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Guidance Document for Flow Measurement of Metal Mining Effluents

Final Report

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Abstract

This document discusses flow monitoring considerations, equipment and procedures for use with metal mining effluents. The document stresses performance-based methods and how such methods should be applied to the mining industry. Topics addressed include the selection, design and installation of flow measurement systems, the development of operation and maintenance procedures, and the development of reporting protocols. Guidelines are also presented for system accuracy and calibration and the selection of monitoring equipment.

The information presented is to support implementation of the proposed *Metal Mining Effluent Regulations* (MMER) promulgated under the *Fisheries Act* by Environment Canada.

More information on the proposed *Metal Mining Effluent Regulations* and associated guidance documents is available on Environment Canada's Green Lane at www.ec.gc.ca/nopp/metals/english/index.cfm .

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SUMMARY

This document provides performance-based guidance for measuring effluent flows from metal mining operations. The performance-based approach permits flexibility in the selection of flow monitoring methods and equipment so long as system accuracy requirements are achieved and can be demonstrated by the reporting of appropriate calibration and verification data. The information provided in this document can assist mine operators in the selection of flow measurement methods, the design and implementation of flow measurement systems, the development of operation and maintenance procedures, and the development of reporting protocols. Guidelines are presented for the selection of monitoring locations and equipment, the determination of system accuracy, system calibration, and the development of Standard Operating Procedures.

The document identifies the recommended elements of a system certification report, presents guidelines for the frequency of system calibration, and identifies the activities that should be undertaken in accordance with documented Standard Operating Procedures. Considerations to be taken into account in locating, selecting, installing and calibrating flow monitoring systems are presented for both open channel and closed conduit systems. Three methods are recommended for the calibration and verification of flow measurement system accuracy: the dilution (tracer) method, the volumetric method and hydraulic model testing.

Guidelines are presented for the development of maintenance and inspection programs, the preparation of Standard Operating Procedures, the logging of information, and the reporting of monitoring data. A discussion of common flow measurement methods for open channels and closed conduits is presented in the appendices.

1.0 Introduction

This document has been prepared to provide performance-based guidance for measuring effluent flows from metal mining operations in support of the proposed *Metal Mining Effluent Regulations* (MMER) that are to be promulgated under the *Fisheries Act* by Environment Canada.

The performance-based approach allows organizations to adapt flow measurement systems appropriate to their situation so long as system accuracy requirements are achieved and can be demonstrated by the reporting of appropriate calibration data. The methods and procedures chosen should, however, be documented as Standard Operating Procedures and used consistently. They should also be available for review upon request by an inspector under the *Fisheries Act* or other federal or provincial legislation.

Performance-based methods identify the measurement standards and data quality objectives that are to be achieved. Defined criteria for system accuracy, design, reliability, calibration, documentation and reporting should be attained in the planning, installation, operation and maintenance of flow measurement systems. The methods and procedures to achieve the standards and quality objectives are, for the purpose of this Guidance Document, considered to be the responsibility of the mine site operators.

The goal of a performance-based method is to provide reasonable flexibility in the choice of flow measurement methods and procedures. This allows for implementation of technical advances in flow measurement techniques, allows for adaptation of techniques to deal with specific mine site conditions, and facilitates continuous improvement and upgrading of Standard Operating Procedures.

This document is intended for use by mine environmental and operational staff and managers, site operators, Environment Canada Inspection and Enforcement personnel, and members of provincial environmental agencies and territorial water boards.

2.0 Mine Site Effluent Stream Characteristics

2.1 Mine Site Effluent Streams

Effluent streams from mine sites can be discharged to the environment from a variety of sources. Typical effluent streams are summarized in this section and illustrated conceptually in Figure 1.

Process effluent can be described as effluent that comes into contact with process materials or results from the production or use of any raw material, intermediate product, finished product, by-product, waste product or wastewater. It can also include blowdown water, effluent that results from plant cleaning or maintenance operations, and any effluent that comes into contact with cooling water or storm water.

Process effluent can be discharged from a mine site to the environment as one or a combination of the following:

- decanted effluent from an engineered impoundment area, referred to as a "tailings pond" or "tailings management area";
- decanted effluent from a polishing pond or clarification pond typically situated downstream of a tailings pond; and
- treated effluent from an effluent treatment plant.

Mine water comprises effluent from the de-watering of underground or open pit mining operations. Mine water is typically retained and discharged from settling ponds or combined with process effluent. Mine water can also be discharged to the environment from underground and open pit mining operations.

Cooling water is used in various mine processes for the purpose of removing heat from equipment, process operations and materials. Typically, spent cooling water is combined with other effluent streams prior to discharge to the environment, such as a tailings slurry discharge to a tailings pond (i.e., process effluent) or mine water stream.

Seepage comprises water discharged to the environment by seepage from waste management areas (e.g., tailings ponds, waste rock dumps) or wastewater impoundment areas (e.g., tailings ponds, clarification ponds, mine water ponds). Seepage may be intercepted by perimeter collector ditches or drain directly to the environment.

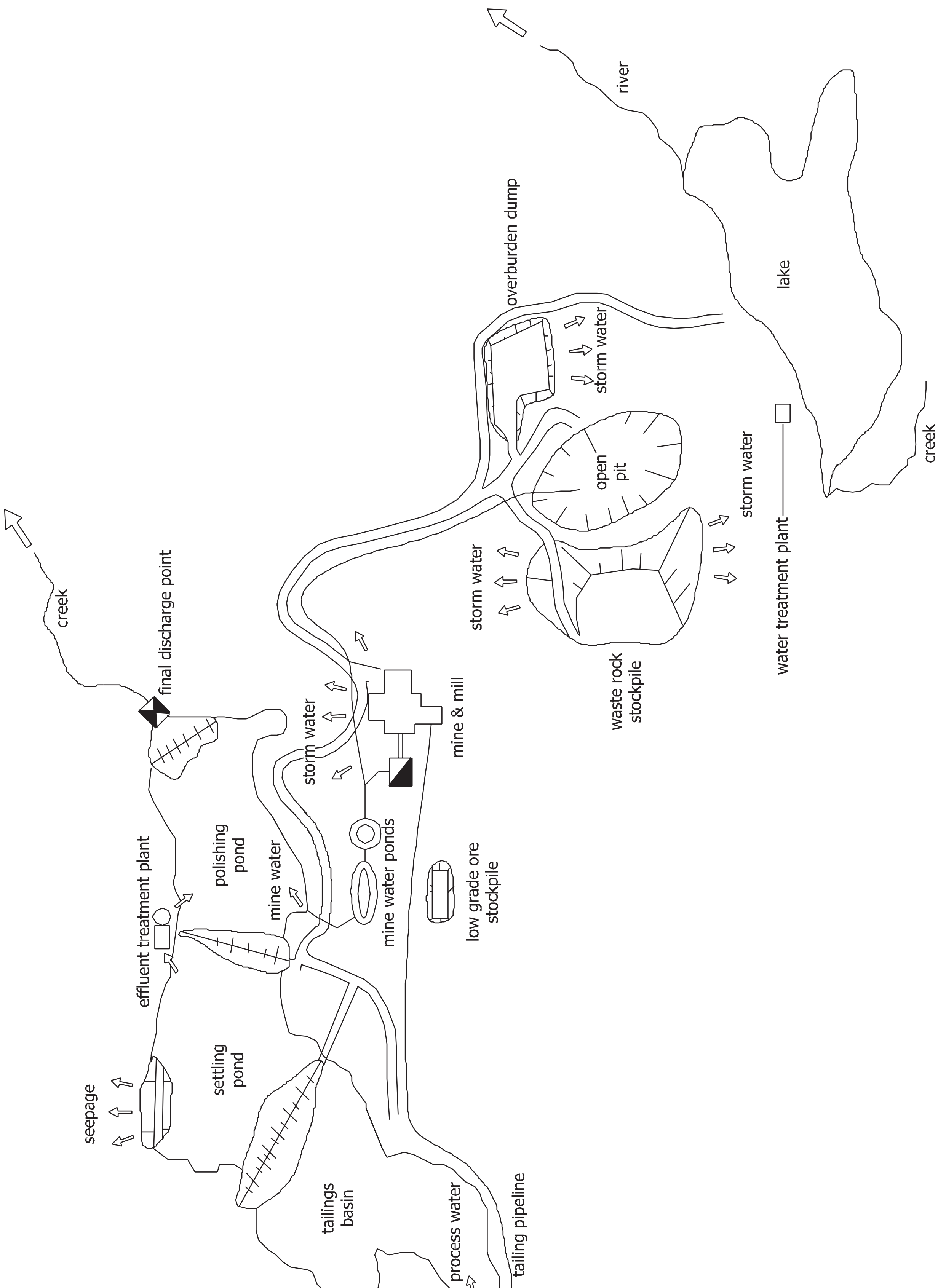
Storm water from a mining operation comprises surface runoff from rainfall, snowmelt and natural drainage. Storm water discharges associated with mining operations can include but are not limited to drainage from mine and mill sites, drainage collection ponds, material handling areas, raw material storage sites and waste disposal areas, including waste rock and overburden dumps. Typically, drainage is diffuse with a large number of discharge points to the environment.

Other effluent streams on a mine site can include but are not limited to sanitary discharges from sewage lagoons, emergency overflows from wastewater impoundment ponds, and backwash waters from potable water treatment plants.

2.2 Final Discharge Point(s)

For the purposes of this document, a "final discharge point" means a discharge point identified by the owner or operator of a mine in accordance with the requirements of the proposed MMER. As stated in the proposed MMER, the owner or operator of a mine must monitor the flow from each final discharge point.

Figure 1 Typical Mine Site and Effluent Streams



3.0 Flow Measurement

For the purposes of this document, flow is considered as the volume of effluent discharged over each 24-hour period during which samples are collected from each final discharge point. Flow measurement is the process of quantifying or systematically assessing the flow or volume of the effluent. Effluent volumes can be determined either by integration of continuous flow rate measurement or indirect batch volume measurement.

3.1 Units of Flow Measurement

Flow measurements for each 24-hour period should be reported in units of cubic metres (m^3) for each effluent stream measured at a final discharge point.

3.2 Flow Measurement and Reporting

The flow measurement system should be capable of accurately reporting the volume of effluent from each final discharge point for each 24-hour period. Therefore, the frequency of flow measurement should be established to accurately record flow variations over that period.

3.3 Flow Measurement Accuracy

For the purposes of this document, it is assumed that all flow measurement systems, methods, devices or calculations will, as per the requirements of the proposed MMER, enable the determination and reporting of effluent flow volumes to an accuracy of within plus or minus 15% of actual flow.

3.4 Frequency of Flow Measurement System Calibration and Verification

The accuracy of all flow measurement systems, methods or devices should be certified by a licensed professional engineer to be within the accuracy requirements identified in this Guidance Document. The certification should be in the form of a report providing the following information:

- general information associated with the on-site calibration procedures including date, time, company, personnel, weather conditions, and equipment used on-site;
- a description of the primary and secondary measuring device, physical site conditions, flow characteristics, and any other pertinent site features;
- a description of the calibration methodology with reference to relevant International Organization for Standardization (ISO) or American Society for Testing and Materials (ASTM) standards;
- reporting of results including an error analysis;
- a statement of certification that the flow measurement system either meets or surpasses the accuracy requirements; and
- the signature and seal of a licensed professional engineer.

Flow measurement accuracy should be verified at regular intervals. Guidelines for frequency of flow measurement system calibration are as follows:

- within 15 days of commissioning of a new flow measurement system;
- at regular intervals not exceeding one year unless otherwise recommended by a licensed professional engineer as part of flow measurement system calibration; and
- within 15 days after the use of an existing flow measurement system with significant alterations, such as a change in method or primary device size.

A quality management and preventive maintenance program should be implemented as part of Standard Operating Procedures in order to ensure continual performance reliability and accuracy of all flow measurement systems. The program should include but not be limited to the following:

- routine cleaning and inspection procedures;
- routine checks on secondary measuring device calibration (i.e., zero setting);
- routine checks of recorded data to detect or diagnose any errors or problems;
- set-up of a filing system for record keeping and reporting; and
- record keeping procedures for inspection and maintenance activities.

Standard Operating Procedures are discussed in Section 6.0.

4.0 Site Selection and Installation Criteria

4.1 General

Effluents from mine site locations can reach the final discharge points through a variety of means such as natural watercourses or ditches, pipes or culverts, and pumping and pipeline systems.

In selecting an appropriate method for flow measurement, consideration should be given to channel or conduit physical characteristics to ensure that proper hydraulic conditions are present to allow accurate flow measurement. In some instances, it may be necessary to modify site conditions upstream, downstream or at the point of flow measurement.

Engineered hydraulic structures and devices for flow measurement have been developed for installation in both open channels and closed conduits. These are collectively referred to as ”primary devices.” Examples of primary devices include weirs and flumes for open channels, and orifice plates and venturi tubes for closed conduits. Flow through the primary device produces a measurable signal such as change in water level (head) or differential pressure according to hydraulic principles. A “secondary device” measures this signal by an appropriate sensing element and transmits the information to associated instrumentation for conversion to flow data. Examples of secondary devices include ultrasonic transducers or level sensors, submerger pressure transducers, and differential pressure transmitters. Most secondary measuring devices can be calibrated for specific ranges of flow through built-in microprocessors. They can also give a visual indication of flow in selectable units and can transmit an electronic signal proportional to flow that can be stored (data logged), physically recorded (i.e., chart recorder) or transmitted to a central location for processing.

A complete flow measurement system includes both a primary and secondary measuring device.

4.2 Site Selection

In planning the flow measurement system, a site selection process should be undertaken to determine the most effective and accessible location for the final discharge point. The following items should be considered during this process:

- nature of the effluent discharge (i.e., year round or seasonal);
- requirements for upstream water level control (e.g., minimum and maximum operating water levels);
- vehicle and personnel access to the site during inclement weather;
- personnel access to equipment for operation and maintenance (e.g., minimization of confined spaces requiring specialized entry and safety procedures);
- power supply to the site (remote locations may require solar-powered systems);
- protection of the equipment and instrumentation from weather, wildlife and vandalism;
- existing soil conditions and their effects on stability and cost of the installation (e.g., proximity to bedrock, frost line, presence of permafrost); and
- proximity to the receiving water body and conveyance of effluent from the flow measurement system to receiving water.

4.3 Equipment Selection and Installation

Once a site has been selected, flow monitoring techniques and equipment should be researched to determine the best system to accurately measure flows at the selected location. The selection of measurement equipment should take into consideration the following:

- the range of flows to be measured;
- accuracy requirements over the range of flows to be measured;
- potential changes in flow with future expansion or changes to the site;
- environmental conditions that may affect the operation of the equipment;
- power requirements;
- approach and discharge channels required for the equipment;
- water quality of the effluent stream (suspended solids and various chemical parameters could have negative effects on the operation of the equipment);

- access to equipment for operation, maintenance and inspection; and
- space available for the installation.

A description of typical primary and secondary devices available for flow measurement in open channels and closed conduits is provided in Appendices 1 and 2.

The detailed design of flow measurement systems should be undertaken by qualified personnel with experience in the design, calibration, inspection and maintenance of flow measurement equipment.

Any equipment shelter considered for protecting or enclosing the system or parts thereof should have adequate space for any necessary or appropriate health and safety equipment in addition to any water quality instrumentation and sampling devices.

Construction and installation considerations include the following:

- the channel or stream to be monitored may need to be temporarily diverted to permit the installation or construction of an engineered hydraulic flow measurement structure;
- on-line flow measurement structures will typically require permits for construction and waterway alteration (off-line systems are preferred); and
- contracting of qualified personnel who are experienced with the system components in order to perform proper installation and commissioning (equipment suppliers often can supply technical staff to assist with equipment installation and commissioning).

The site selection, system design and calibration should be thoroughly documented in report form and be updated as necessary to reflect "as built" conditions. This document should be kept available for review by mine staff, Environment Canada inspectors, and provincial compliance officers.

4.4 Flow Measurement in Remote Locations

Measuring flow in remote locations is often problematic due to site access and power restrictions. Design considerations for remote flow measurement systems include the following:

- provision of a reliable power supply;
- provision of a reliable data logging system to record or transmit flow measurement data;
- ability of primary and secondary devices to operate under cold temperatures if insufficient power is available to operate a heating system;
- minimization of maintenance procedures; and
- provision of an alarm or warning system to identify system problems or shutdowns.

With respect to power supply options at remote locations, if conventional power is not available, solar-powered systems are commercially available that can operate standard instrumentation. Routine inspections of remote flow measurement systems would also include monitoring of the power supply.

Where site access is limited, it is important to design a flow measurement system with data logging capabilities and, if the situation permits, to provide the capability to communicate with the mine site for the purposes of data transmission and monitoring of system status. Communication can be via telephone line or communication cable. Alternative technologies for communication include cellular or satellite telephone systems. If data cannot be transmitted to the mine site, the data logger at the flow measurement site will have to be downloaded on a routine basis.

4.5 Lake/Marine Discharges

Direct discharge to a lake or marine environment can incorporate any one of the flow measurement methods discussed in this section and outlined in Appendices 1 and 2. Flow measurement must take place at a point prior to entry to the marine environment.

4.6 Non-Point Source Discharges

Discharges from a mine site that occur diffusely to the environment are generally not practical to measure independently. These flows typically occur as seepages from on-site wastewater or tailings impoundment areas or as storm water runoff. Should the monitoring of such flows be required, the non-point source flows should be collected by one of the following means:

- a ditch interceptor system to collect and convey effluent to a final discharge point for flow measurement; or
- a collection pond to store and pump effluent on an as-required basis to a final discharge point for flow measurement.

5.0 Device Installation, Calibration and Maintenance

General procedures for the installation, calibration and maintenance of flow measurement devices are summarized in this section.

5.1 Preliminary Considerations

Flow measurement devices should be shipped to the user after having undergone factory acceptance testing by qualified personnel. The shipment should include documented certification reports and operation and maintenance manuals. All information provided with the flow measurement equipment should be kept and filed, and form part of the documentation of a quality management and preventive maintenance program.

Custom-built devices (e.g., weir plates) are acceptable subject to successful calibration of the flow measurement system.

5.2 Device Installation and *In Situ* Calibration

During the installation and commissioning phase, all manufacturers' specifications should be adhered to for providing power or other utility sources and for installing, connecting, programming, operating and maintaining the devices. All aspects of the installation, design and operation should be carefully and accurately documented, and completed by qualified personnel.

All flow measurement systems should be calibrated *in situ* as part of the commissioning phase. *In situ* calibrations are necessary to establish and confirm conformance with the specified requirements for flow measurement accuracy. The calibration method used to establish and confirm flow measurement accuracy should have an accuracy within plus or minus 5% of actual flow.

The following methods provide a level of accuracy acceptable for calibration of flow measurement systems:

- dilution (tracer) method – injection of a solution at a known rate and concentration, and measurement of the fully mixed concentration in the effluent stream to determine the flow (injection solutions can include Rhodamine WT or lithium chloride);
- volumetric method – collection of effluent and weighing over a known time period or measurement of volume of effluent displaced over a known time period; and
- hydraulic model testing – construction of a scale model of the flow measurement system and calibration/verification under laboratory conditions.

These methods apply to both open channel and closed pipe flow measurement systems.

The velocity-area method, whereby in-stream velocity and flow depth are measured to determine flow, can be used as a secondary method to check calibration results but should not be used alone for calibration of flow measurement systems. This is due to difficulties in characterizing hydraulics under non-ideal conditions such as irregular channel characteristics, presence of turbulent flow with eddies or transverse currents, and low flow velocities.

In a case where there is pressure flow in conduits, ultrasonic and electromagnetic methods can be used as a secondary method to check calibration results but should not be used alone for calibration of flow measurement systems. This is due to the potential for non-ideal hydraulic conditions such as partially full pipe flow and air entrainment.

A description of calibration methods is provided in Appendix 3.

5.3 Maintenance and Inspection

Flow measurement systems should be clearly identified, and all inspections and maintenance activities should be logged in detail consistent with Standard Operating Procedures (refer to Section 6.0). Inspection and maintenance activities are required to address the following:

- gradual performance deterioration due to such factors as fouling, wear and tear, and signal drift; and

- sudden failure from acts of nature, inundation, component failure and human error.

Inspection of the primary measuring device should include but not be limited to the following:

- check for sedimentation, debris build-up, algae growth and scum build-up;
- check for ice accumulation that would affect flow measurement accuracy;
- check for signs of cracking or separation from the installation superstructure;
- check for signs of differential settling of the installation superstructure;
- check for corrosion of the device and installation equipment; and
- check for failure of any device components.

Inspection of the secondary measuring device should include but not be limited to the following:

- check of the water level (head) measurement to ensure conformance with reported readings;
- check for any growth or material that may be restrictive to the operation of the device;
- check for signs of damage or wear to the installation system and the device;
- check for corrosion of the device and installation equipment; and
- check for failure of any device components.

An inspection checklist for the flow measurement system should be prepared and used as the basis for recording inspections and maintenance activities.

6.0 Operations Documentation and Measurement Data

6.1 Preparation of Standard Operating Procedures

A Standard Operating Procedure should be prepared for the flow measurement system at each final discharge point. A separate Standard Operating Procedure should be provided for each of the following operations:

- obtaining and recording measurement data, converting measurements to flow data, and describing operating conditions during flow reporting periods;
- performing routine inspection and maintenance procedures; and
- performing routine calibrations of the flow measurement system.

Each Standard Operating Procedure should include the following information:

- The background and objectives of the undertaking.
- Diagrams showing the flow measurement system and surroundings including:
  - access directions and restrictions;
  - identification of all features and devices;
  - location of any reference benchmarks;
  - physical dimensions of installed devices, conduits and channels; and
  - location of safety equipment and electrical supply sources.
- Specifications or descriptions of equipment and devices including:
  - nameplate data;
  - instrument measurement ranges;
  - electrical power supply requirements; and
  - flow conversion tables or calculation coefficients.
- As applicable, descriptions of step-by-step operations to be performed for:
  - routine cleaning and inspection procedures;
  - routine checks on secondary measuring device calibration (i.e., zero setting);
  - maintaining and repairing equipment;
  - record-keeping procedures for inspection and maintenance activities;
  - routine checks of recorded data to detect or diagnose any errors or problems;
  - processing, calculating and reporting flow measurement data; and
  - flow measurement system calibration or verification.
- A list of tools for cleaning and inspection.
- A list of instruments and equipment required for calibrating and verifying accuracy of the flow measurement system.

6.2 Logged Information

A bound log book should be dedicated to each specific flow measurement site for record keeping. The log book should include summary sheets prepared during the performance of Standard Operating Procedures and document all activities related to system inspection, testing, calibration and maintenance.

The following information should be included in the log book:

- the name of the mine site and the final discharge point;
- the date, time and description of the general conditions during inspection and maintenance activities;
- inspection results and observations including any detected malfunctions, upsets or errors;
- identification of any test, measurement, calibration or verification procedure that was performed;
- any recommendations or schedules of subsequent activities or corrective actions to be taken as a result of inspection observations or maintenance activities;
- identification of personnel involved; and
- an authorization signature.

6.3 Data Format and Reporting

All flow measurement reports should include:

- the name of the mine site and the final discharge point to which the report applies;
- the date, time and duration of all measurements used to generate the report;

- general conditions at the final discharge point over the reporting period (e.g., weather conditions, ongoing maintenance activities, equipment modifications, changes in normal mine or mill operating conditions such as temporary shutdowns or changes to major process operations);
- all relevant flow measurement data;
- identification of data discrepancies due to maintenance activities or technical problems; and
- an authorization signature.

Data should be retained in both electronic format and hard copy for a period of at least five years.

7.0 Reference Documents for Flow Measurements

Methods for flow measurement are described in detail in international standards, national standards, association standards and numerous hydraulic textbooks and handbooks. Among the organizations issuing standards are:

- the International Organization for Standardization (ISO);
- the American Society for Testing and Materials (ASTM);
- the American Society of Mechanical Engineers (ASME);
- the British Standards Institute (BSI); and
- the National Institute for Science and Technology (NIST).

This document makes reference to some of the relevant standards from these organizations. Selected ASTM and ISO references pertaining to flow measurement in open channels and closed conduits are summarized in Table 1.

Table 1 ASTM and ISO References of Relevance to Flow Measurement of Metal Mining Effluents

ASTM Ref. No.	ISO Ref. No.	Title or Topic Addressed
General Standards		
D5172-91		Standard Operating Procedure Development Guide
D5612-94		Field Program Guide
D5640-95	8363-1986 (E)	General Guidelines for the Selection of Methods
D4375-96		Basic Statistics – Committee D-19 on Water
	5168-1978 (E)	Estimation of Uncertainty of a Flow Rate Measurement
	7066-1: 1989 (E)	Assessment of Uncertainty – Linear Calibration Devices
	7066-2: 1988 (E)	Assessment of Uncertainty – Non-linear Calibration Devices
	4006-1977 (E/F)	Vocabulary and Symbols
Open Channel Flow Standards		
	4373-1979 (E)	Open Channel – Water Level Measuring Devices
D5674-95	8368-1985 (E)	Flow Gauging
D1941-91	9826-1992 (E)	Parshall Flumes
D5390-93	4359-1983 (E)	Rectangular, Trapezoidal and U-shaped Flumes
D5242-92	1438/1-1980 (E)	Weirs and Venturi Flumes – Part 1: Thin Plate Weirs
D5614-94	3846-1977 (E)	Weirs and Flumes – Free Overfall (Rectangular Broad-crested Weirs)
D5242-92	4377-1982 (E)	Flat-V Weirs
	4360-1984 (E)	Weirs and Flumes – Triangular Profile Weirs
	8333-1985 (E)	Weirs and Flumes – V-shaped Broad-crested Weirs
	4371-1984 (E)	By Weirs and Flumes – End-depth Method for Estimation of Flow in Weirs and Flumes
	4374-1982 (E)	Round-nose Horizontal Crest Weirs
D5389-93	6418-1985 (E)	Ultrasonic (Acoustic) Velocity Meters
D3858-95	748-1979 (E)	Velocity-area Methods
D4409-95	2537: 1988 (E)	Rotating Element Current Meters
D5089-95		Open Channel Electromagnetic Current Meters
D5541-94		Stage Discharge Relation
Closed Channel Flow Standards		
	6416-1985 (E)	Measurement of Discharge by the Ultrasonic (Acoustic) Method
	3313-1974 (E)	Pulsating Flow Orifice Plates, Nozzles or Venturi Tubes
	5167-1980 (E)	Full Pipe Orifice Plates, Nozzles and Venturi Tubes
	6817-1980 (E)	Electromagnetic Flow Meters
	7145-1982 (E)	Method of Velocity Measurement at One Point of the Cross-section
Estimation Methods		
D5130-95	1070-1973 (E)	Slope-area Method
D5243-92		Culverts
D5388-93		Step-backwater Method
Calibration Methods		
	8316: 1987 (E)	Collection of Liquid in a Volumetric Tank
D5613-94	9555-1: 1994 (E)	Tracer Dilution Methods – Steady Flow – Part 1: General
	9555-3: 1992 (E)	Tracer Dilution Methods – Steady Flow – Part 3: Chemical Tracers
	9555-4: 1992 (E)	Tracer Dilution Methods – Steady Flow – Part 4: Fluorescent Tracers

Appendix 1 Open Channel Flow Measurement

Introduction

This appendix provides information on open channel flow measurement, including general guidelines for site selection and a description of the more commonly used techniques. A substantial amount of the information provided in this appendix was obtained from the ISCO Open Channel Flow Measurement Handbook (Grant and Dawson, 1995). Where applicable, this information has been augmented based on the experience of the authors in the design, installation and calibration of flow measurement systems.

Site Selection

Selection of flow measurement locations for open channel application should take into consideration the general design information summarized below.

- A stream or channel with irregularly formed sides or bottom, particularly those that are not engineered or constructed channels, should be avoided. Any irregular surface, slope, bottom or possible protrusion (rocks, vegetation, etc.) can contribute to an irregular flow profile and affect measurement accuracy.
- The flow measurement site should not be subject to either erosion (i.e., of channel surfaces) or sedimentation. A change in channel geometry could alter the performance of the primary device, such as changing the site water level-discharge relationship, and affect measurement accuracy.
- The channel should be straight and uniform for a distance upstream of the flow measurement site of at least 10 times the maximum expected head of liquid. Some devices may require a minimum straight upstream distance of 20 times. For weirs and certain types of flumes (e.g., Parshall flumes), the channel should have minimal or no slope.
- The flow approaching the flow measurement site should be well distributed across the channel, and relatively free of turbulence, waves and eddies.
- The channel downstream of the flow measurement site should permit free discharge from the site for the range of flow to be measured without “backwatering” or submerging the site. Exceptions to this rule are possible with the use of certain primary devices, such as Parshall flumes, which can account for this effect by head or water level measurement at a second location.

Primary Measuring Devices

Many of the primary devices used for open channel flow measurement are hydraulic structures identified as weirs and flumes. Several of the more common weirs and flumes used at mine sites are briefly described in the following subsections.

Weirs

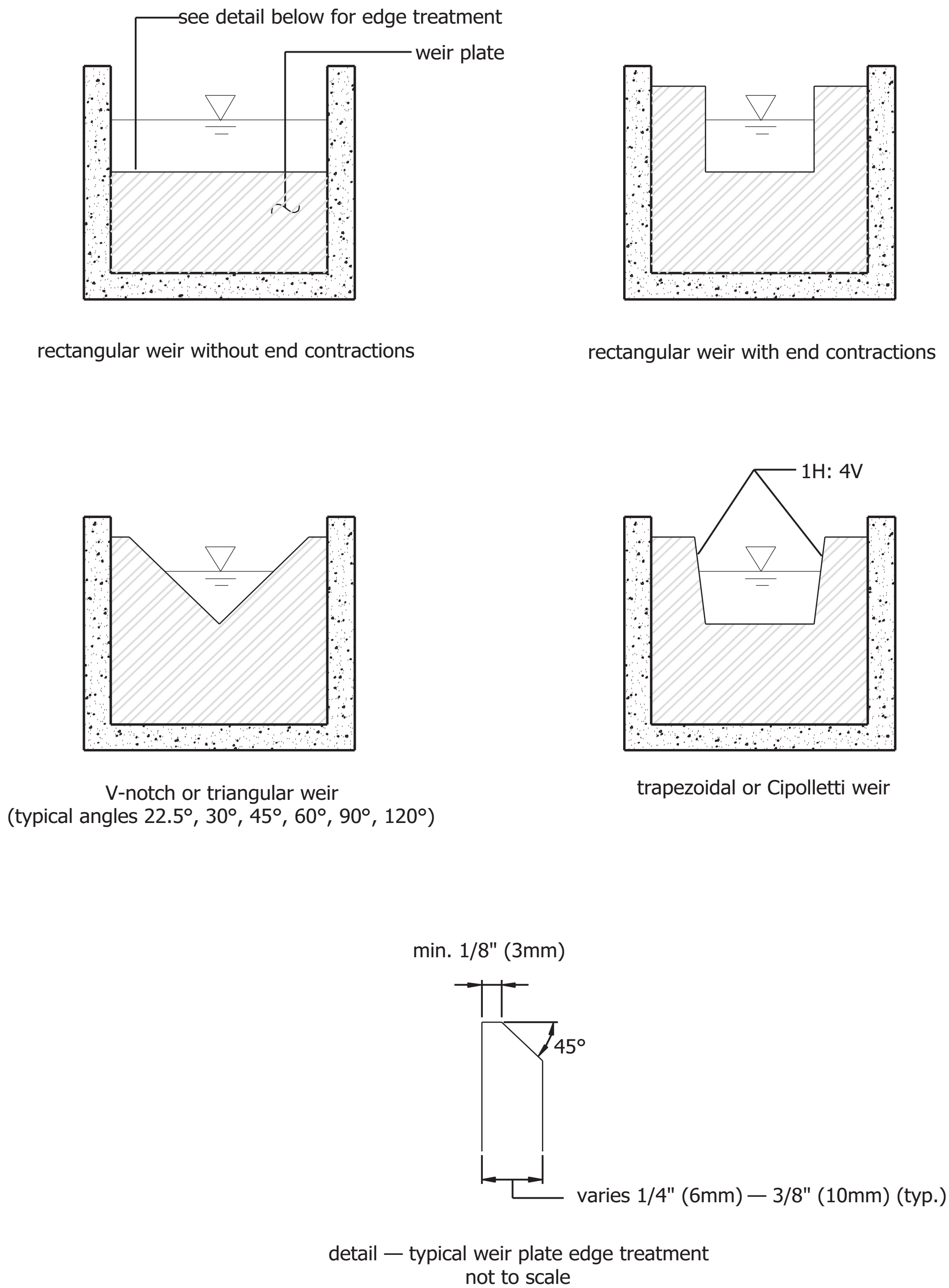
<u>Description</u>

Weirs are hydraulic structures consisting of an obstruction such as a dam or bulkhead placed across the open channel with a specially shaped opening or notch. The weir results in an increase in the water level, or head, which is measured upstream of the structure. Water level-discharge relationships are available for standard-shaped openings or notches.

Weirs are called sharp-crested if their crests are constructed of thin metal plates, and broad-crested if they are made of wide timbers or concrete. Water level-discharge relationships can be applied and meet accuracy requirements for sharp-crested weirs if the installation is designed and installed consistent with established ASTM and ISO standards. Flow measurement installations with broad-crested weirs will meet accuracy requirements only if they are calibrated. Calibration methods are summarized in Appendix 3.

The most common weirs used are sharp-crested with either a v-notch or a rectangular-shaped opening. Several examples are shown in Figure 2. The v-notch weir is typically used to measure low flows within a narrow operating range. The rectangular weir is able to measure higher flows than the v-notch weir and over a wider operating range. As shown in Figure 2, a rectangular weir may be designed with or without end contractions. Other available weirs are the trapezoidal (Cipolletti) weir, Sutro (proportional) weir and compound weirs (combination of the previously mentioned weir shapes).

Figure 2 Typical Weir Configuration



Water level measurement is taken upstream of the weir at a distance equal to four to five times the expected maximum head. The water level measurement is referenced to the bottom point (apex) of a v-notch weir and the horizontal crest of other-shaped weirs.

Installation

- Access to all sections and components of the weir and associated secondary measuring device(s) should be provided to permit regular inspection and maintenance.
- Weir plates for sharp-crested weirs should be a minimum of 6 mm thick with a 45^o downstream chamfered edge. The thickness of the weir plate is dependent on the weir width and head of water to be managed. Typical plate widths are 6 mm, 8 mm and 12 mm.
- Weir plates for sharp-crested weirs should be constructed of stainless steel.
- A staff gauge for head level measurement should be permanently installed upstream of the weir at an appropriate location to provide a quick visual indication of the operating water level.
- Secondary measuring devices should be installed directly in or over the approach channel or in a stilling well.
- The weir should be sized such that the maximum operating flow is about 70% to 100% of maximum weir capacity. Oversizing the weir may result in loss of accuracy at low flows.

Periodic maintenance and calibration

- The weir plate should be kept clean and free of fouling growth and ice build-up.
- The upstream section of the weir installation should be kept free of sediment accumulation and other debris.
- The “zero” reference of the secondary measuring device should be checked regularly under a “no flow” condition. If this is not possible, a calibration plate can be installed to check referencing of the secondary measuring device.
- As applicable, the floor of the stilling well and the intake line should be kept clean and free of sediment.
- Several other items to check during periodic inspections include leveling of the weir crest and vertical plumb of the weir plate, elevation of the weir crest relative to an established benchmark (e.g., check for differential settling of the installation) and condition of the weir plate (e.g., check for damage and excessive rusting).

Parshall Flumes

Description

The Parshall flume is a hydraulic structure of rectangular cross-section with a narrow section and drop in the floor. An example is shown in Figure 3. This device constricts and reshapes the flow through the structure, developing a hydraulic head proportional to flow. This flume consists of a level converging section at the inlet, a throat and a diverging section at the outlet.

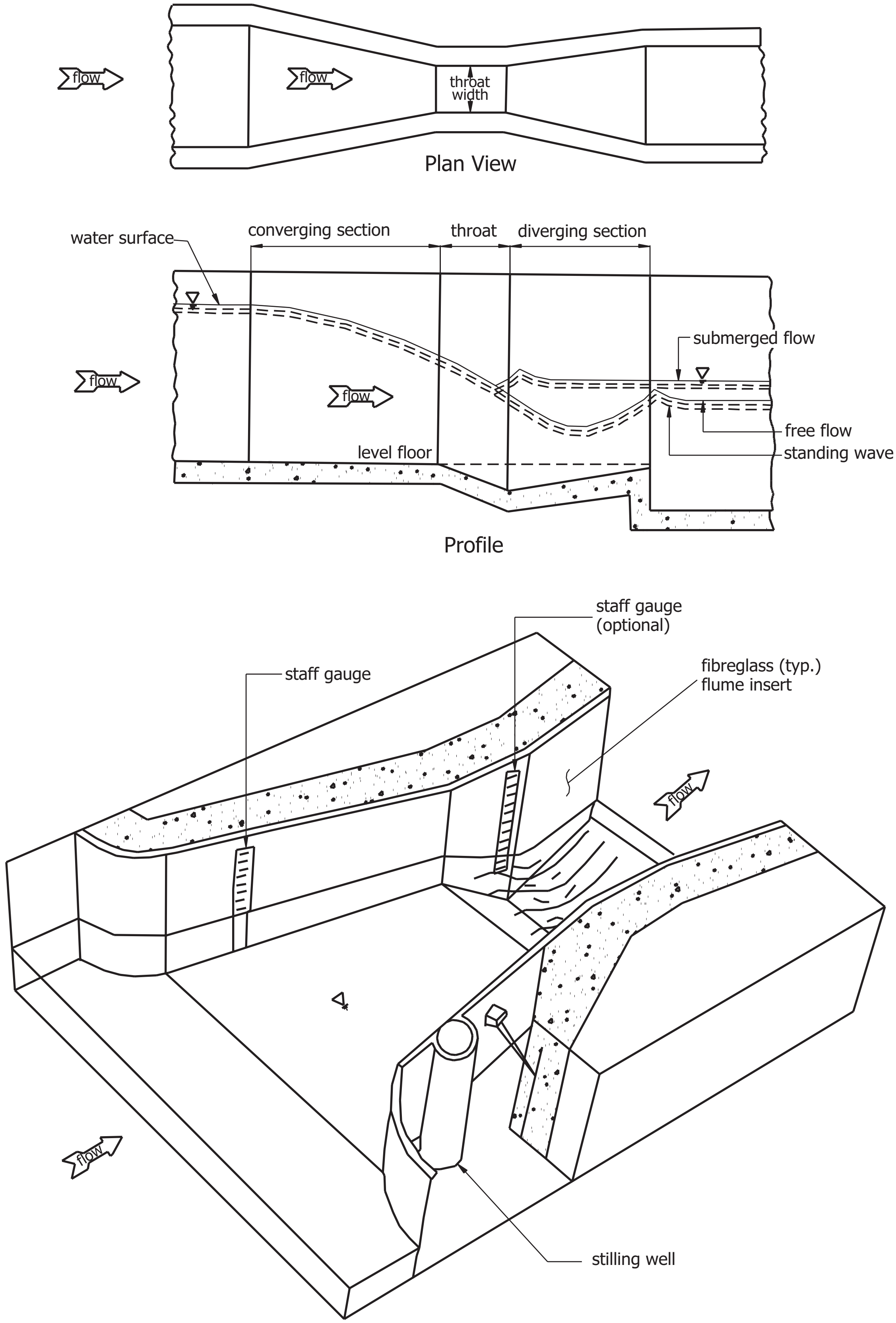
The converging section at the upstream end of the flume results in acceleration of the flow entering the structure. This effect tends to scour the flume surfaces and prevent sediment accumulation. Head measurement is performed in the converging section immediately upstream of the throat. The throat is located in the middle of the flume and has a rectangular cross-sectional shape with a downward sloping bottom. The size of the flume is designated by the width of the throat.

The primary advantages of the Parshall flume include a self-cleaning capability, ability to measure flow over a wide operating range and relatively low head loss. Dimensions are available for this type of flume for throat widths from 25 mm to 15.2 m. The flumes can be either constructed on-site from a variety of materials (e.g., wood, concrete, sheet metal) or obtained from manufacturers as prefabricated inserts or structures. The inserts, which are commonly fibreglass, are typically installed in a concrete superstructure constructed on-site to suit the flow measurement location.

Installation

- The entire structure should be fixed in place with adequate support so that the floor section is longitudinally and transversely leveled, and channel sides will not buckle or distort under high flow conditions.
- Access to all sections and components of the flume and associated secondary measuring device(s) should be provided to permit regular inspection and maintenance.
- A staff gauge for head level measurement should be permanently installed on a side wall of the converging section at the appropriate location to provide a quick visual indication of the operating water level.

Figure 3 Parshall Flume Schematics



(Adapted from Free Flow Inc., 1991)

- A stilling well should be provided for head or water level measurement by the secondary measuring device. The stilling well would be connected to the flume at the appropriate location in the converging section by a small-diameter intake pipe. The floor of the stilling well should be either equal to or below the elevation of the floor of the converging section of the flume.
- The flume should be sized such that the maximum operating flow is about 70% to 100% of maximum flume capacity. Oversizing the flume may result in loss of accuracy at low flows.

Periodic maintenance and calibration

- The flume floor and walls should be kept clean and free of fouling growth. Algae build-up is common on fibreglass flume inserts.
- The floor of the flume should be kept free of sediment and debris.
- The floor of the stilling well and the intake line should be kept clean and free of sediment.
- The "zero" reference of the secondary measuring device should be checked regularly under a "no flow" condition. If this is not possible, a calibration plate can be installed to check referencing of the secondary measuring device.
- Several other items to check during periodic inspections include transverse and longitudinal leveling of the floor of the flume (e.g., converging section), elevation of the flume relative to an established benchmark (e.g., check for differential settling of the installation) and separation of flume inserts from installation superstructure, as applicable.

Palmer-Bowlus and Leopold-Lagco Flumes

Description

Similar to the Parshall flume, these devices constrict and reshape the flow, developing a hydraulic head proportional to flow. These flumes consist of a converging section at the inlet, a throat and diverging section at the outlet. An example is shown in Figure 4.

The converging section at the upstream end of the flume results in acceleration of the flow entering the structure. This effect tends to scour the flume surfaces and prevent sediment accumulation. Head measurement is performed upstream of the converging section. The throat is located in the middle of the flume and has a trapezoidal cross-sectional shape for a Palmer-Bowlus flume and a rectangular cross-sectional shape for a Leopold-Lagco flume. The size of the flume is designated by the diameter of the pipe in which it is to be installed.

The primary advantages of these flumes are similar to those of the Parshall flume. The main difference with this type of flume is that it is suited for installation in existing round conduits (e.g., pipes and culverts) or rectangular conduits. Standard Palmer-Bowlus flumes are available to fit pipe sizes from 100 mm to 1,070 mm in diameter. The flumes, which can be obtained from manufacturers as prefabricated inserts, are installed directly into the conduit and sealed in place.

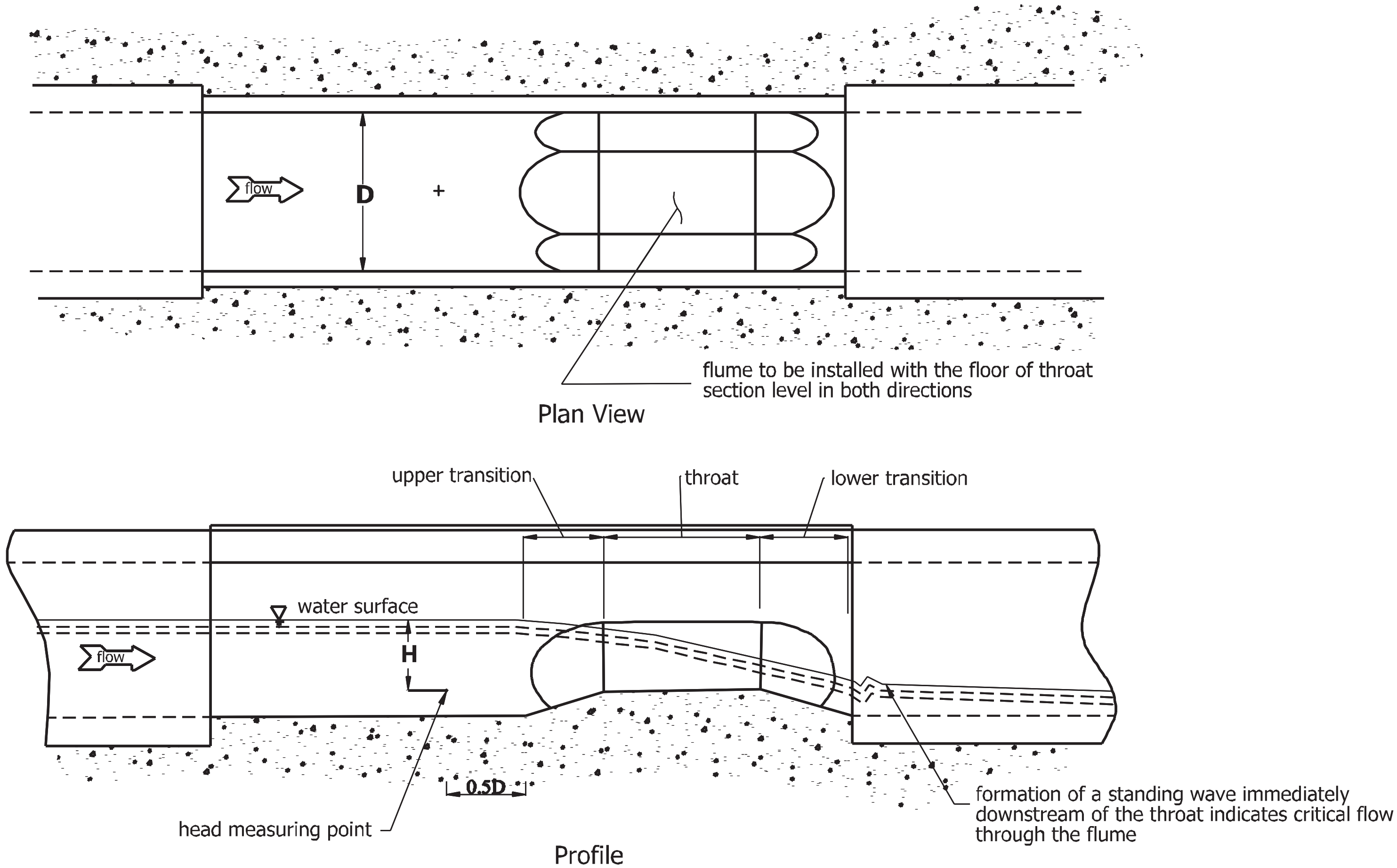
Installation

- The flume must be located at a section of the conduit that has a relatively straight and smooth approach section approximately 10 conduit widths upstream of the device. The maximum permissible pipe slope is 2%.
- The entire structure should be fixed in place with adequate support so that the floor section and channel sides will not buckle or distort under high flow conditions.
- Access to all sections and components of the flume and associated secondary measuring device(s) should be provided to permit regular inspection and maintenance.
- A staff gauge for head level measurement should be permanently installed on a side wall of the converging section at the appropriate location to provide a quick visual indication of the operating water level.
- A stilling well should be provided for head or water level measurement by the secondary measuring device. The stilling well would be connected to the flume at the appropriate location upstream of the converging section by a small-diameter intake pipe. The floor of the stilling well should be either equal to or below the elevation of the floor of the converging section of the flume.
- The flume should be sized such that the maximum operating flow is about 70% to 100% of maximum flume capacity. Oversizing the flume may result in loss of accuracy at low flows.

Periodic maintenance and calibration

- The flume floor and walls should be kept clean and free of fouling growth. Algae build-up is common on fibreglass flume inserts.

Figure 4 Palmer-Bowlus Flume



1. Palmer-Bowlus Flumes are designed to operate properly when laminar flow conditions are present. Channel turns, tee, elevation drops and other disturbance-creating situations immediately upstream (25 pipe diameters) of the flume should be avoided. Excessive slope in upstream piping will result in poor accuracy due to turbulence at the measuring point. Small-size lines to have a 2% maximum slope; larger sizes to have less slope.
2. The downstream channel should have sufficient slope to maintain critical flow through the throat of the flume and prevent the flume from becoming submerged.
3. Head measurements are taken upstream of throat at D/2 point. The zero flow level occurs at the same elevation as the throat. Head measurement (H) to be taken with zero even with floor of throat.

(Adapted from Free Flow Inc., 1985)

- The floor of the flume should be kept free of sediment and debris.
- The floor of the stilling well and the intake line should be kept clean and free of sediment.
- The "zero" reference of the secondary measuring device should be checked regularly under a "no flow" condition. If this is not possible, a calibration plate can be installed to check referencing of the secondary measuring device.
- Several other items to check during periodic inspections include transverse and longitudinal leveling of the floor of the flume (e.g., converging section), elevation of the flume relative to an established benchmark (e.g., check for differential settling of the installation) and separation of flume inserts from installation superstructure, as applicable.

H-type Flumes, Parabolic Nozzles

Description

These are examples of primary measuring devices suitable for installation on the end of a conduit where there is a free-falling discharge. An example is shown in Figure 5. The H-type flume and parabolic nozzle constrict the flow exiting a conduit or pipe. The H-type flume has a rectangular entrance section with a trapezoidal outlet. The outlet is narrow at the bottom and wide at the top. The parabolic nozzle has a circular entrance section with a parabolic outlet. Similar to weirs and flumes, these devices have predetermined relationships between depth of water in the device and flow rate.

There are three versions of the H-type flume to permit measurement of flow over a wide range (e.g., HS, H, and HL flumes). This type of flume is designated by maximum depth attainable in the flume. Standard flume sizes are 120 mm to 1,370 mm. The standard sizes for parabolic nozzles are 150 mm to 610 mm.

Installation

- The flume or nozzle should be located at a section of the conduit that has a relatively straight and smooth approach section approximately 10 throat diameters upstream of the device. The maximum permissible conduit slope is 1%.
- The entire structure should be fixed in place with adequate support so that the floor section and sides will not buckle or distort under high flow conditions.
- Access to all sections and components of the flume/nozzle and associated secondary measuring device(s) should be provided to permit regular inspection and maintenance.
- The secondary measuring devices for H-type flumes should be installed either directly above the flow in the flume or in an attached stilling well. The secondary measuring devices for parabolic nozzles should be installed directly above the flow in the nozzle.
- The flume or nozzle should be sized such that the maximum operating flow is about 70% to 100% of maximum flume capacity. Oversizing the device may result in loss of accuracy at low flows.

Periodic maintenance and calibration

- The flume or nozzle should be kept clean and free of fouling growth, sediment and debris.
- The "zero" reference of the secondary measuring device should be checked regularly under a "no flow" condition. If this is not possible, a calibration plate can be installed to check referencing of the secondary measuring device.
- Several other items to check during periodic inspections include elevation of the flume or nozzle relative to an established benchmark (e.g., check for differential settling and distortion of the installation) and separation of the device from the upstream conduit.

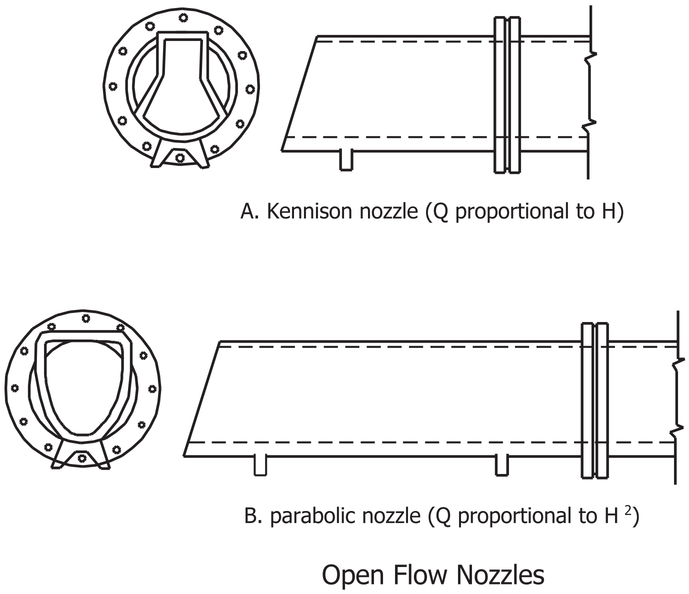
Secondary Measuring Devices

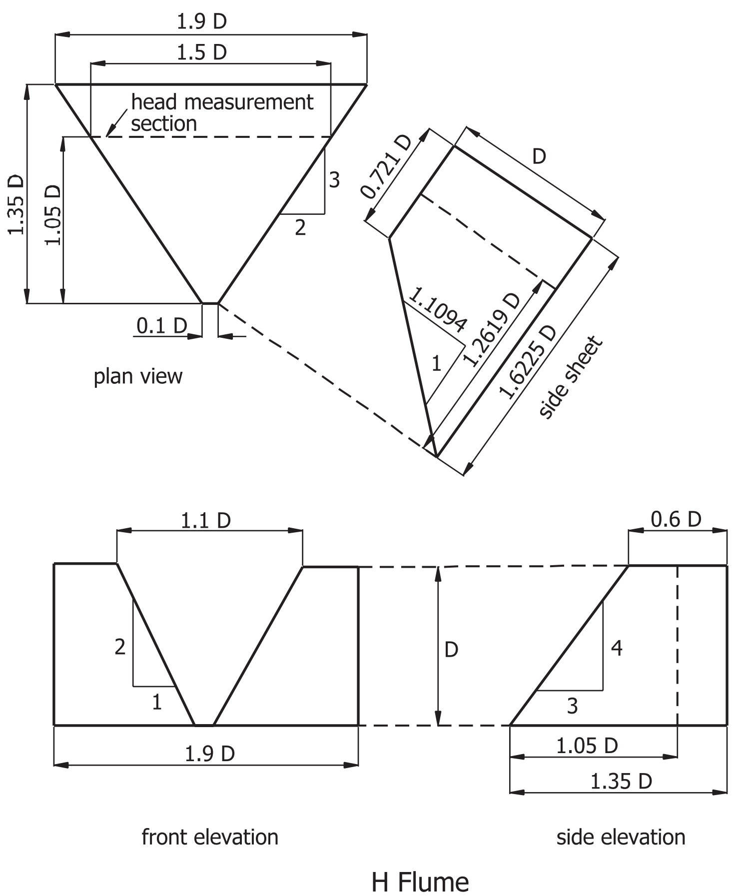
A secondary measuring device is used in conjunction with a primary measuring device and has two functions. The first function is to measure liquid level in the primary device. The second function is to convert the liquid level measurement to a flow rate based on a known water level-discharge relationship. This section addresses the function of the liquid level measurement.

Secondary measuring devices used for measuring water level (head) include the following:

- float system;
- bubbler tubes (measures back pressure from air discharge into the water);
- submerged pressure sensors (various types of mechanical or electrical pressure-sensing devices);
- capacitance probes (electrical current probes); and

Figure 5 Open Flow Nozzles and Typical H Flume





(Adapted from Grant and Dawson, 1995)

- ultrasonic level sensors (mounted above the water to transmit sound waves to the free surface of the water).

Each device has benefits and limitations. The selection of a secondary measuring device should be made with a complete understanding of the site conditions, primary measuring device, and operation and maintenance conditions.

Velocity-Area Methods

This method of flow measurement does not employ a hydraulic structure or primary device in the open channel or partially filled pipe.

<u>Description</u>

Direct measurements are made of the velocity and area (derived from level and channel geometry) of the fluid stream. Flow is calculated as the product of velocity times area following the continuity equation. A velocity-area flow measurement system consists of the required set of sensors installed into the channel or conduit at a suitable location and the associated signal-processing instrumentation. The computation of flow from the sensor measurements incorporates the geometrical dimensions of the stream, as well as site-specific velocity correction coefficients.

This method is applied directly to improved or man-made channels and partially filled conduits or pipes. Hydraulic structures (primary devices) are not required. The method requires only installation of a suitable sensor component assembly that presents minimal obstruction to the fluid stream.

Velocity-area methods are adaptable to any shape and size of conduit or channel. However, most methods require at least a minimum depth and velocity of flow for the installed sensors to perform accurately. To achieve the required flow measurement accuracy in higher flow rates, it may be necessary to mount several velocity sensors in the flow stream. One velocity sensor is often not adequate to characterize the average velocity of the flow regime.

Several types of velocity measurement devices are available on the market that use one of the following measurement methods:

- magnetic principles;
- ultrasonic transit time; and
- Doppler acoustic velocity.

Each method requires a separate head measurement device. The commonly used techniques for water level measurement with the velocity-area method are a submerged pressure transducer and an ultrasonic level sensor mounted above the flow.

<u>Installation</u>

- The channel at the location of flow measurement should be relatively straight over a distance equivalent to 10 times the width of the channel upstream and downstream. The surfaces of the channel or pipe should be smooth and free of irregularities and obstructions to avoid producing a disturbed velocity profile.
- The location of the velocity sensor(s) should ensure an accurate representation of the flow velocity.
- The water depth at low flows should be sufficient to allow proper operation of the velocity sensor(s).
- The sensor assembly is usually installed on a mounting band or support structure designed to suit the contour of the stream, channel or conduit. The sensors should be well fastened or supported within the channel.
- Access to all sensor assembly components and associated secondary measuring device(s) should be provided to permit regular inspection and maintenance.
- A staff gauge for head level measurement should be permanently installed at an appropriate location to provide a quick visual indication of the operating water level.
- The liquid level sensor should be calibrated and corrected to the zero reference level of the bottom or invert of the channel or pipe.

<u>Periodic maintenance and calibration</u>

- The flow measurement location and sensor(s) should be kept clean and free of fouling growth, sediment accumulation and debris.
- The “zero” reference of the secondary measuring device should be checked regularly under a “no flow” condition. If this is not possible, a calibration plate can be installed to check referencing of the secondary measuring device.

References

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Free Flow Inc. 1991. Parshall Flumes for Open Channel Flow Measurement. Bulletin PF. Omaha, Nebraska.

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Appendix 2 Closed Conduit Flow Measurement

Introduction

This appendix provides information on closed conduit flow measurement, including general guidelines for site selection and a description of the more commonly used techniques. Closed conduit flow refers to fluid movement through a conduit in which the fluid occupies the full cross-section and is under pressure. For most effluent applications, the fluid travels under positive pressure (e.g., pumped flow through a pipeline or piped discharge from the outlet of a tank or pond). Flow under negative pressure exists when the flow is through a siphon.

Site Selection

In selecting a suitable site for flow measurement on a closed conduit or pipe, the following should be taken into consideration.

- The conduit or pipe should be of regular shape and well formed throughout the measuring section. Irregular inner surfaces or protrusions, such as severe corrosion or tuberculation, can contribute to irregular flow profiles, turbulence and swirl, affecting measurement accuracy.
- The conduit or pipe should be straight and uniform for a minimum of 10 pipe diameters upstream. Pipe bends, fittings, valves, reducers, expanders, strainers/filters and flow obstructions within 10 pipe diameters upstream may affect flow measurement accuracy.
- Sites should be avoided where sedimentation of solid particles within the conduit may occur as a result of intermittent or low flows or low flow velocities.
- The pipe or conduit should be fully suited to the range in operating flows.

Closed Conduit Measurement Devices

There are various methods to measure flow in closed conduits or pipes. The most commonly used techniques are velocity-area methods (e.g., magnetic flow meter, transit time flow meter) and differential pressure methods (e.g., venturi tube, orifice plate). Other techniques include rotor methods (e.g., turbine meter, propeller meter), vortex shedding, and target and positive displacement methods (e.g., disc meter, piston meter). These less commonly used techniques are not discussed in this appendix.

Velocity-Area Methods – Magnetic Flow Meters

These types of flow meters measure the average axial velocity of the fluid. Flow rate is determined by the multiplication of this velocity measurement with the known constant cross-section of the conduit or pipe. A magnetic flow meter consists of a specially constructed section of conduit, known as a “flow tube,” mounted directly into the conduit or pipeline configuration. Flow velocity is determined with sensors mounted in the flow tube that operate based on electromagnetic principles.

The flow tube, the system’s primary device, creates a magnetic field through which the fluid must pass. Conductive fluids induce an electrical potential or voltage across the fluid, following Faraday’s principle. This voltage is proportional to the velocity of the fluid and is sensed by the sensors (electrodes) that are mounted in the flow tube.

The secondary device, or converter/transmitter, measures the induced voltage across the electrodes and converts it to a process signal proportional to the flow rate. Typically, the converter also provides a transmitted analogue or frequency output (scaled in pulses per unit of flow) and is often provided with a local visual display of flow rate and total flow volume.

Magnetic flow meters are available from a number of manufacturers in common pipe sizes ranging from a few millimetres to two metres. For installation, the devices can be provided with threaded connections or bolt flanges, or they can be supplied as a wafer style for installation between matched flanges.

<u>Installation</u>

- The magnetic flow meter tube should be installed in a uniform section of conduit or pipe that is straight for a minimum of 10 pipe diameters upstream and 3 pipe diameters downstream of the device.
- The magnetic flow meter should be installed at a

location not subject to turbulence of the flow profile caused by fittings, pumps or valves adjacent to the installation.
- The diameter of the tube liner should match the diameter of the adjoining pipe so that it does not obstruct flow and wear out prematurely.
- The installation of the device should be made in a location that is always flowing full. The flow tube can be installed vertically or horizontally with an elevated discharge or in-line "gooseneck" downstream of the meter.
- The flow meter should be located in an accessible location for ease of cleaning and servicing. Consideration should be given to provision of a by-pass around the meter to permit removal of the device for inspection and maintenance.

Periodic maintenance of the flow meter

- On a routine basis, the magnetic flow meter's self-checking features and built-in diagnostic routines should be used to check the flow measurement system.
- The primary measuring device grounding, reference voltage and resistance readings of the sensors should be checked periodically to ensure these values are within the manufacturer's operating specifications.
- Coating of the sensors and sediment accumulation in the flow tube should be checked periodically and the system components cleaned, as required.

Velocity-Area Methods – Ultrasonic (Transit Time) Flow Meter

Transit time flow meters employ the travel time difference method to determine the velocity of fluid in a conduit or pipe. Ultrasonic pulses are transmitted diagonally across the fluid stream upstream and downstream between two fixed transducers. The difference in travel or transit time is directly proportional to the velocity of the fluid in the conduit and is used to compute flow.

Transit time meters can be supplied with transducers welded to "spool" pieces at the designated locations or with transducers designed to be clamped externally onto the conduit or pipe.

Installation

- The ultrasonic flow meter should be installed in a uniform section of conduit or pipe that is straight for a minimum of 10 pipe diameters upstream and 3 pipe diameters downstream of the device.
- The ultrasonic flow meter should be installed at a location not subject to turbulence of the flow profile caused by fittings, pumps or valves adjacent to the installation.
- The ultrasonic flow meter should be installed on conduit or pipe of suitable material (e.g., the material must be able to conduct ultrasonic pulses). Porous material such as concrete and cast iron are not suitable.
- The installation of the device should be made in a location that is always flowing full. The device can be installed vertically or horizontally with an elevated discharge or in-line "gooseneck" downstream of the meter. Aeration and particulate matter in the fluid can attenuate the ultrasonic signal and must be kept within acceptable limits.
- The flow meter should be located in an accessible location for ease of cleaning and servicing. Consideration should be given to provision of a by-pass around the meter to permit removal of the device for inspection and maintenance.

Periodic maintenance and calibration

- On a routine basis, the ultrasonic meter's self-checking features and built-in diagnostic routines should be used to check the flow measurement system.
- The primary measuring device sensor performance should be checked periodically with a calibration block to ensure that signal strength and processing are acceptable and within the manufacturer's operating specifications.
- Coating of the conduit and sediment accumulation in the device should be checked periodically and the system components cleaned, as required.

Differential Pressure Methods

These are precision-machined primary devices installed in a conduit or pipe that is operated full of fluid under pressure. As the fluid passes through the device, a geometrical constriction creates a pressure drop (differential pressure) that is related to the flow. Differential pressure is sensed upstream of the primary device and at a second location either downstream or in the constriction (throat) at specific points. Two common differential pressure methods for flow measurement are venturi tubes and orifice plates.

Venturi tubes are available for common pipe sizes from 50 mm to 910 mm. These flow devices come in a number of configurations and can be installed with threaded connections, with bolt flanges, or between matched flanges. A venturi tube has less head (pressure) loss than an orifice plate.

Orifice plates are essentially a flat metal disc with an accurately sized and bored circular hole. These devices are installed between a pair of flanges in the pipeline. It is critical that the bored hole is concentric with the internal pipe diameter. Orifice plates are available for common pipe sizes from 25 mm to 450 mm.

Installation

- Both venturi tubes and orifice plates should be installed in a uniform section of conduit or pipe that is straight for a minimum of 3 to 12 pipe diameters upstream and 3 pipe diameters downstream of the device. The minimum requirement for length of the upstream straight section varies for each device and associated variants. The minimum straight piping lengths provided should be consistent with manufacturer’s recommendations.
- The differential pressure meter should be installed at a location not subject to turbulence of the flow profile caused by fittings, pumps or valves adjacent to the installation.
- The installation of the device should be made in a location that is always flowing full. The device can be installed vertically or horizontally with an elevated discharge or in-line “gooseneck” downstream of the meter.
- The flow meter should be located in an accessible location for ease of cleaning and servicing. Consideration should be given to provision of a by-pass around the meter to permit removal of the device for inspection and maintenance.

Periodic maintenance and calibration

- On a routine basis, the self-checking features and built-in diagnostic routines associated with the secondary measuring device should be used to check the flow measurement system.
- The differential pressure transmitter should be periodically isolated and a pressure calibrator used to check that performance is acceptable and within the manufacturer’s operating specifications.
- Coating and sediment accumulation in the primary device should be checked periodically and the surfaces cleaned, as required. Venturi tubes are essentially self-cleaning. However, orifice plates mounted in a horizontal conduit can accumulate sediment, which may affect the accuracy of flow measurement.

Appendix 3 Methods for Calibration of Flow Measurement Systems

Introduction

In situ calibrations are necessary to establish and confirm conformance with the specified requirements for flow measurement accuracy. All flow measurement systems for final discharge points should be calibrated *in situ* as part of the commissioning phase. The calibration method used to establish and confirm flow measurement accuracy should have an accuracy within plus or minus 5%.

The following flow measurement methods provide a level of accuracy acceptable for calibration of flow measurement systems:

- dilution (tracer) method – injection of a solution at a known rate and concentration, and measurement of the fully mixed concentration in the effluent stream to determine the flow (injection solutions can include Rhodamine WT or lithium chloride);
- volumetric method – collection of effluent and weighing over a known time period or measurement of volume of effluent displaced over a known time period; and
- hydraulic model testing – construction of a scale model of the flow measurement system and calibration/verification under laboratory conditions.

These methods apply to both open channel and closed pipe flow measurement systems.

The velocity-area method, whereby in-stream velocity and flow depth are measured to determine flow, can be used as a secondary method to check calibration results but should not be used alone for calibration of flow measurement systems. This is due to difficulties in characterizing hydraulics under non-ideal conditions such as irregular channel characteristics, presence of turbulent flow with eddies or transverse currents, and low flow velocities.

For pressure flow in conduits, ultrasonic and electromagnetic methods can be used as a secondary method to check calibration results but should not be used alone for calibration of flow measurement systems. This is due to potential for non-ideal hydraulic conditions such as partially full pipe flow and air entrainment.

Dilution (Tracer) Method

Using this method, a tracer is injected at a constant rate into the effluent stream and sampled downstream at a location where the tracer and effluent are fully mixed. With the known tracer concentration, known tracer injection rate and known tracer concentration in the fully mixed effluent stream, effluent flow can be determined based on the principle of "continuity."

A detailed description of this method is provided in ISO 9555 – Measurement of liquid flow in open channels – Tracer dilution methods for the measurement of steady flow (ISO, 1994).

Typical tracers used with this method are Rhodamine WT and lithium chloride. Selection of an appropriate tracer should be made based on characteristics of the effluent stream and experience with the tracer and respective analytical techniques. For instance, Rhodamine WT is a versatile tracer that can be measured *in situ* during testing by a fluorometer and at very small concentrations (e.g., parts per trillion); however, the test procedure is complex and requires care to ensure that results are not affected by experimental error. Rhodamine WT concentration is sensitive to temperature, and fluorometer calibration requires preparation of precise dilution solutions. Checks also need to be made for dye consumption in the effluent stream (e.g., effluent streams with high suspended solids concentrations and organic matter). Lithium chloride has the drawback that it is not measurable in the field and thus checks cannot be made on the testing procedure (e.g., constant tracer injection, fully mixed flow conditions, attainment of steady-state conditions).

Volumetric Method

The volumetric method can be undertaken by either collection of effluent and weighing over a known time period or measurement of volume of effluent displaced over a known time period. Application of the first approach is limited because the effluent volumes to be managed as part of the testing procedure are typically too large. For mining operations, application of the second approach is also limited as discharges at final discharge points are not typically from tanks or vessels (e.g., with known elevation-volume relationships) but from pond and effluent treatment systems. The respective volume-elevation relationships are generally known but are not to the accuracy required for flow measurement system calibration.

A detailed description of this method is provided in ISO 8316 – Method by collection of the liquid in a volumetric tank (ISO, 1987).

Hydraulic Model Testing

For some flow regimes or site conditions, it may not be possible to calibrate the flow measurement system using either the dilution or volumetric technique. This could occur due to the following:

- there is difficulty in reproducing the full operating flow range in the system;
- testing would potentially result in a release of an unacceptable contaminant loading to the environment (e.g., test flow rates during some times of the year may be limited by downstream receiving water restrictions on flow releases); or
- the site is an emergency overflow that would only convey flow in an emergency situation (e.g., testing cannot be undertaken with effluent due to water quality limitations).

For these conditions, it may be possible to construct a hydraulic model of the flow measurement system and test the model under laboratory conditions. The hydraulic model is designed based on the principle of hydraulic similitude. With this approach, the model represents a geometric reduction of the actual flow measurement system (prototype), which is accomplished by maintaining a fixed ratio (e.g., scale factor) between the model and prototype of all homogeneous lengths, velocities and forces involved in motion. A detailed description of hydraulic similitude and hydraulic model studies may be found in Hwang (1981) and Streeter and Wylie (1985).

In most cases for flow measurement systems, inertial force and gravity force can be considered to be the only dominating forces in fluid motion. In this case, the relationship between flow in the model and prototype can be described by:

$$Q_p = L_r^{2.5} Q_m$$

where: Q_p = prototype flow;
Q_m = model flow; and
L_r = scale factor.

The scale factor should be chosen to provide model flows as close as practical to prototype flows and be consistent with pumping capacity available at the testing facility.

The hydraulic models should be constructed based on field-measured dimensions. Dimensions as shown on design drawings should be confirmed prior to construction of the model. Common construction materials for a hydraulic model are wood and steel.

In laboratory testing facilities, flow rate through the model is usually determined by application of the volumetric method (see above).

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