent and nature of damage, if any, shall be described.

Evidence of water infiltration or broken components shall be noted and documented by photograph or videotape.

Each gate manipulation shall be logged with the corresponding time and the level upstream and downstream from the gate.

All tracer dilution measurements (time, sample number, etc.) shall be logged.

Unplanned events that may affect flow conditions or the measurement thereof (e.g., gate malfunction, sampling malfunction, unplanned flow conditions) during the test shall be described in a log book and the corresponding time noted.

3.4 Reference methods

Area-velocity flowmeters have two measurable components, each of which shall be evaluated independently. Reference measurements for both depth and velocity are required to evaluate the accuracy of depth and velocity readings from each of the tested flowmeter sensors. A calculated flow rate from the reference measurements shall also be used to verify the accuracy of the metered flow.

3.4.1 Reference level measurement

A reference instrument that continuously records depth measurement shall be used to ensure test and reference data sets are comparable in size. Manual level readings shall be collected as frequently as possible to ensure proper calibration of the reference level meter.

The level readings from the reference instrument shall be verified by comparing its readings with manual level readings.

If no level meter meets the specified accuracy, manual readings shall be collected.

3.4.1.1 Manual level measurement

Manual level measurements shall be made at the center and at the bottom of the pipe. A ruler, tape or similar device used for manual measurements shall be capable of measuring the water level to the nearest mm. . Manual level measurements shall be made at intervals of no more than 15 minutes over the duration of each run for Test B, C, D, E and F. Each level determination shall consist at least three separate measurements at intervals of no more than 60 seconds.

Manual level measurement shall be made on a daily basis during the extended duration tests G and H. For this determination the level shall be measured manually at least five times at interval of no more than 60 seconds.

3.4.1.2 Reference level meter

Redundant level measurement shall be provided to assure that level measurements are accurate even under full-pipe conditions. The principle upon which level measurement is made shall be different for the two reference level meters.

The more accurate of the reference level meters shall be used as the primary reference level meter and the secondary reference level meter shall be used to confirm measurements made by the primary reference level meter.

The technology used in both reference level meters should have an inherent precision equal to or greater than the level instrument being tested.

Before a reference level meter is used as reference, it shall be tested against the manual level measurements. The results of this test shall demonstrate the accuracy of the reference level meter over the range of depths and velocities of the tests.

Before the start of testing a reference level meter shall:

- Be subject to performance tests required in Section 3.3 of this Protocol;
- Have its results analyzed in accordance with Section 3.6 of this Protocol;
- Have a frequency distribution of deviation from the manual reading close to a normal curve;
- Have an average accuracy of the highest value between ±½ % of full scale or ±0.02 ft (6 mm) at least 95% of the time (Tests B through F);

If during a test, a reference level meter (primary or secondary) does not perform properly, the level meter shall be recalibrated or replaced and the test repeated.

Reference level measurements shall be logged at intervals of no greater than one minute.

3.4.2 Reference velocity measurement

Whenever possible, the accuracy of the tested velocity readings shall be evaluated with a continuously recorded velocity reference. Using a reference velocity computed from reference flow and reference level measurements shall be used only as a back-up when a reference velocity is unobtainable.

The velocity readings from the reference instrument shall be verified by comparing its readings with the computed velocity from tracer dilution flow and reference level measurements, or with manual velocity readings taken in accordance with the requirements for reference velocity measurement in Section 3.4.2.1.

If no velocity meter meets the specified accuracy, computed velocities from tracer dilution flow and reference level measurements shall be used. A reference instrument that continuously records velocity is preferred to manual velocity measurement and to velocities computed from tracer dilution, since the test and reference data sets are comparable in size.

Reference velocity measurements shall be logged at intervals of no greater than one minute.

3.4.2.1 Manual velocity measurement

Manual velocity readings can be collected using a portable velocity meter. Velocity shall be measured in many small section sections over the total flow section to compute the average velocity over the full section. The velocity of each small section shall be weighed by its percentage of the total area. The detailed procedure for a specific pipe shall be described in the Test Plan.

Manual velocity measurements take time, so this procedure is acceptable only when the flow is constant and the pattern steady. Because such conditions are infrequent, manual velocity measurement shall be used only as a checkpoint for continuous velocity measurement during periods when tracer dilution is not available.

3.4.2.2 Reference velocity computed from tracer dilution

The reference velocity measurement is computed by dividing tracer dilution flow by the cross-sectional area as calculated by the level measured by the primary reference level meter.

3.4.2.3 Reference velocity meter

The technology used in the reference velocity meter (flowmeter) should have an inherent precision equal to or greater than the tested flow instrument.

Before a reference velocity meter (e.g. velocity component of reference flowmeter) is used as reference, it shall be tested with tracer dilution flow measurement. Results of this test shall demonstrate the accuracy of the instrument and that it exhibits no bias for the range of depths and velocities of the tests.

Before the start of testing a reference velocity meter shall:

- Be subject to performance tests required in Section 3.3 of this Protocol;
- Have its results analyzed in accordance with Section 3.6 of this Protocol;
- Have a frequency distribution of deviation from the tracer dilution measurements approaching a normal curve.
- Have an average accuracy of ±2½ % at least 95% of the time (tests B through F).

Reference velocity measurements shall be logged at intervals of no greater than one minute.

3.4.3 Reference flow measurement

Two methods of establishing reference flow measurement shall be used:

- Tracer dilution tests; and
- A calibrated reference flowmeter whose accuracy has been verified by tracer dilutions tests.

When a reference flowmeter is available, the flow measurement of the reference flowmeter shall be used at all times, and reference tracer dilution flow shall be used only to monitor the accuracy of the reference flowmeter.

The flow readings from the reference flowmeter shall be verified by comparing its readings with tracer dilution flow and reference level measurements.

If no reference flowmeter with sufficient accuracy is available, flow measurement by tracer dilution shall be used. A reference instrument that continuously records flow measurement is preferred to tracer dilution, since the test and reference data sets are comparable in size.

3.4.3.1 Tracer dilution methods

Due to the variations in suspended solids concentrations in combined sewers and storm sewers, a tracer such as lithium should be used in dilution studies rather than a dye such as rhodamine wt.

At a minimum tracer dilution tests shall be conducted during two of the three trials in Test C. The first tracer dilution shall be done at the beginning of the first week of test G and the other one at the end of the last week of test G.

The following guidelines should be followed in establishing the tracer dilution method:

- A sample of the measured water without tracer (blank) shall be taken for every six diluted tracer samples taken.
- A sample of the injected tracer shall be taken at the beginning and at the end of the dilution, and at least once every two (2) hours of injection.
- The tracer tank shall be well shaken at the beginning of every test and continuously agitated during the test
- Tracer injection concentration shall be computed to get an optimal analyzed value, with as little dilution as possible in the laboratory.
- The laboratory supplying the tracer shall certify the quality of the product, in respect of laboratory standard methods.
- Injection shall begin early enough to get a constant concentration ahead of the tested flowmeter for at least 30 minutes (ideally) and not less than 15 minutes before taking the first sample.
- Samples of tracer dilution shall be stored in darkness as soon as collected and analyzed within 2 working days after sampling. Every sample shall be stored for at least one month after submission of the final version of the report.
- Samples shall be analyzed in the laboratory, with temperature compensation (if required). Lithium samples shall be analyzed in accordance with Method 3500-Li of Standard Methods for the Examination of Water and Wastewater (American Public Health Association, 20^{th} Edition, 1999) or equivalent. .
- Tracer injection flow rates shall be measured every 30 minutes and a volume or mass balance of the injected tracer shall be done for every test. If the volume or the mass balance fails, the test will have to be repeated, except if a reference flowmeter is used, in which case the measurements of the test may be usable.

- Diluted samples shall be collected at the following frequencies:

  5 minutes minimum
  2 minutes when a real rain event is used, during steps of high flow

3.4.3.2 Reference flowmeter

The technology used in the reference flowmeter should have an inherent precision equal to or greater than the tested flow instrument.

Before a reference flowmeter is used as reference, it shall be tested with tracer dilution flow measurement. Results of this test shall demonstrate its accuracy and show no bias for the range of depths and velocities of the tests.

Before the start of testing a reference flowmeter shall:

- Be subject to performance tests required in Section 3.3 of this Protocol;
- Have its results analyzed in accordance with Section 3.6 of this Protocol;
- Have a frequency distribution of deviation from the tracer dilution measurements approaching a normal curve;
- Have an average accuracy of ±7¾ % at least 95% of the time under dry weather flow conditions (during periods of flow equal or below 1½ times the maximum dry weather flow in Test B or E)
- Have an average accuracy of ±9¼ % at least 95% of the time under wet weather flow conditions (during periods of flow over 1½ times the maximum dry weather flow in Test C and D or E).

Reference flow measurements shall be logged at intervals of no greater than one-minute.

If it is found during a test that the reference flowmeter is not operating properly, testing shall be discontinued until the reference flowmeter is recalibrated. Otherwise, tracer dilution shall be used.

3.5 Quality Assurance /Quality Control

The quality assurance project plan (QAPP) is developed to ensure data quality and integrity. Careful adherence to these procedures will ensure that data generated from the verification will be useful for general and performance verification.

3.5.1 Quality assurance responsibilities

The Testing Organization shall be responsible for ensuring that the Test Plan and the QAPP are properly implemented and that the quality assurance and quality control (QA/QC) tasks are periodically realized. Written or electronic records shall be maintained for calibrations, sample collection and data manipulation. During flowmeter verification, the Testing Organization shall ensure:

- Monitored data from the reference meters corresponds to display reading by comparing 5 results (at the beginning of the verification only)
- Sampling equipment for tracer studies is positioned to collect representative (at the beginning of the verification only)
- Measurement instruments have been recently calibrated in accordance with manufacturer's instructions (when applicable and at the beginning of the verification only)
- Accuracy of the reference meters by comparing their measures with manual and/or tracer dilution measures.

In flowmeter testing, sources of error may include drift of the level or velocity probes; miscalibration of reference meters calibration, systematic bias of measurements, intrinsically inaccurate probes. Quality of reference measurements is ensured by frequent manual calibration of the level meter and tracer dilution to calibrate the reference velocity and flowmeters. Manual level measurements and tracer velocity or flow results will be added to the reference flowmeter graphs daily to ensure timely follow-up during the verification.

3.5.2 Tracer dilution

In tracer dilution testing, sources of error may include factors such as variation of total suspended solids, injection flow variation, variation of tracer concentration in wastewater, insufficient mixing, error in measurement of tracer concentration, error in dilution of samples, and manipulation and analysis error. To ensure the quality of tracer dilution measurement, the Test Plan shall describe the QC procedures such as collecting blank samples, stirring tracer solution continuously during the tests, waiting for constant concentration at the sampling site, minimizing laboratory dilution by optimizing the tracer concentration, storing samples in the darkness and analyzing samples in laboratory within 48 hours.

Tracer dilution analysis shall be verified by an independent laboratory. At the end of the test where tracer dilution will have been done, the following procedure shall be followed to control the laboratory results:

- If samples are analyzed by the Testing Organization, 10% of samples shall be selected randomly, split and the new series of samples sent to an independent laboratory.
- If samples are analyzed by an independent laboratory, an additional 10% of samples shall be selected randomly, split and the series of samples sent to another independent laboratory

Comparison of analysis results from the tracer dilution team and the laboratory shall be presented in a table.

If problems arise or any data appears unusual, they shall be thoroughly documented and corrective actions shall be implemented as specified in this section.

3.6 Data Management and Analysis

Performance data related to the accuracy of a flowmeter shall be reported in such a way that they can easily be interpreted by the reader. This section describes how performance data is to be analyzed and presented graphically.

At a minimum, the data shall be represented graphically using the following three methods:

- Non-time series analysis: Scatter graphs of the velocity or flow against the depth present a visual analysis of the precision of the depth and velocity measurements and of the flow calculation in the case of a site where the flow pattern is always the same at a given depth. Only Test C presents the hydraulic conditions required to plot a scattergraph showing the expected curve.
- Time series analysis: Graphs of level, velocity or flow against time present a visual analysis of the accuracy of the flowmeter when the curve of the reference level, velocity or flow measurements is added to the graph.
- Frequency analysis: Bar graphs of the frequency distribution of standard deviation for the level, velocity and flow present a visual analysis of the distribution of errors.

3.6.1 Non-time series analysis graphs

To characterize the bias and precision of the test flowmeter, a single scattergraph shall be generated from the three trials of Test C. The graph shall plot velocity versus depth, for all data of the three repetitions of Test C with the tested flowmeter. In the absence of a downstream control, the flow-depth relationship should be well defined and the curve should collapse to a single line. If the flowmeter measures accurately and without bias, all data points should fall on the reference system curve shown on the graph. The reference system curve shall be established once at the beginning of all tests, by plotting the same graph with the reference flowmeter values. An example of this chart can be found in Appendix B. Data collected at one-minute time intervals, without averaging, shall be plotted. The following elements shall be shown on this graph:

- Velocity versus depth curve for the test flowmeter;
- Reference system curve established with the reference flowmeter

3.6.2 Time series analysis graphs

Two types of time series analysis graphs shall be generated:

- One series to present the results of the test flowmeter;
- One series to present the results of the continuous reference measurements (reference level meters, reference velocimeters and reference flowmeter) compare to of the non-continuous reference measurements (manual level readings and tracer dilution).

The following sections present the graphs to produce for each group.

3.6.2.1 Test flowmeter results

Separate plots of level, velocity, and flow versus time shall be generated for each trial of tests B, C, D, E, F, that are conducted. A plot of flow versus time shall be generated for tests G and H (extended operation). Each plot shall be generated as a Shewhart chart. Shewhart charts are commonly used in industry to evaluate process quality control and use rules of analysis that can be found in any good handbook on statistical process control. In this application, the charts demonstrate if a flowmeter is accurate in its measurement of velocity and level and its calculation of sewer flow by comparison to the reference data. An example of this chart can be found in Appendix C.

Values of the reference standard deviation of the flow (σ_f), velocity (σ_v) and level (σ_l) measurement are required to present Shewhart charts. In this application, the three values of standard deviation shall be the same for all flowmeters tested. Values of the reference standard deviations (σ_f, σ_v and σ_l) shall be determined by the following methods:

- Standard deviation for the level (σ_l): Calculate the standard deviation of the reference level meter from manual level measurements, using data collected during the tests B, C, D and G or E, F and G.

- Standard deviation for the velocity (σ_v): Calculate the standard deviation of the reference velocity meter from reference velocity calculate with tracer dilution flow and manual level measurements, using data collected during the tests B, C, D and G or E, F and G.

- Standard deviation for the flow (σ_f): Calculate the standard deviation of the reference flowmeter from reference tracer dilution flow measurements, using data collected during the tests B, C, D and G or E, F and G.

The lower acting limit curves shall be computed from the curve of the corresponding reference meter averaged over a 5-minute period (averaged over 5 values collected every one-minute) by subtracting 2σ (computed above) to average data series. The same way, the higher acting limits curves shall be computed from the curve of the corresponding reference meter averaged over a 5-minute period (averaged over 5 values collected every one-minute) by adding 2σ (computed above) to average data.

3.6.2.1.1 Level data

For each trial performed under Tests B, C, D, E and F, a chart shall plot the level measurements made by the test flowmeter at one-minute increments (without averaging) versus time. Acting limit curves shall be added to the graph as numerical markers to show how far the level meter curve diverges from the reference curve. Acting limits curves shall be generated from data of the two reference level meters averaged over 5-minute periods. The plot shall show the following for the full duration of the trial:

- Level curve of the test flowmeter;

- Level values measured manually;

- Lower acting limit: Curve of the average of both reference level meters -2 σ_l (dashed line)

- Higher acting limit: Curve of the average of both reference level meters +2 σ_l (dashed line)

Similar charts shall be generated using data from Tests G and H, except that level measurements collected at 5-minute increments from the test flowmeters (rather than 1-minute increments) shall be plotted. Given the extended time of tests G and H, the time span covered on any single chart will likely not encompass the entire test duration. Multiple charts may be required for a single test.

3.6.2.1.2 Velocity data

For each trial performed under Tests B, C, D, E and F, a chart shall plot the velocity measurements made by the test flowmeter at one-minute increments (without averaging) versus time. Acting limit curves shall be added to the graph as numerical markers to show how far the velocity meter curve diverges from the reference curve. Acting limits curves shall be generated from data of the velocity curve of the reference flowmeter averaged over 5-minute periods. The plot shall show the following for the full duration of the trial:

- Velocity curve of the test flowmeter

- Lower acting limit: Curve of the reference velocity meter -2 σ_v (dashed line)

- Higher acting limit: Curve of the reference velocity meter +2 σ_v (dashed line)

Similar charts shall be generated using data from Tests G and H, except that velocity measurements collected at 5-minute increments from the test flowmeters (rather than 1-minute increments) shall be plotted. Given the extended time of tests G and H, the time span covered on any single chart will likely not encompass the entire test duration. Multiple charts may be required for a single test.

3.6.2.1.3 Flow data

A graph shall plot the flows recorded by the test flowmeter at one-minute increments (without averaging) versus time. Acting limit curves shall be added to the graph as numerical markers to show how far the flowmeter curve diverges from the reference curve. Acting limits curves shall be generated from data of the flow curve of the reference flowmeter averaged over 5-minute periods. The chart shall show the following for the full duration of the trial:

- Flow curve of the flowmeter under verification

- Lower acting limit: Curve of the reference flowmeter -2 σ_f (dashed line)

- Higher acting limit: Curve of the reference flowmeter +2 σ_f (dashed line)

3.6.2.2 Reference data

To show accuracy of the reference flowmeter and reference level meter as compared to the tracer dilution and manual level measurements, Shewhart charts shall be generated from the reference level, velocity, and flow measurements from Test G. Acting limits curves shall be added to the graph as numerical markers to show velocity and flow values from the tracer dilutions and level values from manual measurements. Data collected at one-minute time increments, without averaging, shall be plotted. The acting limits curves, which are computed from the flow curve of the reference meter averaged over a 5-minute period.

The reference level chart shall show the following:

- Level curve of both reference level meters

- Manually measured level values

- Lower acting limit: average curve of both reference level meters -2 σ_l (dashed line)

- Higher acting limit: average curve of both reference level meters +2σ_l (dashed line)

The reference velocity chart shall show the following:

- Velocity curve of the reference flowmeter

- Velocity values calculated from the tracer dilution flow and the average of both reference level meters

- Lower acting limit: Curve of the reference velocity meter -2 σ_v (dashed line)

- Higher acting limit: Curve of the reference velocity meter +2 σ_v (dashed line)

The reference flow chart shall show the following:

- Flow curve of the reference flowmeter

- Tracer dilution flow values

- Lower acting limit: Curve of the reference flowmeter -2 σ_f (dashed line)

- Higher acting limit: Curve of the reference flowmeter +2 (σ_f dashed line)

3.6.3 Frequency Analysis Graphs

For each of Tests B, C, D, E, F, G, and H, the one bar chart shall be generated showing the frequency distribution for the deviations between the flow recorded by test flowmeter and the flow recorded by reference flowmeter. Data from the three trials of each test shall be combined for the plot of each test.

APPENDIX A

FLOWMETER SOFTWARE CHECKLIST

Test description	Manufacturer's section	Tester's section	
	Feature's characteristics	Feature's characteristics	Comments and observations
Number of possible sites	Number :	Number :	
Length of identification tag of each site	Length :	Length :	
Length of the description field	Length :	Length :	
Allows user to select from non-round pipe shapes	❑yes ❑no	❑yes ❑no	
Allows user to enter a relation: area = function of depth	❑yes ❑no	❑yes ❑no	
Allows user to enter and modify Manning coefficient	❑yes ❑no	❑yes ❑no	
Allows user to compute flow using Manning formula	❑yes ❑no	❑yes ❑no	
Allows user to compute flow using open-channel flow equations other than Manning	❑yes ❑no	❑yes ❑no	
Allows user to compute flow using flumes and other primary devices	❑yes ❑no	❑yes ❑no	
Allows user to configure the meter to take account of the silt level in calculating the cross sectional area	❑yes ❑no	❑yes ❑no	
Allows user to enter different engineering units	❑yes ❑no	❑yes ❑no	
Allows user to select different logging frequency	❑yes ❑no	❑yes ❑no	
Allows user to configure meter for varying logging frequencies (asynchronous data)	❑yes ❑no	❑yes ❑no	

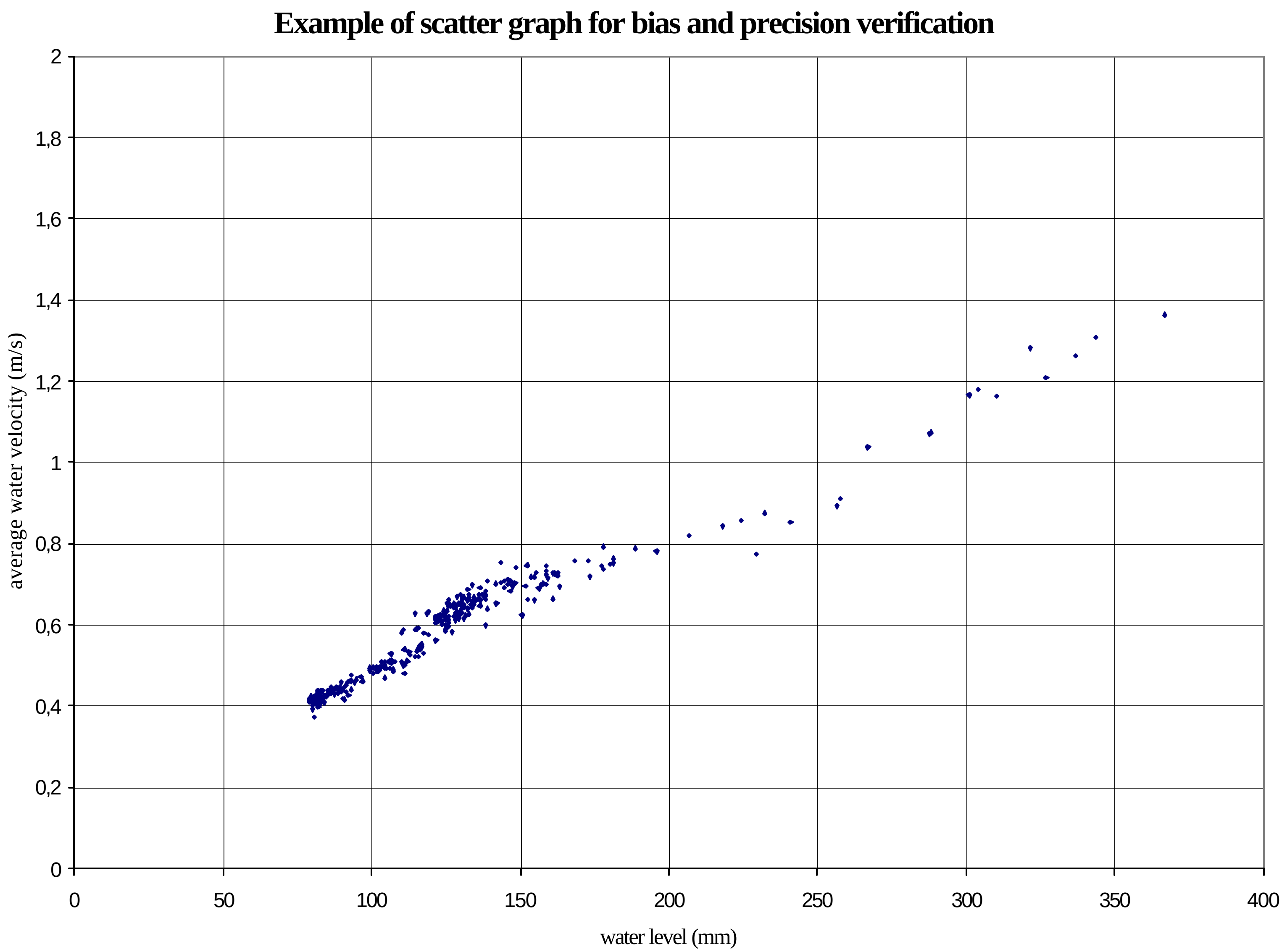
Test description	Manufacturer's section	Tester's section	
	Feature's characteristics	Feature's characteristics	Comments and observations
Allows user to configure parameters such as:			
• Damping period (0 to 60 seconds)	❑yes ❑no	❑yes ❑no	
• Offset (positive and negative)	❑yes ❑no	❑yes ❑no	
• Weight (if applicable)	❑yes ❑no	❑yes ❑no	
Allows user to select different data logging method	❑yes ❑no	❑yes ❑no	
FIFO (first in, first out) or not overlapping session	❑yes ❑no	❑yes ❑no	
Data compression or time tag measurement	❑yes ❑no	❑yes ❑no	
Allows user to retrieve the configuration in the flowmeter without altering the original configuration file	❑yes ❑no	❑yes ❑no	
Allows user to export data	❑yes ❑no	❑yes ❑no	
Allows user to export as much data as that the flowmeter can log	❑yes ❑no	❑yes ❑no	
Allows user to configure the form of the export file	❑yes ❑no	❑yes ❑no	
Select from multiple formats for date, hour and data	❑yes ❑no	❑yes ❑no	
Select from multiple separators	❑yes ❑no	❑yes ❑no	

Test description	Manufacturer's section	Tester's section	
	Feature's characteristics	Feature's characteristics	Comments and observations
Select from multiple parameters to include in the export file:			
• Date	❑yes ❑no	❑yes ❑no	
• Hour	❑yes ❑no	❑yes ❑no	
• Level	❑yes ❑no	❑yes ❑no	
• Average velocity	❑yes ❑no	❑yes ❑no	
• Measured velocity	❑yes ❑no	❑yes ❑no	
Flow compute with level and velocity	❑yes ❑no	❑yes ❑no	
Flow compute using Manning formula	❑yes ❑no	❑yes ❑no	
Select the column number of each parameter to include in the export file	❑yes ❑no	❑yes ❑no	
Select from multiple formats :			
• Excel	❑yes ❑no	❑yes ❑no	
• Lotus	❑yes ❑no	❑yes ❑no	
• ASCII	❑yes ❑no	❑yes ❑no	
• Text	❑yes ❑no	❑yes ❑no	
Allows user to generate and format printed tabular and graphic reports	❑yes ❑no	❑yes ❑no	
Allows user to schedule a prescribed set of reports and graphs	❑yes ❑no	❑yes ❑no	
Allows user to enter external reference flow measurement to validate data on a graph	❑yes ❑no	❑yes ❑no	
Allows user to plot scattergraph with pipe curve for the installed site	❑yes ❑no	❑yes ❑no	
Allows user to plot scattergraph with manual reference measurements shown	❑yes ❑no	❑yes ❑no	

Test description	Manufacturer's section	Tester's section	
	Feature's characteristics	Feature's characteristics	Comments and observations
Allows user to display overlapping hydrographs from a single site (e.g. 1 month displayed weekly)	❑yes ❑no	❑yes ❑no	
Allows user to edit data based on the pipe curve for the site	❑yes ❑no	❑yes ❑no	
Allows user to validate data	❑yes ❑no	❑yes ❑no	
Allows user to view the following information:	❑yes ❑no	❑yes ❑no	
Number of days logged for the current logging period	❑yes ❑no	❑yes ❑no	
Number of lasting days in the memory for the current logging period	❑yes ❑no	❑yes ❑no	
Current battery voltage and expected lifetime	❑yes ❑no	❑yes ❑no	
Number of records logged for the current logging period	❑yes ❑no	❑yes ❑no	
Quality status of sensor data	❑yes ❑no	❑yes ❑no	
Real time reading of level, velocity, flow and temperature	❑yes ❑no	❑yes ❑no	
Allows user to configure the tipping bucket rain gauge in multiple units (0.1 mm, 0.2 mm, 0.01 in., etc.)	❑yes ❑no	❑yes ❑no	
Allows user to print hyetograph of rain data:			
• As an individual graph	❑yes ❑no	❑yes ❑no	
• Combine with its corresponding hydrograph	❑yes ❑no	❑yes ❑no	
Compatibility with Win95, Win 98 and Win NT for serial communication	❑yes ❑no	❑yes ❑no	

APPENDIX B

Example of a velocity function of depth scattergraph



APPENDIX C

Example of a time series graph for extended operations verification tests

APPENDIX D

ESTIMATION OF THE TIME REQUIRED TO INSTALL, OPERATE AND SERVICE THE FLOWMETERS			
Activities	**Work class work (general labor, technician, engineer, etc.)**	**Person-hour**	**Frequency (if applicable)**
Physical installation			
Configuration of the transmitter			
Calibration of the velocity measurement			
Calibration of the level measurement (Zeroing of the level probe)			
Start-up and trouble shouting			
Replacement a level probe			
Replacement of desiccant			
Replacement of on-board memory battery			
Replacement of the input board in the transmitter			
Replacement of the output board in the transmitter			
Replacement of the main board in the transmitter			
Other operating and maintenance procedures recommended by the flowmeter manufacturer			