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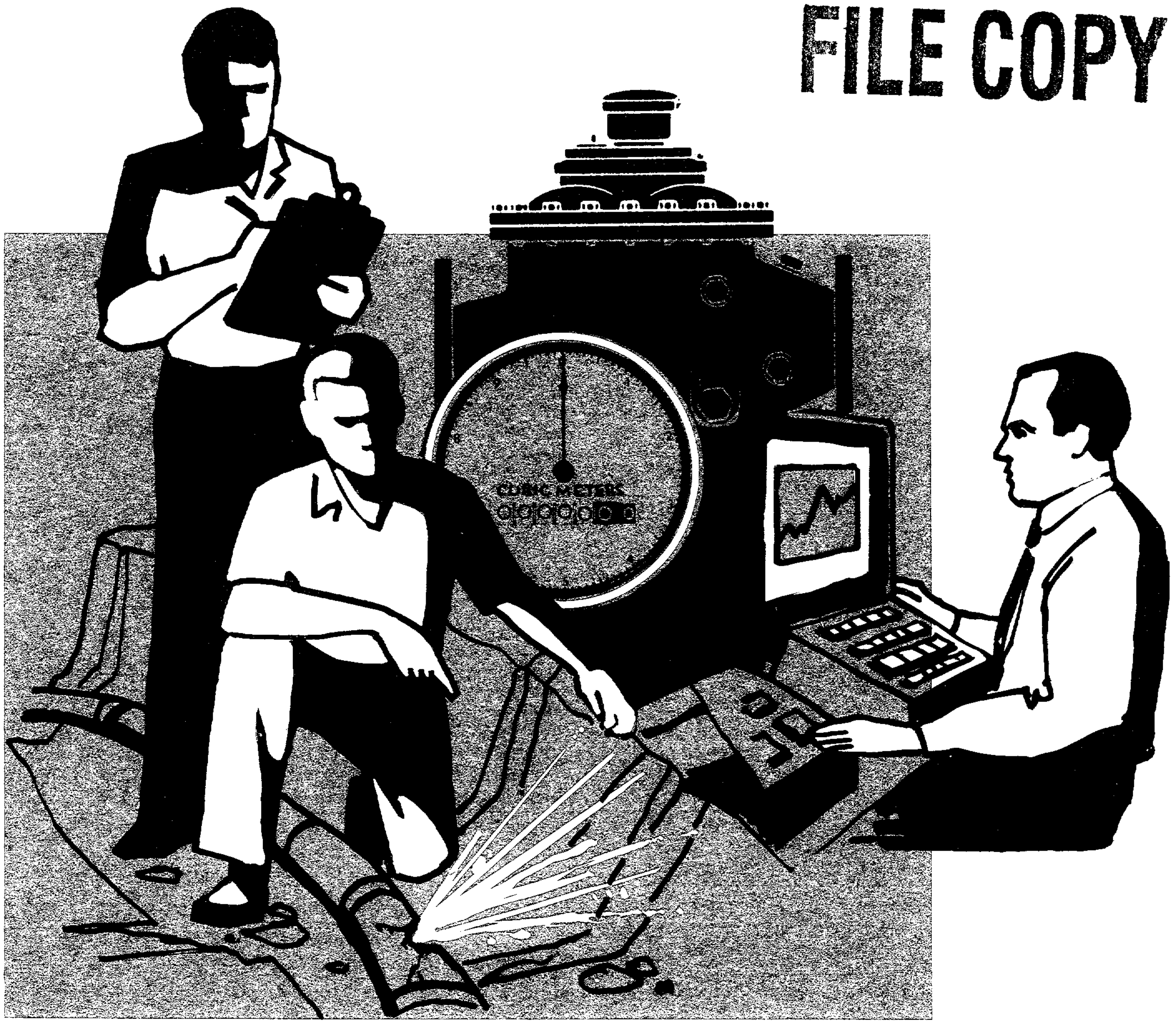
WORLD BANK TECHNICAL PAPER NUMBER 111
WATER SUPPLY OPERATIONS MANAGEMENT SERIES

Large Water Meters

Guidelines for Selection, Testing, and Maintenance

Philip Jeffcoate and Roy Pond



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Large Water Meters

Guidelines for Selection, Testing, and Maintenance

WATER SUPPLY OPERATIONS MANAGEMENT SERIES
(Distribution Systems Management)

The management of water supply infrastructure is a complex activity, involving both the operation and maintenance of existing facilities and the construction of new facilities. Water supply managers in developing countries, however, sometimes give a lower priority to operation and maintenance of old facilities than to the construction of new ones. Moreover, the management of water supply distribution systems often has a relatively low status in many water companies compared to the attention given to production facilities. As a consequence, there are large water losses caused by the premature deterioration of water mains, frequent metering failures and decreased revenues. This, in turn, can lead to economic inefficiencies caused by doubtful investment decisions.

This series of technical papers is intended for waterworks managers, distribution system maintenance engineers, and those concerned with making investment decisions for the rehabilitation or replacement of water supply facilities and the construction of new works. A subseries on Distribution Systems Management, of which this is one volume, aims to provide guidance on some of the most pressing institutional, technical and social problems faced by the managers and engineers of water supply distribution system in developing countries. Two other volumes in this subseries are currently available:

- Corrosion Protection of Pipelines for Water and Waste Water: Guidelines

- The Reduction and Control of Unaccounted-for Water: Working Guidelines

Proposed future volumes in the Distribution Systems Management subseries will cover topics such as selecting, procuring, and maintaining small domestic water meters; the political, social, institutional, and organizational implications of programs to reduce water losses; detecting and regularizing illegal service connections; and the scope for privatization in operation and maintenance.

Topics likely to be addressed in the main operations management series include reducing losses at source, raw water transmission and water treatment; meter reading, billing, and collection; and the characteristics of users who connect to available supply sources. All of these concerns influence the timing and scale of additional facilities.

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WATER SUPPLY OPERATIONS MANAGEMENT SERIES

Large Water Meters

Guidelines for Selection, Testing, and Maintenance

Philip Jeffcoate and Roy Pond

Commissioned by the United Kingdom
Overseas Development Association
on Behalf of the World Bank

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ABSTRACT

These guidelines explain how water utilities can achieve a good accounting of water production and consumption through the use of large meters, and are designed to answer the questions about large meters most frequently asked by engineers and system managers in developing countries. These guidelines are especially useful for managers interested in the accurate measurement of water production and distribution in various parts of their pipe networks.

About half of the revenues of a typical water supply entity come from sales through large meters. Sometimes these meters are poorly selected or improperly installed because of insufficient technical information, resulting in under-registration and a consequent loss of revenues. These guidelines are meant to provide an easy-to-follow methodology for selecting the correct design for the range of flows to be measured, and for the correct installation and subsequent calibration of large meters.

The selection and installation of source meters requires a general knowledge of the meter designs currently available. These are described in the guidelines, and annexes provide lists of technical institutions, research organizations, and flow measurement calibration facilities that specialize in large meters.

District meters, used particularly in assessing unaccounted for water, are similar to source meters, except that their sizing and location are more complex. The guidelines provide information on the models that are now in use, together with a comprehensive description of the available secondary instrumentation.

The guidelines also contain important suggestions on institutional arrangements, organization, manpower, and training needs. The methodology for maintaining each kind of meter is dealt with in sufficient detail that a distribution system manager can design and implement a meter maintenance system.

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ACKNOWLEDGEMENTS

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The data relating to equipment produced on the American continents and in Japan were collected by James M. Montgomery, Consulting Engineers, Inc., acting directly with the World Bank. We are grateful to Mr. David B. Bird and Mr. Murray Todd, not only for producing these data but also for providing some of the drawings and descriptive material, particularly that relating to open channel meters.

Many professional friends have provided a wealth of information regarding their operational experiences with various types of meters. Numerous manufacturers have provided detailed literature on their products.

We are grateful to Dr. R.A. Furness, formerly of the Cranfield Institute of Technology of Cranfield, England, for advice on sources of information, and to Mr. Graham Fowles for his work on the recent development of submersible, battery-operated electromagnetic meters and for his enthusiasm in introducing these developments to us. We thank both these gentlemen and Dr. R. Herschy for reading the first proof and for making helpful comments.

PREFACE

These "Guidelines for the Selection, Testing, and Maintenance of Large Water Meters" have been prepared by consultants commissioned by the United Kingdom Overseas Development Administration (O.D.A.) on behalf of the World Bank.

When "Working Guidelines for the Reduction and Control of Unaccounted-for Water" (World Bank Technical Paper No. 72) was circulated in draft, potential users asked advice on selecting meters to measure production, district, bulk, and large consumer quantities. The World Bank initiated the production of the present work to meet that demand. These guidelines are designed to further the Bank policy of encouraging increased revenue, improved control of waterworks systems, and greater economy in providing water supplies in developing countries.

Every effort was made to ensure that the schedules of technical institutes, research organizations and flow calibration facilities given in the Annexes are comprehensive. Assistance was requested from all the embassies and national trade organizations for the industrialized countries in Europe and Asia. Written inquiries were made to major national research organizations and finally to all the companies listed in the appropriate sections of the latest available editions of "KOMPASS" (the catalogue of manufacturers and products published by the Confederation of British Industries) for all the European countries. Nevertheless, the current industrial developments in this field are very rapid and there may still be some omissions which can be made good only in the next edition.

ABBREVIATIONS

A.C.	Alternating current
BS	British Standard
D	Diameter
5D	Length of pipe equal to 5 times the diameter
D.C.	Direct current
DIN	German standard for equipment and materials
D.P.	Differential pressure
h	Head (over weir or flume)
IEC	International Electro-technical Commission standard
ISO	International Standards Organization
l/min	Liters per minute
l/sec	Liters per second
m.	Meters
m^2	Square meters
m^3	Cubic meters
m/sec	Meters per second
mm.	Millimeters
m^3/h	Cubic meters per hour
P_H	High pressure
P_L	Low pressure
Q	Flowrate
U.F.W.	Unaccounted-for water
V	Velocity

NOTE: For definitions of accuracy, range, and other performance terms, see Section 5.2. Costs throughout the text are in U.S. dollars, circa mid-1987, unless otherwise specified.

SECTION 1

INTRODUCTION

1.1 Purpose of the Guidelines

These guidelines are the follow-up and complement to the World Bank Technical Paper No. 72 (The Reduction and Control of Unaccounted-for Water/Water Supply Operations Management Series), regarding the need to accurately know the flows of water produced and distributed, and the quantities sold to large consumers such as bulk supplies to neighboring communities, industries, military camps, large government institutions, etc.

They represent an important element in setting out the equation Production-Losses-Consumption and subsequently to implement the measures to reduce the high volumes of non-revenue producing water, a serious problem reported in the Bank FY88 Water Supply and Sanitation Annual Sector Review: "The persistence of high levels of unaccounted-for water (UFW) and the difficulty of achieving expected reductions in the share of production that is unaccounted for are the most striking findings... Over the six-year period for which data were analyzed for each project, the aggregate annual revenue loss due to UFW was 43 percent of actual sales revenue."

The guidelines should assist management to deal with practical problems of installation, calibration, operation, and maintenance by selecting the most suitable meters for water produced and distributed through pipe networks and for large consumers, ensuring that they are kept in good operating order.

The meters fall into three categories with distinct requirements:

1. Source production meters, which measure the total volume of water delivered into the network. These are normally delivery pipeline meters but may be open-channel meters measuring flows within or from treatment works. The latter may not directly measure the flows into a network but may be acceptable as the only measure of production, provided the flows can be satisfactorily adjusted to account for changes in volume stored. Otherwise, they may be useful to calibrate source meters operating under pressure.

2. District meters, which indicate the quantities of water delivered into each waterworks district.

3. Large consumers' meters, which measure (a) quantities sold (or purchased) in bulk to (or from) neighboring water authorities; and (b) large supplies to industrial, commercial, civil government, or military establishments.

1.2 **Control of the Undertaking**

During recent decades, provision of increased supplies of piped water in developing countries has been a major aim in order to improve living conditions for rapidly expanding populations. Investment in new works has brought some success, but growth in water demand has frequently exceeded the rate at which works can be expanded and has imposed continuing pressures on management. These pressures have inhibited attention to effective and efficient control of operations. Works are more than fully stretched, and this has prevented careful planning. Deficiencies in both equipment and management personnel have often restricted collection of accurate data necessary for full understanding of waterworks systems.

1.3 **Quantities of Water Produced**

Because of lack of suitable meters and maintenance facilities, we often do not know how much water is actually going into the system. Where source meters have been installed, other demands on the service have prevented proper operation and maintenance, and many systems have been allowed to fall into disrepair. Typically, the quantities of water delivered into the network have then been based on estimates that assumed that:

(a) the pumps continue to deliver as they did when designed and installed; and,
(b) the suction and delivery pressures, voltage, and other operating conditions are in accordance with original design criteria. Quantities actually delivered into supply frequently bear no relationship to such estimates.

1.4 **Control of Unaccounted-for Water--District Meters**

Until quantities of water produced are known, any estimates - whether of water loss by leakage or revenue loss due to deficiencies in domestic metering--are worthless. First measures in controlling such unaccounted-for water (U.F.W.) are best achieved by monitoring flows to major network districts.

Quantities distributed to the different major pressure zones or supply districts are rarely measured, and there is usually no way to estimate such flows. Even where flows can be estimated, for example, by test measurements of volume changes in isolated service reservoirs, such data are not often obtained. Thus, the most cost-effective measures for improvements both to supplies and to control of U.F.W. cannot be confidently assessed, and consequently water production and conveyance flows should be accurately metered in the same vein as the water delivered to users.

1.5 **Potential Reduction in Operating Costs**

Without detailed knowledge of any system, the cost of different elements of the operation cannot be determined. There may be some knowledge of which pumps operate most or least efficiently, but this is not enough to show how to modify a system to minimize energy costs. Potential savings in operating costs, apart from those resulting from reducing leakage by improved control, cannot be fully assessed.

1.6 **Potential Increase in Revenue**

Loss of revenue results from deficiencies in consumer metering. These losses may be related to use of many small domestic meters, and it is a mammoth task to eliminate such deficiencies. In many systems, much of the water is sold to industrial, commercial, and military establishments through relatively few, large meters. Bulk supplies to or from other authorities may also represent a significant part of the total. The selection, operation, maintenance, and calibration of appropriate large meters for such purposes offer significant potential for increased revenue. These are logical first steps to increase revenue and improve control of any undertaking. Additional metering costs are normally more than fully justified. Experience shows that even in large, relatively well-organized water authorities in developed countries, frequent testing and recalibration of large consumer meters rarely receive adequate attention.

1.7 **Financial Constraints**

Costs of installing and maintaining meters for production, district flows and major consumptions are insignificant compared with the potential increase in revenue and savings in operation and future investment costs.

1.8 **Operational Problems**

While management may recognize these problems, the apparent difficulties envisaged in installing meters in systems that operate continuously but still provide an inadequate supply often deter effective action. Frequently, the possibilities of installing modern meters without interfering with the continuity of supply are not fully appreciated.

1.9 **Metering Costs**

A large investment in production and district metering may not be readily acceptable, particularly where the urgent need for increased production seems paramount. There are considerable differences in costs of the equipment and the installation of the various types of meters now available. This aspect, although possibly important, should not alone dictate the choice of meter appropriate to the prevailing circumstances. It is important to consider both the investment and annual costs, as well as the difficulty of keeping meters operating accurately.

SECTION 2

HOW TO USE THE GUIDELINES

2.1 Large Consumers' Meters

Most water authorities in developing countries have installed meters for all large commercial and industrial consumers, even where domestic consumers are not metered. Often a significant part of the revenue comes from sales through large meters. Such meters often record very inaccurately, and this inaccuracy may lead to a considerable loss of revenue. The first priority in any improved metering program is to deal with this problem. In this section, we suggest a typical routine to provide improved metering, essential not only to control U.F.W. but also for full understanding of the operation of the supply system.

Deal first with large consumers' meters (more than 100 mm. diameter). The records of consumption should be examined to determine the probable maximum rates of flow to be measured by each meter installed and to compare this with the rated maximum flow of the meter.

Where there is a large disparity, inspections are necessary to confirm the maximum flow occurring. Where necessary, the meter should be changed to one of appropriate diameter, to ensure that the installed meter is not unnecessarily large and can measure all flows, particularly the lowest flow occuring, with acceptable accuracy. This study should begin with the very largest meters and gradually extend into the smaller range. Large consumers' meters are normally rotary-vane or helix meters (see Section 3.1.4). If they are constantly failing due to grit in the pipes or not recording accurately because of air, they should be changed to some other type.

A budget should be provided to cover the cost of the inspection, replacement, refitting, testing, and future maintenance of all large meters. Normally, this cost will be more than met by resulting increased revenue.

Where any large supplies are provided that were not previously metered, such as to government premises, meters should be installed and records begun to determine the unit quantities supplied to the premises in relation to population or any other parameter that seems appropriate.

Where a large meter has not recently been changed, refitted, or tested for accuracy, this should now be done after cleaning or replacing the strainer normally fitted ahead of the meter. A flow test may be made in situ, using a test meter installed on a hydrant or standpost. Otherwise, the meter should be replaced by a meter that gives an accuracy of ± 2 percent over the full working range. Where access is poor or pipework does not allow the meter to record accurately, the meter siting must be changed.

Where the range of flow is very wide and significant quantities are taken at very low flow rates, consider replacement with a combination meter of an appropriate size.

At this stage, based on the evidence of the useful working life of installed meters and associated strainers, a program should be established for:

(a) cleaning or replacing meter strainers annually, quarterly or, if necessary, monthly, to extend the useful operating life of the meter;

(b) replacement with cleaned and tested meters every five years, three years, or even, if justified, annually.

Extend the operation into the range of smaller meters to gradually include all domestic meters.

Allocate an agreed part of the additional revenue derived from improved meter maintenance to supplement the budget for improved metering of water produced from sources and distributed to the various districts.

Keep studying all developments in large meters in order to reduce operating and maintenance costs by replacing old meters with more modern ones.

2.2 Source Meters

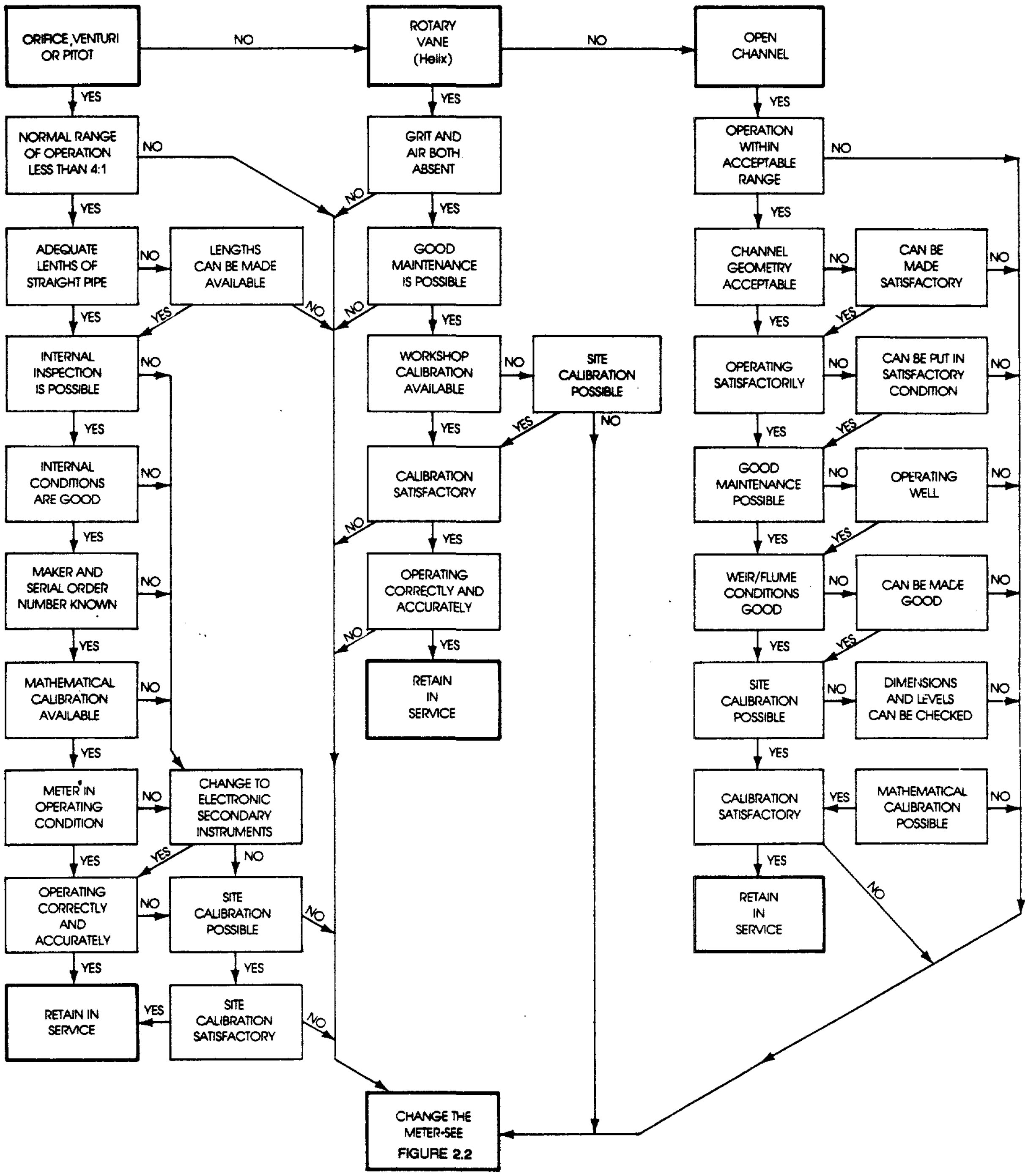
A survey should be made of all existing sources and the associated source meters where they exist; details should be tabulated as shown in Figures 6.1 and 6.3.

All existing meters should now be evaluated to determine whether they are satisfactory or should be replaced. For this purpose, a simplified checking procedure should be adopted. See the algorithm or selection diagram, Figure 2.1. Changes in the meter, the pipework, or the operating conditions since installation may make it inappropriate for accurate measurements. This may dictate changing the type of meter or operating conditions.

The types of meters referred to in the algorithm are fully described in Section 3 and their appropriate applications in Section 6.

If the meter is normally in operation and maintenance is no problem, its accuracy must be established. Any existing meter operating on a pipeline of more than 300 mm. diameter is likely to be of the orifice, venturi, or pitot type, all of which measure the flow in relation to the difference in pressure associated with the velocity. The pressure difference measured is proportional to the square of the velocity. Thus, this type of meter becomes inaccurate for low flows of less than one-fourth of the maximum flow rate measured. Mechanical meters, as well as the more modern electromagnetic and ultrasonic meters, measure parameters that have a linear relationship with the flow velocity and thus are accurate over a much wider range of flow.

Figure 2.1 - Review of Existing Source Meters



Note: This figure should only be taken as a quick working guide to procedure. Before taking positive action, the full text of the guidelines should be studied.

In orifice, venturi, and pitot meters, the pressure difference is usually measured by a manometer. If the meter is not working or is frequently out of order, this is often due to careless operation or lack of maintenance. In many developing countries, this is a normal problem. Modern sensors, using transducers for pressure measurement and electronic conversion to flow velocity, are less likely to fail because of operator ignorance, and they require little maintenance. Thus, if the meter is not operating reliably, first consideration should be given to changing the sensors.

If, however, the range of flow to be measured is appreciably more than 4:1, any meter of the differential pressure type is unsuitable for the conditions and should be replaced at the first opportunity.

Such meters only measure flow accurately when there are sufficient lengths of straight pipe before and after the meter, normally at least 10 diameters before and 5 diameters after. Pipework alterations since the original installation may have changed the pipe geometry and thus produce an irregular flow pattern so that the meter can no longer register accurately. In such circumstances, the meter should be replaced with one less susceptible to turbulence and the delivery pipework changed to ensure more uniform flow.

Establish a budget to cover the cost of replacing existing source meters where necessary and installing new source meters where none exist. The budget should cover not only the costs of supply, installation, and testing, but also the annual costs of maintenance and replacement.

Where, following Figure 2.1, it appears that the existing production meter should be retained, arrangements should be made for all necessary repairs and testing.

Assuming that conditions appear suitable for retaining the meter, it may still not be registering accurately and may need recalibration.

Site calibration is an extremely difficult procedure that may only be achieved where the supply can be taken out of service and the meter tested at fixed rates over the operating range by volume measurements on a suction tank or an isolated service reservoir. In either case, the tanks and pipework must first be tested to ensure that no leakages exist or, if they do, that leakage rates can be determined for volume adjustments. Such calibration may best be achieved by calling in specialists (see Annexes 2 and 3).

Where site calibration is impracticable, an orifice or venturi meter may be calibrated theoretically. This requires internal inspection of the pipeline to ensure there are no deposits, scale or erosion, and then caliper measurement of the inside of the pipeline and the diameter of the throat or orifice. Otherwise, if the internal condition is good and the meter's serial number can be traced, the maker may provide a calibration curve.

If the existing meter is of the pitot type, calibration may be possible provided the pitot can be moved across the full horizontal and vertical diameters to record accurately the flow profile. The meter can then be calibrated theoretically over the full working flow range. The averaging pitot may have advantages in this respect.

If the existing meter is of the mechanical type (helix or similar), its performance will depend on regular, efficient maintenance. As for any other meter, its accuracy cannot be taken for granted. If facilities exist for regularly replacing moving parts and conducting workshop volume tests, such meters are very satisfactory and may be retained. However, if the water carries sand or grit, or if frequent shortage of supply results in exposure to air, such meters are not only expensive to maintain but are unreliable and can be very inaccurate. Even where maintenance is good, it is becoming very costly; this alone may justify replacing these meters.

Where new production meters are to be installed, the selection of the appropriate type or types of meter is readily given by the algorithm in Figure 2.2. In general, the more modern electromagnetic and ultrasonic meters, both with electronic conversion units, are more accurate over a wider range than the traditional orifice, venturi, or pitot meters and require little or no maintenance. They appear to have a useful life well in excess of 10 years. The investment cost for such meters may be somewhat higher than for orifice meters. They also require a source of external power, which entails a very small operating cost; but this is normally more than offset by very low maintenance costs. Where it is impossible to shut off a pipeline for a few days to allow a meter to be fitted, under-pressure installations may be satisfactory, but some accuracy has to be sacrificed.

In certain circumstances (fully described in Section 6), it may be more appropriate to use an existing open channel meter or install a new meter of this type.

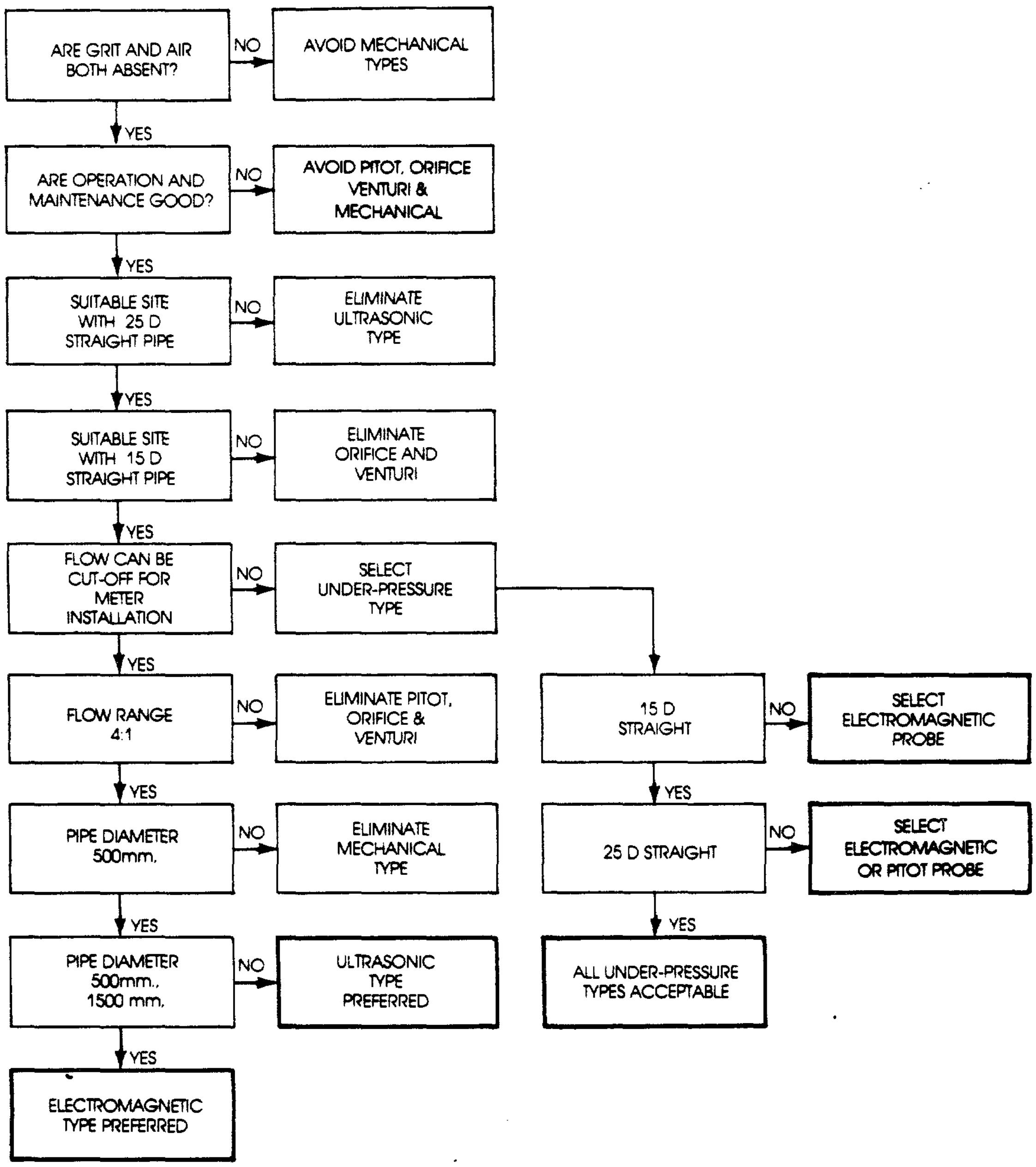
When the most suitable type or types of source meter are determined, outline specifications can be prepared and prices obtained for supply and installation. Such bids may also be required to include contracts for annual maintenance to cover existing meters as well as new ones.

2.3 District Meters

When the sources of water are all metered with sufficient accuracy and the large consumers' meters have been checked for accuracy, the smaller domestic meters have to be treated similarly. (Selection of small meters is excluded from these guidelines).

A full appreciation of the operation of the system of supply and the beginning of a logical control of U.F.W. demand the installation of district meters. Such meters are required initially to measure inflows and outflows from service reservoirs. These will normally indicate the flow to each pressure zone and each major geographical area. Such districts may be successfully broken down into smaller areas so that, by test isolation if not at all times, the flows to all parts of the system can be checked regularly and any unaccountable changes investigated.

Figure 2.2 - New Source Meter Selection Diagram



Note: This figure is a quick reference guide but the selection proposed may not indicate the only choice in particular circumstances. For careful selection a reading of the full text is advised.

All the meters required for such purposes normally have to operate over a wide range. Historically, in developed countries, helix-type meters have been selected for this purpose, since they have an acceptable accuracy over a wide range, may be readily installed in remote situations, and require no input of external power. They are not necessarily required to provide records continuously, but only at selected times, to determine daily flows or variations in flow rate during diurnal or weekly periods. They are usually best installed with a bypass.

In recent years, the high cost of regular replacement, servicing, and calibration has made such meters less popular; many are being replaced by electromagnetic and ultrasonic meters.

In developing countries, operating conditions are more difficult, since sand, grit, and rust particles (which occur regularly in the distribution networks) demand frequent cleaning of strainers and may cause blockage and erosion of moving parts, even when strainers are used. The networks often contain air, which causes inaccurate registration of water flow. Generally, good maintenance is not easily achieved and, as a result, such meters cannot easily be kept operating.

The preferred type of meter for district installation in less developed countries may therefore be electromagnetic or ultrasonic. Any external electric power that is available may be subject to repeated and extended breakdowns, but this difficulty can be overcome by incorporating rechargeable batteries in the circuits.

The difficulty still to be overcome is the need for protection from the elements, vandalism, and theft. Sealed watertight protection is essential, and some equipment must be sited where there is no risk of flood damage.

Designs are constantly changing, and floodproof equipment, battery-powered and vandal-proof, may become available in the future. In the meantime, district meter installations may be restricted to sites where adequate protection can be provided. At present, electromagnetic meters are preferred to ultrasonics for this application, because of lower cost (except in the very large sizes) and less difficult pipework geometry and installation conditions.

2.4 Bulk Supply Meters

These meters are in a special category because they are required to indicate sales of water between two water authorities. They are normally well protected and their operation does not present any difficulties.

They are usually well maintained in order to satisfy the interests of both parties. If large (more than 300 mm. diameter), they may be of the orifice/venturi type, but otherwise are likely to be of the helix type.

In spite of close attention by two parties, their accuracy may still be open to serious doubt, particularly if they are of the orifice/venturi type and the operating range of flow greatly exceeds 4:1. Calibration is essential; where this cannot easily be undertaken, there may be good reason for replacement.

Given adequate protection, regular attendance, and no problems with power supply (which might even be a simple battery), the preferred new or replacement meter for this application is the electromagnetic type.

2.5 Institutional Arrangements

2.5.1 Organization

Although this subsection appears last, it calls for continuing attention from the outset of any metering program. Traditionally, metering has almost always been considered only in the context of sales, but since it is the most important aspect of control--not only of U.F.W. but of the whole supply system--it calls for a much broader approach.

An immediate review is required of all aspects of existing metering, including arrangements for meter reading, meter changing, refitting, testing, statistical processing and billing.

Although these guidelines concern only large meters, whether for consumption or production, a review of metering must be all-embracing in order to ensure the best future metering practice. Because this demands the coordination of all metering, the existing organization must be examined to determine how such coordination can be achieved.

No improved metering program can be obtained without establishing the necessary financial input. This is the first priority. It may well be that the increased revenue resulting from changes in metering of sales can be applied partially to improvements in production and district meters. Whether or not such immediate results can be achieved, there is little doubt that in most authorities, economies derived from improved control of U.F.W. justify installing production and district meters. Investment and maintenance budgets must be established to cover the costs of installation, maintenance, and replacement of all such meters.

One of the most important tasks is to motivate the employees to believe that proper measurement of supplies and control of waste are of the utmost importance. Effective management in supply and distribution should be rewarded by salary levels that reflect their value to the authority. Increasingly, these employees will be using the latest technology and will be technically better informed than the managers in other sections, including the design of new works. Moreover, they will be the repository of most of the knowledge about the detailed operation of the water supply system.

It is essential that the employees concerned know that their skill and efforts are recognized by the head of the authority.

2.5.2 Meter Service

Traditionally, servicing of meters is done in-house and confined to consumers' meters. Maintenance and servicing of production and district meters, if any, is perfunctory and unorganized, except in the most efficiently operated organization. Existing practices must be critically reviewed. Attention must be paid to communication of information from meter readers to management and to the use of such data for statistical purposes. Information is particularly required about the frequency of changing large consumers' meters, the percentage in operation at any time, and the average accuracy of all such meters, as determined by sample tests. Following such review, potential increase in revenue from improvements in servicing may be estimated and future policy thereby determined.

2.5.3 Equipment

Study of current practice in refitting and testing of the larger meters will determine whether accurate testing should be carried out and what methods should be employed. The meter fitting shop may be well organized for dealing with small domestic meters, but not with larger meters. Provision of additional equipment and associated facilities has to be considered and facilities for maintaining any new production and district meters must be contemplated. Otherwise, maintenance contracts may be more economical.

2.5.4 Manpower

A study is required of the quantity and quality of labor available to service large meters. Methods should be explored for recruiting the highest possible level of ability from all professional and technical sources. If suitably skilled employees are not available for employment directly by the authority, maintenance might be undertaken satisfactorily by either locally-based contractors or the manufacturers.

2.5.5 Training

Where sufficiently able, local manpower appears to be available, satisfactory maintenance may be achieved by obtaining training facilities, either from the companies providing the meters or elsewhere. Modern electronic meters require little maintenance, but are usually of a kind not normally available in water undertakings in developing countries.

2.5.6 Specialist Assistance

Meter manufacturers and other specialized companies may undertake maintenance and operational training of the authority's personnel or may operate maintenance contracts themselves. Even when skilled labor and equipment seem to be available, arranging for meter maintenance by contract has to be considered before embarking on any metering improvements. Such contracts could be limited to large meters. Separate contracts may be necessary for mechanical and electronic meters. A contract that provides for maintaining and reading all meters, and even billing and collecting revenue, might be feasible and economical.

Consultants may be called in to undertake a study of current practice and possible improvements in all aspects of metering, either by the authority's employees or partially or wholly by contract. For details of specialized sources, see Annexes 2 and 3.

SECTION 3

AVAILABLE METERS

3.1 Closed Pipeline Types

3.1.1 Differential Pressure (D.P.) Meters

This group includes venturis, dall tubes, nozzles, and orifice meters, all of which may be integral with the pipeline or formed by special inserts. Also included are the various types of pitot meter. Some of these meters are shown in Figures 3.1, 3.2, and 3.3.

The orifice/venturi meters operate on the principle that, for a change in velocity, and hence kinetic energy, of the flowing liquid resulting from restriction in the pipeline, there is a corresponding variation in the pressure energy. The pitot meter converts the kinetic energy of the flow to hydraulic pressure and measures the difference in the total pressure obtained and the static hydraulic pressure. In all of these meters, the pressure difference is proportional to the square of the velocity. This relationship limits the range of accurate flow measurement of all meters in this group.

In the past, the range was taken from maximum to 10 percent of maximum flow rate, but less if conditions were not ideal. More recently, experts in the field have stated that the range should be only from maximum to 25 percent of maximum flow rate to ensure accuracy of ±5 percent.

Traditionally, the differential pressure has been measured by mercury manometer. In developing countries, repeated failures of such meters have frequently resulted either from ignorance or lack of care of the operators, causing a loss of mercury from the manometer.

With the introduction of pressure transducers and electronic signal conversion of the recorded differential pressure, this difficulty has been overcome. Provided the meter characteristics are known or can be traced through the manufacturer from the serial number, such a meter can be recalibrated to suit electronic equipment. This must only be undertaken if no changes have occurred in the pipe configuration since installation or in the pipeline condition due to scale, sediment, corrosion, or erosion.

Given appropriate flow conditions, such meters might now be reconditioned and successfully maintained for future operation. Although use of transducers simplifies operation and maintenance, inherent inaccuracy at low flows remains because of limitation in the operating range of the differential pressure cells.

Accuracy is considerably affected by pipe configurations such as valves and bends. Manufacturers have always recommended installation with at least 10 diameters of uniform straight pipe upstream and 5 diameters downstream, but this is only a general guide; the dimensions depend very much on the type of upstream disturbance. See Section 5.6.

Figure 3.1 - Venturi Tube

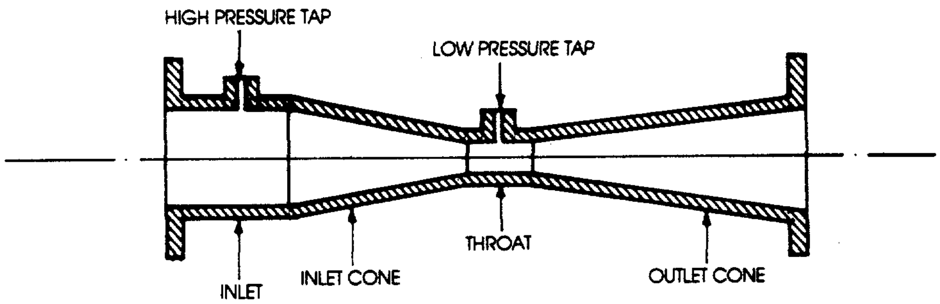


Figure 3.2 - Square-Edged Orifice Plate

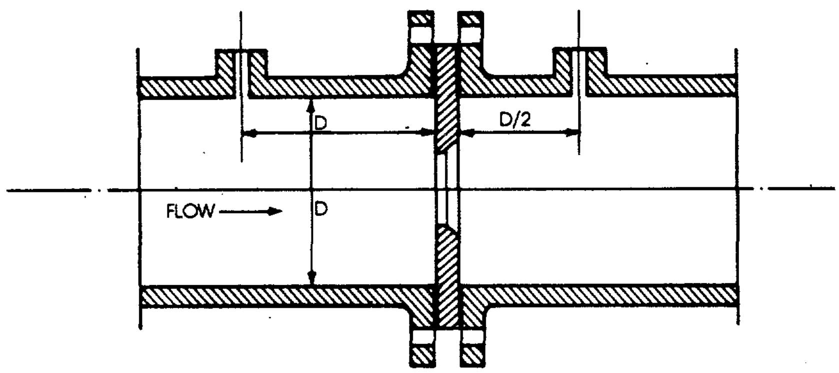
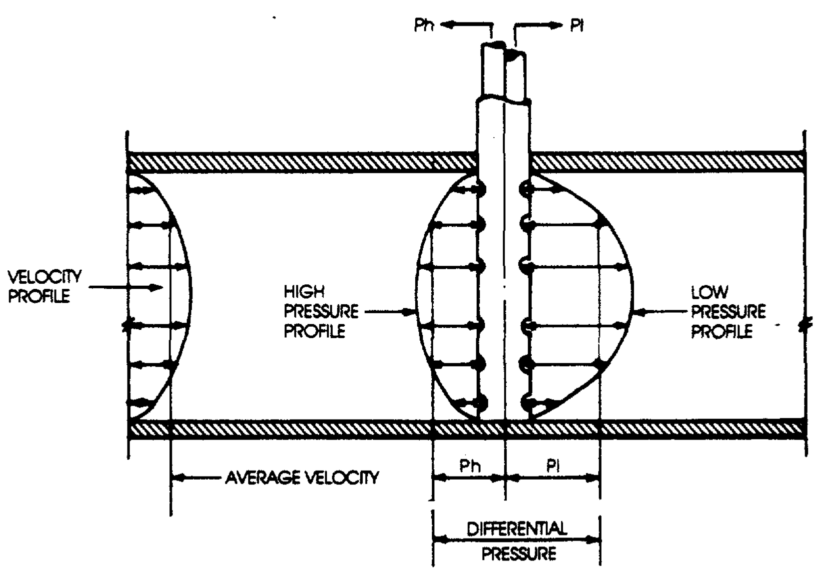


Figure 3.3 - Averaging Pitot Meter



3.1.2 Electromagnetic Meters (See Figure 3.4)

Developed since World War II, these meters depend on the principle that when a conducting fluid moves through a magnetic field, a voltage is induced perpendicular to the axis of flow and directly proportional to the flow velocity. Electrodes measure the induced voltage and this is converted electronically to flow velocity or (by reference to the pipe cross-sectional area) to flow quantity. These meters can be used in extremely large pipes (up to 2,000 or 3,000 mm. diameter) and can sustain the high pressures normally experienced in waterworks practice. Their accuracy is not affected by high levels of suspended solids. They offer no restriction to flow and produce no pressure loss (other than the equivalent length of straight pipe).

The relationship between induced voltage and velocity of flow being linear, the effective operating range at acceptable accuracy is much greater than for differential pressure meters.

In the original design, they operated using an alternating field, but subsequet developments have changed this to a D.C.-pulsed field. This allows automatic zero adjustment to be obtained without stopping the flow. They must be constructed with a suitable pipe lining to avoid short circuiting of the sensor electrodes.

Because these meters measure average pipe flows rather than flows at a single point, they are well adapted to measure accurately where the flow profile is elongated or disturbed by pipe roughness or upstream interferences such as bends.

Generally these meters require a length of uninterrupted straight pipe of only 5 diameters upstream and 2 diameters downstream to ensure reliable accuracy.

Because the meters are subject to interference from other electrical equipment that may be nearby, adequate insulation is necessary. To provide insulation under all conditions, a fully submersible specification is usual. Both the metered liquid and the meter body must be grounded. Where pipelines have current flowing through them (cathodically protected), the meter should be bypassed by a surrounding bond. If the pipeline has an insulating lining and is nonmetallic, ground contact flanges should be fitted between the meter and the pipeline.

The meter usually consists of a flanged metering tube made from non-magnetic material and/or lined with an insulating material. Two field windings are placed opposite each other and a laminated yoke encapsulates the center of the metering tube. Two measuring electrodes are fitted diametrically opposite each other and flush with the inside of the tube-lining material. The flux-sensing coil is placed in the magnetic field between the upper-field winding and the tube. The complete detector head is enclosed in a housing generally made of glass-reinforced plastic.

Liners can be obtained for almost all types of fluid measurements, including corrosive liquids, but for clean water applications, the

Figure 3.4 - Principle of Operation of a Magnetic Flowmeter

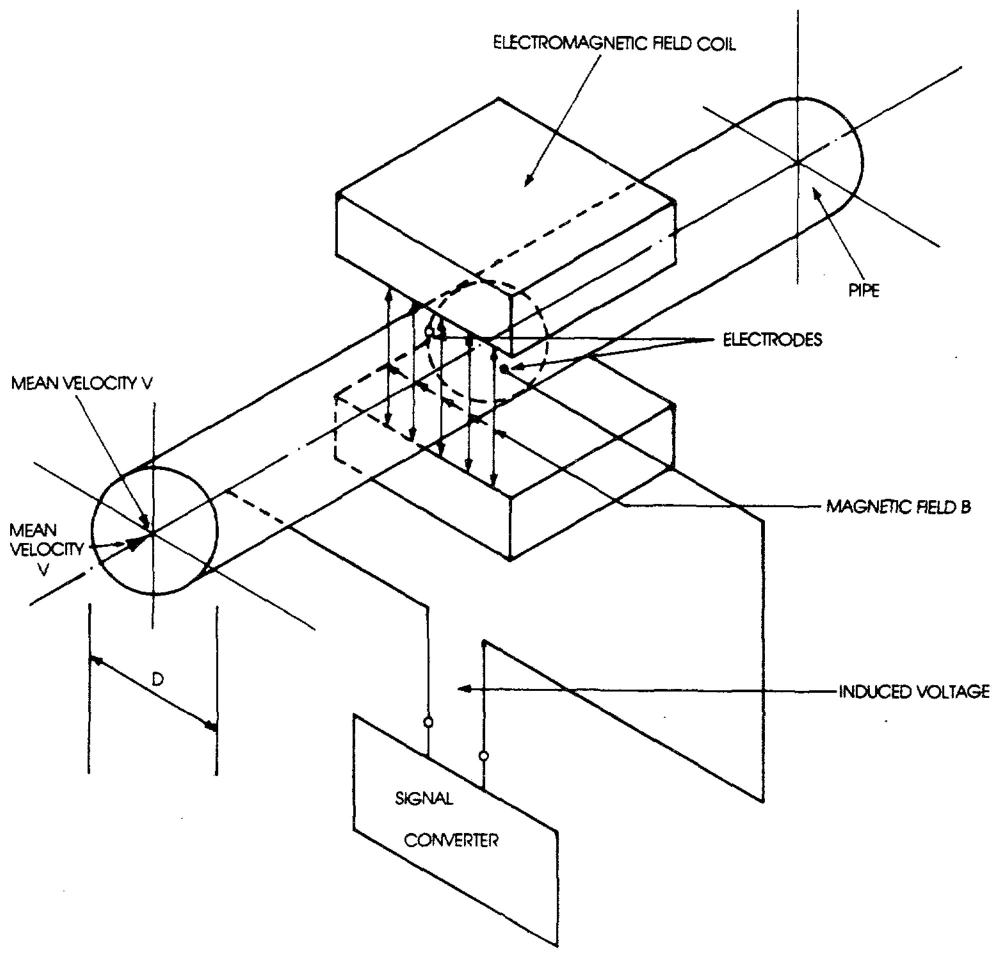
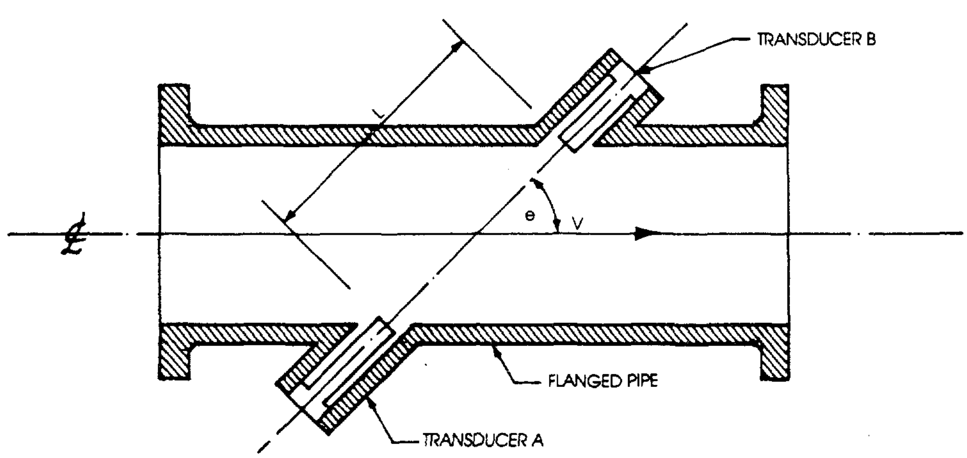


Figure 3.5 - Ultrasonic Flowmeter - Transit Time



Liners can be obtained for almost all types of fluid measurements, including corrosive liquids, but for clean water applications, the material is usually neoprene, EPDM, or PTFE. Usually the pipework installation has a totally waterproof, protective enclosure.

Whether the field system is a D.C.-pulsed field or an A.C. field, a signal converter is required from the induced voltage output of the meter. The D.C. pulse is recommended for low power consumption and high accuracy. The A.C. pulse is necessary for high solid content and low electrical conductivity, but it is not normally required for a treated water supply.

The electronics usually enable a flow-velocity range to be set, a dual range to be chosen, or a variable range to be continuously adjustable. The output analogue voltage is converted to a milli-amp signal or a milli-amp frequency pulse for computer or data logger connection or electro-mechanical counter output.

A calibrator is required, depending on the converter used, to check the performance of the converter. Frequently, the calibrator is an integral part of the converter. It is used to simulate the voltage signals and can also be used to calibrate in situations where the flow signal has been degraded by adverse site conditions. Many variations of converters exist, and a micro-processor is often employed with the meter "constant" to provide flow information according to preference.

Each manufacturer has a range of converters to suit the customer's needs; a decision must be made on the refinements required. Quality manufacturers of meters will supply quality converters, and the best option will normally be to buy for the least maintenance. In dirty water conditions, the detector electrodes can lose accuracy due to deposits. An electrode cleaning unit can be used to remove deposits by imposing an alternating voltage on the detector heads, removing deposits by electrolysis; or an ultrasonic electrode cleaning head can be employed to remove deposits by resonance. Electrode cleaners are probably not required for normal treated water.

3.1.3 Ultrasonic Meters (see Figure 3.5).

An ultrasonic flow meter has only become practical within the past 20 years, with the development of transducers. There are two main types of ultrasonic meters, one depending on the "Doppler" effect, a frequency shift that occurs when a sound wave bounces off a moving object. The Doppler-type meter can be used only if the fluid to be measured contains particles or bubbles from which the sound waves can be reflected; it is therefore suitable for dirty water applications and sludge. It is not generally suitable for treated water and will not be considered further.

The second type of ultrasonic meter is the "time-of-flight" meter, which is designed according to the theory that a sound wave traveling in the direction of flow of a fluid requires less time between one fixed point and another than a wave moving in the opposite direction.

The usual design provides two ultrasonic probes located on diametrically opposite sides of the metering tube at an angle to the tube's center line. Both probes can transmit and receive ultrasonic waves. Usually this is done alternately, thus effectively removing the velocity of sound from the calculation. The difference in transit times clearly is an indication of the flow rate of the fluid being measured. A signal converter uses the difference in time between transmission and reception to calculate the mean-flow velocity. The meter can be uni- or bi-directional and, for additional accuracy, twin time-of-flight tracks may be used to allow for non-uniform velocity profiles.

Considerable accuracy can be obtained with factory-made metering tubes calibrated under works conditions. Ultrasonic flow meters can also be obtained in a clamp-on pipe form or a kit for welding to an existing pipe. Their metering accuracy is dependent both on the accuracy of setting out and site welding and on the ability to establish the other variables, such as pipe thickness, precise diameter, shape, and condition.

The accuracy of ultrasonic flow meters is more susceptible to upstream disturbances than that of electromagnetic meters. Manufacturers recommend up to 15 diameters of straight pipe upstream and 5 diameters downstream for dual channel meters. For single channel instruments, the upstream straight length should be 20 to 50 diameters.

3.1.4 Rotary Vane (Helix) Meters (See Figure 3.6)

This general heading covers all meters of the full-bore type with a rotating propellor vane or Helix, whether this is fixed in the horizontal or vertical axis.

There is some confusion over the names used for these meters--they are often called turbine meters, which they resemble very closely. The fundamental differences are in the quality of construction and therefore cost, and in the means of measuring the quantities. Rotary vane meters are made to a less exacting standard than turbines (see 3.1.6). They measure the volume passed in unit time not directly, but by inferential means. To measure a flow rate, they have to be fitted with a counting device on the rotating registration dial so that the revolutions are equated to the rate of flow.

As used in this document, the term rotary vane meter will include Helix, Woltman, and propellor types.

Rotary vane meters are generally used for pipes of 15 mm. to 500 mm. in diameter and flows up to 1815 m^3/hr. This type of meter has a very large capacity for its size with very little loss of head. Provision for withdrawing the vane and counter mechanism complete is a normal facility that greatly assists maintenance and calibration.

Historically, these meters all derive from the designs of Reinhard Woltman in the 18th century; many still retain his name in their description.

The meter mechanism is usually of the dry type, through a magnetic coupling between the rotation of the vane to the gear train of the counter mechanism. The flow is proportional to the kinetic energy, and hence the rotation of the vane. Thus, each meter needs to be individually calibrated at the factory. The modern meter can be fitted with an electronic pulse for use with a data logger, and some can be bi-directional, although the flow in the reverse direction is not so accurately recorded.

Meters up to 300 mm. require 3 diameters of straight pipe upstream and from 400 to 500 mm. require 5 diameters. There should be no abrupt contractions immediately downstream of the meter.

The range is 10:1, adequate for all normal applications. Where this range is significantly exceeded, these meters are normally replaced by combination meters.

3.1.5 Combination Meters

A combination meter comprises a rotary vane meter with an integral, non-return changeover valve and incorporates a bypass containing a small diameter meter, also with an integral, non-return valve.

At small flows, the changeover valve remains closed; all the flow goes through the small meter and is thus accurately measured. As soon as the flow reaches a predetermined level, the changeover valve opens due to differential pressure, and the flow is recorded by both meters. The small meter is usually between 15 and 30 mm. in size and of the type generally used for domestic supplies.

3.1.6 Turbine Meters

These meters are similar to rotary vane types. They consist of a multi-bladed rotor supported by upstream and downstream bearings, supported from the pipe walls. Except for a very small clearance, the blades sweep the full diameter of the bore of the meter.

The kinetic energy of the liquid turns the rotor at an angular speed proportional to the main axial velocity of the liquid. A pick-up coil is mounted in the casing of the meter, and the passage of the rotor blade past the coil induces in it a pulse which, after amplification, is fed to a pulse counter. For greater accuracy, several pick-up coils may be used around the diameter.

This meter is again inferential and has to be calibrated, but it can be used to measure flow rate as well as volume by measuring the speed of the rotor.

These meters can be made extremely finely and accurately and are commonly used for custody fiscal measures. This means that they tend to be much more expensive than rotary vane types and more susceptible to rotation failure, because the smaller clearance between pipe and blade may become blocked. They are not generally used for water supply purposes since their high cost is not warranted.

Turbine meters are affected by the shape of the upstream velocity profile and should be preceded by straight pipe of at least 10 diameters, preferably 20. There should also be 5 diameters of straight pipe downstream.

3.1.7 Under-Pressure Installations

Although the instruments described here are for under-pressure installation, they can, of course, be installed in shut-down or zero-pressure situations if the form of meter has been selected as the most suitable for the particular purpose. Indeed, some pitots, although similar to under-pressure models, have to be fitted under shut-down conditions. However, it is assumed that the various types of meter described in the following sections may be chosen mainly because access to the point of measurement is not available, except under normal working (i.e., pressure) conditions.

Many manufacturers supply under-pressure tapping equipment. For iron or thick steel pipes at normal working pressures, the tapping is generally made directly into the pipe wall. This method is not satisfactory if the pipes have thin walls (because there are not enough threads to prevent tapping blowouts) or if they are made of plastic or asbestos cement. In these cases, a saddle must be fitted to the main to take the tapping before the main is drilled under pressure to receive the insertion instrument. If saddles are used, the point at which the meter enters the pipe is more difficult to establish, and the calibration of the main has to be done more carefully. Flanged connections already on the mains (such as at hydrant points) can also be used, and welded bosses are an alternative for suitable steel pipes.

For under-pressure installation, a ferrule with tapered thread is inserted into the main and a gate valve is attached that then receives the body of the insertion flow-meter probe. With the gate valve open, the insertion meter can be moved through it into the pipe, to measure either the velocity at the center or the mean velocity where it is calculated to occur.

Unless an averaging pitot is being installed, the method employed for accurate results with velocity probes is to measure the mean velocity with a number of local velocity measurements traversing the full diameter of the pipe. The instrument may also be used to obtain an accurate pipe bore. Measurements should be made along at least two diameters perpendicular to each other--preferably along three diameters equally spaced around the pipe's circumference. These measurements are integrated to give a fairly accurate estimate of the mean velocity in the pipe.

If the flow regime and velocity profile are reasonably consistent, so that the point where the probe is positioned continues to measure the mean velocity, an insertion meter can be used to obtain continuous readings. These are ideal for survey work.

They give quick results if the surveyor estimates pipe size, takes a reading at the center of the bore, and assumes that this represents (about)

1.2 times the mean velocity. Clearly, the accuracy in this case is of a low order.

(a) Insertion Turbines

In turbine meters, the rate of rotation is directly proportional to the fluid velocity; the rotor is either directly or magnetically coupled to give a counter reading or pulse output. This frequency-transduced signal is amplified and used electronically to provide a flow rate indicator and/or recording system. Since this type of meter is frequently used for survey purposes, it is common for the equipment to have the option of battery operation. As with all types of turbine meter, it has to be calibrated for site conditions.

For very low-velocity situations, it is important that the friction and drag be minimal to ensure accurate readings. Because of the delicate nature of the apparatus required to provide low-flow results, it is susceptible to bearing wear, impeller wear, and mechanical damage, especially in any kind of abrasive situation. Some turbine or propeller types are not recommended for velocities below 0.3 m/sec.

(b) Pitot Meters

A simple pitot meter comprises a single orifice facing the stream direction and measuring the total pressure (velocity pressure plus static pressure) in the flowing liquid, together with one or more remote orifices that measure the static pressure. The latter may be in the probe or in the pipe wall.

A more sophisticated type of pitot is the multi-orifice, designed to completely cross the pipe diameter and measure the velocity at several points across the diameter. This orifice meter has a true static pressure sensing hole. The multi-ports permit the velocity profile to be measured accurately across the pipe; provided the profile has the same shape when viewed from any direction, a true mean velocity is integrated accurately. The device allows for changes in velocity profile that may be brought about by changes in flow rate.

The pitot meters suffer from the disadvantage of all differential pressure devices: they relate this pressure to velocity by a square-law function, thus making it difficult to measure low velocities with accuracy.

(c) Electromagnetic Probes (See Figure 3.7)

Electromagnetic velocity probes or insertion meters are essentially an inside-out version of the electromagnetic flow meter and are usually used to measure the flow velocity at a point. To improve accuracy, it is possible to use two or more probes, equally spaced within the pipe diameter to measure average velocity more precisely. Accuracy is considered as ± 3 percent of reading under perfect conditions for a single probe in a pipe up

Figure 3.6 - Rotary Vane (Woltman) Meter

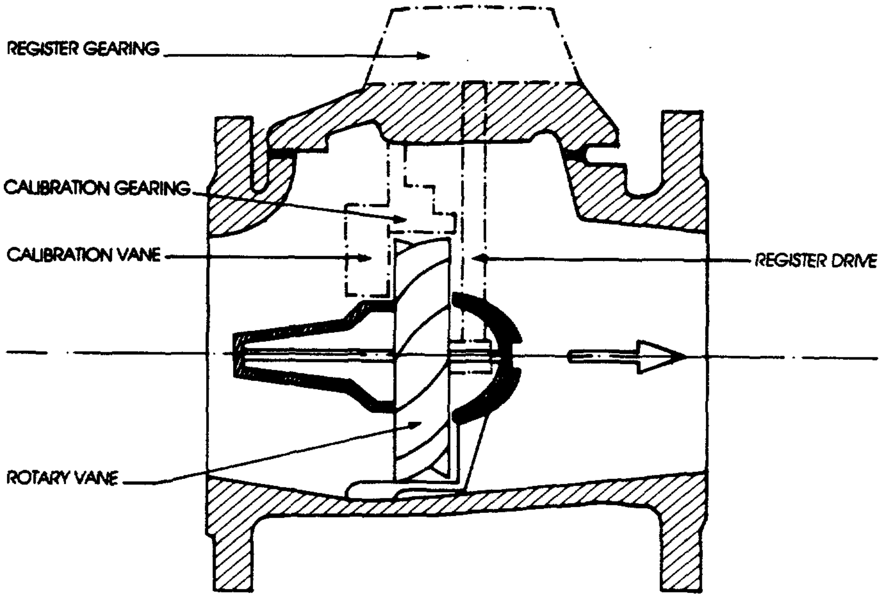
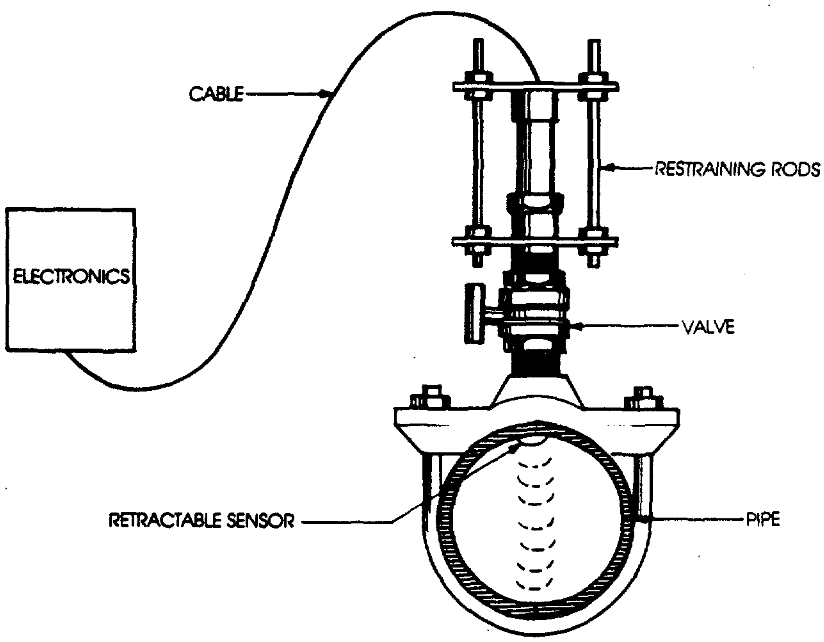


Figure 3.7 - Insertion Electromagnetic Meter



to 350 mm. diameter, but manufacturers recommend two probes for pipes above 400 mm. diameter and four probes above 1000 mm. diameter. Some of these meters have a central orifice in the probe aligned axially. In effect, this acts in the same way as the full magnetic meter, because the flow through the orifice surrounded by the field coil is proportional to velocity. In other types, the probe is a shaped blade, again only measuring point velocity by the effect of the fluid flow over the magnetically induced field.

(d) Ultrasonic Probes

These meters are not strictly probe velocity meters at all, but ultrasonic time-of-flight probes can be inserted by under-pressure methods. However, most installations of this type actually require shut-down and accurate welding of the ultrasonic sensors to the pipe line. This has to be done with as much accuracy as possible, using alignment sets and tools provided by the manufacturer. If the pipeline is made of a material other than steel or ductile iron, we recommend the clamp-on type of ultrasonic meter.

With under-pressure installation of ultrasonic insertion-probe meters, it is difficult to place a fairly bulky attachment on the pipe accurately enough to position the sound sensors at the correct angles. So far we have found only one manufacturer who supplies such equipment. The procedure is to tap the pipe normal to the axis and insert angled sensors.

3.1.8 Vortex Shedding Meters

These meters rely on the insertion of an element into the pipe flow to create vortices. The vortices cause periodic fluctuations of velocity and pressure, and these provide a pulse output proportional to flow rate. While these meters are now widely used in industries with factory production, they have been used only experimentally in the water industry. In order to provide accurate results, the fluid velocity must be higher than is normal in water supply, and they must be installed in conditions completely free of extraneous turbulence. This degree of precision in installation is not generally possible in the water industry, so at this point we cannot recommend them for general use.

3.2 Open Channel Types

3.2.1 Weirs and Flumes--General (See Figure 3.8)

Weirs and flumes develop a head that is used to measure the flow rate, which is established from physical dimensions without calibration. The head is measured directly from the level of the liquid upstream of the device, the secondary instrumentation directly giving the flow volume regardless of density. The mathematical relationship is exponential but varies according to the geometry of the weir or flume. Designs are clearly defined in International Standards; for weirs, ISO 1438 and for flumes, ISO 4359. Provided the standards are rigorously followed, the meters are theoretically accurate to ±1 percent over a very wide range; but in practice, accuracy is limited by uncertainty of head measurement to about ±5 percent.

3.2.2 Weirs

Weirs are the simplest, least costly, and probably most common primary measuring devices for open channels. They are essentially surface apertures in bulkheads over which the liquid flows. The common types are:

(a) Triangular or V-notch;

(b) Rectangular (with or without end contractions);

(c) Compound (rectangular and V-notch); and

(d) Trapezoidal.

Each type of weir has an associated equation determining the head flow relationship, the head being the difference between the level of the pool upstream of the weir, measured at the correct distance (see below), and the horizontal crest of the weir--or, in the case of a V-notch, the bottom, or vertex, of the V. The top edge or crest of the weir plate is thin (1 mm. to 2 mm.), cut square and beveled on the downstream face at not more than 45 degrees to the face of the plate. Weirs previously referred to as sharp-crested are now more commonly called thin-plate weirs (long-base or broad-crested weirs are rarely used in waterworks). The plate must be truly perpendicular and square to the sides of the channel. The edge of the weir must be truly level, or, in the case of a V-notch, the edges must subtend equal angles to the horizontal. The nappe must fall clear and be ventilated if necessary to prevent adherence to the plate.

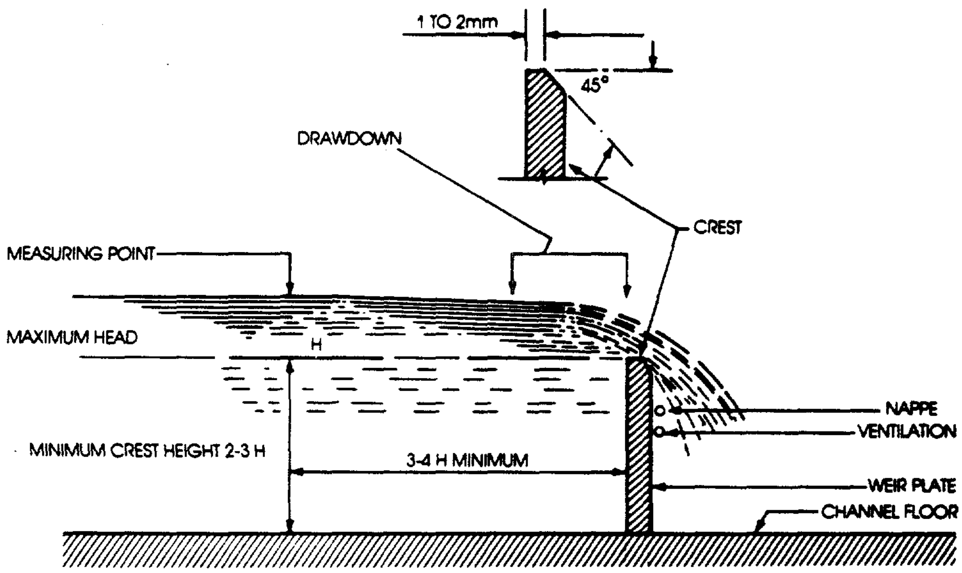
A slight drop in the liquid surface occurs upstream of the weir, beginning at a distance of at least twice the head. This is called the drawdown (or sometimes the surface contraction) of the weir. To avoid errors caused by drawdown, the point at which the head is measured must be located between three and four times the maximum head upstream of the weir face. At a greater distance, there is a potential error due to the normal surface gradient associated with the velocity of approach, which should not exceed 0.1 m/sec. This is normally achieved, provided:

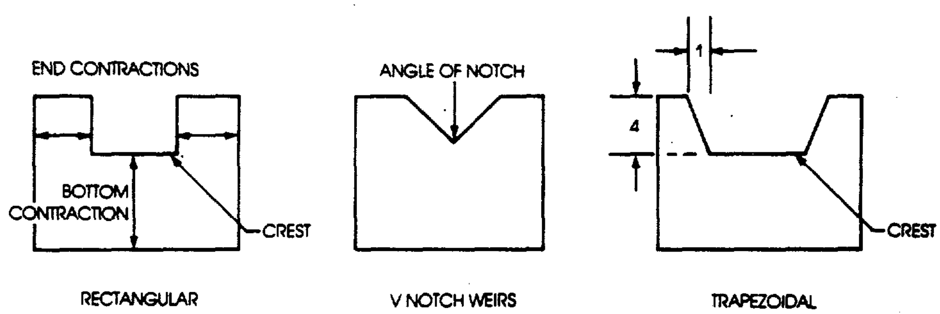
(a) The height from the channel invert to the crest is at least twice the maximum head over the crest, with a minimum of 310 mm.; and

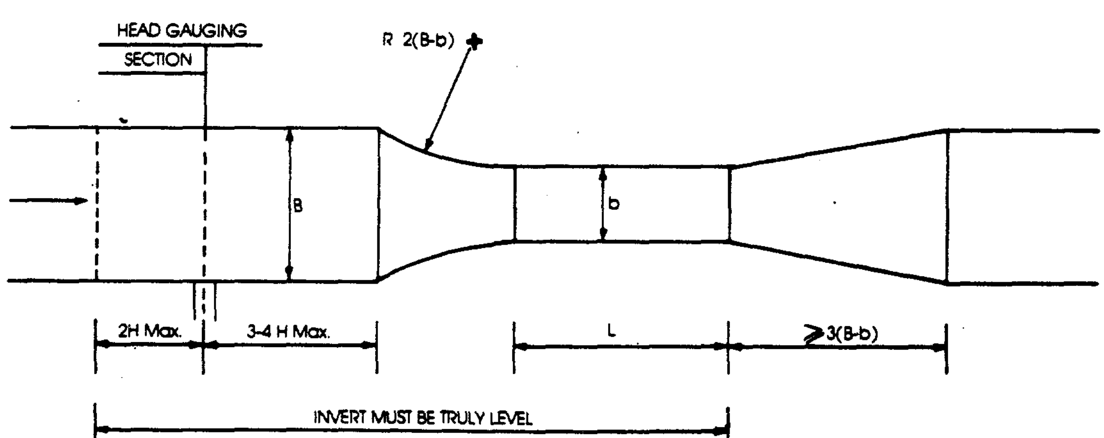
(b) The channel cross-sectional area exceeds eight times that of the nappe at the crest.

Although weirs are comparatively easy to construct correctly and convenient to use, they are not always suitable for channel flow measurement.

Figure 3.8 - Weirs and Flumes







Weirs are not at all suitable for low-gradient channels where the head loss is critical.

They are also not suitable for water carrying significant quantities of silt or grit in suspension, which will be deposited in the approach channel or pond upstream of the weir and destroy the conditions necessary for accurate flow measurement.

If weirs have to be used in such conditions, the deposits may be removed regularly by flushing through an opening formed in the bulkhead below the weir. A gate normally closes such an opening, but care must be taken so that no leakage occurs while the gate is closed. Care must also be taken to ensure that the gate fixings do not interfere with the flow pattern or the nappe so as to affect the head/ discharge relationship.

(a) V-notch (Triangular) Weirs

The bottom of the V-notch, triangular weir is the vertex. The included angle of the notch most commonly used is 90 degrees, although V-notches with angles of 60 degrees, 45 degrees, 30 degrees, and 22½ degrees are also used in the USA. ISO 1438 provides for notches where the tangent of the half-notch angle is 1.0 (90^o), 0.5 ($53^o8'$) and 0.25 ($28^o4'$). As the included angle becomes smaller, the difficulty of producing the correct geometry at the vertex increases, and, in the low head flow range, the head/discharge relationship becomes unreliable as the capillary effect restricts the flow at a surprisingly high head.

The 90-degree V-notch is an accurate flow-measuring device particularly suited to low flows for which the head is greater than for rectangular weirs. It is the best weir for measuring flows less than 30 l/sec, but it retains acceptable accuracy up to 300 l/sec. The effective range for a discharge coefficient accuracy of ±1 percent is 100:1 (though other factors affecting the meter's accuracy may reduce the overall accuracy to ±2 percent and the range to 20:1). The minimum head should be at least 60 mm. to prevent the nappe from clinging to the weir; the maximum head is limited to 610 mm. to assure accuracy of the head/flow relationship.

The minimum distance from the top edge of the V to the side of the channel is twice the maximum head over the weir. The minimum depth from the vertex of the V to the channel invert is also twice the maximum head over the weir. (Other limits are imposed by ISO 1438).

(b) Rectangular (Contracted or Suppressed) Weirs

Rectangular thin-plate weirs are of two types. The first consists of a rectangular opening with a width significantly less than the channel width. This is called a contracted rectangular weir, because a curved flow path or contraction occurs within the nappe of narrower section than the weir width. The extent of the contraction depends on the width of the weir in relation to the width of the channel.

Where the channel bed and walls are remote from the weir crest and sides, the channel boundaries do not significantly affect the contractions, and they are then referred to as fully developed. In the second type of rectangular weir, end contractions are completely suppressed by extending the crest across the full width of the channel. The sides of the channel then act as the sides of the weir, and there are no lateral contractions. This type is called the rectangular full-width, or suppressed, weir.

The minimum head on a rectangular weir must be 61 mm. to prevent the nappe from clinging to the crest, and the maximum head is normally limited to half the crest width. These weirs must be vented if necessary to ensure that the nappe falls clear of the weir plate. Rectangular weirs are used to measure flows greater than those suitable for a V-notch, usually a minimum of 200 l/sec., and the opening is designed to permit the above minimum and maximum operating heads. Although the accuracy of the discharge coefficient may be ± 1 percent, the accuracy of the meter may be ± 5 percent. As for V-notches, both the depth from crest to channel invert and the distance from the side of the weir to the side of the channel must be at least twice the maximum head over the weir.

(c) Trapezoidal Weirs

The trapezoidal thin-plate weir is similar to the rectangular weir with end contractions, except that the sides incline outwardly to produce a trapezoidal opening. When the end inclinations are 4 vertical to 1 horizontal, the weir is known as a Cipolletti weir, after the Italian, Cesare Cipolletti, who first proposed it. Although it is contracted, it discharges as though the end contractions were suppressed. Thus, no correction is required for the crest width and the discharge equation is simplified.

The Cipolletti weir offers a slightly wider range than the rectangular weir, but the accuracy of measurement is inherently less than in either the rectangular or the V-notch weir. The minimum and maximum recommended heads are the same as for the rectangular weir, as are the minimum dimensions between weir, channel walls, and channel invert.

(d) Compound Weirs

When a weir is required to measure larger flows than can be accommodated in a V-notch and yet have an extended range into the lower flows, a compound weir that incorporates a V-notch below the crest of the rectangular weir is used.

Though accurate for both very low and higher flows, this type of weir can be inaccurate for intermediate flows, where the flow over the rectangular crest is very small and the nappe is not free. Thus, it is of limited practical value for most applications.

3.2.3 Flumes

The second class of commonly used, open channel primary measuring device is the flume. A flume is a specially shaped open channel section providing a restriction in cross-sectional area, which may include a change in invert slope or a hump in order to reduce the downstream level. The restriction results in an increased velocity and a change in the level of the liquid, which provides a measure of the flow rate. Normally, a flume comprises a converging section to restrict the flow, followed by a throat section and a diverging section that assures that the downstream level of the liquid is less than in the converging section. In the preferred design, the flow rate is determined by measuring the head at a single point. The head/flow relationship may be defined either by test data (calibration curves) or by an empirically-derived formula.

A number of factors should be considered when selecting a flume to assure the optimum accuracy in flow measurement. The first is size. Because of a wide overlap in the range of flume discharges, it is possible to pass a given flow through any number of different-sized flumes. The choice requires consideration of other factors besides capacity and range, but, in the interests of economy, the smallest practical size should be adopted. It may be necessary to use a trial and error system, but normally selection is made on the basis of the original channel dimensions.

Most flumes in use today are of the following types: the Venturi, the Parshall, and the Palmer-Bowlus.

In order to avoid confusion with the closed-pipe meter, the Venturi type is now described as either the rectangular-throated or the trapezoidal-throated flume; the designs are covered by ISO 4359. International standards for the Parshall and the Palmer-Bowlus are still being drafted.

(a) <u>Rectangular- and Trapezoidal-Throated Flumes</u>

These flumes may be the best suited for use by less developed countries' water authorities because the dimensions are simple, clear, and geometrically similar for different sizes, so that accurate construction is readily achieved. Generally, their accuracy is acceptable over a very wide range. If the theoretical accuracy is not the highest, this may be only of academic concern, because, as with any open channel meter, it is limited by the accuracy of dimensions in the construction and by the measurement of head (see Section 3.2.1).

(b) <u>Parshall Flumes</u>

The development of Parshall flumes was based on extensive and meticulous research, resulting in the production of detailed discharge tables for every standard size. The sizes are designated by the throat width and are classified as very small (25 mm. to 75 mm.), small (150 mm. to 2500 mm.), and large (2500 mm. and larger). For a given throat diameter, all the other dimensions are rigidly prescribed. Care must be taken to construct the flumes according to the dimensions given for each size because the flumes are not geometrically similar. For example, it cannot be assumed that a dimension in a 3600 mm. flume will be three times the corresponding dimension in the 1200 mm. flume. The theoretical accuracy in the head/flow-rate relationship in these flumes is exceptionally high over a wide range of 100:1 or more, but again for practical reasons, an overall accuracy of ±5 percent is the best that may be expected.

(c) Palmer-Bowlus Flumes (U-Shaped Flumes)

The Palmer-Bowlus flume was developed as a simple and effective flow measuring device that depends upon existing conduit slope and channel contraction. This type of flume arose from a desire for a primary measuring device that could be inserted into an existing conduit with minimal site requirements other than suitable slope.

This is a type of venturi flume characterized by a throat of uniform cross-section and with a length approximately equal to one diameter of the pipe or conduit in which it is to be installed.

Designed to produce a higher-than-critical flow in the throat, it is essentially a restriction in the channel. The flume is very often available in pre-cast form suitable for use in manholes, open-round, or rectangular-bottom channels.

It is useful as a temporary installation to provide flow data for calibration of an existing meter, or for determining flume size and equipment requirements for a permanent installation. Its advantages include reasonable accuracy of measurement, low energy loss, and minimal restriction to flow typical of all flumes. Its principal advantage is that it can be installed easily in existing conduits because it does not require a drop in the conduit invert. However, Palmer-Bowlus flumes have a smaller useful range of flow (20:1) than other flumes. Also, their resolution is not as good as that attainable with other flumes: a given change in flow rate produces a small change in head. Thus, the most sensitive head-measuring instrumentation is required to achieve acceptable overall accuracy.

Palmer-Bowlus flume sizes are designated by the size of the pipe into which they fit. For maximum accuracy, the size of the flume should be determined by the expected volume of flow. The ideal location for the level measuring point is at a distance 1/2 D upstream from the end of the throat section.

Before installation, it is important to consider a minimum and maximum downstream channel slope to assure proper flow.

(d) Flow Nozzles

The open-flow nozzle is actually a combination of a thin-plate or sharp-crested weir and a flume. It is designed to be attached to the end of a conduit flowing partially full and must discharge to a free fall. It can therefore be very useful for calibrating a closed pipeline meter where there is provision in the system for discharge to waste.

As with weirs, the design of a flow nozzle is such that a predetermined relationship exists between the depth of the liquid within the nozzle and the rate of flow. There are two designs of flow nozzles. (1) the Kennison nozzle, where the cross-section is shaped so that this relationship is linear; and (2) the Parabolic nozzle, where the relationship is a parabola, so that each unit increase in the flow produces a smaller incremental increase in head.

Open-flow nozzles are factory calibrated and offer reasonable accuracy, even under rather severe field conditions.

Parabolic nozzle lengths are roughly four times the pipe diameter, while Kennison nozzle lengths are twice the diameter.

Flow nozzles require a length of straight pipe immediately upstream of the nozzle, and the slope of the approach pipe must not exceed certain limits or else the calibration will be in error. Unlike the conventional weir, the flow nozzle can handle suspended solids effectively through a self-scouring action, and relatively large solids will pass without clogging. The loss of head through the device will be at least one pipe diameter, due to the restriction in the pipe cross-sectional area presented by the nozzle.

SECTION 4

SECONDARY INSTRUMENTATION

4.1 General

All flow meters require instruments of one kind or another, electrical or mechanical, to convert the physical parameters representing the flow into a more suitable format.

Although the type of instrumentation is governed to some extent by the primary measuring device, there is now such a large variety of indicating instruments available that the correct selection is becoming just as difficult as the correct choice of flow meter.

In fact, the range of manufacturers' instrumentation is far too great to do more than describe what is available in general terms. The normal procedure is, of course, to select the type of conversion equipment offered by the manufacturer of the primary metering device.

4.2 Suitability for Use

In the water industry, it is common for instruments to have to survive and continue to operate under the most adverse conditions, including accidental damage from heavy plant and machinery, high humidity, flood, cannibalization, malicious or mischievous attack, and operator ignorance. "Ingress Protection Standards," such as BS 5420, DIN 40050 (IEC 144), exist for the specification of instruments in the most adverse climatic and environmental conditions.

It is important, therefore, to ensure that the equipment offered by a manufacturer will survive under the arduous circumstances that are likely where the instrument is to be used. In case of doubt about the manufacturer's claims regarding the product's suitability, there is no real substitute for having equipment supplied on a trial basis. It would be advisable to inform the manufacturer beforehand of any problems at the point of installation, such as heat, humidity, dust, and water, so that he can apply the correct standards to the equipment. Assuming the equipment is watertight and shockproof, it may be prudent to immerse it in water and shake it vigorously. If the manufacturer is not prepared to subject the article to reasonable tests in accordance with his claims, his product may seem less desirable.

If a developing country's water authority plans to make the purchase from another country, it has to be borne in mind that all developed countries have water industries, research organizations, specialists, and consultants who advise on products. There are also independent testing agencies to report on suitability (see Annexes 4 and 5).

4.3 Pressure Measurements

The measurements normally taken are of relative pressure, whether relative to a vacuum (absolute pressure), related to atmospheric pressure at that location, or relative to gauge pressure. In the water industry, the measurement usually required for metering purposes is the pressure difference (differential pressure or D.P.), which is proportional to the square of the flow velocity.

4.4 U-tube Manometers

These are two long, transparent tubes connected by a U-shape at the bottom, normally used with water or mercury. The two pressures to be measured are applied to the respective limbs of the "U" tube. The difference in pressure is represented by the weight-per-unit area of the displaced manometer liquid. Various corrections to the results are required for temperature, capillary effects, etc.

4.5 Differential Pressure Transducers

Most differential pressure transducers ultimately derive from the use of a "Wheatstone Bridge," measuring very small changes in resistance brought about by converting the pressure difference to a change in electrical resistance.

There are a great many types and manufacturers concerned with these products, which are required for a wide range of industries as well as for water supply. Many of these manufacturers specialize in products used in arduous situations for very long periods without attention.

4.5.1 Variable Reluctance Transducer

This instrument is constructed as a differential transformer, with the primary winding coupled to two opposing secondary windings via a core moved laterally by the displacement of bellows in relation to the applied differential pressure. The applied differential pressure is, therefore, related to the output of the secondary coils.

4.5.2 Differential Capacitance Transducers

The pressure is applied to a constant area diaphragm, which is connected to one plate of a dialectric capacitor so that the spacing of the capacitor plates, and hence the capacitance, varies inversely with the pressure. The capacitance is determined by applying a constant voltage/constant frequency signal across the capacitor plates and measuring the resultant current.

4.5.3 Strain Gauge Transducers

The strain gauge transducer uses the physical property that electrical resistance in a stretched wire increases in proportion to the strain. The gauge consists of an isolating diaphragm whose deformation by the differential pressure is measured by a strain gauge. A Wheatstone-bridge arrangement converts the resulting resistance changes into corresponding current or voltage changes.

4.6 Analogue Output

In all of the transducers mentioned above, the current or voltage output is analogous to differential pressure and it has to be linearized by abstracting the square root to provide a signal proportional to flow rate. The modern pressure transducer incorporates electronics to convert the analogue output to flow rate by means of a microprocessor, which is preprogrammed with the installation and meter constants.

A further type of pressure transducer has a ceramic diaphragm that deflects in response to differential pressure. The movement is sensed by capacitive electrodes that provide digital signals. With this type of transducer, square root or linear function is selectable.

4.7 Installation

Pressure-differential devices are required to measure very small pressure differences. The initiation of the signal, to either a manometer with mechanical balance and clock operation or an electronic transducer, is by basic plumbing, running the pressure tubing, with the correct manifolds and valves, to the D.P. device.

In the case of electronic transducers, the plumbing runs can be quite short, with the D.P. device mounted on the pipe; but in any event, the maximum accuracy of the meter and transducer will only be achieved if the "plumbing" is carried out properly and exactly, according to the manufacturer's instructions. It is particularly important that there not be the slightest sign of any weep on the connections.

4.8 Digitizing

Digital devices are the essential link between the analogue device and data acquisition. The most usual form is the counter/timer, which measures the pulse rate (frequency), total number of pulses in unit time, and time intervals. For instance, the pick-up coil on the turbine meter propagates a series of pulses which, if totaled over a certain period, will indicate turbine-blade revolutions and, hence, total flow. The frequency will also measure mean pipe velocity.

In essence, a counter/timer consists of a pulse counter and totalizer. The totalizer electronically converts the number of pulses passing the counter into a numerical display. Timing is by means of an oscillator that generates pulses at precise intervals, usually milliseconds.

4.9 Analogue-to-Digital Converters

Several analogue-to-digital techniques are used for conversion of signals. With one common type, the analogue-input-voltage signal is applied to a comparator-integrated circuit whose output is fed to a frequency clock-counter microchip. A digital code value is generated and an equal-to-input, voltage feedback signal is returned to the comparator, thus completing the measuring circuit. The digital value can be displayed in numerical format or fed into a data-acquisition system for further processing.

4.10 **Rotary Vane (Helix) Meters**

This type of meter provides direct reading and can also be fitted with a pulse unit to provide flow rate and integration. One method of achieving this is by means of photo-electronic detection of a revolving disc in the counter mechanism. Another method is an electronic impulse generator driven by the counter of the meter by reed contact. A further device is a low torque probe with a magnetic-dependent resister, which is used to derive a voltage dependent upon the proximity of the magnet fixed to the rotor blades.

4.11 **Quantity Measurement**

According to their design, meters measure primarily the flow volume in unit time or the flow rate. Helix and rotary vane meters of the Woltman type measure volume as their primary output by means of a mechanical registration or phonic wheel. They can also produce a derived output, based on the speed of rotation, to give a flow-rate reading by means of a speedometer-type indicator or a frequency counter. Axial turbine meters measure flow rate directly, based on the frequency of rotation measured by pick-up coils.

Differential pressure devices, such as the venturi, nozzle, orifice, and pitot, measure flow rate as their primary output by means of a manometer or differential pressure cell. Volumes are derived as a secondary output by integrating flow-rate readings from a continuous recording chart, or by mechanical or electronic integration after square root abstraction.

Electromagnetic and ultrasonic flow meters measure flow rate as their primary output by means of a voltmeter, ammeter, or frequency counter and derive volume as a secondary output from a pulse counter. These signals can be indicated and integrated directly, and they can easily be quantity-ranged over wide velocity bands, typically 0.3 m./ sec. to 3.0 m./sec. Open channel measurement by weir or flume primarily consists of measuring depth by a staff gauge, float, probe, or pressure device and converting this to flow rate by the physical characteristics and empirical formula for the weir or flume with a chart or a mechanical or electronic device. Volume is obtained by integrating flow readings mathematically or by mechanical or electronic devices.

4.12 **Electronics**

Major developments in meter technology over the past 20 years have resulted from the availability of new materials and technology, such as super-magnetic materials, optical fibers, integrated circuits, liquid crystal displays, and opto-electric components. These, together with microchips, have not only much improved meters but, assisted by microprocessors, have enabled them to be used without regular calibration or maintenance for long periods. In the case of electronics, they have become so cheap as to make "throwaway" components the most economical option.

The microchip has enabled removal of non-linearities in meter characteristics, carrying out of mathematical conversions, compensations for systematic error, and data processing to provide the information from the meter in the form required.

It also enables the meter to be self-diagnostic and self-checking and permits remote or automatic range-changing and storage of flow data. This can all be done with environmentally protected units which, once installed,--even buried in wet ground--can be left secure until they stop working, which may be for as long as 10 years. When they cease operating, they can be removed and replaced with virtually no effort.

The transmission of data has also advanced to such a stage that, with reliable and cheap equipment, all information (and, if required, operation) can be transmitted to one control point via hardwire lines, optical fiber, cable, or radio link. In developing countries, radio transmission is likely to prove most reliable.

The major difficulty of providing a reliable power supply at the metering point has probably been solved by reducing operating power needs and using very long-life, submersible batteries.

4.13 Meter Reading

Since the transmission of data can now be readily accomplished with a small power source, all meters can now be equipped, if so desired, with local, electronically-operated, remote reading dials. In situations where it is not desirable for the meter reader to have direct access to the meter position, a remote readout location enables monitoring of supplies to proceed without access problems.

It might also be desirable to have meter consumption recorded by a data logger, which can be operated by battery for as long as 10 years, sealed for life, and constructed for all environmental conditions. A meter reader or consumer can interrogate the data logger from a locally fixed recorder and integrater or a pocket display unit. If desired, the meter readings can be transmitted directly to the billing office, either by a hard wire system (e.g., telephone lines) or by radio.

4.14 Open Channel Sensors

The flow rate or discharge through a weir or flume is usually a function of the liquid level in or near the primary measuring device. A secondary measuring device (or open channel flow meter) is used in conjunction with a primary measuring device to measure the rate of liquid flow in an open channel. The purpose of a secondary measuring device is twofold: (1) to measure the liquid level in the primary measuring device; and (2) to convert this liquid level into an appropriate flow rate according to the known level/flow rate exponential relationship of the primary measuring device. This flow rate may then be integrated to obtain a total volume and, if required, transmitted to a recording device. The level can be measured by the open channel flow meter using a number of different methods:

(a) Staff Gauge--A graduated staff gauge attached to the side of the weir flume, using a point hook-gauge, preferably with a vernier scale, to achieve reasonable accuracy.

(b) Float--In combination with either a cable and pulley or a pivoting arm, a float converts the liquid level (as measured by the float) into an angular position of a shaft, which is proportional to liquid level.

(c) Dipping Probe--A probe is lowered on a wire by a motor until a sensor in the probe makes electrical contact with the water. This generates a signal that makes the motor reverse and retract the probe slightly. After a few seconds, the probe is lowered again until it makes contact with the surface and retracts, thus repeating the cycle. The cable turns a drum connected to a potentiometer, whose output signal is proportional to the liquid level.

(d) Electrical--This type of level measurement system utilizes one of the variables in an electrical circuit caused by a changing level in order to indicate the liquid level. Most designs use a capacitive-type probe.

(e) Ultrasonic--The liquid level is measured by determining the time required for an acoustic pulse to travel from a transmitter to the air-liquid interface (where it is reflected) and return to a receiver.

(f) Bubbler--A bubbler tube is anchored in the flow stream at a fixed depth, and a constant bubble rate out of the tube is established by a supply of pressurized air or other gas in the flow meter. The pressure required to maintain the bubble rate is measured by transducer; this pressure is proportional to the liquid level.

(g) Submerged Pressure Transducer--This system is similar to the bubbler, but instead of using a bubbler system, a sealed pressure transducer is submerged directly in the flow stream. The pressure measured by the transducer is proportional to the liquid level.

Whatever method of level measurement is adopted to obtain accurate readings, it should be installed in a separate stilling well to reduce the effect of surface irregularities.

Conversion of the head on the open channel flow meter to the corresponding flow rate can be accomplished by a number of different methods:

(a) Direct--Reading the level from a staff gauge and converting the reading to flow through a given table.

(b) Mechanical Cam--A mechanical cam, whose profile follows the level-flow rate relationship of the primary measuring device in question, is rotated by the level measuring device. The position of the cam follower is then proportional to flow rate.

(c) Electronic Analogue-Function Generator--In this type of conversion system, a solid-state, analogue-integrated circuit device converts an electrical analogue of the level into a flow-rate analogue; the output of the device is the flow rate corresponding to that level.

(d) Electro-Mechanical--The motion of a float is converted into an electrical signal, which is converted by an electronic processor into the flow rate.

SECTION 5

COMPARATIVE ANALYSIS

5.1 General

Each of the meter types described in Section 3 has features that render it less or more attractive for a particular purpose. In this section, these features are considered and compared in order to clarify the differences and guide the selection of the appropriate type or types to meet particular needs.

Although some types measure primarily the flow velocity and others the flow volume, this variation does not normally affect their suitability for waterworks installations.

5.2 Performance

One matter of great importance is the general performance of the meter as portrayed in the manufacturers' catalogues.

In their descriptive literature and specifications, manufacturers refer to various characteristics, such as repeatability, accuracy, effective range, and rangeability. When comparing different types and makes of meter, the buyer needs to understand the meaning of such terms; these are described in this section. It is also important to note that the terms different manufacturers use for meter performance do not always mean the same thing; however, the following definitions are the most generally accepted.

Meter performance is affected by physical properties, such as temperature, density, viscosity, and the type of flow (i.e., streamline or turbulent), and some manufacturers quote different meter performance for different values of these variables. It is important to select a meter for the right conditions, but density and viscosity are unlikely to apply to water supply, and Reynolds number can be ignored.

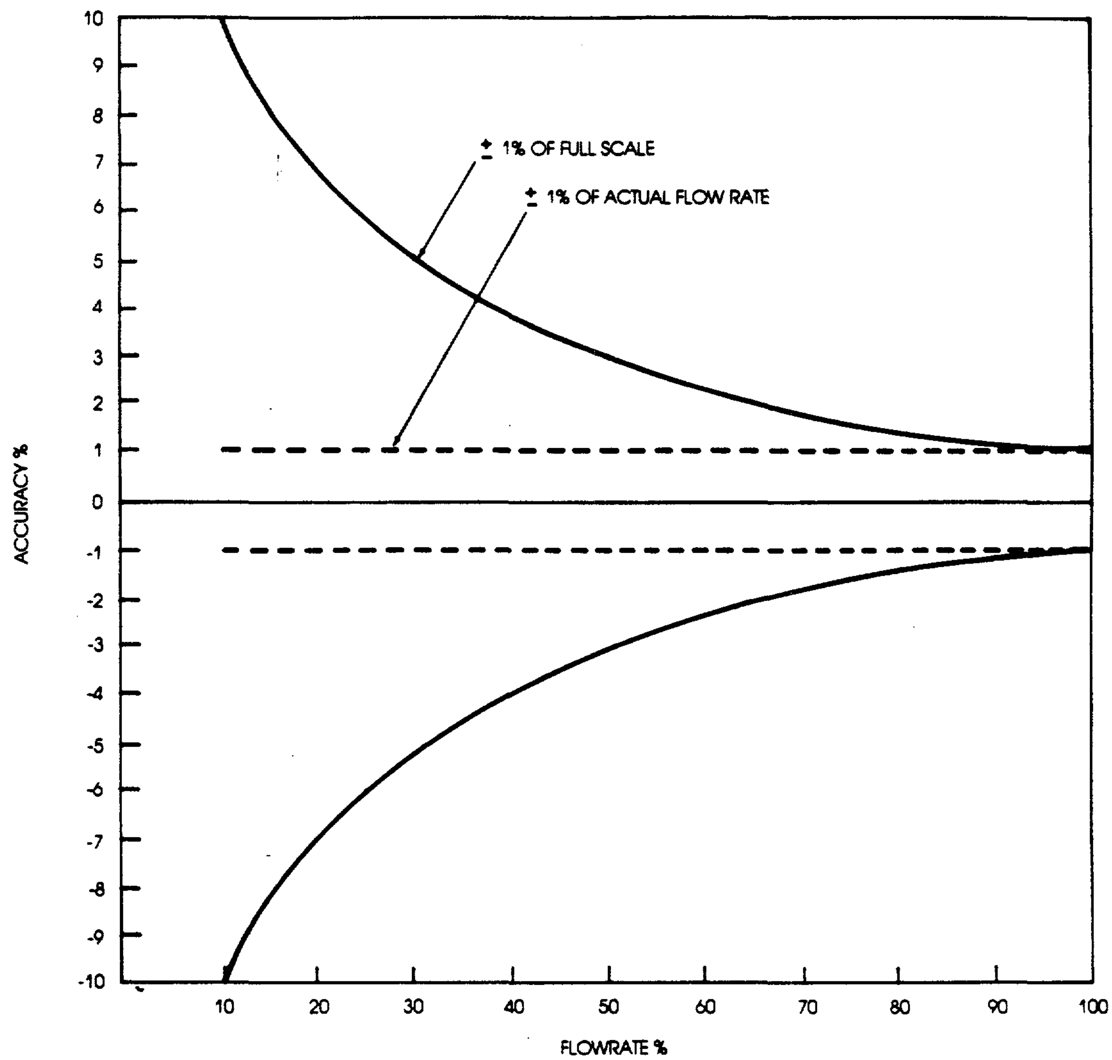
5.2.1 Effective Range and Rangeability

The "effective range," or simply "range," of an instrument is defined as the range of flow over which it meets some specified accuracy requirements. The ratio from the maximum flow to the minimum flow within the specified accuracy requirements is also often called the "rangeability" of an instrument--or, in the case of a flow meter, its "turndown ratio" or "turndown."

5.2.2 Accuracy

Some manufacturers quote "accuracy" as a percentage of full-scale reading, others as a percentage of actual reading. The difference becomes highly significant when an instrument is working near the bottom of its range: For example, at one-fifth of the scale maximum, an accuracy of "1% of full-scale" is equal to an accuracy of "5% of reading" (see Figure 5.1).

Figure 5.1 - Graphical Comparison of Accuracy Expressed as Percentage of Flow Rate and Percentage of Full Scale



In the U.K., a current proposal suggests replacing the term "accuracy" with "uncertainty."

5.2.3 Linearity

Linearity is a measure of the extent to which the performance over the effective range departs from the ideal (expressed as a percentage of K-factor). Numerically, it should be a small percentage value, say 0.1 to 1.0 percent. In graphical terms, linearity is shown by plotting K-factor (described below) against flow rate Q; for perfect linearity, the characteristic curve would be a straight line over the effective range of the meter. In practice, the characteristic curve is a wavy line with small positive and negative departures from the ideal. This term should not be confused with the "linear" relationship between the measured parameter and flow rate in some meters.

5.2.4 Repeatability

An instrument's repeatability indicates its ability to give the same result when it is used to measure the same quantity several times in succession. A numerical value of repeatability can be explained experimentally by installing two identical flow meters in series and comparing their readings many times. For comparison purposes, it is expressed as a percentage that should be of a low order--say, 0.01 to 2 percent for a good meter. Repeatability may be good, and yet the accuracy may be unacceptable.

5.2.5 Meter Factor

This term is usually applied to meters measuring total volume (i.e., rotary vane); it is a ratio of the true volume passing in unit time divided by the indicated volume.

5.2.6 K-factor

This term describes the performance of a meter where the output is a series of electrical pulses, where the total pulse count is normally proportional to the volume passed, and the pulse frequency is normally proportional to the flow rate. The K-factor is the ratio of the total pulse count divided by the true volume in unit time.

5.3 Accuracy

Acceptable accuracy implies low linearity coupled with high repeatability. The performance of the types of meters considered under Section 3 is shown in a comparative table for ready reference (Table 5.1).

Venturi, Orifice, and the **Averaging Pitot Meters** can be very accurate, depending on installation and calibration as well as the type of differential pressure measurement device. They are not suitable for low and variable flows because of the small range. If properly installed, their accuracy should be long-term, although traditional manometer devices require care in operation and maintenance.

Turbine Meters are very accurate but have high initial cost. It may be difficult and expensive to maintain them and to ensure that their initial accuracy is retained. They are not normally installed in waterworks, except for very special purposes.

Rotary Vane, Helix, or Woltman Meters. These meters, less accurate but also much less costly, require simple annual maintenance. Again, to retain accuracy, they should have new internal mechanisms installed or be recalibrated annually.

The **Insertion Turbine Meter** may be a useful instrument and reasonably accurate when first installed, but it is generally not suitable for continuous use without loss of accuracy, or even effective operation, due to wear on the somewhat delicate mechanism required for operation under low-velocity conditions.

Electromagnetic Meters. When first introduced some years ago, their reliability was open to question, but they are now very accurate. When manufactured to the correct specification and installed correctly, they have an indefinite life without any significant maintenance.

Ultrasonic Meters. If factory manufactured as a metering tube and calibrated, ultrasonic meters are very accurate but more prone to installation defects (see "Installation," Section 5.6). There is no reason to suspect anything but continued accuracy over a long life for this type of meter. Again, little significant maintenance is required. The "under-pressure tapping," "weld-on," or "clamp-on" types have a lower order of accuracy.

The **Electromagnetic Probes** shown in the table are reasonably accurate, but development is such that they are likely to show much greater promise in the near future as a very reliable metering probe. Current versions are worthy of serious consideration when a probe meter is necessary, but they are unlikely to be as accurate as full-diameter meters.

Open Channel Meters. There is some confusion over the accuracy attained with open channel meters. The coefficient of discharge given by the head/flow relationship formula for the particular device may reasonably achieve an accuracy of ± 1 percent full-scale over a wide range, but the overall accuracy of this meter also depends on:

(a) the measurement of the primary device;

(b) the standard of construction of the primary device;

(c) the correction coefficient for the velocity of approach;

(d) the installation conditions; and, most important of all,

(e) the zero setting and the reading of the liquid level.

Using most traditional secondary instrumentation, one can only expect an overall accuracy of ± 5 percent full-scale. For network flow audit

Table 5.1 - Meter Performance Analysis

Type	Max, Meter Size mm	Linearity	Repeatability	Installed Accuracy	Turndown (Range)	Pressure Drop	Reverse Flow	Output	Signal
Venturi	3000	*	0.1-0.2% F.S.	±2% F.S.	4:1	Low	No	Rate	Sq. rt.
Flow Tube/Nozzle	1200	*	0.1-0.2% F.S.	±2% F.S.	4:1	Low	Possible	Rate	Sq. rt.
Orifice	Pipe	*	0.1-0.2% F.S.	±2% F.S.	4:1	Medium	No	Rate	Sq. rt.
Averaging Pitot	Pipe	*	0.5-0.2% R.	±2% F.S.	3:1	Low	No	Mean vel.	Sq. rt.
Helix (Woltman)	500	±2% R.	±0.02-0.5% R.	±2% F.S.	10:1	Medium	Possible	Rate	Linear
Turbine	500	±0.15-1% R.	±0.02-0.5% R.	±1% F.S.	10:1	Medium	Possible	Rate	Linear
Insertion Turbine	Pipe	±0.25-5% R.	±0.1-2% R.	±2% F.S.	10:1-40:1	Low	No	Velocity	Linear
Electromagnetic	2400	°	±0.1% R. to ±0.2% F.S.	±0.5% R 1% R.	10:1-100:1	None	Yes	Rate	Linear
Insertion E/M	Pipe	°	±2% F.S.	±3% R.	30:1	Very low	Yes	Rate	Linear
Ultrasonic (tube)	3000	±0.1-1% R.	±0.2% R. to 1.0% F.S.	±0.5% F.S. to 1.0% R.	10:1-300:1	None	Yes	Rate	Linear
Ultrasonic (Clamp)	3000	°		±5% R.	40:1	None	Yes	Rate	Linear
Flume				±2-5% F.S.	10:1-75:1	Low	No	Rate	Non-Linear
Weir				±2-5% F.S.	75:1-500:1	Medium	No	Rate	Non-Linear

* Depends on D.P. device   % Full Scale = % F   % Rate = % R.   ° Information not available

purposes, the accuracy of measurement of change of any volume stored in tanks (necessary for correction) is an additional adverse factor.

Generally, it must be concluded that, to achieve reasonable continuing accuracy, equipment requiring no site maintenance is likely to prove the most satisfactory in developing countries.

5.4 Water Quality

Meters that depend on rotating vanes running on bearings (that is, the Woltman types) clearly are unreliable in water supplies, which can contain abrasive particles of grit. They can also be clogged by any soft matter that can wrap around the vanes, or by larger particles wedging between the vanes and the sides of the tube. This effect seems to happen in the best regulated water-supply operations, and it has to be offset by regular maintenance. Experience of the particular system will suggest how often this should be, but as an initial arrangement, maintenance should occur no less frequently than annually.

To avoid stopping the mechanism between maintenance, these meters must be fitted with strainers and preferably installed on a bypass (see Section 5.6).

Meters of this type are not suitable where the water may contain air. They not only register incorrectly, but are liable to excessive wear and damage. If they have been installed in such conditions, and it is practicable to do so, they should be replaced by some other type of meter. Insertion turbines are particularly vulnerable to grit and cannot be protected by strainers. All other pipeline meters are acceptable where grit or air may be present.

If a channel meter is used, weirs require regular attention when grit is present; in such conditions flumes are preferable.

5.5 Environmental Considerations

Although consideration must be given to the manufacturers' recommendations regarding the effects of ambient temperatures, humidity, and pressure, these factors normally create no problems in waterworks installations, whatever the type of meter. The proximity of other apparatus may be most important. Electromagnetic flow meters are particularly susceptible to errors due to power cables near sensors and control cables. Caution dictates that proximity to drains and sewers also be avoided. Recent experiences suggest that electromagnetic meters may also be affected by lightning.

For waterworks use, it is almost inevitable that the meter unit, including secondary electrical and electronics equipment, will become submerged at some time; for this reason, it is essential that all of the equipment be waterproof. None of the types is particularly vulnerable in this respect, but waterproofing of some may be more difficult and costly.

5.6 **Installation**

5.6.1 Correct Size

To measure flow accurately, it is essential for all types of meters that the size selected be suitable for the flows expected. One of the major causes of inaccurate measurement of flows is using meters that are too large and designed to measure high flows that are unlikely to occur.

The inherent head loss is insignificant in a well-designed meter that tapers down in size and then increases to suit the correct meter capacity. All rotary-type meters have a lower limit of velocity, at which the blade rotation ceases to accord with the theory of design and thus creates inaccuracy or even failure to measure. This lower limit of velocity or flow rate is shown on the meter specification and is often called the "parting line." In effect, it is the point at which the velocity becomes too low to provide a reading within the normal accuracy of the meter, and where the meter characteristic curve departs rapidly from its approximation to a straight line.

Pressure-differential devices are "square-law" instruments such that the flow is proportional to the square root of the differential head. At very low velocities, if the differential head is small, the square root becomes minute. Furthermore, even accurate transducer measurements can easily be offset by plumbing inaccuracies of the pressure tubing and by other effects.

The ideal velocity range for electromagnetic flow meters is 1.0 to 4.0 m/sec. Although they can be used for different velocities, it is usually desirable to choose a meter size within the optimum limits, and economic considerations would normally favor the highest acceptable velocity. The electromagnetic flow meter can, however, have the significant advantage of two or even three flow ranges, so that although the prime choice should be for high velocity, it can be used with acceptable accuracy with velocities as low as 0.3 m/sec.

Whatever type of pipeline meter is selected for a particular duty, it should be installed with suitable tapers if the normal velocity is low. This will, of course, create a small irrecoverable pressure loss quite separate from that of the meter. Care must also be taken to ensure that the taper angle does not cause turbulence and that the manufacturer's recommendations on length of straight pipe are adhered to, both upstream and downstream of the meter.

Open channel meters are more tolerant in the matter of size, but the maximum velocity of approach in the channel is limited for accurate depth measurement, the limit depending on the size (see Sections 3.2.1 and 3.2.3). Subject to this consideration, the selected size should be the smallest possible for accurate measurement of low flows. For weirs, the average upstream velocity of approach should not exceed 0.1 m/sec.; for small flumes 0.5 m/sec.; and for large flumes 2.0 m/sec.

5.6.2 Location

If the meter is installed properly, in accordance with the appropriate standards and the manufacturer's recommendations, high levels of accuracy will result. In practice, the matter is largely one of common sense--the pipeline meter will perform to its best specification when operating in the "turbulent" flow range, whereas the open channel meter requires streamline flow conditions. Under uniform conditions, the velocity profile in the pipe in this range will be a uniform flattened parabola with a velocity at the center of the pipe of about 1.2 times mean velocity.

To achieve this, the effect of rotation and swirl of the water must be eliminated as far as possible; upstream of the meter there must be a sufficient length of straight pipe without bends, junctions, tapers, valves, connections, and so on. The optimum distance will depend on the severity of the obstruction, or change of direction in creating disturbance to the flow, and on the characteristics of the meter (see below).

For weirs, an upstream length of straight channel is required equal to 15 to 20 times the maximum head over the crest. Also, the cross-sectional area of the upstream channel must be eight times that at the crest. For flumes, the upstream straight is less critical, but the flow must be evenly distributed across the full width and free from turbulence.

Production meters normally need to be located as close as possible to the source station. The location is then limited by the straight-length pipeline requirements necessary to provide a sufficiently stable flow profile for the particular type of meter. Similarly, for district and bulk-supply meters, the pipe configuration and space limitations may be overriding factors in meter selection.

5.6.3 Pipeline or Channel Configuration

The ideal recommendations in regard to lengths of straight pipe in terms of the diameter (D) before and after the meter are given below.

	Upstream	Downstream
Venturi/Dall	10-30 D	(a)
Orifice	10-20 D	10-15 D
Electromagnetic	5 D	2 D
Ultrasonic- Single Channel	15-50 D	5 D
Two Channel	0-15 D	5 D
Rotary Vane	3-5 D	-
Turbine	10 D	5 D
Insertion-Pitot	8-25 D	4 D
Turbine	10 D	5 D
Flumes	varies	
Weirs	20 h (b)	

(a) inherent design obviates need to quote downstream distances.
(b) h = the maximum measured head at the flume or weir.

To give optimum results, the length of straight pipe, whether before or after the meter, depends on the degree of turbulence created by any upstream or downstream obstruction. The table above can only be considered indicative with the shorter lengths relating to minor obstructions such as tapers, and the longer lengths to major flow disturbances, such as sharp bends and tee-junctions. Pump outlets are particularly bad for creating swirl and asymmetric flow; for this reason, the distances of straight pipe from pump installations should, if practicable, be increased beyond those given in the preceeding table.

An example is probably the best way to demonstrate the difficulty in achieving meter accuracy. Thus, taking a venturi nozzle with a throat area ratio of 0.35, to achieve zero-effect on the meter would require the following lengths of straight pipe from various fittings:

	Upstream	Downstream
90° bend	12 D	5 D
2 No. 90° bends in same plane	16 D	5 D
2 No. 90° bends in different plane	36 D	5 D
Taper 2D to D	5 D	5 D
Gate valve fully open	12 D	5 D

If the flow is bi-directional, the choice for a single meter is limited to rotary vane (Helix), electromagnetic, or ultrasonic meters.

Where space is severely limited, or for other special reasons, the installation of a channel meter may be a practical alternative at a source station, even though a much reduced accuracy must be accepted. The location of such a meter requires special attention. Details are fully described in ISO 1438 and ISO 4359.

5.6.4 Bypass

Rotary vane (Helix) meters should always be fixed on a bypass to enable strainers to be cleaned and the meter to be regularly serviced. If the meter does not normally need to be full pipe-bore size, a bypass is a further advantage. The bypass needs to be valved to enable the meter to be dealt with without interrupting the supply. Preferably, it should be double-valved with a bleed valve, to ensure that no part of the flow can bypass the meter during readings.

Because they do not significantly disturb the flow or require a shutdown for repair or maintenance, other types of meters do not need a bypass or a strainer. In most circumstances, the additional cost, including the associated pipework to provide acceptable lengths of undisturbed straight pipe, may be prohibitive (see Section 5.7). A decision whether to provide a bypass must take into consideration that except for insertion meters, a replacement cannot be fitted without a shutdown. For source meters, this may be important, but for district meters it is not usually a problem.

5.6.5 Strainers

Even when the water is of the highest quality, it is essential to install strainers ahead of all full-diameter rotary vane, helix, and turbine meters. If the flow is bi-directional, strainers on both sides are necessary. Many manufacturers provide a strainer enclosed in a standard meter casing, so that the strainer can be removed and a spare standard meter installed, thus providing further flexibility of operation. Routine maintenance of cleaning the debris from strainers is essential. Only operational experience can determine frequency, but once a month may be necessary where the network is not regularly flushed. With all other types of pipeline meters, strainers and the associated operational problem of frequent, regular cleaning, are avoided. Open channel weir meters suffer loss of accuracy if the water contains grit and must, therefore, be cleaned regularly.

5.6.6 Power Supply

Since many of the meters now available require a reliable electrical supply, it is helpful for this type of meter to be adjacent to a suitable power source. If no power supply cable is near enough, battery power has become a possible alternative, and very rapid developments are now foreseen in this field. Previously, the types of meters that would normally be used for measuring district flows were limited, but it now appears that all types may be usable in the near future.

5.7 Operation and Maintenance

Where skilled maintenance staff are not available to the water authority, it is necessary to make other arrangements. For meters that need frequent, regular maintenance, it might be best to set up a performance contract for meter installation and maintenance that ties the contractor's payment to continuance and number of readings (subject, of course, to inspection and audit). General guidelines on types of care follow:

Orifice Venturi Flow nozzle Dall tube Pitot	Pay attention to the plumbing of the sensor pipework to ensure that no slight leakages seriously affect accuracy. Nearly all equipment maintenance relates to the differential-pressure device. If this is based on a manometer, regular, competent maintenance is required. If a D.P. transducer is fitted, it can be environmentally protected so that virtually no maintenance is required. If the unit fails, it may have to be replaced to the manufacturer for repair or disposal.

Helix Propeller Woltman Rotary vane	Strainers are essential for all rotary-vane meter installations, and they will probably require frequent cleaning. Routine maintenance depends on the amount and type of suspended matter in the supply and the regularity of strainer cleaning. For the largest sizes, it may be cost-effective to replace the complete internal operating section annually from a spare kept in store and then replace or renovate the spare for use on the next meter.
Electromagnetic	The correct type is virtually maintenance-free and has indefinite life. Replace completely when the unit fails.
Insertion turbines	If these are used permanently, regular maintenance (probably weekly) will be required.
Insertion electromagnetic	Virtually maintenance-free. Battery-operated meters require a proper arrangement of systematic battery changes.
Ultrasonic	With factory-produced measuring tubes properly installed and calibrated, little maintenance is required or practicable. For other types, lack of information on users' experience prevents valid comment at this time.
Open channel	Regular cleaning of all exposed surfaces is required to remove any adhering fibers, growths, slime, and scale. The upstream channel and float, or sensor chamber, must be regularly purged to remove all accumulations of silt or grit. In these respects, weirs require much more attention than flumes.

5.8 Economic Considerations

These must include the initial cost of the supply and installation of the meter and its associated equipment, together with the operation and maintenance, loss of pressure energy, and, in particular, the replacement cost. Costs must also be considered in relation to reliability, availability of spares, and obsolescence. As stated earlier, the least economical option is a useless, non-working, or grossly inaccurate meter. On the basis of high cost representing high value and vice versa, it is quite wrong to make cost the sole criterion for purchase of this type of equipment.

A simple example illustrates this point:

At a unit water price of $\$0.356/m^3$, and a standing charge of \$5,161 per year for a 150 mm. water meter (typical U.K. prices expressed in U.S. dollars), the unit cost of water per cubic meter on the basis of average flow rates and a normal working day would be about $\$0.37/m^3$. If these prices represented the supply to a factory and the meter were out of action for three months, the loss of revenue would be \$5,365.

This may be ignored because the terms of supply would permit charging on a previous period of use, and it is assumed that there would probably be no significant loss to the water authority. This can be a false assumption because meter failure is normally preceded by a long period of under-registration on which the estimated charge is based.

The economic value of installing a production meter, or a meter for the measurement of district flows, can be assessed only in terms of improved knowledge of the system and improved control of unaccounted-for water. See World Bank Technical Paper No. 72, The Reduction and Control of Unaccounted-for Water.

It is possible only to give some very general ideas of the costs of installing the various types of meters, especially since these costs vary from country to country and according to the quantities supplied. (Installation costs do not include site calibration where this is called for; see Section 5.9). Factory prices as of mid-1987 are indicated in Table 5.2 and Figure 5.2.

In the case of differential-pressure meters, the pitot entails negligible loss of pressure energy and usually has the lowest instrument cost, but it is less accurate than the orifice-type meters in the lower velocity range. The various types of venturi meter have been developed in order to reduce the overall loss of pressure energy and, at the same time, to keep the investment costs to a minimum. The minimum loss is achieved by the venturi, but the more recently developed dall tube is nearly as effective. The orifice plate has the highest overall loss of pressure energy for differential-pressure devices fitted in the pipeline, but it also has the lowest investment cost.

Rotary vane meters have a degree of pressure energy loss similar to orifice-type meters but are relatively cheap to buy and install. These meters are also limited in maximum size and require more maintenance. Electromagnetic and ultrasonic meters produce practically no significant loss of pressure energy at all.

5.9 Calibration

Calibration of pipeline flow meters is an expensive operation requiring special facilities not normally available within a water undertaking. For this reason, it is infinitely better for calibration to be carried out in the manufacturer's factory or at a special calibration laboratory. The test rig should accurately represent potential use conditions. In their literature, most manufacturers describe how their flow meters are calibrated. Many developed countries have national laboratories that undertake calibration at reasonable cost, and they will, if necessary, carry out calibration in situ. There are also private, specialist contractors who undertake this work.

The engineering standard of pressure is a deadweight piston tester, which can be used to calibrate a precision Bourdon gauge. The precision Bourdon gauge consists of a fused quartz tube wound into a helix with one end of the quartz tube sealed. When pressure is applied to the open end the unwinding effect of the helix rotates a beam of light from the sealed end and thus provides an accurate rotational measure related to the pressure standard. The tube is fitted into a vacuum enclosure at constant temperature and pressure and can be used for pressure ranges from 0.01 to 35 bars.

The precision manometer is used as a standard to calibrate differential-pressure flow devices.

On site, the only methods of accurate calibration entail installing laboratory-calibrated flow meters to use with the meter to be calibrated. This can usually only be done on large pipelines with an insertion type of instrument; unless it is very precisely done, errors can be significant.

The in situ meter can also be calibrated by measuring the volume passed in a fixed time to or from a storage tank under steady hydraulic conditions. Unfortunately, unless the difference in tank head represents only a very small proportion of the total head, it is impossible to keep the discharge uniform and determine rate of flow. Before any such calibration, the system must be tested in no-flow conditions for leakages. These and other methods of calibration are discussed in more detail as follows:

For venturi and other D.P. devices (i.e., flow-rate meters), the calibration consists largely of determining the discharge coefficient to modify flows calculated by the physical laws relating to the actual dimensions of the tube or orifice. If these characteristics are not changed by deterioration, the coefficient remains constant; and if the serial number of the instrument or the manufacturer's supply information is available, the meter can be recalibrated by direct calculation. If necessary, new secondary instrumentation can be provided to suit the calculated D.P. at various flows.

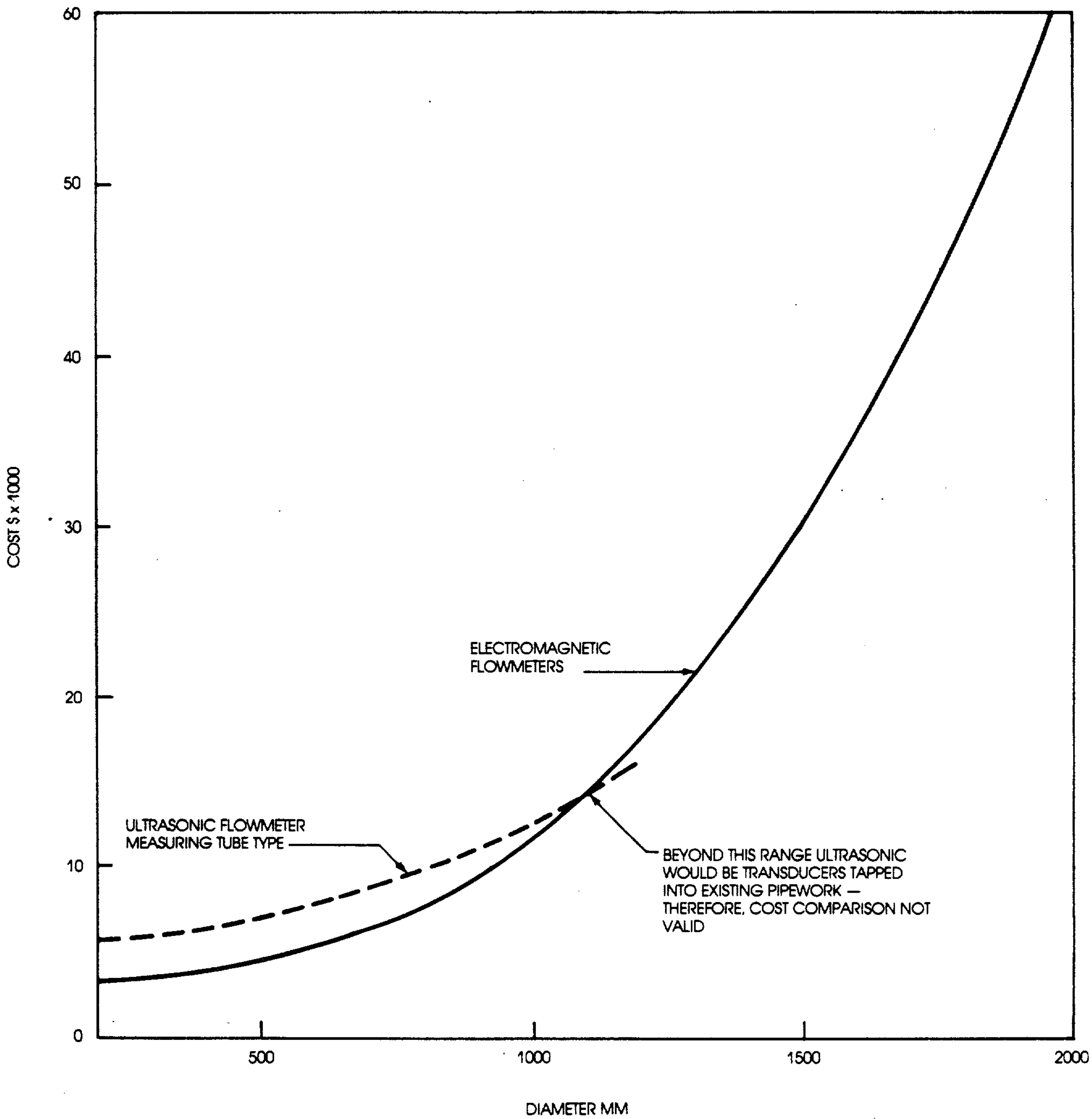
Table 5.2 - Meter Costs (a)(b)

Meter type	Factory cost 150 mm	Factory cost 400 mm	Installation costs without bypass 150 mm	Installation costs without bypass 400 mm	Installation costs with bypass 150 mm	Installation costs with bypass 400 mm	Annual calibration & maint. costs	Annual power consumption costs
Venturi	3500	9000	8000	28000			120	50
Flow tube	2000	5500	6000	20000			120	50
Orifice	1600	2500	3500	6500			50	50
Rotary vane	1000	6500	5000	19000	6500	24000	120	0
Rotary vane with elects.	1600	7500	6000	19000	7500	25000	120	100
Averaging Pitot	1300	2500	3500	6500			70	50
Electromagnetic	3500	6500	6500	20000	8000	24000	70	50
Ultrasonic	3500	6500	7500	21000	10000	26000	70	50
Turbine	4000	16000	9000	29000	11000	34000	120	100
Flume (c)	1000	3000						
Weir (d)								

(a) All with associated transducers and electrics where appropriate.
(b) All costs in U.S. dollars.
(c) Requires local construction and channel shaping upstream.
(d) Constructed locally.

Figure 5.2

Factory Costs Comparison Between Ultrasonic and Electromagnetic Flowmeters



If the manufacturer's information is unavailable, but it is physically possible to measure (with considerable accuracy) the internal dimensions of the device (and if it is in good condition), experts in measurement hydraulics can calculate the flow at various pressure differentials by assuming a coefficient of discharge from published experimental information.

If the device is in good condition but no information is available, it is possible to calibrate the tube by secondary measurement, but with inherent loss of accuracy.

For volumetric meters (Helix or rotary vane) the calibration checks on the accuracy of a newly manufactured article designed to achieve the standard results under standard conditions. Calibration of each new instrument is a quality check to ensure maintenance of performance, and only minor adjustment is usually necessary by the manufacturer. Only the internal mechanism is tested in a standard meter case, and experienced employees can adjust the regulating vane very quickly in the test shop. Testing methods are described by the manufacturer and a certificate is issued for each meter.

On-site calibration may become necessary to determine how much accuracy has varied after continuous use, but routine replacement of the internal mechanism may be preferable. Replacement with a factory calibrated mechanism will probably give the same degree of accuracy as removing the meter for a tank-calibration test.

Electromagnetic and ultrasonic meters are individually tested for the appropriate flow conditions and calibrated with a flow constant which, when inserted into the equation of flow, provides accurate discharge information. This is usually done within the electronics of the power converter installation.

Velocity insertion meters--turbine, pitot, or electromagnetic probe--require accurate flow profiles and calculations for flow-rate calibration. If this is carried out to the detailed specification in accordance with British Standard 1042 for D.P. devices and with similar procedures for other meters, very accurate results are obtainable. To acquire this degree of accuracy, skilled operation is necessary.

Channel flow meters, like D.P. devices, are calibrated by determining the discharge coefficient. This entails accurate checking of all dimensions, levels, and any erosion. The error in flow rate is directly proportional to errors in dimensions. Attention is then directed to channel conditions, particularly to the velocity of approach, any backing up of the lower channel, and (for weirs) clearance of the nappe, over the full operating range. The secondary instrumentation is then examined. In particular, it is necessary to check the zero setting and potential errors in reading of the liquid level due to capillary action, friction, or other causes.

Alternative means of calibration employed on site may have varying degrees of accuracy, but they are acceptable when circumstances require. Accuracy depends on the degree of precision with which the tests are carried out. Examples are:

(a) Volume Measurement--If the total supply can be conveyed from or to a suitable reservoir or storage tank and the volume of a series of uniform rates of flow measured over fixed periods of time, a calibration curve can be produced. A precision hook gauge will be necessary to measure change in water depth in the tank.

(b) Standard Meter--If the entire flow can be diverted through a temporary standard calibrated meter, the readings from the standard meter can be used to calibrate the main meter. A mobile test rig can do this kind of calibration on site for smaller meters. Standard test rigs can be supplied by meter manufacturers or fabricated by using an accurate meter such as a properly calibrated electromagnetic or similar high-accuracy measurement device. The full flow through the meter to be calibrated passes from one or more hydrant connections to the test rig, and a calibration curve is produced from various flows. The low flow reading is the crucial one. In some types of Helix meters, the regulatory vane can be adjusted without removing the meter from service. However, replacing the internal mechanism may be cheaper and easier.

(c) Weir Gauge--In some cases, it may be preferable and easier to obtain an accurate reading by passing the flow from a small, in situ meter to an accurately constructed weir tank with a 90-degree V-notch. This device can measure a depth over the notch as low as 50 mm. or about 3 m^3/hr., or as much as 500 mm. or about 800 m^3/hr. Thus, calibration of meters between 150 mm. and 250 mm. can be carried out for low flows and continuous rating.

(d) Pumps--The known discharge characteristics of recently installed, new pumps may be used to obtain an order of discharge and calibrate the meter. The accuracy will be low, perhaps $\pm$10% or worse.

5.10 Choice

Choosing a new meter or examining existing meters to check their suitability and reliability depends on working conditions. This process will be examined in more detail under the following sections, "Source Meters," "District Meters," "Large Consumer Meters," and "Bulk-supply Meters."

However, comparative analysis indicates some general areas of choice:

(a) Venturi Tubes--Classical and short tubes are expensive to manufacture and install. They are a sound method of fluid measurement but, because of the "square law" relationship between the flow and the differential pressure (D.P.), accuracy reaches an acceptable level only if the minimum flow rate is not less than about 25 percent of the full flow rate. They are only as good as the secondary instrumentation.

(b) Orifices, Dall Tubes, Nozzles and Similar D.P. Devices--These are cheaper than venturis to manufacture but still fairly expensive to install. They are only really satisfactory if the range does not exceed 4:1 because they suffer the same limitations as venturis.

(c) Averaging Pitot--This meter is cheaper to buy and install, but still a "square-law" instrument. It is better for a non-uniform flow profile. It requires small range--say 4:1--and good secondary instrumentation.

(d) Helix--The Helix is cheap to buy but does require regular maintenance of internal parts. Not really practicable above 300 mm. When installed as it should be with a strainer and on a bypass, its cost rises rapidly and it loses its "cheapest buy" status. At the present situation, and it is probably the most used meter in the world.

(e) Electromagnectic--These meters require a power supply that can come from a battery. Little maintenance is required. In sizes smaller than 300 mm., they are more expensive than the Helix, but because there is no intrusion or moving parts, a bypass is not normally necessary, thus saving installation costs.

(f) Ultrasonic (Measuring tube factory-calibrated)--This "time-of-flight" instrument is comparable to the electromagnetic meter. As there is no intrusion in the bore, the direct installation cost can be lower. However, total installation costs may be higher than the electromagnetic because of the need for greater lengths of straight pipe.

(g) Ultrasonic (Under pressure installation, weld-on, or clamp-on)--This meter is much cheaper than the measuring tube and comparable to the averaging pitot in price, but accuracy is much lower. Properly installed, it may be acceptable in situations where a new metering tube cannot be inserted.

(h) Insertion Turbine--The insertion turbine is cheap to buy and install but not normally acceptable for continuous use. It is ideal for survey work. Its accuracy depends on the care of the instrument, the skill with which it is used, and the accuracy with which all the parameters are measured.

(i) Insertion Electromagnetic--Unlike the insertion turbine, in the insertion electromagnetic meter there are no working parts. Although there is still little operational experience, it appears that properly used, the instrument could provide a long-term solution to flow measurement in a situation where a metering tube cannot be inserted.

The choice of the correct meter will always be subjective and will depend to some extent on the purchaser's experience and point of view. There is no doubt, however, that the most modern electromagnetic and ultrasonic meters will play an increasing part in water authority use in the future. In most current situations these meters compare very favorably with others on any rational basis for rating benefits. The electromagnetic meter may have a slight advantage over the ultrasonic meter in relation to requirements for straight pipe preceding the meter.

Finally, choice must be made with the knowledge that specific application requirements affect different types of meters in different ways. Again, all of the factors, including the effect on the overall system, should be considered and, if possible, quantified before any firm selection is made.

SECTION 6

APPLICATIONS

6.1 Source Meters--Closed Pipelines

6.1.1 Types of Meters

In normal waterworks practice, it is usual to meter the quantities of water delivered from each source into the pressurized supply. In this section, we consider meters designed to measure flows in closed pipelines running full. The flow of water at a source may also be metered in open channel at the pumping station or gravity intake before it enters the pressurized system; these meters are dealt with in Section 6.2.

6.1.2 Source Stations and Pipelines

Meters are required at all source stations and, where there is more than one transmission line from a station, a meter is necessary on each. The system must be examined in relation to each source and transmission line.

If there are numerous sources, it may be practicable to isolate each source in turn for preliminary inspection to determine the appropriate meter site and then to isolate them again long enough to permit installation, testing, and necessary calibration. The procedure is similar to replace an unsatisfactory existing meter. Where there is more than one transmission line from any source station, each line may be isolated in turn in order to install or replace a meter. With either method, selecting a new meter is not restricted by any problem of maintaining the water supply.

Such facilities may not be available and the delivery pipelines may not be able to shut down for any significant period. In these cases, the choice of meter is limited either to the types described in Section 3.1.7 (accepting the associated loss of accuracy) or to a weir or flume in open channel upstream at the headworks, before the water is delivered into the network.

In a multi-source station where a number of separate borehole pumps deliver to a single manifold, there may be good reason to establish a meter at each source, as well as one for the total station output.

6.1.3 Physical Conditions

For each source meter site a schedule should be prepared giving the physical conditions. If a meter already exists, these conditions may well differ from those when the meter was installed. To clarify the situation, these data might be tabulated as shown on Figure 6.1. Variations in these conditions, as between stations, will affect the degree of uniformity possible in the selection of new meters.

Figure 6.1 - Schedule of Meter Particulars, Closed Pipe

Date: ________________

WATER UNDERTAKING

Source Works or Pumping Station

Pipe Outside Diameter....................Pipe Inside Diameter.............
Pipe Material...........................Pipe Joints.......................
Maximum Flow Rate...
Minimum Flow Rate...
Meter Maximum Scale Flow Rate.....................................
Working Preference..
Operating Flow Range (Max. Flow/Min. Flow)........................
Pressure Loss Acceptable (If Critical)............................
Upstream Pipe Straight Length, Above Site of Proposed (or Existing Meter)...
Downstream Pipe Straight Length Below Site........................
Motive Power Preceding (i.e, Centrifugal Pump Reciprocating Pump Treatment Plant, etc..
....
Pipeline Configuration Below Site.................................

Existing Meter (If installed)

Type of Meter...
Nominal Bore..
Capacity Max..
Manufacturer..
Serial Number...
Age...

Secondary Instrumentation

....
....

General Particulars

Power Supply Available..
Telemetry (i.e., Signal, Cable or Radio)..........................

Normal Operating Conditions (i.e., Continuous No. of Hours/Day Intermittent...
Is Supply Direct to Distribution and Consumers or Via a Service Reservoir...
If Service Reservoir, State: Capacity.................................
No. of Hours Supply at Average Demand........
Distance from Source Works..................
Transmission Main Particulars................
....

Site Conditions

Space for Alterations (If Necessary)..............................
....
Facilities for Pumping to Waste...................................
....

Bearing in mind the particular features of each type of meter described in Section 3, these conditions must be considered when deciding which types of meters would be suitable and which would not.

6.1.4 External Access

The information for Figure 6.1 may not be obtainable without full external access to the pipeline at the proposed site. Limitation of external access may restrict the choice of meter, particularly if an existing meter has to be replaced. The questions under "Site Conditions" should clarify whether space exists for an installation or for changes to an existing meter. Any such restrictions might dictate use of an under-pressure installation or open channel metering.

6.1.5 Internal Access

Before any existing meter is retained or any new site is accepted for installation, it is essential to know the internal condition of the pipeline and any existing metering device. It is especially important to know about any erosion, corrosion, tuberculation, scale, loose stones or sediment.

To rehabilitate an existing meter that consists of a differential-pressure device such as a venturi tube, dall tube, or orifice, internal access is neceessary. The meter's accuracy will depend on the internal state of the pipeline, which, depending on age or characteristics of the water, could be partially blocked by settled sediments, tuberculated or eroded.

For pipelines with a diameter of more than 800 mm., internal access is normally possible from a suitable flanged connection during a shutdown. For smaller pipelines, internal access is not practicable, but some limited degree of internal examination may be possible from the outside during a shutdown through a suitable flanged or branch connection. It is also possible to carry out an inspection with closed circuit television cameras. Many firms specialize in carrying out this operational service, as well as providing a complete report and copies of the inspection film. It is also possible to examine the inside of small pipes with a flexible endoscope inserted through a hydrant point or other suitable connection. In most circumstances, however, the best way of determining the internal condition of a small pipeline is by removing a section of pipe.

6.1.6 Operation and Maintenance

All types of meter may be suitable as source meters, depending on operating conditions. Generally speaking, traditional meters--whether of the mechanical type, with an internal moving rotor, the orifice/venturi type, or a pitot--require careful operation and regular maintenance of the meter or its secondary instrumentation by skilled mechanics. More modern, electromagnetic or ultrasonic meters, with electronic secondary instrumentation and no moving parts, offer no resistance to flow and are sealed units, requiring no operating skill and little or no maintenance.

In cases where skilled operators are not available, there is every incentive to select one of the more modern meters for all new installations of source meters.

It is essential, however, to provide the manufacturer with the correct flow requirements so that initial calibration is done at the factory for the appropriate site conditions.

Where other types of meter must, for some reason, be accepted, proper basic training of all operators and maintenance mechanics is imperative. The orifice/venturi type, with mercury manometers for measuring difference in pressure, are easy to put out of operation. In addition to normal operation, there is a need for regular maintenance, cleaning, and checking of the equipment used to convert pressure difference to flow. Electronic transducers may be used to measure the pressure difference instead of a mercury manometer. Such equipment may include chart recorders; these are also prone to failure if not maintained adequately. Normally, provided the flow indicator and the integrator are operating well, the recorder can be ignored, since the chart information is very rarely useful for management. See also Section 6.1.8.

A mechanical meter is normally used only for smaller sources with pipelines up to 500 mm. Its advantage is that no motive power is required, but it is particularly difficult to maintain in accurate operation when the water contains grit in suspension (as from many well sources) or frequent large pockets of air. It must always be fitted with a strainer upstream, and this must be cleaned as often as necessary, possibly every month or even every week. Frequency of cleaning can only be determined by operating experience. Whether fitted under pressure or not, small-diameter turbine meters with very fine clearances are particularly susceptible to wear on moving parts, are difficult to maintain, and should be avoided at source stations.

6.1.7 Power Requirements

If new meters or new sensors for existing meters are installed, they almost certainly require a suitable power source, whether they are pressure-differential devices, Helix or electromagnetic. Secondary instrumentation for new meters should be electronic if at all possible, with provision for flow rate, quantity integration and future information transmission.

Power supply should not present any problems at source works and pumping stations; but in rare circumstances where non-electric prime movers have no secondary electric power, the meter may operate using very long-life batteries, provided the batteries receive regular attention.

6.1.8 Calibration

This matter is dealt with fully in Section 5.9. For new production meters, site calibration is normally not required, provided they are specified to suit site conditions and are installed according to the maker's instructions, preferably by the suppliers (see Section 6.1.11).

A problem arises with insertion-type meters installed where limited access precludes full inspection of pipeline geometry or condition; the same is true of the clamp-on type of ultrasonic meter. In such conditions calibration may be done by measuring volume changes in a section tank or an associated service reservoir, provided that the latter can be isolated from the system and that tests for leakage have been undertaken.

Where there is external channel flow at the source headworks, the meter may be calibrated against a weir installed in the channel.

For the smaller sizes, it may also be possible to calibrate against one or more test meters fitted on stand-pipes.

Where such facilities do not exist, every effort should be made to avoid installing any production meter that the maker has not pre-tested.

6.1.9 Communication Facilities

The method of informing management about water supplied from source must be reviewed. The usual requirement is to record the daily quantity supplied in appropriate units and to measure it at the same time each day for comparable results.

If meters are read manually and the results telephoned to the central administrative center, it is usually convenient to take and transmit readings daily at, say, 0900 hrs. Or all the required information can be stored locally and transmitted daily.

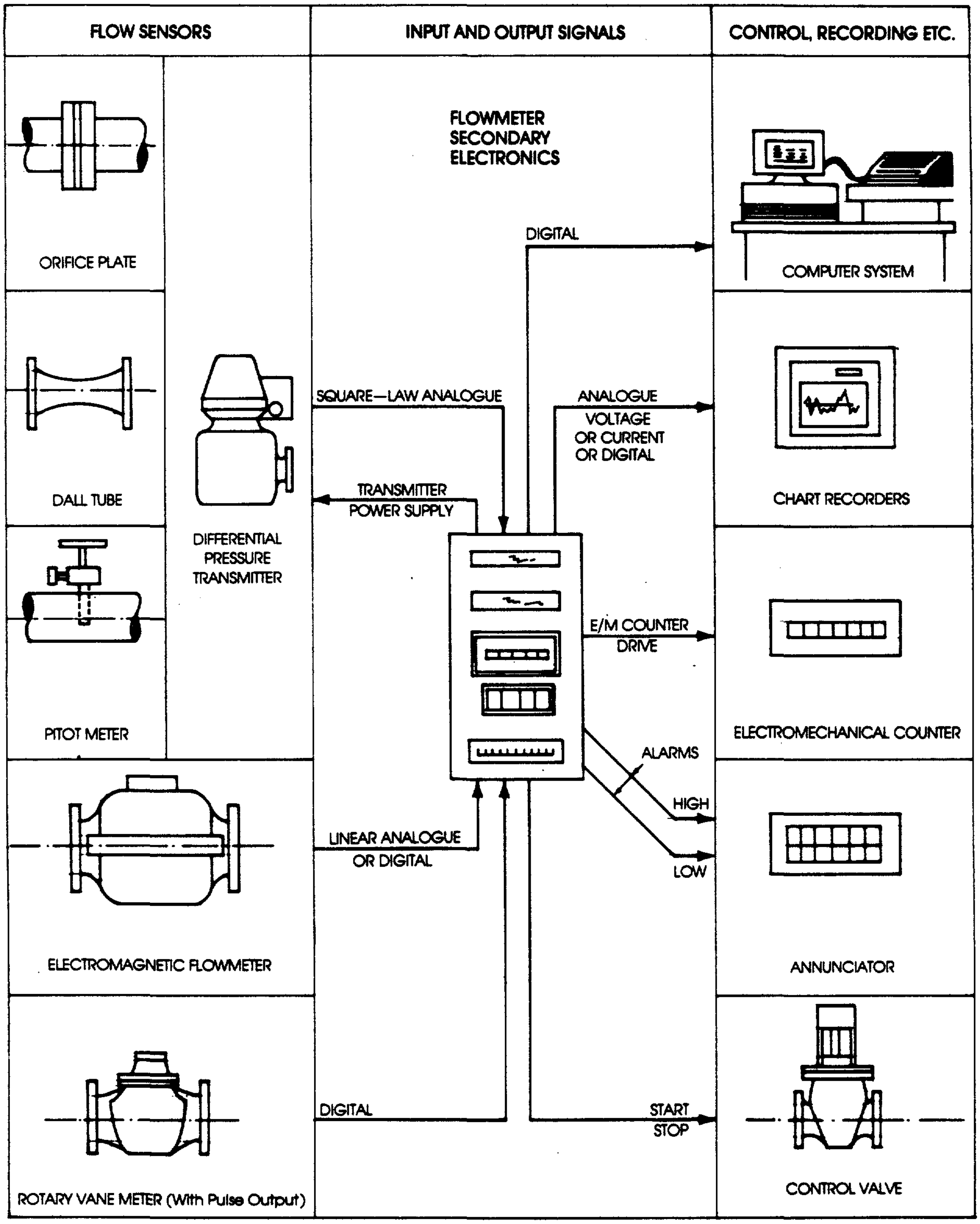
Many water authorities have difficulties because of the extensive lines of communication from sources to divisional or control headquarters.

In developing countries, difficulties of communication have been compounded by unreliable telephone or electricity services and inadequately skilled or trained personnel in out-stations.

Recent radio developments have improved this situation, and radio may now reliably transmit data, such as meter flow readings, direct to the central organization. Where there is a lack of skilled operators, these developments offer enormous advantages and can provide improved control of the undertaking. Every opportunity should be taken to use the facilities now becoming available worldwide, applying the new techniques not only to new meter installations, but also to existing meters. We suggest that both installation of new meters and rehabilitation of existing ones be done with the prospect of an ultimate telemetry link to a main center. This means transmitting a digital signal.

Figure 6.2 shows some typical telemetry configurations from various meters to local secondary electronics and local or remote control and recording.

Figure 6.2 - Secondary Instrumentation and Telemetry Control



6.1.10 Existing Meters

If the existing meter and secondary instrumentation appear to be satisfactory, are installed correctly, with sufficient straight pipe upstream and downstream, and are working under the proper conditions (particularly in regard to operating range), only a calibration check is necessary, preferably by the manufacturer. Otherwise, we recommend a specialist laboratory or an "in-house" performance test (as described in Section 5.9).

If the meter and instrumentation are not working or if some other plant performance parameter (energy balance, fuel consumption, etc.) suggests an error, further investigation is needed. Frequently, failure results from lack of mercury in a manometer, easily revealed by brief inspection. Otherwise, detailed inspection must follow. First it is necessary to distinguish between meter primary and secondary (or between meter and readout). Faults could lie in either or both, or perhaps in the fittings associated with the meter. A blocked filter or an isolating valve that has been partially closed could be responsible.

If the meter has ceased to function or is damaged, replacement of primary or secondary, or both, is inevitable; returning the meter to the manufacturer is usually the best course of action, if practicable. Replacement should be made in the light of the latest technology and bearing in mind these guidelines. Where the meter seems to be reading incorrectly, it should be possible to look for the fault and find out if it is functional or due to wear or other causes, and whether the primary or secondary is the cause.

Because of the diversity of meter types, it is not feasible to give detailed guidance on a fault-finding routine. The principle is to detach the primary from the secondary and substitute other means of signal read-out. If an incorrect or no signal is received, the fault is in the primary. If a signal is received, the fault may be in both primary and secondary, or in the secondary alone.

In the first case, the meter may have to be stripped or removed and stripped. In the second case, if a substitute signal for the missing primary can be applied to the secondary, it should be possible to tell if the secondary is at fault. The signal may be a turning shaft (in the case of a mechanical register) or an electric source, depending on the meter type.

6.1.11 New Meters

The first choice for a new meter at a source works may well be an electromagnetic meter or an ultrasonic, "time-of-flight" meter (see Section 3). It is vital to ensure that the meter is the correct size and made of appropriate materials and protected as necessary for site conditions. The manufacturers should be given full details of environmental conditions before bids are accepted.

It is most important to install the meter correctly in accordance with the manufacturer's instructions and these guidelines.

If a flow meter breaks down, it may need to be removed from the pipeline in which it is installed. Depending on the meter type, the breakdown may prevent fluid passing through the faulty meter. The consequences of a breakdown may be minimized by design that provides:

(a) Isolating valves either side of the meter;

(b) a drain valve to empty the meter;

(c) ease of access to the meter;

(d) ease of removal of the meter from the pipe;

(e) space to dismantle the meter in situ;

(f) a bypass loop to allow flow to continue during repair;

(g) air bleeds to facilitate filling the meter when it has been replaced; and,

(h) a spare meter.

Depending on the type of installation, not all these precautions may be necessary. Nevertheless, it is too often assumed that once installed, a flow meter will run and perform according to its original calibration forever.

After periods of use, flow meters do not retain their original calibration but in most cases continue to give a read-out, which may be believed or disbelieved, depending on the shrewdness and experience of the observer. If this situation is foreseen, checking flow rate at regular intervals may become a routine part of checking plant efficiency. This may be done by temporarily installing a master meter in a specially provided bypass loop, incorporating isolation and bleed valves, or by providing connections for insertion meters.

Having suggested many advantages in the use of electromagnetic or ultrasonic meters, we must emphasize that the day of the traditional venturi or orifice meter is not over, especially with new electronic instrumentation, because of lower cost and relative ease of maintenance.

Therefore, provided the effective range requirements are in the order of no more than about 4:1, and all other factors required for accuracy can be complied with, the differential-pressure device, fitted with modern secondary instrumentation, remains a viable choice for new installation.

All these comments assume that the supply can be interrupted long enough for an "in-line" installation. If this is not the case, the choice will have to be an insertion meter for a small range. An averaging pitot probably has marginal virtues. If the flow range is large, however, an electromagnetic insertion meter is preferable.

6.2 Source Meters--Open Channel

6.2.1 Types of Meters

In most countries, waterworks generally measure production by closed pipeline meters as water enters either the transmission line or the distribution network or both. In many developing countries such meters may never have been installed. In some countries, notably in South America, it may be more common to meter source flows by weirs or flumes in open channels before they enter the reticulation system.

6.2.2 Source Stations

These meters may be situated at the entry to the treatment plant. If the flow varies, the meter may not then accurately register the quantity entering the network. For that figure, a correction is necessary to allow for changes in water levels (and thus in storage) in the various tanks and channels in the treatment plant. This is disadvantageous when attempting any audit of inflows and outflows. If the meter is sited at the exit from a treatment plant, the problem is smaller, though there may still be a need to correct for level changes in any clear water tank or sump pump.

Although open channel meters may be less accurate than many closed pipeline meters, many of the latter have been allowed to fall into disrepair, while open channel meters have been better maintained. This may be because they have often been used to control the treatment process. The need for extremely careful construction, as well as good maintenance, has not always been fully appreciated. Section 3 shows that many careful measurements and operations are necessary to obtain meaningful results.

6.2.3 Physical Conditions

On beginning or reactivating a meter installation program, the procedure should be as for installation of closed pipeline source meters. A schedule must be prepared, with the data tabulated as in Figure 6.3.

In an existing meter installation, present conditions may well differ from those when the meter was installed (such as additional flows entering from a new upstream side channel). These should be clarified in Figure 6.3. Varying physical conditions between stations will affect the degree of uniformity possible in new primary devices, but not necessarily the type of secondary instrumentation. See Section 3 for descriptions of meter types and various applications.

6.2.4 Access

Access to any meter or any proposed metering site requires careful consideration, but is unlikely to be a major factor in the choice of an open channel meter. Before retention of any existing meter is decided, full access is necessary to check the structural condition and the dimensions and levels of all detailed points. This may present some difficulty.

6.2.5 Operation and Maintenance

Both the primary device and the secondary instrumentation in these meters may require regular maintenance, as well as skilled and careful operation to assure optimum accuracy. The primary device requires regular cleaning of all inverts, walls and weir plates, removal of all deposits, slime and growths, and inspection of hydraulic passage to the stilling well. There can be no downstream deposits or restrictions that could cause backing up. In the case of weirs, one must check that the nappe is clear at low flows.

If the secondary instrument is a simple staff gauge or float, only a very easy but regular cleaning is required. The same is true for the bubbler mechanism, but with some specialized mechanical attention to the air pressurizing mechanism. While valuable for sewage or dirty water, bubbler equipment has little application for clean water.

Electrically and electronically operated devices may remain in operation continuously with no attention. Avoid all unskilled tampering and leave maintenance to electronic specialists.

6.2.6 Power Requirements

In their simplest form, these meters require no external power input. However, because their accuracy largely depends on accurate reading of the zero and the actual water level, some form of electronic sensor and conversion equipment is normally used for more accurate registration. Power requirements for that purpose are small and, if necessary, can be provided by batteries if these are adequately protected.

6.2.7 Calibration

These meters are calibrated entirely by hydraulic calculation. If they are accurately constructed, they require no site calibration and may be utilized for site calibration of pipeline meters.

6.2.8 Communication Facilities

Even if the existing secondary device is a simple staff gauge or float, electronic instrumentation can replace it when desirable. Such instrumentation permits easy transmission of flow rates, by cable or radio, either locally or to a central control station.

Figure 6.3 - **Schedule of Meter Particulars, Open Channel**

Date: ________________

SOURCE WORKS OR PUMPING STATIONS

Site

Type of Source (Well/Spring/River/Reservoir, etc.)........................
Type of Treatment Plant (Pressure/Gravity)................................
Maximum Flow Rate...................Minimum Flow rate.....................
Water Datum Level at Source Before Treatment: Max........Min..............
Water Datum Level at Discharge From Treatment: Max........Min..............
Available Head at Entry to Plant..

Existing Channel:	At Entry Plant	At Discharge From Plant..
Width	....	....
Max. Depth	....	....
Min. Depth	....	....
Gradient	....	....
Straight Length Above Site	....	....

Maximum Levels of All Tanks and Channels in Plant..........................
Minimum Levels of All Tanks and Channels in Plant..........................
Water Volumes of All Tanks and Channels in Plant...........................
Max............................. Min..................................
Water Levels of all Tanks and Channels After Discharge:
Max............................. Min..................................
Water Volumes of All Tanks and Channels After Discharge:
Max............................. Min..................................

Existing Meter (If Installed)

Type of Meter...
Dimensions..
Manufacturer..
Capacity: Max.................... Min..................

Primary Device

Construction Details......................................
Condition...
Dimensions and Levels.....................................
Age.................Calibration Levels (If Any).............

Secondary Instrumentation

Level Measuring Device....................................
Method of Conversion to Flow..............................

General

Power Supply Available....................................
Telemetry Facilities......................................
Normal Operating Conditions...............................

Site Conditions

Amount of Space for Alterations Such as Extra-Straight Channel:
....
Facilities for Bypassing Flow:............................
....
Facilities of Discharge to Waste:.........................

6.2.9 Existing Meters

Where existing meters are in good operating condition, it does not follow that they are registering accurately. They must be checked regularly to see that all the essential flow conditions are maintained continuously over the whole flow range.

Even where these meters exist, there should be a considerable advantage in also installing closed-pipeline meters for a far more accurate flow audit of the network. Then the open channel meter can be retained for plant control and may also be valuable for meter calibration.

6.2.10 New Meters

When the metering program is planned or under review, the first option for measuring production is undoubtedly the closed pipeline meter. If, for some reason, a full-size meter is not practicable, then the open channel meter may offer a practical alternative to the probe meter and may have other advantages.

6.3 District Meters

6.3.1 Types of Meters

District meters have almost always been of the mechanical, rotary vane type where the pipeline size has been less than 500 mm. This is because they require no external source of power or other installation apart from a chamber to accommodate the meter. In sizes larger than 500 mm., a differential-pressure meter, such as a venturi, dall tube, nozzle, orifice plate, or pitot, used to be customary.

The present choice for such meters is now much wider. It is practicable to consider electromagnetic meters from 100 mm. to 2000 mm. in size, as well as ultrasonic meters and insertion electromagnetic probes. All of these meters are described in Section 3, but some important considerations are amplified in this section.

6.3.2 Type and Size of District

The type of meter will depend on the type and size of the district. For instance, if the district is a separate supply area with its own service reservoir or water tower storage, the supply is likely to be continuous at a fairly uniform rate. During the normal working day, the meter records peak demand to the area, supplemented by backflow from the reservoir, and at night measures much lower flow for use but, at the same time, measures the reservoir replenishment for the next day.

On the other hand, a meter may meet the daily demand with virtually no storage in the system, when, in the absence of substantial leakage, demand in the early hours of the morning might be very low indeed. (This condition may be rare in developing countries, particularly where local, private storage tanks offset supply deficiencies).

In the latter case, a meter must be sensitive enough to record very low flow rates that would otherwise go unmeasured. Although they assist in controlling waste water, district meters are not waste meters (which require very low sensitivity). Better results will be achieved in monitoring demand by siting district meters where a significant flow rate is always going to occur.

6.3.3 Physical Conditions

District meters should be arranged to measure the flow from the larger diameter distribution mains to the smaller mains representing the general consumer network.

It can be a complex problem to choose meter locations that will enable the total supply to be divided into areas where knowledge of the supply to that area will be useful and, at the same time, to choose positions where the sum of the consumptions recorded by the installed meters will approximate the total supplied. The most sophisticated method of achieving this design is to carry out a network analysis for a range of flows. The optimum bulk-meter locations should then be readily apparent.

If, as is often the case in developing countries, network analysis cannot be achieved in the near future, the meter locations can only be determined by applying common sense to local knowledge. Some situations will be obvious, such as the feed main to a separate district or township or even a large shopping complex. Other situations may require arbitrarily dividing the area and making small adjustments to supply arrangements to measure only the supply to the selected area. The main thing is not to be too ambitious at the outset and keep the arrangements simple and operable, using available manpower.

It is generally assumed that some 2,000 to 10,000 properties would be involved, but very much larger districts are viable, especially if consolidation eliminates the need to isolate areas from each other by closing too many valves, or having to subtract or add other meter records of flow in or out of the system. It follows, therefore, that when district meters are referred to, they are commonly in the range of 100 mm. to 250 mm.

Without detailed knowledge of a particular water system, it is difficult to provide much guidance on setting up the areas to be measured by district meters, but the local manager or distribution engineer will certainly have definite ideas about meter location.

Some caution is necessary in selecting districts. It is better to have a manageable number of districts, and therefore meters, to start with, even if the resulting areas are large and cover populations of 100,000 or more. Otherwise, it is tempting to spend money installing meters for relatively small areas without having the resources to use them effectively. The use of district meters will also be complicated by change in flow direction. If sites can be chosen where the flow direction is always one way, so much the better.

In order to aid in the selection of districts and to provide the engineer and the manufacturers of the chosen meter with accurate information, it is highly desirable to carry out a survey of chosen locations for district meters, using a portable, insertion-type pitot or turbine flow meter at each site for enough time to be able to determine the diurnal variation in flow rates.

6.3.4 External Access

A site may already be committed where an existing district meter is installed; otherwise, a site should be chosen on the pipeline so that access is possible under all circumstances for meter reading, repair, and maintenance. District meters should usually be installed on a bypass with suitable stop valves, but the type of meter and cost considerations may dictate otherwise.

6.3.5 Internal Access

Internal access is unlikely, considering the sizes of pipeline used for district meters. However, the internal condition of the pipeline is a significant factor in selecting a suitable meter, and its condition may be known from department records if recent repairs or alterations have been carried out. It is possible to examine the inside of the pipe with an endoscope, but this may only be worthwhile if serious doubts about internal conditions exist. Removing a section of pipe for inspection may be better.

6.3.6 Operation and Maintenance

In theory, all types of meters may be suitable as district meters, but by definition, a district meter is usually situated far from a normal working base, probably difficult to access and usually without an electricity supply.

For this reason, these meters have almost always been of the rotary vane, mechanical type (see Section 3 for complete reference to problems in their use and maintenance). If the environmental conditions are suitable and these meters can be adequately maintained, they are ideally suited to district meter use. As mentioned in 6.3.1, electromagnetic meters are now a viable alternative to the rotary vane type and require virtually no maintenance. If they are battery-powered, however, provision must be made for routine annual battery replacement, based on present battery life.

It is extremely important that electromagnetic meters not be placed where they may be affected by other power sources. Otherwise, the meters must be shielded from power sources.

Unless very large supplies are involved in exceptional conditions, use of differential-pressure type meters as district meters is unlikely; but if they are, see Section 6.1 for maintenance information.

There seems to be no inherent reason why an ultrasonic meter (metering-tube type) should not function as a district meter, but no evidence is yet available of their use in such circumstances. Electromagnetic meters are likely to be more suitable and less costly in district-meter sizes.

Other alternatives, such as insertion-type turbine meters, are ideal for survey conditions and relatively short periods of use, but are too weak for prolonged use. They are also easily damaged during transport from site to site, so that constant care is required for accurate results.

6.3.7 Power Requirements

The power requirement for use of electromagnetic meters has already been mentioned. It is fundamental that the choice of meter should not inhibit use of the latest technology, either initially or in the long term.

All meters can now be electronically adapted to provide remote read-out and integration or can transmit the meter reading by hard wire or radio, to a control depot or a central computer. Although a battery can serve all these purposes, a site with a reliable power source should be selected if available.

6.3.8 Calibration

This is fully dealt with in Section 5.9.

District meters of conventional sizes are somewhat easier to calibrate than larger meters. This can be done in a workshop with tank testing facilities or on-site, by registering discharge from the pipe beyond the meter through a calibrated check meter. A refurbished and calibrated replacement or new internal mechanism from the manufactures is a satisfactory alternative to a new meter.

6.3.9 Meter Monitoring and Communication

Normally, all district meters are read at least weekly at about the same time of day. We advise weekly measurement of the large consumers in the district, until a norm for large consumption is established. Depending on the amount of detailed data required and the means of collecting or transmitting data, it is ultimately possible to examine flow variations on a daily or nightly flow basis. Initially, however, weekly readings will provide a norm that can be used as a basis for comparison with other districts.

The full value of district meters, and their use with source meters and consumer meter records, only emerges when information is available daily, or even hourly, to the supply and distribution manager. Thus, the meter should be suitable for transmission of meter data as often as management needs it.

6.3.10 Existing Meters

The choice of an appropriate meter for district consumption records will be dictated by the districts selected and by user experience with existing district metering, which is likely to be of the rotary vane type. If existing meters operate satisfactorily with reasonable maintenance, it is sensible to continue using this type of meter. They should be installed according to the recommendations in Section 3 and satisfactorily calibrated.

6.3.11 New Meters

If there is no grit in the distribution system and the water is clear and free of filamentous matter or significant air pockets, the rotary vane type of meter, protected by a strainer, is cheap and accurate over wide-ranging flows and probably provides the easiest and cheapest district metering.

Frequently, however, the supply situation is such that maintenance cannot be provided for rotary vane meters. Either through inherent characteristics or subsequent entry of harmful matter during repairs, water may be unsuitable for the continuous operation of rotary mechanical meters.

In these circumstances, electromagnetic flow meters should receive full consideration. Provided the range of flow can be given to the manufacturer, these meters are calibrated in the factory and require virtually no maintenance once installed. If a power supply is unavailable, they can be supplied from a long-life, disposable battery, which also provides the power for a data logger to store flow records. At present, assuming continuous full use, battery life is about one year; but this life will probably increase (up to 10 years) very soon.

In exceptional circumstances, it may be impracticable to shut down the supply; in this situation, an insertion-type electromagnetic probe, properly calibrated for the local conditions, can provide a reasonably accurate alternative.

6.4 **Large Consumer Meters**

6.4.1 Types of Meters

Large consumer meters are likely to be in the size range from 100 mm. to 500 mm., the latter for very large industrial concerns. It is probable, therefore, that the meters will be of the rotary vane type described in Section 3.1.4.

Meters for large consumers differ from those used for the water-authority control purposes in two very important ways:

(a) The consumer may wish to keep records of water use to regulate his own consumption and check his accounts, or even to compare with his own plant meter--an extra control that should be encouraged. It is desirable, therefore, that read-out and integration be readily available to both parties.

(b) Under normal supply agreements, the customer has the right to challenge the accuracy of the meter; if he does so, the water authority has to calibrate it and satisfy him that it is operating within an agreed tolerance.

The various means of calibration are dealt with in Section 5, but it is also worth exploring the consumer's facilities. If he has a suitable tank or reservoir into which the supply passes, this may be used to carry out a joint volumetric test satisfactory to both parties with the meter in place.

6.4.2 Types of Consumer Installation

In order to maximize revenue, accurate measurement is extremely important. For larger consumers, it is usually worthwhile to record meter readings more frequently than usual, say monthly, and present their accounts monthly to assist the authority's cash flow. Recommendations on installation in Section 5 should be followed. The meter should be fitted with a strainer and a bypass, so that removal and refitting do not interfere with the consumer's commercial processes.

The types of meters we refer to here are similar to district meters described in Section 6.3. Many meters for smaller supplies will be of other types not covered in these guidelines, but general principles of installation still apply.

We have dealt with the size of meters for particular flows in Section 5.6. Correct size is so fundamentally important for accurate metering of sales that it merits repetition. Because a rotary vane meter is required on, say, a 200 mm. supply, it does not have to be a 200 mm. meter. The sealed bypass supply must be maintained at full diameter to provide for fire fighting or other emergency demand. The meter has to be sized to suit the normal maximum rate of demand, determined by careful observation and bearing in mind the normal range of 10:1 for low flows. The rate of normal maximum consumption, particularly if the consumer has private storage, may be only a fraction of the maximum flow that could pass through the supply pipe. If the rate of demand regularly fluctuates widely, installing a combination meter may be necessary, if unusual. An electromagnetic meter may be more satisfactory.

6.4.3 Physical Conditions

Conditions of installation of large consumer meters must be properly recorded. A separate card-index system related to meter-reading records, will show details of the meter, supply pipework and installation. Drawings should be referenced to readily identifiable fixed walls or buildings so that the meter can always be found.

6.4.4 External Access

It is important to have very ready access for checking the physical conditions of the pipework, reading, maintenance, and changing either the strainer or the meter to minimize metering losses. Access for reading should also be available to the customer.

6.4.5 Internal Access

As mentioned in 6.3.5, internal access is improbable and unlikely to be a vital factor. To examine the internal condition of the pipe, use of an endescope or removal of a section of pipe may be necessary.

6.4.6 Operation and Maintenance

It is vitally important to keep large revenue meters operating continuously. Since so many of them are likely to be of the rotary vane (Helix) type, they will operate more satisfactorily and retain accuracy if they are preceded by a strainer assembly and fitted on a bypass. The valve(s) fitted on the unmetered, direct-supply pipe should be sealed closed by the authority; it is, however, common for the consumer or fire service to be able to break the seal in the event of fire or other emergency.

Some manufacturers produce strainer boxes identical to the casting that houses the meter assembly, where a spare meter might be installed as a temporary expedient.

Once the meter is properly installed, depending on local conditions, it is essential that maintenance be carried out at correct intervals. This can only be done with knowledge of the distribution system; it may mean cleaning strainers monthly and removing internal mechanisms at six-monthly intervals to check operation and ensure effective measurement.

It is not unusual for water authorities to derive the bulk of their commercial revenue from a few large water consumers. These meters require special attention for commercial reasons. Smaller commercial consumers and domestic meters should not be neglected, but they will inevitably have lower priority.

6.4.7 Power Requirements

Large consumer meters will probably not have a power supply, but most will have power close by. Provision should be made for a power supply for new meters if practicable, and by battery if no other sources are available. Remote reading of data from the meter can then be incorporated at a mutually acceptable position, either at the time of installation or later. In this way, data logging and transmission of information can be employed in the future.

If an electromagnetic meter is installed, a power supply will be necessary from the start. This can, if necessary, be provided by long-life batteries, but in many locations, power can probably be furnished from the consumer's supply on agreed terms. If the power supply is unreliable, adequate power to operate a water meter can be maintained by incorporating a rechargeable battery into the circuit.

6.4.8 Calibration

Accurate calibration is not only necessary for the correct measurement of the water consumption but is vital to reassure the large consumer that the bill he is paying is correct. The consumer will usually be prepared to accept a manufacturer's certificate of accuracy for a relatively new meter, but, after a period of some years, both he and the authority will require assurance that accuracy is still within acceptable limits.

See Section 5.9 for information on calibration of all types of meters.

6.4.9 Meter Monitoring and Communication

For large consurmers, meter monitoring is a visual examination of the record of the last period of consumption compared with previous use. A check such as this ensures that no serious problems in supply or measurement are occurring. If the billing system is computerized, the computer can compare consecutive readings and draw attention to deviations from the norm.

Although the existing meter reading may be entirely manual, it is likely that some form of automation will be employed in the foreseeable future. This may consist of a data logger, which the meter reader can interrogate with a hand-held logger that immediately displays or records the reading for printout at headquarters.

6.4.10 Existing Meters

Unless there are exceptionally large supplies to consumers (say over 500 mm.), the existing meter will probably be of the rotary vane or Helix type.

The existing system may be satisfactory. If not completely satisfactory, the existing meters might benefit from appropriate maintenance and calibration. There may be an overwhelming need to fit strainers and initiate a cleaning program in order to obtain satisfactory service.

In rare circumstances, efforts to measure and accurately charge large domestic customers prove unsuccessful, due to particulate matter in the supply pipes. If improved maintenance does not lead to satisfactory operation of these large meters, there is a case for replacement by electromagnetic or ultrasonic meters.

6.4.11 New Meters

If the existing rotary vane type meters are working satisfactorily or will do so with improvements in operation and maintenance, it is probably desirable to continue to use these meters for large commercial consumers. This is because the consumer must understand and accept the measurement and may feel more confident if the charge is based on a traditional measuring device. If, however, the rotary vane types are not operating satisfactorily under the environmental conditions, it will be essential to make changes. These changes may be fundamental or necessitate efforts by management to improve the quality of water in the distribution system.

Because they will probably give more reliable information, new meters of the electromagnetic and ultrasonic types should be considered for a situation where water quality or operational conditions are less than satisfactory.

6.5 Bulk Supply Meters

6.5.1 General

The purpose of bulk supply meters is to record the quantity of water sold to or purchased from another organization or water authority. The terms for such bulk-supply arrangements may vary from government acts to local legal agreements to an exchange of letters. In each case, however, the normal agreement to supply or receive water will be at an agreed volume and an agreed price-per-unit of volume--usually a cubic meter (m^3).

Thus, the accuracy of metering is of considerable importance to both parties and, in the case of very large supplies, may have considerable financial impact on total revenue or expenditure.

6.5.2 Types of Meters

The quantities supplied under bulk supply agreements can vary from an isolated supply for a few hundred properties to the entire supply of a large city or region. The correct choice of meter is, therefore, not only important but includes the full range of meters available from the manufacturers.

In general, the comments and information we have already given (on source meters in Section 6.1, district meters in Section 6.3, and large consumer meters in Section 6.4) will apply. A bulk supply could be by gravity through an open channel, in which case see Section 6.2.

6.5.3 Physical Conditions

Physical conditions will play an important part in determining which type of meter is most suitable, and such considerations are likely to include the size and the remoteness of the location. Depending on need, bulk supply agreements between authorities may be bi-directional; in these circumstances, either separate meters operating in each direction with suitable valving arrangements or a bi-directional meter is required. In the latter case, only electromagnetic and ultrasonic meters are worth considering.

For the very large supplies, quantities may be fairly uniform, in which case traditional venturi or orifice meters may be satisfactory, especially since the meters on such supplies will probably be checked by both parties to the agreement and subject to more satisfactory maintenance than many other types of meter installation. If the bulk supply arrangements give rise to extreme variations in flow rate, as is often the case, the traditional differential-pressure devices will be very inaccurate; linear output meters, such as electromagnetic and ultrasonic types, will produce better results.

For the smaller bulk-supply meters, the mechanical rotary vane types will probably be satisfactory with proper maintenance, although the battery-powered electromagnetic meter is a new and viable alternative.

In some circumstances, the bulk supply may be provided as raw or untreated water for treatment by the receiving authority. In this case, the meter may need to be able to deal with sand and silt and/or organic material.

Under such conditions, the mechancial meter is unsuitable, even with a filter. According to the flow range and other factors described in Section 3, a non-obstructive meter--such as a venturi, electromagnetic or ultrasonic--is preferable. With proper calibration to achieve the necessary degree of accuracy, an electromagnetic-probe meter might be desirable if a shutdown for installation is impracticable.

6.5.4 External Access

For existing meter sites where replacement or reconditioning is necessary, the site and degree of access will already be determined and will only have to be changed if it is physically impossible to provide a replacement meter to operate under prevailing conditions in the available space.

For new meters, the location should provide the best possible access. It is often desirable, and in some cases necessary, that bulk-supply meters be installed on a suitably valved bypass so that supply may continue if the meter has to be removed or repaired.

6.5.5 Internal Access

To check the pipeline's condition and the effect of conditions on an existing meter or their probable effect on a proposed new meter, sufficient internal access will be necessary. Comments on internal inspection are in Sections 6.1.5, 6.3.5, and 6.4.5.

6.5.6 Operation and Maintenance

Bulk supplies received provide some or all of the water for distribution. If a meter's failure can actually interrupt supply, then meter repair and normal maintenance must be as good as that in source treatment and pumping stations. Even if the supply continues when measurement fails, a significant financial problem may result if the meter is not maintained properly and replaced or repaired promptly.

As stated earlier, the type and size of bulk-supply meters can cover the entire manufacturing field; if in-house facilities do not provide the required high levels of maintenance, it should be obtained by contract.

Special consideration will be needed if the bulk supply is of untreated water.

6.5.7 Power Requirements

Comments in Section 6 apply to bulk-supply meters. However, where these meters are large, affect daily management, and need daily records of water balance and U.F.W., it is highly desirable for the meter site to have a suitable power supply. A power supply gives more options among meters and the most technically advanced, eletronic secondary instrumentation. It also makes it possible for flow data to be transmitted to headquarters, if required.

It is preferable for the power supply from the mains to be through a charging circuit to batteries, to avoid interrupted operation due to power failure. If a mains supply is unavailable, battery power can be considered as an alternative.

6.5.8 Calibration

Calibration has been fully discussed in Section 5.9. The necessity for accurate metering of bulk supplies is the same as for source works, but the unit-volume cost may be significantly greater, either as a received revenue or as an expenditure. Both parties to the bulk-supply agreement should satisfy themselves that the measurement of transferred water is accurate.

6.5.9 Monitoring and Communication

If bulk supplies are significant, monitoring the meter and communicating information to headquarters has the same priority as information from source meters does in Section 6.1.9. For lesser bulk supplies, the system for monitoring and communication should be similar to the one for district meters in Section 6.3.9.

6.5.10 Existing Meters

Existing bulk-supply meters should be critically examined and their current use compared with their design characteristics. It is best to use a table like the one in Section 6.1.

There may be very significant financial implications if the existing meter is providing false information. Unless this can be rectified with little difficulty, replacement with a more suitable meter should be technically and financially rewarding.

6.5.11 New Meters

For large bulk supplies with more than a 4:1 range of flow rate, an electromagnetic or ultrasonic meter is preferred. For smaller supplies with grit and air-free water, rotary vane types are suitable, but battery-operated, electromagnetic or ultrasonic meters may be even more suitable for a variety of reasons.

SECTION 7

INSTITUTIONAL ARRANGEMENTS

7.1 General

No progress can be achieved in any metering program unless satisfactory arrangements are made to overcome current problems of organization. All too often in water authorities, different aspects are dealt with in "watertight compartments" so that deficiencies resulting from lack of coordination are not understood. Metering is no exception. Emphasis may be placed on consumer meters while other aspects of metering--not under the control of the same department--are ignored. An organization must be established in which all aspects of metering receive full recognition.

7.2 Organization

7.2.1 Measurement

In the water industry, it is not uncommon for the manager to be ignorant of how much water is produced from sources, how much is treated, and how much is delivered to the customer. Even worse, he may believe that he knows all these quantities when, in fact, the metering is grossly inaccurate and the resulting figures are meaningless.

In the past, it was extremely difficult to account for quantities of water with any reasonable degree of accuracy. New technology, however, is providing better methods and refining techniques used with older instruments.

New types of meters and transducers, together with micro-electronics and telemetry, now permit satisfactory measurement of both water quantities from sources and amounts delivered to different districts, so that resources can be managed more effectively.

These are timely developments because, in many instances, it is becoming increasingly difficult to supply more water to make up for losses from leakage. It is fundamental to effective management to know the following information for each day of the year:

(1) Amount of water produced;

(2) Amount of water treated;

(3) Amount of water passed into supply;

(4) Amount of water consumed by customers.

(The last of these can be only a continuously updated estimate based on the previous average of consumer meter readings or estimates of consumer use. It is also necessary to make adjustments to allow for increases or decreases in reservoir storage.)

There will always be differences between (3) and (4) that represent losses in trunk mains, distribution systems, and reservoirs. If this difference is small, say less than 20 percent, the problem is not significant. If the differences are larger (and figures of 60 percent are not unusual), substantial sums of money are being wasted.

In most water systems, many sources and many areas of supply are readily identifiable as geographic areas, pressure zones or separate towns, villages or districts. Further refinement of the distribution system can provide daily information on the water supply to each of these discrete areas through the installation of district meters. The sum of all of the district meters should eventually approximate the total from all source meters.

Unfortunately, accuracy may never be enough to achieve close agreement between the sums of all the district meters and the larger supply meters. However, it is the correlation of this information that provides the basis for good management and understanding of the system. Only then can plans be made for future additional sources of supply, the economic reinforcement of the network to meet increasing needs, and effective leakage control.

THE CORRECT SELECTION, OPERATION AND MAINTENANCE OF SOURCE METERS, DISTRICT METERS, BULK-SUPPLY METERS AND LARGE METERS ARE VITAL FOR EFFECTIVE MANAGEMENT.

7.2.2 Financial Arrangements

No systematic arrangements to effectively measure supplies, to obtain the full benefit of revenue or to reduce leakage will succeed unless the proper financial arrangements are made and adhered to.

This means making an adequate sum available in the capital budget each year for purchase and installation of new meters on the scale deemed necessary in the overall plan. Proper provision must be made annually in the revenue budget for maintenance of meters that are installed. With proper revenue collection, these operations should be self-financing.

7.2.3 Employee Motivation

Employees engaged in supply, distribution, measurement, and maintenance of the system need incentives to approach their task with the enthusiasm shown by those who may seem to be engaged in more constructive work, such as design and research. In reality, it is day-to-day maintenance that is the most valuable contribution to the authority and to the supply of water. Employees must be motivated to see this.

This motivation should take the form of financial reward, but public recognition of the value of the task is also necessary. Savings through measurement and control of supplies should be publicized, and effective management should be rewarded. The most technically competent employees should be engaged in supply, distribution, measurement, and control.

In some developing countries, the salary structure may not permit adequate financial rewards to attract sufficiently able people. For this reason, much work may have to be contracted out. The highest levels of management have to recognize this problem and take action accordingly.

In many modern water undertakings, use of the latest technology in supply and distribution has altered the status of the engineers and technicians involved so that they are now the key employees. This is, of course, an incentive to effective management and control.

In the more developed countries, engineers in this new technological situation have their own computers with geographic plans of the entire water area and all of the water services recorded on digital maps. They can look at the whole area on a monitor screen or zoom into a particular junction and examine a particular water connection in detail. These engineers continually update network analysis of the distribution system on the computer for both the whole and parts of the supply area, monitoring the quantities supplied throughout the area, often by evaluating flow data directly transmitted to their computer data bank and printout records.Each day the engineers can produce a water balance between output and consumption, direct the operation of sources, and control maintenance and investigation from their technical center. In this sense, they are the new day-to-day managers of the water system.

In developing countries, the same situation must emerge eventually, and all installations now proposed should be planned accordingly. Although the immediate aim must always be to improve things just a little where that seems possible, the best way to attract and keep the best technical staff is to provide for gradual introduction of the most up-to-date technology. This can be achieved only by making the necessary financial provisions.

7.3 Meter Service

Meter maintenance would normally be divided, with the supply manager responsible for source meters and the distribution manager responsible for bulk-supply and revenue meters.

The staff of either of these managers would do the meter reading, or the meter-reading staff might be under the direct control of the financial manager.

Who does what is not important, but the actions that arise from these functions are; it is essential that the following rules be followed:

(a) One person (with suitable supporting personnel) should be responsible for the statistical records, reporting directly to the senior, engineering or financial manager, or, preferably, to the general manager. This employee should correlate the supply information with distribution and financial information and carry out a water balance audit. It would be logical for him to be responsible for the control of U.F.W.

(b) The meter reader must have a formal means of communicating meter failure (or obvious error), the need to clean strainers, repair or exchange meters to the appropriate manager for action.
(c) The financial and engineering managers should examine regularly (at least quarterly) the financial implications of lack of repair and the loss of revenue.

(d) If it cannot perform any function adequately, the authority should contract it out under proper tender procedure with financial and technical control.

Small organizations with minimal service facilities will merely replace failed domestic meters with new ones. Larger organizations may have a meter shop with some tank testing facilities for domestic meters. Only the very largest organizations are likely to have repair and test facilities for large meters (over 100 mm.).

If these facilities do not exist, it will either be necessary to equip a workshop with repair and testing facilities and recruit suitable staff, or carry out routine maintenance and calibration by contract. The guidelines indicate future possibilities for reduction in maintenance, but in the meantime, most large meters, whether for consumers, bulk supply, or districts, will be of the rotary vane (Helix or Woltman) type.

Unless the authority can employ suitable skilled personnel, specialist contractors must be employed to ensure correct installation, calibration where necessary, operation, and proper maintenance of installed meters.

This means making proper provisions in the annual budget. Each type of meter must be assumed to have a "life" of limited duration, and the budget allocation phased to replace the correct proportion annually at the right time interval (five to 10 years, depending on the type).

The right feedback must come from other sections in the organization. Most important, meter readers should have a standard reporting procedure on inoperable meters to the operational and maintenance departments. There is hardly anything so worthless as a meter that does not work. It may be worth considering contract meter reading, maintenance, and repair. In this way, with a carefully worded contract, it is possible to provide the financial incentive to keep the system working, since a working consumers' meter could produce a profit, and a non-working meter a loss, to the contractor. Clearly, proper inspection and supervision are necessary. This whole matter would have to be considered with the general reading and maintenance of consumers' meters, which is outside the scope of these guidelines. However, where there is a choice, maintenance should be reduced to the lowest possible level.

If the water undertaking is of such size that it employs skilled personnel to service and maintain consumers' meters, it should find little difficulty in absorbing the extra work involved in maintaining source and district meters. It may be necessary, however, to employ an additional specialist in electronics.

It is essential that large consumer meters operate properly. (See the information on calibration in Section 5). If one of these meters is out of action, the easiest operation is to replace an internal mechanism, but these are not interchangeable between different manufacturers. Otherwise, a new or refurbished, recalibrated meter is necessary. (Contract work may be necessary and the manufacturer's agent should be able to assist.) The proper functioning of consumers' meters can then be followed by correction of any of the other types that require attention.

7.4 Equipment

All meter manufacturers supply equipment for workshop repair and testing for most sizes of meter. They also provide mobile test equipment as described in Section 5. Usually, this plant and test equipment is for meter sizes below 300 mm. (although larger units can be supplied). Larger meters would normally be dealt with by the manufacturer's agent or calibration agencies (see Annex 3).

7.5 Manpower

By whatever means the short-term objectives are achieved, the long-term aim should be to recruit and train suitable employees with skills for all types of water measurement.

This is necessary whether the work is to be carried out in-house or by contract. In the latter case, fewer employees will be required and their role will be to supervise contract work.

In the future, skills required for this work will be mechanical, electrical, and electronic; higher levels of management will need to understand radio, telemetry, and computer operation.

The aim should be to prepare a proper manpower plan with provisions for financial resources to enable the organization to progress; then recruit the best people from universities and technical colleges, bearing in mind the goal of a reliable and wholesome water supply. The manpower plan should include development of management skills for all specialists so that they can play a role in the higher management of the authority. This includes civil, mechanical, electrical, electronic, financial, managerial, economic, environmental, chemical, bacteriological, and any other professional staff that directly contribute to effective operation of the authority.

7.6 Training

All the principal meter manufacturers have training facilities that they can usually provide at the authority's works or in their home country. Many technical institutions, national engineering laboratories, and research institutes hold courses on the principles of fluid measurement. In addition, major water undertakings in the developed countries are glad to assist in training personnel in the developing countries, or in assigning them to their own organizations.

7.7 Specialist Assistance

Reputable manufacturers can give specialized advice on water measurement, and the major water undertakings and research organizations in the developed world and in some more advanced developing countries will give independent advice.

In addition, facilities exist all over the world for assistance, advice, and calibration by specialist firms, measurement consultants, technical institutions, and individuals. These are listed, as far as possible, in Annexes 2 and 3.

ANNEXES

ANNEX 1. SCHEDULE OF MANUFACTURERS AND PRODUCTS: EUROPE

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION			INSTRUMENTATION	
							MAG	TURB	PITOT	CLOSED PIPE	OPEN CHANNEL
(1) Accusonic	U.K.										*
(2) Arada Ltd.	Israel			*							
(3) Auriema Ltd.	U.K.					*		*	*	*	
(4) Auxitrol Ltd.	U.K.								*	*	
(5) Bestobell Mobrey	U.K.			*	*	*		*		*	*
(6) Bosco & Co. Torino	Italy			*							
(7) Brooks Instruments B.V.	Dutch			*							
(8) Brooks/Meineche	U.K.	(see Meineche, F.R.G.)									
(9) Caleray Ltd.	U.K.				*					*	
(10) Colnbrook Instruments	U.K.						*				
(11) "Magflow" Danfoss Flowmetering	U.K.				*						
(12) Danfoss A/S	Denmark				*	*					
(13) Detectronic Ltd.	U.K.										*
(14) Endress & Hauser Ltd.	U.K.				*						
(15) Fischer & Porter Ltd.	U.K.	*			*						*
(16) Klaus Fischer	F.R.G.		*								
(17) Flonic Schlumberger	France			*							
(18) Flowline Systems Ltd.	U.K.					*	*				
(19) Foxboro KC Controls Ltd.	U.K.		*		*						
(20) Gendeal Ltd.	U.K.					*					
(21) Gervase Instruments Ltd.	U.K.	(Special D.P. Meter)									
(22) Guest & Chrimes Ltd.	U.K.			*							
(23) GWF Gas-Und Wassermesserfabrik	Swiss			*							
(24) Hawker Electronics Ltd.	U.K.										*
(25) Faure Herman	France			*				*			
(26) Honeywell Control Systems Ltd.	U.K.				*						
(27) Hydrologic	France										*
(28) Hydrometer GmbH	F.R.G.			*				*			
(29) ISA Controls Ltd.	U.K.	*	*								
(30) KDG Flowmeters	U.K.		*	*							

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION			INSTRUMENTATION	
							MAG	TURB	PITOT	CLOSED PIPE	OPEN CHANNEL
(31) Kent Industrial Measurements	U.K.	*	*	*	*	*	*				
(32) Krohne Measurement & Control	U.K.				*	*					
(33) Andrae Leonberg	F.R.G.			*							
(34) H. Meineche AG	F.R.G.			*				*			
(35) Monitek GmbH	F.R.G.					*	*				*
(36) Neptune Measurement Ltd.	U.K.			*	*		*				
(37) Nixon Instrumentation Ltd.	U.K.				*		*				
(38) A. Ott GmbH	F.R.G.										*
(39) PMA Process Measurement Ltd.	U.K.								*		
(40) Pollux-Spanner GmbH	F.R.G.			*		*					*
(41) Quadrina Ltd.	U.K.							*			
(42) "Ramapo" Texcel Ltd.	U.K.							* dyn.			
(43) Franz Rittmeyer Ltd.	Swiss	*			*	*					
(44) Samson Controls (London) Ltd.	U.K.			*							
(45) Satt Control U.K. Ltd.	U.K.	*	*								
(46) Phillip Schenk GmbH	Austria		*								
(47) Sereg Schlumberger	France				*						
(48) Serk Glocon	U.K.							*			
(49) Siemens Ltd.	U.K.				*						
(50) Socom (Pont a Mousson)	France			*							
(51) G. Bernhart's Sohne	F.R.G.			*							
(52) Space Age Electronics Ltd.	U.K.										*
(53) AB Svensk Varmematning SVM	Sweden			*							
(54) Tekflo Ltd.	U.K.								*	*	*
(55) Toshiba International Co. Ltd.	U.K.				*						
(56) Turbo Werk Messtecknik GmbH	F.R.G.				*		*				
(57) Ultraflux	France					*	*				

Note: Manufacturers who only make instrumentation are shown in the last column. All meter manufacturers make instruments for their products.

SCHEDULE OF MANUFACTURERS AND PRODUCTS: THE AMERICAS AND JAPAN

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION			INSTRUMENTATION	
							MAG	TURB	PITOT	CLOSED PIPE	OPEN CHANNEL
(100) Advanced Instrumentation Inc.	U.S.A.										*
(101) Airflow Develop. (Canada) Ltd.	U.S.A.								*		
(102) Alphasonics Inc.	U.S.A.				*	*					
(103) American Meter Company	U.S.A.	*	*	*							
(104) American Sigma	U.S.A.										*
(105) Amprodux Corporation	U.S.A.										*
(106) Anderson Samplers Inc.	U.S.A.		*						*		
(107) Aquamatic Inc.	U.S.A.			*							
(108) Arjay Engineering	U.S.A.										*
(109) AST/Servo Systems Inc.	U.S.A.			*							
(110) Atlantex Industries Inc.	U.S.A.			*							
(111) Auburn International Inc.	U.S.A.				*	*					
(112) Autotrol Corporation	U.S.A.			*							
(113) Badger Meter Co. Inc.	U.S.A.	*	*	*							*
(114) Bailey Controls Co.	U.S.A.				*	*					
(115) Baird Controls Inc.	U.S.A.			*	*	*					
(116) BayTech	U.S.A.				*	*					
(117) Beckman (Paul) Company Inc.	U.S.A.				*	*					
(118) Bestobel C&I Level & Flow Div.	U.S.A.			*	*	*					*
(119) BIF, Unit of General Signal	U.S.A.	*	*		*	*					*
(120) Bolt Technical Ceramics	U.S.A.				*	*					
(121) Brandt Instruments	U.S.A.								*		
(122) Bristol Babcock Inc.	U.S.A.		*								*
(123) Brooks Instruments	U.S.A.			*	*	*					
(124) C J Instruments Inc.	U.S.A.			*							
(125) Capital Controls Company Inc.	U.S.A.	*									
(126) Channel Industries Inc.	U.S.A.				*	*					
(127) Computer Instruments Corp.	U.S.A.										*
(128) Consolidated Electric Company	U.S.A.										*
(129) Controlotron Corporation	U.S.A.				*	*					*

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION			INSTRUMENTATION	
							MAG	TURB	PITOT	CLOSED PIPE	OPEN CHANNEL
(130) Cox Instrument S&K (Ametec,Inc)	U.S.A.			*							
(131) Daniel Industries Inc.	U.S.A.	*	*	*							
(132) Data Industrial Corp.	U.S.A.			*							
(133) Delta Controls Corporation	U.S.A.										*
(134) Dieterich Standard Corp.	U.S.A.								*		
(135) Digital Valve Company	U.S.A.	*									
(136) Drexelbrook Engineering Co.	U.S.A.								*		
(137) Dwyer Instruments Inc.	U.S.A.								*		
(138) Dynasonics Inc.	U.S.A.				*	*					
(139) Eckardt Process Instrument Ltd.	U.S.A.				*	*					
(140) Edo Corporation	U.S.A.				*	*					
(141) EFM Inc.	U.S.A.			*							
(142) Electro Numerics Inc.	U.S.A.			*							
(143) Electronic Flowmeters Inc.	U.S.A.			*							
(144) Endress + Hauser Instruments	U.S.A				*	*					*
(145) Engineering Measurements Co.	U.S.A.			*							
(146) Enterra Instruments Tech.Inc.	U.S.A.				*	*					*
(147) Exac Corporation	U.S.A.				*	*					
(148) Ferranti Ore Inc.	U.S.A.				*	*					*
(149) Fielding Crossman & Associates	U.S.A.										*
(150) Fischer & Porter Company	U.S.A.	*	*	*	*	*					*
(151) Fisher Control International	U.S.A.				*	*					
(152) Flo-Tech Inc.	U.S.A.			*							
(153) Flow Measurements Systems	U.S.A.			*							
(154) Flow Research Corporation	U.S.A.			*							
(155) Flow Technology Inc.	U.S.A.			*							
(156) Flowmetrics Inc.	U.S.A.			*							
(157) Foxboro Company	U.S.A	*	*	*	*	*			*		*
(158) Free Flow Inc.	U.S.A.										*
(159) Fuji Electric Corp. of America	U.S.A.				*	*					

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION			INSTRUMENTATION	
							MAG	TURB	PITOT	CLOSED PIPE	OPEN CHANNEL
(160) Full Electric Corp. of America	U.S.A.			*							
(161) General Oceanics Inc.	U.S.A.										*
(162) Hersey Products Inc.	U.S.A.			*							*
(163) Industrial Technology Inc.	U.S.A.										*
(164) Invalco Measurement & Control	U.S.A.		*	*							
(165) Inventron	U.S.A.										*
(166) ISCO, Inc.	U.S.A.				*	*					
(167) ITT Barton	U.S.A.		*	*							
(168) J-Tec Associates, Inc.	U.S.A.				*	*					
(169) K-FLOW	U.S.A.				*	*					
(170) Kahl Scientific Instrument Corp	U.S.A.			*							*
(171) Kay-Ray Inc.	U.S.A.										*
(172) Kent Meters Inc.	U.S.A			*							
(173) Kent Process Control Inc.	U.S.A	*	*		*	*			*		*
(174) Konigsburg Instruments	U.S.A.				*	*					
(175) Krohne-America Inc.	U.S.A.				*	*					
(176) Land Combustion Inc.	U.S.A.								*		
(177) Leeds & Northrup Instruments	U.S.A.		*		*	*					
(178) Leupold & Stevens	U.S.A.										*
(180) Manning Technologies Inc.	U.S.A				*	*					*
(181) Marsh-McBirney Inc.	U.S.A.				*	*	*				*
(182) Mead Instruments Corp.	U.S.A.			*							*
(183) Measurements Inc.	U.S.A.			*							
(184) Meriam Instrument	U.S.A.		*						*		
(185) Micro Motion Inc.	U.S.A.				*	*					
(186) Mid West Instruments	U.S.A.		*						*		
(187) Milltronics Inc.	U.S.A.				*	*					*
(188) Monitek Inc.	U.S.A.				*	*					*
(189) Montedoro-Whitney Corp.	U.S.A.				*	*					*
(190) Moore Products Company	U.S.A.				*	*					

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION MAG	INSERTION TURB	INSERTION PITOT	INSTRUMENTATION CLOSED PIPE	INSTRUMENTATION OPEN CHANNEL
(191) Moore Technologies Inc.	U.S.A.										*
(192) Neotronics of NA Inc.	U.S.A.								*		
(193) Neptune Measurement Company	U.S.A.			*	*	*					
(194) No Loss Flow Tube	U.S.A.	*									
(195) Nusonics Inc.	U.S.A.				*	*					
(196) Oilgear Company	U.S.A.			*							
(197) Omega Engineering	U.S.A.			*	*	*					*
(198) Orange Research Inc.	U.S.A.				*	*					
(199) Pace Transducer	U.S.A.			*							
(200) Pacific Meter Inc.	U.S.A.				*	*					
(201) Panametrics Inc.	U.S.A.				*	*					
(202) Perry Equipment Corp.	U.S.A.	*	*								
(203) Plasti-Fab Inc.	U.S.A.										*
(204) Polysonics Inc.	U.S.A.				*	*					
(205) Preso Industries Corp.	U.S.A.	*							*		
(206) Proteus Industries	U.S.A.			*							
(207) Quality Control Equipment Co.	U.S.A.				*	*					*
(208) Ramapo Instrument Co. Inc.	U.S.A.										*
(209) Ramsey Engineering	U.S.A.				*	*					
(210) RJL System	U.S.A.				*	*					
(211) Robertshaw Controls Co.	U.S.A.										*
(212) Rosemount Inc.	U.S.A.		*		*	*					
(213) S J Controls Inc.	U.S.A.			*							
(214) Schutte & Koerting, Ametec Inc.	U.S.A.		*	*							
(215) Sepcor Engineering Inc.	U.S.A.				*	*					*
(216) Signet Scientific	U.S.A.			*	*	*					
(217) Singer Company	U.S.A.	*	*	*	*						
(218) Smith Meter Inc.	U.S.A.			*	*	*					
(219) Sparling Instruments Co.	U.S.A.			*	*	*					
(220) Spectron Development Labs. Inc.	U.S.A.				*	*					

MANUFACTURER	COUNTRY	VENTURI OR DALL	ORIFICE	ROTARY VANE (HELIX)	ELECTRO-MAGNETIC	ULTRA-SONIC	INSERTION			INSTRUMENTATION	
							MAG	TURB	PITOT	CLOSED PIPE	OPEN CHANNEL
(221) Taylor Instrument Inc.	U.S.A.	*	*		*	*			*		*
(222) Texas Nuclear Corp.	U.S.A.				*	*					
(223) Thermal Instrument Co.	U.S.A.				*	*					
(224) Toshiba International	U.S.A.				*	*					
(225) Total Instruments Inc.	U.S.A.			*							
(226) TSI Inc.	U.S.A.				*	*					
(227) Turbo Instruments Inc.	U.S.A.		*		*	*					
(228) Turner Designs	U.S.A.										*
(229) Validyne Engineering Corp.	U.S.A.								*		
(230) Vickery-Simms Inc.	U.S.A.										*
(231) Wallace & Tiernan	U.S.A.										*
(232) Waugh Controls Corp.	U.S.A.			*							
(233) Yokogawa Corp.of America	U.S.A.				*	*					
(234) Compania Ind.Y.Com. America SA	Mexico										
(235) Conaut	Brazil				*						
(236) Engistrel	Brazil				*						
(237) Flowtech	Brazil			*							
(238) Leopold de Brazil	Brazil	*									
(239) Liceu de Artes	Brazil			*							
(240) Onel	Brazil				*						
(241) Medidores Inca	Argentina			*							
(242) Santos Zaghi	Argentina	*									
(243) Dipl. Bruno Schillig	Argentina	*									
(244) Fuji Electric Company	Japan				*	*					
(245) Toshiba Corporation	Japan				*	*					
(246) Yamatake Honeywell Co. Ltd.	Japan				*						
(247) Yokogawa Corporation	Japan				*	*					

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TECHNICAL INSTITUTES AND RESEARCH ORGANIZATIONS

Country	Institute or Organization
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Federal Republic of Germany	Deutscher Verein des Gas-und- Wasserfachs-DVGW- Postfach 5240 6236 Eschborn 1 Federal Republic of Germany Tel. 06196 70170
	Physikalisch-Technisike Bundesanstalt Laboratory 1.32 (Dr. Zander) Bundesallee 100 3300 Braunschweig Federal Republic of Germany Tel. 0531 5921320
	Verband der Deutschen Wasserzahlerindustrie -WDDW- Dr. Conrad Dirchweg 1 6072 Dreieich Federal Republic of Germany Tel. 06103-65500
France	Electricite de France Chatou, Paris, France Tel. 3 071 7244
	Fondation de l'Eau Rue Edward Chamberland 87100 Limoges, France
	Hydroplan Centre Mediterranean de Commerce International 2, Rue Barbusse 13241 Marseilles Cedex 1

The Netherlands	Delft Hydraulic Laboratory P.O. Box 1772600 MH Delft The Netherlands Tel. 31(0) 15-569353
	Service of Metrology Dordrecht, The Netherlands. Tel. 078 40844
Norway	Norwegian Institute for Water Research P.O. Box 333, Blindern, N-0314 Oslo 3, Norway
United Kindgom	AOT Flow Calibration Laboratory Andover, England Mr. C. Griffiths Tel. 0264-65961
	Cranfield Fluid Engineering Unit Cranfield Institute of Technology, Cranfield, Bedford MK43 OAL, England Tel. 0234 750111
	Dyer Engineering Consultants Hilton House 41, Thorn Road, Worthing BN11 3ND, West Sussex, England Tel. 0903-212388
	Hydraulics Research Station Ltd. Wallingford, Oxon OX10 8BA, England Tel. 0491 35381
	Institute of Measurement and Control 20 Peel Street, London W8 7PD, England Tel. 01 727 0083
	International Water Supply Association 1, Queen Anne's Gate London SW1H 9BT, England Tel. 01 222 8111

Moore, Barrett & Redwood
London, England
Dr. A.T.J. Hayward
Tel. 01-430-1831

National Engineering Laboratory
East Kilbride, Glasgow
G75 OQU, Scotland
Tel. 035 52 20222

SIRA Institute
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Mr. I. Knott
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The Water Research Centre
Henley Road, Medmenham
Marlow, Bucks., England
Tel. 0491 66531

United States

American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235
U.S.A.

ANNEX 3

FLOW MEASUREMENT CALIBRATION FACILITIES

Country	Firm or Agency
Australia	Snowy Mountains Engineering Corps., Fluid Mechanics Lab.
	State Rivers and Water Supply Commission of Victoria.
Czechoslovakia	Water Conservancy Research Institute.
	Water Meter Verification Station.
Denmark	Danfoss A/S DK-6430 Nordberg
Federal Republic of Germany	All-System GmbH Postfach 109 8012 Ottobrunn bei Munchen Tel. 089 6091056
	Bopp & Reuther GmbH P.O. Box 31 01 40 D 6800 Mannheim 31 Tel. 0621 7490
	Degussa AG Zweigneiderlassung Hanau Postfach 1351 6450 Hanau 1
	Endress + Hauser GmbH D 78 64 Maulburg
	Fischer & Porter P.O. Box 1843 D-3400 Gottingen

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Tel. 0981 18060

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8072 Manching
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Spanner-Pollux GmbH
Postfach 211009
6700 Ludwigshaven
Tel. 0621 69041

Turbo Werk
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D-5000 Koln 91

France	Electricite de France, Direction des Etudes et Recherches, Chatou
The Netherlands	Altometer BV Krausstraat 14-18 3364 AD, Sliedrecht
	Brooks Instrument NV Postbus 56 Veenendaal
	Dutch States Mines/DSM Geleen

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	Netherlands Kiwa NV, Testing Institute for Water Supply Commodities Rijswijk (ZH)
	Service of Metrology Hugo de Grootplein Dordrecht
	Stork Servex P.O. Box 8090 3301 BA Dortrecht
	Waterloopkundig Laboratorium Delft
New Zealand	Auckland Regional Authority
Switzerland	Flowtec AG Kagenstrasse 4 GH-4253 Reinach BL1
United Kingdom	Central Electricity Generating Board, Midlands Region Hydraulic Calibration Centre Hams Hall, Minworth, Nr. Sutton Coldfield, Warwicks B76 0BG
	Dept. of Industry Flow Measurement Division National Engineering Laboratory East Kilbride, Glasgow G75 0QU
	Kent Instruments Ltd. Biscuit Road Luton, Beds LU3 1AL
United States	Alden Hydraulic Laboratory Worcester Polytechnic Inst. Worcester, MA
	American Meter Co. Philmont Avenue Philadelphia, PA

The Foxboro Co.
Foxboro, MA

St. Anthony Falls Hydraulic
Laboratory, University of
Minnesota
Minneapolis, MN

United States National
Bureau of Standards
Washington, D.C. 20234

Together with other sources, the above list has been abstracted from NEL Report No. 622, "Flow Measurement Calibration Facilities of the World," by R.W.W. Scott, published in the United Kingdom by the National Engineering Laboratory for the Department of Industry, dated September 1976.

ANNEX 4

COMMON CAUSES OF ERRORS IN METER PRIMARY DEVICES

(a) Orifice Plates Orifice plates are subject to edge rounding by erosion, buckling by over-pressure or thermal stresses, roughening and encrustation of the upstream pipe, buildup of dirt, misalignment and partial blockage of pressure tappings. Probably the most serious effect is rounding of the upstream sharp edge of the plate, which causes an increase in discharge coefficient and, hence an underestimation of the flow.

(b) Venturi Meters, Nozzles, etc. These devices are subject to roughening and dirtying of the throat, with a consequent decrease in the discharge coefficient, leading to an overestimation of the flow. Like the orifice plate, these meters may have roughening and encrustation of the upstream pipe, misalignment and partial blockage of pressure tappings. Venturi meters of the looseliner type are susceptible to liner leakage, leading to discharge coefficients greater than unity.

(c) Electromagnetic Meters These meters are sensitive to dirty electrodes; the potential difference between meter body and pipe must be the same as between meter body and secondary; the insulation liner must be undamaged.

(d) Rotary Vane (Helix) Meters Progressive wear of the bearings usually decreases the meter factor, particularly at low flow, leading to underestimation of the flow. Partial blocking of the flow passage or material adhering to the blades affects the calibration of the meter in an unpredictable manner. Overspeeding of the meter may occur when a meter is cleaned. Blades may be damaged or broken off, with consequent alteration to calibration.

If it is apparent that the cause of error is not simple to rectify, it may be better to install a new meter and secondary instrumentation of the most suitable type.

ANNEX 5

COMMON CAUSES OF ERROR IN SECONDARY INSTRUMENTATION

(a) Pressure Differential Devices, Manometers, etc. Pressure-tubing leakage from the primary to the secondary is often a source of trouble, particularly at joints and junctions. The throat or low-pressure tube may be at a pressure below atmospheric and will draw in air through a bad joint and diminish the output signal. The manometer equalizing valve can cause trouble if it is not leak-tight.

(b) Electrical/Electronic/Electromechanical Devices Pulse counters are frequently affected by the proximity of other electrical machinery because the counter leads are not adequately screened. Stray pulses give an overestimation of the quantity passing.

(c) Electromagnetic Flow Meter Read-outs Zero shift is the most common cause of error. Modern circuitry has minimized the problem, but it may still exist in an old flow meter. The range setting should be checked to ensure that the meter is operating on the correct range.

(d) Differential Pressure Transducers The frequency response must be adequate, and the transducer should be calibrated at a similar ambient pressure to that of the flow meter.

(e) Mechanical Counters These are usually very reliable, but the magnetic coupling between primary and secondary, now frequently used, can cause slippage if friction in the secondary increases due to wear or corrosive attack.

As in the case of the meter, unless the cause of error is easily rectified, the best option is to install new secondary instrumentation. In this case, the choice should be for the latest type of transducer with electronic components constructed and sealed so as to be tamper- or environment-proof and require no further attention.

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