GUIDELINES FOR IRRIGATION WATER MEASUREMENT IN PRACTICE

By

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"Irrigation Water Measurement: The application of flow measuring devices in irrigation water management"

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Executive Summary

1. Introduction

The Water Research Commission of South Africa initiated a research project in 2000 in order to review the current situation and needs in the field of irrigation water measurement in South Africa. It commenced in 2001 and was undertaken by the Department of Civil and Biosystems Engineering of the University of Pretoria together with the Agricultural Research Council's Institute for Agricultural Engineering and NB Systems. The initial project proposal provided for a three year project period but during the second year the project steering committee recommended that the project be extended with an additional year, and the extension was approved by the WRC. **The main objective of the project was to develop guidelines for the correct choice, installation and management of water measuring devices by Water User Associations for canal, pipeline and river distribution systems**.

The main objective was achieved through the four project aims as included in the original project proposal, and listed below:

- **Aim 1**: To identify the methods and technologies for water flow measurement (hydraulic, mechanical, electrical) used in different water distribution systems (canals, pipelines, rivers) on irrigation systems under South African conditions, and
- **Aim 2**: To investigate the effectiveness of the various flow measurement methods and technologies through laboratory and field evaluations.
- **Aim 3**: To determine the reasons for not measuring water use in practice by means of a field survey amongst farmers
- **Aim 4**: To Compile guidelines for the correct choice and management of water measuring devices for irrigation systems under different conditions

2. Project activities

A series of field visits to prominent irrigation areas in South Africa as well as visits to a number of measurement equipment manufacturers and the relevant government departments were undertaken to address Aim 1. A comprehensive literature study of flow measurement in irrigation was also conducted.

A considerable amount of time was spent on the activities required to reach Aim 2, which was addressed through the installation of various flow measurement devices at irrigation schemes. Different types of flow meters as well as water level sensors were installed at a number of WUAs, and monitored for extended periods of time. Shorter evaluations were conducted under laboratory conditions.

Surveys were conducted amongst water users from 6 different water user associations with different water distribution systems, irrigation systems and farming conditions as part of Aim 3. The areas covered were the Lower Riet River, Umlaas River, Loskop, Vaalharts, Hartbeespoort and Dendron. In addition to the farmer survey, a discussion forum on reliable measuring methods was held in Bloemfontein in April 2004. The purpose of the discussion forum was to provide an opportunity for stakeholders in irrigation water use and management to provide inputs into the final phases of the research project against the backdrop of the legal requirements according to the National Water Act, current water management practices, and available measuring methods. The Forum took place on 29 April 2004 in Bloemfontein, and although initially only about 25 people were invited, a total of 58 attended in the end.

As part of Aim 4, the water measuring guidelines included in this report were compiled and a computer based database of commercially available measuring devices for irrigation water (KBS) was developed.

3. Project results

The process of planning and installing measurement devices in the field exposed the project team to some of the constraints that WUAs has to face when implementing water measurement as required by legislation. The contact with specific WUAs helped to create a better understanding of the day-to-day activities on the schemes, and assisted in developing practical guidelines for water measurement, which was the main objective of this project.

A good practical working knowledge of measuring devices was established and information on different devices that are available both locally and internationally was gathered. The first hand experiences of the project team have definitely led to the development of new skills that will hopefully be put to good use in future.

The contact with water management staff and users showed that irrigation water measuring cannot be considered in isolation but is rather one of the tools that can be used by WUAs and of which greater awareness is necessary, especially as far as new technological development is concerned. This, together with the interest that was shown in the Discussion Forum, definitely points to a need for the transfer of information to WUAs and water users.

Conversations between project team members and participants during and after the forum indicated that there is a need for information to be made available to stakeholders at grassroots level. It was clear the participants were looking for information and clarity on how measurement should be implemented, and therefore they were also the ones that had to be consulted on the needs to be addressed by this report.

It was found that suitable measuring devices are available, but in order for them to be used successfully, they need be installed correctly, well maintained, and read accurately. In other words, a WUA's water measuring system has to be managed. This approach of managed implementation consists of at least the following components:

- A reason for measuring ("trigger"),
- Acceptance and support by the water users,
- Assessment of the current situation and planning the system,
- Choosing appropriate technologies,
- Correct installation by skilled technicians,
- Sound operation and maintenance policies,
- A system for data retrieval and management,
- Comprehensive financial planning, and
- Procedures for handling disputes and tampering

The guidelines that were compiled it aimed at implementing this approach successfully in practice, and give a detail description of the actions that need to be taken under each component listed above. The guidelines include a chapter on the approach that is recommended for implementing irrigation water measurement successfully in South Africa. There is currently no policy to guide WUAs in this and it is hoped that this chapter will provide some guidance to policy makers with regard to the issues that have to be addressed.

4. Research Products

Except for the knowledge and skills that were collected and developed by the project team members, the most important products were two publications:

- the Guidelines for the selection, installation and management of devices for irrigation water measurement, which forms part of the final project report, and
- the KBS (Knowledge Base System), a computer based database of irrigation measuring devices and their characteristics with extensive search and sort functions.

5. Conclusions and recommendations

The following conclusions could be drawn at the end of the project:

- The project team obtained valuable insight into irrigation water measuring practices and problems.
- A wide network of useful contact was established during the initial field visits and maintained through the field and laboratory evaluations that took place over three years.
- A good practical working knowledge of measuring devices was established and information on different devices that are available both locally and internationally was gathered.
- Each WUA's situation is unique, in order to identify the relevant measuring requirements, needs to be evaluated as such. No two WUAs can blindly use or apply the same devices or methods.
- Suitable technologies are definitely available, and their failure is more often than not linked to incorrect application (unsuitable for specific conditions), installation practices or lack of maintenance.
- Greater awareness of the availability of suitable devices amongst WUAs is necessary, especially as far as new technological development is concerned.
- There is an urgent need for water measuring policy to guide WUAs in selecting appropriate measuring devices and systems.

The following recommendations are made:

- A water measuring policy should be drawn up as a matter of urgency to provide a reference for implementation procedures.
- A special technical committee should be set up (by SANCID) to look after the interest of the irrigation sector in terms of measuring water including policy and institutional issues.
- A knowledge center should be created at the Department of Civil and Biosystems Engineering at the University of Pretoria, to continue research, prepare and distribute information, train students and provide a field service to WUAs in assisting them with measuring implementation, evaluating devices and trouble-shooting.
- A training manual and other training material based on the Guidelines and the KBS should be developed and this information transferred to interested parties through short courses or seminars.
- For the KBS to stay relevant, it will have to be maintained and updated regularly, and it is recommended that a way be found to do this on a website

6. Capacity building

6.1 Individuals

The following students from the Department of Civil and Biosystems Engineering completed projects based on specific components of the project activities as part of their studies and graduated in the course of the project, arranged according to completion date of studies:

- Ms TA Khumalo (M Inst Agrar): Allocation and Management of Water on Small-Scale Irrigation Schemes in South Africa
- Mr SB Ghezehei (MSc Applied Sciences): Comparison and performance testing of selected flow meters in-field and at a hydraulic laboratory
- Mr FH Hidad (MEng Agric) : Measurement of irrigation water losses from Canal D of the Gamtoos Irrigation Scheme
- Mr AJ Komakech (MEng Agric): Categorization and quantification of water losses in a lined canal and balancing dam at the Gamtoos Irrigation Scheme
- Mr YA Tsehaye (MSc Applied Sciences): Comparison of irrigation water measuring methods at the Umlaas Irrigation Board
- Ms I van der Stoep (MEng Agric): Evaluation of an indirect method for measuring irrigation water abstracted from rivers with centrifugal pumps

6.2 Communities

The farmers from the Kama Furrow community on the Zanyokwe Irrigation Scheme were involved with the installation of meters at their farms.

6.3 Organisations

The staff of the Orange-Riet Water User Association benefited from the project activities, but largely through their own initiative supported by the project team. In their search for measuring solutions, they have explored various options and set an example to other WUAs in this regard. The project team members have assisted them with the calibration of the prototype power-based meters purchased by the WUA, and learnt valuable lessons themselves in the process.

Through the field work conducted at this scheme, the water management staff was exposed to various measuring methods and devices. They supported the project team through assistance with data collection and maintenance to equipment. Mr Xolisa Ngwadla of MBB Consulting Engineers in the Eastern Cape has also benefited from the project through his involvement with the Gamtoos field tests. Mr Ngwadla is an agronomist by training, and although he has had no technical background, he successfully assisted the project team in managing the equipment at the scheme. He has obtained experience in telemetry systems, datalogger programming and operation, and been involved with measurements done by the DWAF Hydrometry staff.

The water bailiff from this Irrigation Board, Mr Owen Odell, was also actively involved with the field evaluations that took place at a river pump station. As a result of the evaluations, the Irrigation Board became aware that their method of measuring is in need of serious attention and that large errors are being made during measurement.

ACKNOWLEDGEMENTS

The funding of this project by the Water Research Commission is sincerely appreciated. The members of the Steering Committee are thanked for their significant contributions towards this project. The Steering Committee comprised of the following members:

Dr GR Backeberg	:	Water Research Commission (Chairperson)
Mr BEL Bold	:	Sensus Metering Systems
Mr RT Cresswell	:	Elster-Kent Metering
Mr FJ Du Plessis	:	MBB Consulting Engineers Inc
Mr FPJ van der Merwe	:	Department of Water Affairs & Forestry
Mr DFM Korff *	:	Department of Water Affairs & Forestry
Mr HL du Toit	:	Department of Water Affairs & Forestry, Northern Cape
Mr NE Knoetze	:	Oranje-Riet Water Users Association
Mr JH Posthumus	:	Oranje-Riet Water Users Association
Mr AJ Pott	:	CPH Water
Mr AT van Coller	:	Department of Agriculture

We would also like to personally acknowledge all those who assisted in the project, including organisations and people over and above the steering committee members who have made major contributions:

- All the attendees at the Discussion Forum on Water Measurement, at Bloemfontein, for their valuable inputs and lively participation.
- A number of Water User Associations (WUA) and Irrigation Boards (IB) and their personnel for their assistance and support with the field evaluations and completion of questionnaires:
  - Oranje-Riet WUA (Free State)
  - Gamtoos IB (Eastern Cape)
  - Umlaas IB (Kwa-Zulu Natal)
  - Oranje-Vaal WUA (Northern Cape)
  - Hartbeespoort WUA (North West)
  - Stellenbosch Helderberg WUA (Western Cape)
  - Loskop IB (Mpumalanga)
  - Worcester East IB (Western Cape)
- The various farmers for their assistance in making equipment available for field evaluations.
- A number of meter suppliers / manufacturers for their technical inputs, equipment supplied, meter calibration facilities as well as their technical inputs. A few that can be mentioned are
  - Sensus Metering Systems
  - Elster-Kent Metering
  - Flowmetrix SA
  - Actaris Metering (Pty) Ltd.
- The following organisations for their valuable inputs:
  - The ARC-ILI for their Hydrolab's personnel, technical inputs and equipment.
  - MBB Consulting Engineers for technical inputs and support.
  - University of Pretoria's equipment for the field evaluations / measurements.

* Mr Danie Korff sadly passed away during 2004.

PART A PROJECT REPORT

1. INTRODUCTION

1.1 Background to project

The Water Research Commission of South Africa (WRC) initiated a research project in 2000 to review the current local situation and needs in the field of irrigation water measurement. It commenced in 2001 and was undertaken by the Department of Civil and Biosystems Engineering of the University of Pretoria together with the Agricultural Research Council's Institute for Agricultural Engineering and NB Systems. The initial project proposal provided for a three year project period but during the second year the project steering committee recommended that the project be extended with an additional year, and the extension was approved by the WRC. **The main objective of the project was to develop guidelines for the correct choice, installation and management of water measuring devices by Water User Associations (WUAs) for canal, pipeline and river distribution systems**.

1.1.1 Project aims

The main objective was achieved through the four project aims as included in the original project proposal, and listed below:

- **Aim 1**: To identify the methods and technologies for water flow measurement (hydraulic, mechanical, electrical) used in different water distribution systems (canals, pipelines, rivers) on irrigation systems under South African conditions, and
- **Aim 2**: To investigate the effectiveness of the various flow measurement methods and technologies through laboratory and field evaluations.
- **Aim 3**: To determine the reasons for not measuring water use in practice by means of a field survey amongst farmers
- **Aim 4**: To Compile guidelines for the correct choice and management of water measuring devices for irrigation systems under different conditions

1.1.2 Project method

The activities undertaken in the course of the project period were determined by the requirements of each specific project aim.

Aim 1 was addressed through a series of field visits to prominent irrigation areas in South Africa, as well as visits to a number of measurement equipment manufacturers and the relevant government departments. A list of the organisations is shown in Table 1.1.

A comprehensive literature study of flow measurement in irrigation was also conducted. It covered the principles and methods of flow measurement in both open channels and closed conduits, and included a preliminary list of local equipment suppliers.

During the second project year, the need for a computer-based data basis of commercially available measuring devices and their specifications was identified. This work was a continuation of Aim 1, and also contributed to Aim 4, the compilation of water measurement guidelines for WUAs. It was decided to call the data base the "Knowledge Base System" (KBS), and it would be published in electronic format on CD. A number of water meter suppliers were contacted and visited to collect relevant water meter information that could be captured in KBS. A total of 57 measuring devices were captured with one or more pictures linked to them. Supplier contact information was also captured and it is linked to all records for easy reference. An icon and a CD image were designed for KBS to give it a professional and distinct look. WUAs and farmers would use KBS as a reference manual for any water measurement device information. The supplier would use KBS as a vehicle to advertise and supply clients with relevant water measuring device information and contact details. KBS should be the "Yellow pages" of irrigation water measuring devices. The KBS is presented and discussed in detail in Appendix B.

Table 1.1 Organisations contacted during field visits for Aim 1

Area	Organisation
Mpumalanga	TSB Sugar (Pty)Ltd Crocodile River Irrigation Board Malelane Irrigation Board Komati River Irrigation Board Lomati River Irrigation Board Driekoppies Dam (KOBWA) White River Valley Conservation Board Nkomazi Irrigation Expansion Program Low's Creek Irrigation Scheme Department of Water Affairs & Forestry (Regional) Provincial Department of Agriculture
Northern Cape/Free State	Vaalharts Government Water Scheme Lower Riet River Irrigation Board Douglas Irrigation Board Oranje-Riet WUA Taung Emerging Farmers Department of Water Affairs & Forestry
Eastern Cape	Sundays River Irrigation Board Gamtoos River Irrigation Board Department of Water Affairs & Forestry
Western Cape	Helderberg/Stellenbosch WUA Riviersonderend WUA Groenland WUA Austratech Department of Water Affairs & Forestry
Other visits	Department of Water Affairs & Forestry: Directorate Water Utilisation Hartebeespoort Irrigation Board Impala Irrigation Board (Pongola) Loskop Irrigation Board Blyde River Irrigation Board (Hoedspruit)
Emerging farmers	Nkomazi Irrigation Expansion Program Low's Creek Irrigation Scheme Taung Irrigation Scheme Dingleydale Irrigation Scheme Tshiombo Irrigation Scheme
Meter manufacturers	Actaris Metering (Pty)Ltd Elster-Kent Metering (Pty)Ltd Sensus Meters (Pty)Ltd Flowmetrix SA cc Flowtronics cc

A considerable amount of time was spent on the activities required to reach Aim 2, which was addressed through the installation of various flow measurement devices at irrigation schemes.

Preliminary identification of suitable sites for the field evaluations took place during the initial field visits, as well as identification of possible laboratory tests that need to be conducted. Different types of flow meters as well as water level sensors were installed at a number of WUAs, and monitored for extended periods of time. Shorter evaluations were conducted under laboratory conditions. A summary of the field and laboratory evaluations is shown in Table 1.2. The details of the field and laboratory evaluations are included in the other chapters of this report where relevant.

Table 1.2 Summary of field and laboratory evaluations

Nr	**Location**	**Experimental work**	**Dates of activities**
1	ARC-ILI laboratory	Laboratory evaluation of the clamp-on transit time ultrasonic meter	November 2002
2	Oranje-Riet WUA	Field evaluation of a paddle-wheel type mechanical flow meter Field evaluation of a bypass type mechanical flow meter Laboratory evaluation of a paddle-wheel type mechanical flow meter Laboratory evaluation of a Doppler type ultrasonic flow meter Field evaluation of the prototype electronic flow meter Field evaluation of an experimental differential pressure measuring method Comparative field tests of a paddle-wheel and a turbine type mechanical meter, and an electromagnetic meter	April - June 2002 July – October 2002 November 2002 June 2003 Sept-Dec 2004
3	Stellenbosch WUA	Field evaluation of a previously installed electromagnetic flow meter Field evaluation of the prototype electronic flow meter	April – June 2002
4	Worcester East IB	Field evaluation of a turbine type mechanical flow meter Field evaluation of the prototype electronic flow meter	April – June 2002
5	Orange-Vaal WUA	Field evaluation of a turbine type mechanical flow meter	June-August 2002
6	Gamtoos IB	Field evaluations of submersible flow depth sensors, dataloggers and a telemetric communication system Field evaluation of a non-contact ultrasonic flow depth sensor Field evaluation of the slope-area method for measuring canal flow	December 2002 – February 2003
7	Umlaas IB	Field evaluation of an experimental differential pressure measuring method Field evaluation of a paddle-wheel type mechanical flow meter Field evaluation of a telemetric communication system	November 2003 – February 2004
8	Zanyokwe Irrigation Scheme	Field evaluation of a paddle-wheel type and turbine type mechanical flow meters	January 2004

The process of planning and installing measurement devices in the field has exposed the project team to some of the constraints that WUAs have to face when implementing water measurement as required by legislation. The contact with specific WUAs has helped to create a better understanding of the day-to-day activities on the schemes, and assisted in developing practical guidelines for water measurement, which was the main objective of this project.

Aim 3 was completed by conducting surveys amongst water users from 6 different water user associations with different water distribution systems, irrigation systems and farming conditions. The areas covered were the Lower Riet River, Umlaas River, Loskop, Vaalharts, Hartbeespoort and Dendron. The results are presented graphically and discussed in Chapter 2 of this report.

In addition to the farmer survey, a discussion forum on reliable measuring methods was held in Bloemfontein in April 2004. The purpose of the discussion forum was to provide an opportunity for stakeholders in irrigation water use and management to provide inputs into the final phases of the research project against the backdrop of the legal requirements according to the National Water Act, current water management practices, and available measuring methods. It was aimed to obtain insight into the role of measurement in water management as perceived by the various role-players, and what aspects they consider as important. It also served as an opportunity to confirm preliminary conclusions and definitely added value to the project outcomes.

The Forum took place on 29 April 2004 in Bloemfontein, and although initially only about 25 people were invited, a total of 58 attended in the end. The number of participants from different groups of stakeholders was as follows:

- Water User Associations: 22
- Government departments: 14
- Researchers (project team and other WRC projects): 11
- Consultants: 7
- Meter manufacturers: 4

The program for the day included presentations by project team members as well as manufacturers, and opportunities for group discussions. Participants were divided into groups in such a way that there were representatives from all five of the stakeholder groups mentioned above in each discussion group.

Conversations between project team members and participants during and after the forum indicated that there is a need for information to be made available to stakeholders at grassroots level. It was clear the participants were looking for information and clarity on how measurement should be implemented, and therefore they were also the ones that had to be consulted on the needs to be addressed by this report. The discussions that took place resulted in a total of 45 issues being raised by the five discussion groups, of which 21 issues were unique. The issues were sorted according to their frequency of occurrence, and the result is shown in Table 1.3.

	Primary measurement issues	Secondary measurement issues
1	Clear guidelines needed from DWAF (8)	Water registration / legitimate use
		WC/DM strategy counter-productive?
		Water licences
		DWAF river measurements
		Transfer of DWAF assets to WUAs
		Bulk DWAF measurements are insufficient
		Leaching requirements
2	Cost of meters (4)	DWAF commitment on meter subsidies?
		Financing from DWAF?
		Who pays?
3	Technical committee on measuring in WUA organisation (4)	Training needed
		Reference manual needed on measuring devices
		Skilled "implementing agents" needed
4	Meter choice: hidden advantages (3)	Trigger must illustrate benefit
		Create awareness amongst farmers
5	Further development of kW meter (3)	Continue development
		Continue development
6	Correct design of new schemes / systems (3)	Different approach to new developments
		Inform SABI designers of correct design/choice
7	Bulk measurement of canal flows (accuracy?) (3)	Bulk metering vs private use
		Inaccuracies make water balances impossible
8	New tech's for canal measurement (2)	Inaccuracy of sluice gates
9	Guidelines from DWAF needed on min accuracy (2)	Why measure <5% if losses > 30%
10	Cost of installation (2)	Guidance on "hidden" costs
11	Comparative testing of donated meters	
12	Unique situations at different schemes	
13	Area-crop factor methods should be first step	
14	River pumps need management solutions	
15	Ownership of meters	
16	Meter maintenance	
17	Measuring will not have a big effect on already efficient schemes	
18	Pro-active approach is beneficial	
19	Use SCADA for real-time monitoring	
20	A phased approach should be followed	
21	KBS should be maintained and updated on the internet	

Table 1.3 Summary of issues raised at the Discussion Forum

As part of Aim 4, the water measuring guidelines included in this report were compiled and further work was done on the database of measuring devices for irrigation water (KBS). A proposal and budget for the further development and maintenance of the KBS was submitted to the WRC at the conclusion of this project, and the future of the product was still unknown at the time writing this report.

Other activities that contributed to the project but were not directly linked to a specific aim are the following:

- Collaboration took place with the Department of Water Affairs and Forestry in their pilot studies on the implementation of the Water Conservation and Demand Management Strategy for the Agricultural Sector
- Collaboration took place with the Department of Agriculture in a number small-scale farmer rehabilitation initiatives in the Northern Province and Eastern Cape
- A paper on the project was presented at a conference on Hydraulic Measurement and Experimental Methods organized by the American Society of Civil Engineers and the International Association for Hydraulic Research in Colorado, USA in August 2002
- A presentation on the project was presented in Moama, Australia, at a workshop organized by the Australian National Committee on Irrigation and Drainage (ANCID) on "In-field verification of flow meters".
- A paper was presented on some of the preliminary findings of the project at a congress of the South African Irrigation Institute (SABI) in July 2003 at Goudini Spa, Western Cape.
- A workshop organized by the United States Committee on Irrigation and Drainage (USCID) on water measurement in open channels was attended by one of the project team members in February 2004 in Arizona, USA
- A paper was presented on some of the field work results at a conference organized by the South African National Committee on Irrigation and Drainage (SANCID), held at the Fish River Sun, Eastern Cape from 17 to 19 November 2004.

1.1.3 Capacity building objectives

It was envisaged that capacity building would take place in the following ways:

1.1.3.1 Individuals

At least one post-graduate student, from a previously disadvantaged group, who is interested in developing research skills, would be included as a member of the project team. This student would be registered with the Department of Agricultural and Food Engineering, or alternatively with the University's Post Graduate School of Agriculture and Rural Development.

As part of the post-graduate degrees offered by the University, a dissertation has to be completed and it was envisaged that a specific element of the proposed project would be identified on which the student(s) could focus for this part of his/her studies.

1.1.3.2 Communities

The fair distribution of water on small-scale irrigation schemes in the former homeland areas is probably one of the biggest causes of conflict among their participants. Often conventional water management procedures are inappropriate, or water management infrastructure is vandalized by farmers claiming that they are not receiving their fair share. This makes it almost impossible for anyone on the scheme to irrigate successfully.

The project would include the monitoring of measurement practices on small-scale schemes, most likely in the Northern Province or Eastern Cape where other rehabilitation initiatives are currently being undertaken. Project activities should have involved the evaluation of appropriate technologies as well as an investigation of the acceptability and the transfer of improved measurement practices to developing communities.

1.1.3.3 Transfer of research results

As stated in the project objectives, it was aimed to establish directives for the correct choice and management of measurement techniques for irrigation systems under different circumstances, as a result of the research undertaken. The transfer of these directives to Water User Associations (WUAs) and their members for implementation as best management practices in Agricultural Water Management Plans, will imply that intensive capacity building will take place on various levels of the irrigation sector (irrigators, extension officers, provincial government, agricultural training organisations, development funders, etc.). The implementation of this process will also contribute to establishing a national network of knowledgeable role players in this field.

The report on capacity building is included in Appendix C.

1.1.4 Project outcomes

The activities undertaken during the project period all contributed to completion of the main objective of this project by providing the project team with the background, insight and experience of practical irrigation water measurement.

This report provides an overview of the technical results of the field and laboratory evaluations in the context of implementation guidelines for irrigation water measurement. It has been compiled in two parts, Part A and Part B.

Part A consists of Chapters 2 to 4, where the project activities and approach to implementing irrigation water measuring is discussed. Chapter 2 provides background to the irrigation sector in South Africa, and describes the environment within which measurement must take place, including legal aspects, typical scheme management approaches, practical requirements and possible constraints.

The project activities and experiences of the project team are described in Chapter 3. The content includes the results of various field and laboratory testing of measuring devices, as well as the results of a survey conducted amongst farmers in six irrigation areas in South Africa.

The conclusion and recommendations addressing the original project aims of the research project are included in Chapter 4.

Part B, consisting of Chapters 5 to 9, is the guidelines for selection, installation and management of irrigation water measuring devices, in other words, the technical detail.

Chapter 5 serves as an introduction to the recommended implementation approach, based on the project team's experience, and recent international trends. The content of this chapter can be seen as a possible basis for an irrigation water measuring regulations in South Africa.

In Chapter 6, a comprehensive overview of the technical aspects (hardware and software) of irrigation water measuring infrastructure is provided. These aspects are discussed in detail in the following three chapters, which is organised according to open channel measurement (Chapter 7), closed conduit (pipe) measurement (Chapter 8), and system operation and data management (Chapter 9).

Further information on terminology and the KBS are attached as appendices.

2. BACKGROUND TO IRRIGATION WATER MEASUREMENT

2.1 Introduction

The main objective of the project was to develop guidelines for the correct choice, installation and maintenance of water measurement devices for canal, pipeline and river distribution systems. The legal requirements of the National Water Act (NWA) (Act 36 of 1998) are clear. In order to successfully manage and license water usage it is necessary to quantitatively verify water use. Undoubtedly the most obvious method would be accurate measurement at all points of control. In the course of this project it was found that this is easier said than done. Accurate measuring devices are expensive and all measuring devices are dependent on correct installation, regular maintenance and calibration while capturing and recording readings are either labour or instrumentation intensive. It has become quite apparent that across the board over night introduction of measuring water volumes is neither economically or physically possible.

While the NWA is drastic in many respects, policy and practice is to phase in changes progressively over time. Demand management strategies recognise this and emphasis is placed on achieving continuous and planned improvement. While recognising that considerable improvement is necessary and desirable it must also be appreciated that we have developed water management and administrative procedures that really work and are possibly equal to the best in the world. In the course of the project it has been possible to establish what methods and equipment are available in South Africa and elsewhere in the world and to gain valuable insights into what works and what doesn't work.

2.1.1 Why measure irrigation water?

2.1.1.1 Legal compliance

In 1998, the previous water law was replaced by the National Water Act (Act 36 of 1998), which is to be implemented through the National Water Resources Strategy (NWRS), which makes provision for, amongst others, the establishment of Catchment Management Agencies (CMAs) and Water User Associations (WUAs) in each of the 19 water management areas in the country, as declared in Government Notice 1160 in October 1999 (Department of Water Affairs and Forestry, 2000).

The CMAs are statutory bodies, established by Government Notice, with jurisdiction in a defined water management area. The functions and responsibilities of the CMAs include the development of catchment management strategies, management of water resources and co-ordination of water-related activities, and any other functions delegated by the Minister.

WUAs are co-operative associations of individual water users who wish to undertake water-related activities at a local level for their mutual benefit. They operate in terms of a formal constitution and are expected to be financially self-supporting from water use charges paid by members. A WUA falls under the authority of the CMA in whose area it operates, if the agency has received powers from the Minister to operate the WUA's activities. According to Schedule 5 of the Act, one of the functions of a WUA can be "to supervise and regulate the distribution and use of water from a water resource according to the relevant water use entitlements, by erecting and maintaining devices for measuring and dividing, or controlling the diversion of the flow of water".

Through the constitution and business plan it must be shown how "the WUA makes progress towards measuring the quality and quantity of inflows and outflows, losses and water supplied to its customers, and towards the use of acceptable measuring devices or techniques." (Department of Water Affairs and Forestry, 2000)

Further provisions for monitoring and information systems for water resources, and responsibilities for providing water-related information, are provided in Chapter 14 of the Act. The Act empowers the Minister to require any person to provide data and information, either on an ad hoc or regular basis, for the national monitoring and information system, to facilitate the management and protection of resources (Department of Water Affairs and Forestry, 2002).

The strategy and implementation of the business plans are currently being tested through three pilot studies on the development of water management plans for the Gamtoos, Oranje-Riet and Orange-Vaal WUAs. The Water Management Plans that will be the results of the project should reflect the current and expected water demand as well as proposed water conservation measures. At all three WUAs, water measurement is considered of fundamental importance for water management, but the cost of providing and installing the necessary infrastructure causes concern amongst the farmers as well as the water management staff.

2.1.1.2 Practical water management

Except for the legislative reasons for measuring irrigation water, many other benefits related to practical water management, are derived from upgrading water measurement programs and systems, some of which are the following (United States Bureau of Reclamation, 1997):

- Accurate accounting and good records help allocate equitable shares of water between competitive uses both on and off farm.
- Good water measurement practices make record keeping possible, resulting in fewer problems and easier operation.
- Accurate water measurement provides the on farm decision-maker with the information needed to achieve the best use of the irrigation water available while minimising negative environmental impacts.
- Installing canal flow measurement structures reduces the need for time consuming current metering, which is frequently needed after making changes of delivery and to make seasonal corrections for changes of boundary resistance caused by weed growth, sectional bank slumping or sediment deposits.
- Instituting accurate and convenient water measurement methods improves the evaluation of seepage losses in unlined channels. Thus, better determinations of the cost benefits of proposed canal and ditch improvements are possible.
- Permanent water measurement devices can also form the basis for future improvements, such as remote flow measurement and canal operation automation.
- Good water measurement and management practice prevents excess run-off and deep percolation, which can damage crops, pollute ground water with chemicals and pesticides, and result in drainage flows containing contaminants.

2.1.1.3 Financial incentives of measuring

In all discussions with water users or management staff on water meters, the issue of cost is brought up sooner or later. A major concern is the initial cost of the meter and installation; although a commercially available mechanical meter can be bought and installed for less than R8,000 on most irrigation pipe systems (usually smaller than 300 mm in diameter). However, most farmers use more than one pump, at different sites, to abstract water.

The question is whether the cost of the measuring device is actually significant? On the assumption that the meter serves one 50 hectare centre pivot complete with pump and piping representing an investment of R750 000 the meter price is insignificant at approximately one per cent. In many areas the WUA would be billing the farmer for some R37 500 annually for water costs alone for typical cash crop production and this would not increase to any major extent if the cost of the meter was annualised. To further put this into perspective the production costs for inputs only for onion planted under the 50 ha centre pivot would be R2,250 000! Even a low input crop such as wheat represents a cash requirement for inputs of R300 000 and a gross profit of R200 000 what matters is yield and quality and if accurate metering is required either to ensure a fair share of available water or production levels then R20 000 for an electromagnetic or acoustic meter might not be out of line.

The significance of the measuring cost can be questioned further when considering the potential benefits to the water user and WUA. If a measuring system is implemented, accounting for individual water use combined with pricing policies that penalise excessive use is possible. The combined result at WUA level can improve the operation and cost recovery of the organisation and also put it into a strong bargaining position with higher organisations, such as CMAs.

2.1.2 The measuring environment

At most WUAs, there are two levels of the water supply system where measurement can be used as a tool to manage the water effectively. Firstly, the main supply and distribution system (the main canal, pipeline or river in the scheme) can be monitored and controlled through measurement at critical points. Secondly, the individual abstractions may need to be managed in some way to ensure that fair allocation takes place, and measurement can be implemented at farm off-takes to assist in this process.

2.1.2.1 Approaches to the management of the main water supply

"On demand" approach (continuous flow)

In this system, the scheme manager aims to maintain the supply in the system so that any user can abstract water at any time. In canal and river systems, this usually means that he has to monitor the flow depth at strategic points, and adjust the in-flow to the system accordingly. In pipeline systems, the pressure (and sometimes the flow rate) in the conduit have to be monitored and controlled.

The scheme manager needs to be experienced and know the system and farming practices on the scheme well in order to operate a scheme in this way. Especially in the case of the river schemes he needs a few seasons to understand the flow in the river, since water releases can take up to a few days to reach the point in the system where there is a shortage.

The system lends itself well to the use of telemetric monitoring of the critical points, since it eliminates driving to the point itself to observe the flow. All the pipeline schemes that were visited are already using SCADA systems to manage the water demand.

This approach is often used when there is a lack of measurement devices to quantify the flow in the distribution system, since no quantitative flow rate measurements are needed.

"Request" approach

The objective of this management system is to supply only the amount of water that is requested by the users in advance, making provision for distribution losses. This system is usually found on the former government canal schemes. Farmers request the water they will need, specifying the flow rate at which they will abstract the water, the period of time they will be abstracting it for, and the time during the week they will be abstracting. The scheme manager then uses this information to estimate how the water releases into the system will have to be adjusted to meet the demand within the constraints of the system.

Flow rate measurements are required at the system inlet and all the branches to ensure that the water is conveyed to the designated abstraction points.

Irrigation turn approach

In this approach, each user is only allowed to abstract water at certain times within a (weekly) schedule. The system is usually followed when the distribution system has insufficient capacity for an "on demand" approach to be taken. The system works best if water can be stored on-farm, since a farmers irrigation turn may come at a time when he doesn't need to irrigate (for example, if he had rain the day before), or he may need water during a hot spell but his turn is still a few days away.

Irrigation schemes in the former homeland areas were often designed to be operated using irrigation turns. The scheme was divided into blocks along the main canal, and farmers in each block could irrigate on certain days. However, the rigidity of the system have caused it not to be used as intended, with farmers using it as an "on demand" system, and then complaining that the canal has insufficient capacity during times of peak irrigation requirements.

Even if flow measurement devices are in place, the system is usually managed without using them, and merely by maintaining an adequate (often maximum) flow in the system.

Water quality management approach

The objective of this approach is to maintain an acceptable water quality in the distribution system by monitoring the water quality and releasing additional water from the source if necessary. The quality of the water is the limiting factor rather than the quantity that needs to be abstracted by users in the distribution system.

As with the "on demand" approach, the scheme manager needs to know the system well and a calibrated simulation model can be of valuable use.

Flow measurement and water quality measurements are required to operate the system, and a SCADA system will make optimum efficiency possible. However, the effect of the water quality on the accuracy of any sophisticated sensors and other equipment has to be taken into account.

2.1.2.2 Approaches to the management of individual abstractions

The approach that is taken depends on whether the individual abstractions are measured or not, and this affects the way in which users are requested to pay fees to the irrigation board (WUA).

No measurement takes place at individual abstractions

On many schemes, the individual abstractions are not measured, even though the rate of abstraction may be specified. In most of the river systems, no quantitative data on the abstractions are available.

There are two ways in which farmers can be required to pay for their water use:

- They pay for their full quota (or at least a part of it), regardless of the actual amount of water used, and have to request water, usually weekly, which is monitored and compared with the quota
- They pay for the amount of water they should be using based on the areas planted under a specific crop and the average crop water requirement in that area

The users of this system argues that it is a cost-effective management approach, and will not encourage wastage of water by farmers since pumping water unnecessarily will increase their electricity consumption (and therefore increase production costs). However, this approach does not allow for a mechanism that can be used in times of water shortages, and there is no way of preventing a farmer at the beginning of the distribution system of taking as much as he can, or proving that he took more than he should have.

Measurement takes place at individual abstractions

If a measurement device is in place at each individual abstraction point, it makes it possible to determine each farmer's water use, as long as the device is accurate and the change in status since the previous reading can be reflected in a sensible way. For instance, a Parshall flume is a measurement device, but reading it once a month is not going to provide any information on the month's abstraction, but a flow meter showing cumulative flow can reflect a month's abstractions. If the Parshall flume is fitted with a pressure sensor that is connected to a datalogger, then useful information can be obtained. This approach does therefore only include situations where a quantitative change in status can be recorded. If this is not possible, the situation is not considered as measured.

The flow data can be handled in the following ways:

- The measuring device is read periodically (monthly, quarterly, etc.) by a water bailiff
- The measuring device records readings at relatively short intervals and stores it in a datalogger from where it is downloaded periodically by a water bailiff by hand (via a handheld terminal, for instance)

- The measuring device records readings at relatively short intervals and stores it in a datalogger from where it is downloaded via a telemetric system (modem or radio frequency)
- The measuring device records readings continuously, compare it with a programmed allocation and is able to control the abstraction at the measuring point on a volumetric basis

2.1.2.3 Measurement devices and systems

Regardless of whether measurement takes place in the water distribution system or at individual abstractions, there are five components of the method that are always present. They are the following:

- A physical component that is installed (for example a hydraulic structure or flow meter)
- A scientific principle that can be evaluated (for example critical flow depth or electromagnetic induction)
- A sensor that detects a certain aspect of the scientific principle (for example a pressure sensor or propeller)
- A component that converts the output from the sensor into useful data (for example a display unit or device that sends a signal to a datalogger)
- A component where the data is collected and transmitted for processing (for example a water bailiff reading meters or a telemetric transmitter)

Any measurement system consists of a combination of these components and the level of sophistication varies from one site to the next, depending on the specific needs and available funds.

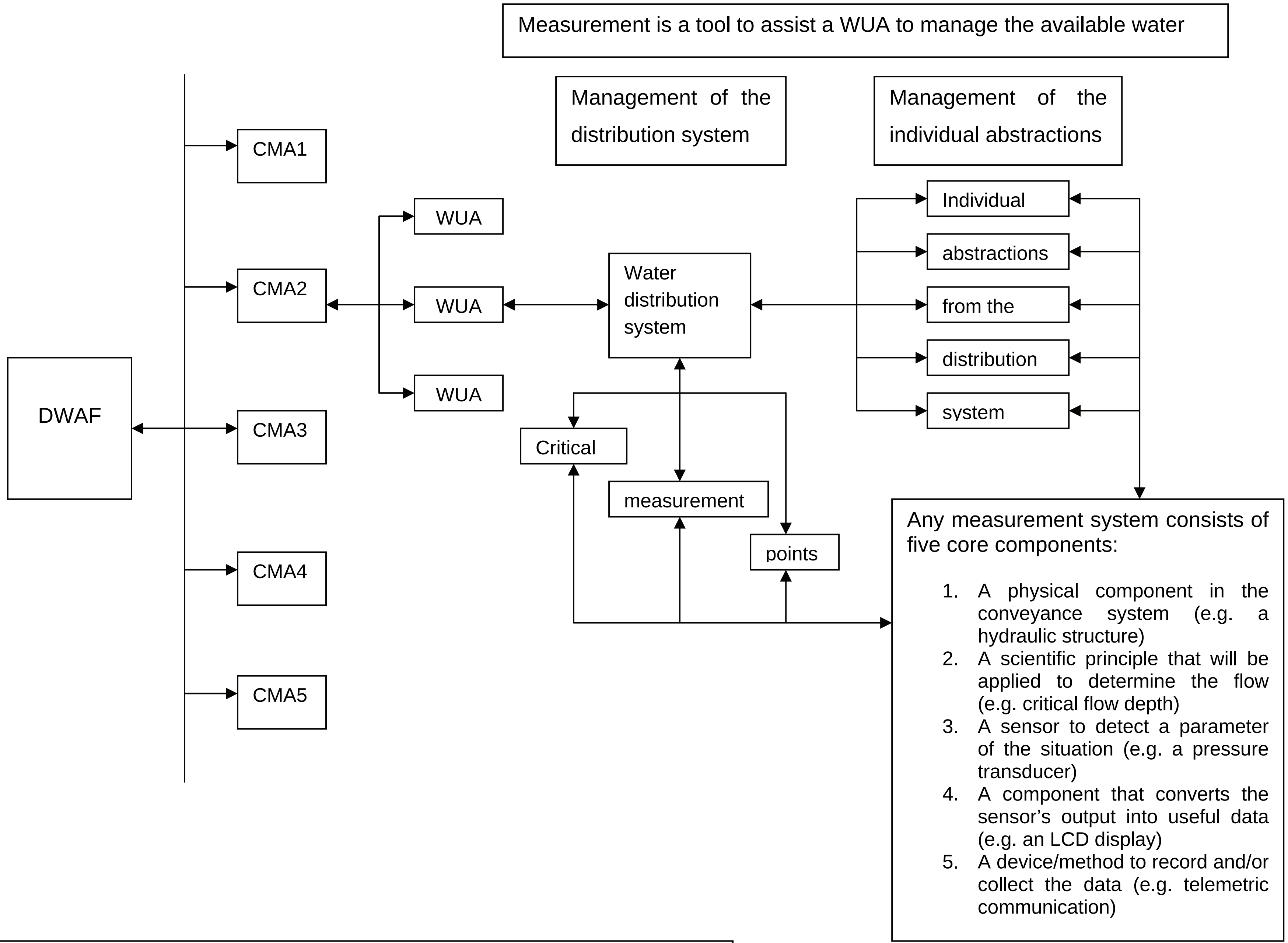


Figure 2.1 Schematic representation of measurement as a management

2.1.3 Constraints

Although there are valid reasons for implementing water measuring, there are also valid objections and real constraints that can obstruct the process. Participants at the Discussion Forum, including senior representatives of the WUAs where the water demand management pilot studies have been completed recently, were concerned by the lack of clear guidelines and directives from the Department of Water Affairs and Forestry. This included the issuing of water use licenses (by when?), the transfer of GWS assets to WUAs, improved bulk measurement in rivers (typically at gauging stations), as well as required measuring accuracy should metering at farm level become mandatory. An additional issue concerned how the cost of measuring devices can be covered. Questions have been raised on possible subsidies or financing arrangements from DWAF. Other issues concern installation, maintenance and monitoring practices.

2.1.3.1 Supply costs

In all discussions with water users or management staff on water meters, the issue of cost is raised sooner or later. A major concern is the initial cost of the meter and installation; although a commercially available mechanical meter can be bought and installed for less than R8,000.00 on most irrigation pipe systems (usually smaller than 300 mm in diameter), most farmers use more than one pump, at different sites, to abstract water. A mechanical meter is also the least accurate meter available (usually within ± 5 % of the actual flow under ideal conditions), but better accuracy comes at a higher price.

Although this cost could be spread over a number of years to make it more affordable, some water users have indicated during interviews that they do not feel that the installation of meters would have any effect on their water use (increasing efficiency) and they could not see how the cost of the meters would be recovered, therefore feeling that the expense of measuring water use at farm level could not be justified in the first place.

2.1.3.2 Installation

Measuring sites are usually located at fairly remote places that may be difficult to reach, especially in poor weather or with heavy machinery. The pumps are often not enclosed in a pump house that can be locked and electrical connections and wiring substandard. These conditions increase the risk of vandalism or damage to measurement devices, making the installation of expensive equipment even less appealing.

Most of the meter installations required in WUAs will be at existing off-takes. In order for the meter to operate correctly, most measuring devices require a straight section of pipeline or canal of at least 5 (preferably 10) times the diameter of the pipe or flow depth upstream of the device, and at least 3 (preferably 5) times the diameter or depth downstream of the device to ensure a fully developed flow profile in the meter. At most systems these requirements cannot be met without major changes in the existing pipeline or structure, which often requires construction at difficult sites.

The installation of a measuring device also increases the head loss in pipelines and increases the flow depth upstream of the device in canals. If a reduction in pipe diameter is required, this may also affect the duty point of the pump and influence the pressure available at the irrigation system at the end of the pipeline. In may be the case that the pump cannot meet the additional pressure head requirements and the installation will then influence the efficiency of the irrigation system. In the case of canals, this may lead to spillages upstream of the device, or a reduction to the capacity in the canal.

The cost and difficulties of installing direct measuring devices have also contributed to the interest shown in indirect measuring methods. It is much simpler and cheaper to install for instance an hour meter on a pump than a mechanical meter. However, the savings incurred may be lost due to the lack of accuracy.

2.1.3.3 Operation

Data can be retrieved either using manual methods, which involves regular visits to each device, or via various telemetric methods that eliminates the need for visits. Dataloggers can also be used to obtain continuous data and reduce the number of visits.

By spending more on the equipment, for instance investing in a telemetric communications system or buying a datalogger with more storage capacity, the cost of data collection can be reduced considerably since it could eliminate visits to the installation sites, which are often remote and may be inaccessible in bad weather conditions. However, provision will have to be made for maintenance on equipment that may be sensitive to extreme temperatures, rain, etc.

2.1.3.4 Maintenance

One of the constraints mentioned most often by water management staff of the WUAs, is the problems caused by physical and chemical impurities in the water. Physical impurities include water grass, sticks, frogs, sand, silt, or any other object or substance that can be conveyed by the water. The larger objects can get stuck in the rotor of a flow meter, and sand or silt can cause excessive wear of the meter's mechanisms or casing, thereby affecting meter accuracy and necessitating expensive maintenance.

The chemical quality of irrigation water abstracted from rivers is often poor due, firstly to groundwater return flows containing a large amount of salts that have been leached from the irrigated fields adjoining the river, and secondly from reduced natural flow in the river caused by diversion structures or upstream control (limited releases from a dam in the river). Poor quality water also causes excessive wear of the meter mechanisms and casing, or it may cause precipitation and chemical reactions in the meter.

In order to avoid reduction in accuracy as far as possible, a regular maintenance program has to be in place, where devices are systematically checked seasonally or annually. This may require laboratory facilities or in-field verification equipment as well as skilled staff, all of which can be expensive to obtain and keep in good order. If it is available however, it can also be put to good use to solve disputes about device accuracy, or to investigate cases of meter tampering.

2.1.4 Finding solutions for the way forward

One of the important changes brought about by the N W A is that there is a move away from water allocation according to scheduled areas, and flat rate charges, towards volumetric allocation and charges. Water services organisations rely on income from water management charges to perform their functions and it is to be expected that in the course of time CMAs and WUAs will fall in line with this outlook. Irrigation water is to be managed volumetrically so metering appears to be logical and inevitable but this is a mammoth task that will have to be implemented progressively over time.

The comment was made at the discussion forum that in the case of well-managed WUAs where members were satisfied that the water was being equitably distributed and charged individual farm take-off metering would do little to improve irrigation efficiency. A number of WUAs have given considerable attention to improvements in water management. These include two of the three Demand Management pilot projects where there is rigid monitoring of the areas under specific crops on each farm. This is coupled to scientifically established and generally agreed values for efficient water use. A WAS module has been developed that computerises this process incorporating satellite imagery and GIS.

The costs of a measuring system is often seen as a constraint to implement measuring, but since cost is linked to accuracy, there are often more options available than what WUAs are aware of, and these should be explored. Accuracy however, is also linked to the availability of water, and this may influence the final decision.

Suitable technologies are definitely available, and their failure is more often than not linked to incorrect application (unsuitable for specific conditions), installation practices or lack of maintenance. Water quality is a very important aspect to consider.

Capital costs can be spread over a number of years by phasing in new technologies over a period of time. The management cost of a device will also be an annual expense, and has to be taken into account during decision-making. A device that costs more initially may be less expensive to maintain and retrieve data from than a more affordable one. A cost analysis of different options needs to be performed.

3. PRACTICAL WATER MEASUREMENT

3.1 FIELD EXPERIENCES

3.1.1 Mechanical meter evaluations

In the course of the project a wide variety of mechanical meters were evaluated by comparing readings from the meters with the discharge measurements taken by a portable transit time meter. In many cases the required straight pipe diameter lengths before the meter as required by the manufacturer was not met. This influenced the meters' performance as can be seen from the results from a number of tests shown below.

3.1.1.1 Oranje-Riet Water User Association

Impeller type meter

The meter that was evaluated, was a newly installed impeller type meter with a pulse output. The pumping system is used to abstract water from a canal and deliver it to two center pivot irrigation systems. The system was previously fitted with a turbine type meter which was still in place but not registering any flow on the counter, probably due to stripped gears or the turbine being jammed.

The farmer experiences a lot of problems in summer with algae and other organic material in the water, and this was probably also the cause of the old meter's failure. Despite the trash screen in the canal at the pipe inlet, strings of algae and water grass still find its way into the system and can get caught in the mechanism of the flow meter. Eventually the turbine stops turning and no flow is recorded.

The impeller type meter is said to be more resistant to failure due to the effect of dirty water since the impeller is fitted at the top of the meter casing and only partially obstructs the flow path of the water. Furthermore, the system is fitted with a strainer, and the new meter was installed downstream of the strainer (the old meter was in front of the strainer). See Figure 3.1.

A number of positions for installation of the transit time meter were tested, and the best found to be between the turbine meter and the strainer, where a good signal strength and repeatability of readings were observed. At positions downstream of the pump, problems were encountered with maintaining a strong signal due to vibration of the pipe (steel) and excessive turbulence due to the butterfly valves, especially when one of the valves were partially closed.

Readings with both the mechanical and the transit time meters were taken over a flow range of 20 to 250 m^3/h by adjusting the butterfly valve downstream of the impeller type meter. Although the data points show a slight tendency of decreasing error with increase in discharge, the points are erratically scattered, mostly indicating errors between –5% and +50 %. The meter seems to give too high readings, but it had not been in use for very long at the time of the test, so the readings may decrease overall after some time of use.

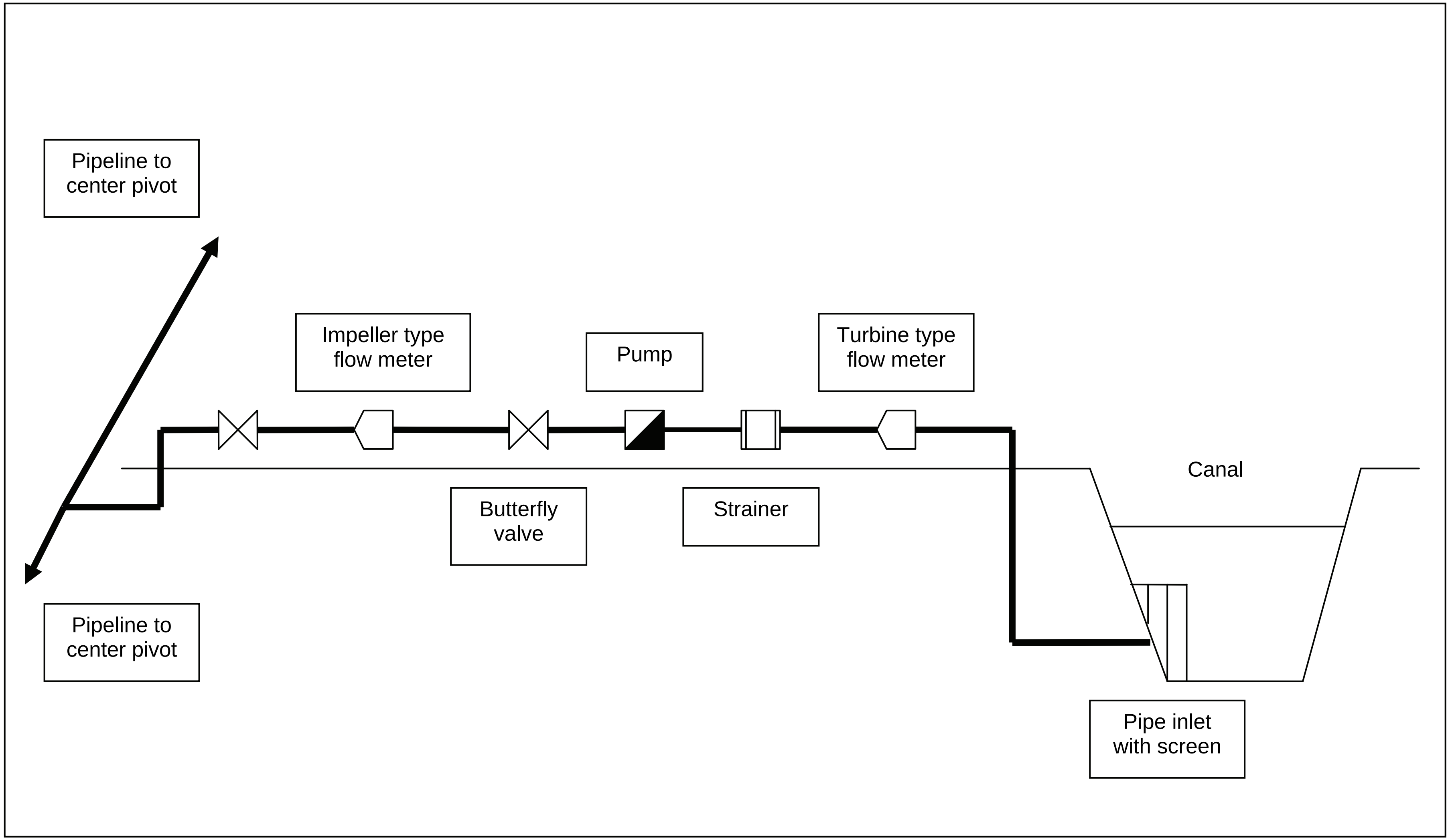


Figure 3.1 Pumping system lay-out: Oranje-Riet WUA (elevation, not to scale)

Although it had been installed according to the manufacturer's installation instructions, it is down-stream from the pump, a butterfly valve and a 90 degree bend which may be causing excessive turbulence in the pipe. During the test it was observed that the counter on the dial did not turn smoothly, almost as if it was getting stuck or becoming unbalanced, but whether the results are superficial cannot be said for certain. Another factor is the high concentration of algae and other physical impurities in the water.

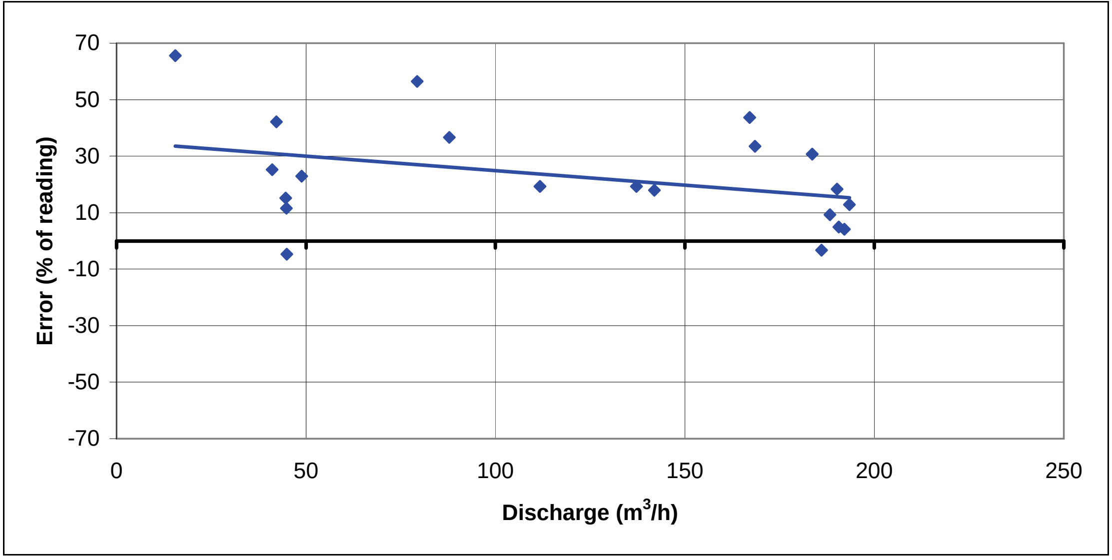


Figure 3.2 Accuracy of the impeller type meter at Oranje-Riet WUA

The contradicting readings taken with different measuring devices at the Dasram pump station were further investigated by conducting laboratory tests on the mechanical meter and the portable ultrasonic meters used in the field. Initial tests were conducted in the laboratory of the WUA at Jacobsdal, and the mechanical meter was also later returned to the manufacturers to be tested in their laboratory in Johannesburg.

In the Jacobsdal laboratory, the meter was installed according to the necessary requirements for proper operation (accuracy within ±5% of actual reading) and its readings compared with those of the calibrated reservoir.

The results were not satisfactory, since there seemed to be a delay in the reaction of the calibrated reservoir during tests, resulting in unknown errors in the reference readings. In order to verify the reservoir readings, the portable ultrasonic meter was also used (accuracy within ±0.2% of actual reading) and it was found that there were differences between these readings and those of the reservoir as well.

Table 3.1 Results from Jacobsdal laboratory

Test nr	Average flow rate, m^3/h	Flow rate (reservoir), m^3/h	Flow rate (mechanical meter), m^3/h	Flow rate (ultrasonic meter), m^3/h
1	20	17.3	31.2	20.2
2	85	75.5	113.1	86.0
3	225	204.6	252.9	226.3

The meter was evaluated at three flow rates and the percentage errors and repeatability were calculated. The results are summarized in Table 3.2 below. It was decided that the tests were inconclusive due to these problems encountered, and that the mechanical meter would be returned to the manufacturer for testing in their laboratory.

The results of the manufacturer's tests confirmed that the meter was producing errors of +7.8 % of reading on average across the range of flow rates tested at.

The project team investigated the data recorded by the meter since the day of installation and found that the verification done in the field on the day of installation also indicated high readings, although at that stage it was assumed the readings were influenced by the installation conditions. The manufacturers' tests however confirmed that it is possible that the meter was faulty from the beginning.

Table 3.2 Analyses of Jacobsdal results

	Percentage error, % of reading		Repeatability, % of span	
Test nr	Reservoir reference	Ultrasonic reference	Reservoir reference	Ultrasonic reference
1	78.33	54.46	18.25	48.20
2	49.96	31.51	5.70	37.60
3	23.80	11.75	2.60	19.60

Discussions with the manufacturer's quality manager indicated that the meters are imported completely assembled and calibrated from Italy, and not recalibrated in South Africa before distribution. Due to this incident, the manufacturer has now decided that all imported meters should from now on be calibrated on arrival in South Africa to avoid repetition of this problem.

A complete report on the field and Oranje-Riet laboratory tests was compiled by a post-graduate student of the Department of Civil and Biosystems Engineering at the University of Pretoria.

Bypass type meter

A mechanical proportional type meter was installed at another off-take from a canal on the irrigation scheme. A similar meter had been installed during 2002 at a river pump station on the Riet River, and although it was still in working condition, its accuracy have not been verified in the field with the portable ultrasonic meter due to the rusted condition of the pipe.

The meter works on the principle of a part of the total stream is directed into a bypass fitted with a small flow meter, parallel to the main stream, using a venturi. The small stream flows through the meter and back into the main stream. At the inlet to the bypass there is a sieve to prevent dirt from entering the meter. The particular type of meter was chosen because the water has a high algae load which can get tangled in a rotor or impeller. It was thought that this particular design would let the algae through in the main stream.

After the meter was installed, it seemed to function well initially. However, after registering about 300 m^3 of flow, it started running in reverse and continued to do so. When the meter was opened, it was found that the sieve was completely blocked, causing the water to flow pass the inlet of the bypass, enter at the outlet and flow in the wrong direction through the meter, resulting in the register running in reverse. Since the outlet, which has no sieve, was not blocked, it was decided to remove the sieve to see whether the algae would not be able to pass through without it. However, this worked for a short period, but then the meter stopped completely due to the algae entering the bypass.

Although these meters are used successfully in the Western Cape at schemes with pipe distribution systems, a similar experience as the one discussed above was reported by the water management staff of the Gamtoos Irrigation Board. However, in that case the bypass was blocked by silt and not algae. It can therefore be recommended that the use of this type of meters be avoided in cases where water carries a lot of physical impurities.

The project team would like to thank Mr Hanke du Toit for his assistance in installing and monitoring the meter at the Oranje-Riet WUA.

3.1.2.2 Oranje-Vaal WUA

A turbine type meter was installed at a river pump station on the Vaal River upstream of the Douglas weir in February 2003, but during the first follow-up visit in March 2003 it was observed that the datalogger had malfunctioned and it was removed for repairs. On return to the site to re-install the datalogger, it was found that the farmer had removed the flow meter from the system because he felt it caused too much additional head loss in the supply pipe to the irrigation system. Although there was in fact adequate pressure available at the irrigation system even if the flow meter was installed, the farmer would not agree to re-installing the flow meter, and it was decided to move the equipment to another site.

The size of the meter was chosen to suit the flow rate in the system, and this happened to be one pipe size smaller than the mainline into which the meter had to be installed. The necessary measurements and calculations were performed and it was found that only about 0.5 m of additional friction loss would occur, therefore putting no serious additional load on the pump and motor. There would still be adequate pressure available at the irrigation system inlet for the system to perform as required despite the section of smaller diameter pipe added, and the farmer was informed of this. The meter was installed together with the necessary reducers, fittings and pipework. About 58 000 m^3 passed through the meter before the farmer decided the remove it because he felt the section of smaller diameter pipe was causing too much pressure loss in his system and that it could not function properly, although there was no evidence of this.

3.1.1.3 Loskop Irrigation Scheme

Method

On request of the Loskop Irrigation Board, 15 mechanical water meters were evaluated from 8 to 10 September 2004 to determine the in-field accuracy by comparing the recorded measurements with reference meter readings.

The procedure that was followed at each site involved the installation of a portable ultrasonic flow meter to provide a reference measurement of the volume of water passing through the mechanical meter. Meter readings from both meters were taken simultaneously at 10 minute intervals for a half hour period. The evaluations were performed at the flow rate at which water is normally abstracted. In cases where water was abstracted regularly at more than one flow rate (for example to a center pivot and micro irrigation system), the test was repeated for the most common flow rates.

For the purpose of this study, the discharge measurements were made with a portable ultrasonic transit-time meter with a typical measuring accuracy of ± 2 % of reading for flow velocities >0.3 m/s. The meter has the advantages of being non-intrusive to the flow path, and able to measure velocities of between -12.2 and 12.2 m/s (rangeability of 400:1). Due to the well-laid out meter installations at the Scheme, adequate straight pipe sections were always available to install the meter as required by the manufacturers.

Some problems were encountered with rust inside the pipes on which measurements were taken, but in all cases suitable pipe segments could be found where acceptable sound speed and signal strength values were observed. The mechanical meters that were evaluated were of the mechanical by-pass type, all 150 mm in size, and have been installed for more than 2 years. The meter works on a bypass principle, with a proportional part of the total flow being diverted through the meter mechanism which is parallel to the main meter body. The meter mechanism is a single jet meter with a dry register and self flushing turbine.

According to the manufacturers, the meter is suitable for untreated water and will maintain its accuracy of ± 5 % of reading if installed according to the requirements as shown in Figure 2. These requirements were met at all the sites where evaluations were performed, except at site A222/1A where the meter was installed without the 20 diameters of straight pipe length, but incidentally the mechanical meter at this site performed second best of all the meters evaluated.

The only other deviation that was observed was at site A224/10, where water was abstracted at an average flow rate of 11.2 m^3/h which is lower than the recommended minimum flow rate of 20 m^3/h required in the 150 mm diameter flow meter, for a measurement accuracy of ± 5 % to be maintained.

The flow meter is fitted with a sieve to prevent dirt particles from entering the by-pass section of the meter. However, these sieves had been removed by the Irrigation Board shortly after installation because of clogging problems. In order to investigate the effect of the removal of the sieves on meter accuracy, one of the meters were evaluated with and without the sieve at the same site.

Results

A summary of the results according to site number is shown in Table 3.3.

Table 3.3 Summary of evaluation site data at the Loskop Irrigation Scheme

Site nr	Flow rate m^3/h	Error %	Water delivered to?	Pump in pipeline?	Sieve in meter?
A222/1A	55.0	6.4	Micro irrigation	Yes, before meter	No
A222/1	57.7	33.3	Centre pivot	Yes, after meter	No
A222/2	99.0	24.7	Centre pivots (x2)	Yes, after meter	No
A222/3	83.3	10.2	Centre pivot	No	No
A223/4	54.6	42.9	Centre pivots (x2)	Yes, after meter	No
A223/5	86.9	39.0	Quick-coupling sprinklers	Yes, after meter	No
A223/6	83.3	13.1	Centre pivot	Yes, after meter	No
A223/7	103.9	46.0	Centre pivot (moveable) & 5 garden sprinklers	Yes, after meter	No
	95.2	37.8	Centre pivot (moveable)	Yes, after meter	Yes
A223/8	151.7	33.9	Centre pivot	No	No
A224/9	35.2	-8.8	Micro irrigation	Yes, after meter	No
	121.3	-5.0	Centre pivot	Yes, after meter	No
A224/10	11.2	27.6	Micro irrigation	No	No
	71.1	91.9	Centre pivot	Yes, after meter	No
A224/11	96.1	17.4	Centre pivots (x2)	No	No
A224/12	100.2	20.4	Centre pivot	No	No
	114.4	24.3	Quick-coupling sprinklers	Yes, after meter	No
A224/13	105.0	6.9	Centre pivots (x2)	Yes, after meter	No
A224/14	77.8	5.4	Centre pivot	No	No
A224/15	107.9	18.5	Centre pivot & micro irrigation	No	No
	76.5	16.1	Centre pivot	No	No

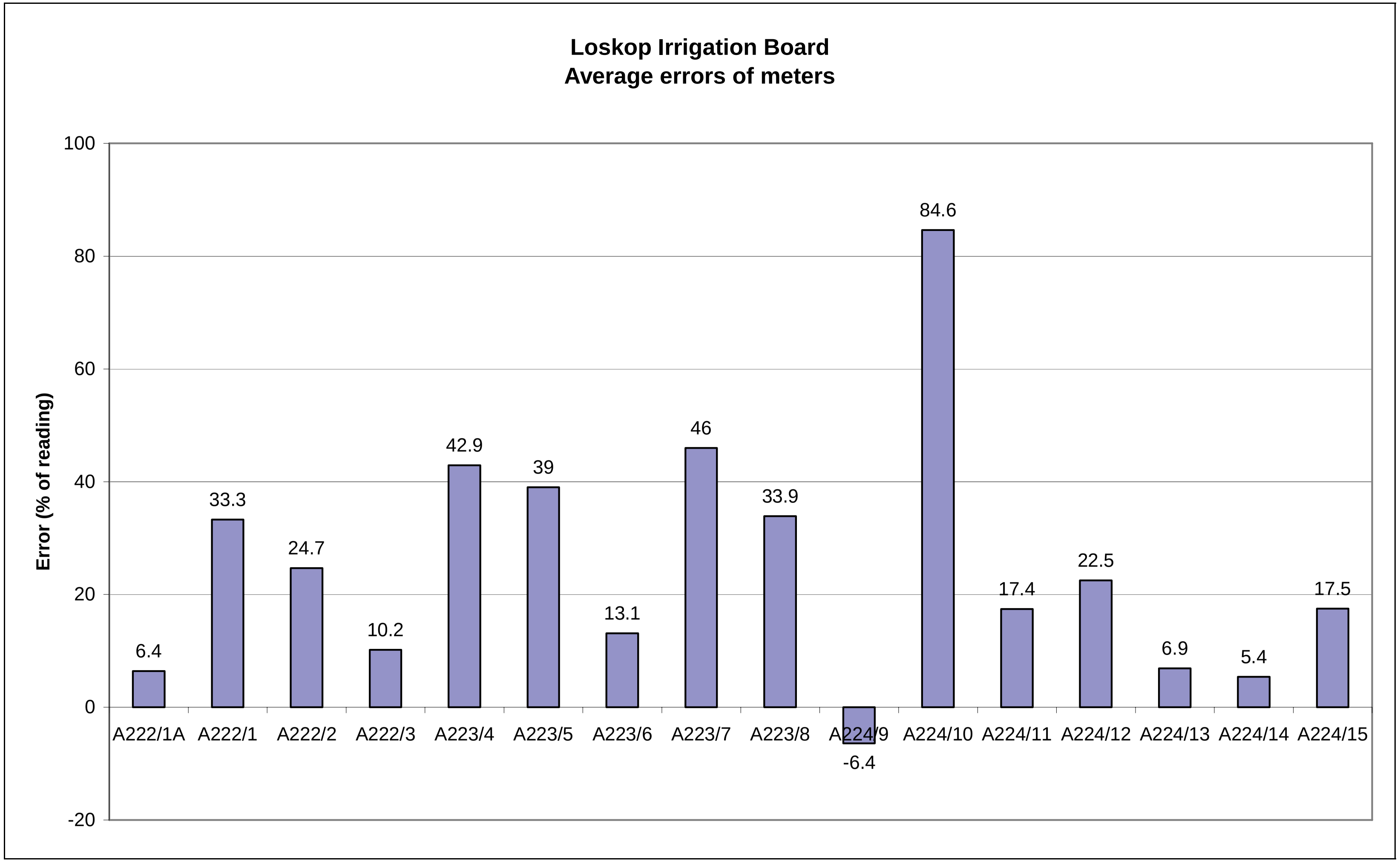


Figure 3.3 Average measurement errors per site

The meters performed poorly in general, with the average error of all the evaluations being 24.8 %. This means that on the average, if 100 m^3 of water passed through the meter in a specific time period, the reading on the register will show that 124.8 m^3 passed through the meter in that time period.

The measurement errors per site are graphically presented in Figure 3.3. The values from the sites where more than one evaluation were performed is based on the average of all the evaluations performed at the specific site. It can be clearly seen that all the meters except for one (A224/9) produced readings larger than the actual volumes of water that passed through them.

The flow rates shown in Table 3.3 are those measured with the reference meter, and are therefore assumed to be within ± 5 % of the actual flow rate at the specific site.

An analysis was performed to determine whether there was any relationship between the size of the errors and the flow rates, but none could be found. All the error values were plotted against flow rate, as shown in Figure 3.4, and it was attempted to fit a trend line through the data points. However, the points are widely scattered and the resulting trend line was close to parallel to the horizontal axis of the graph (angle = -0.0009), indicating that there was no true increase or decrease of error with an increase in flow rate.

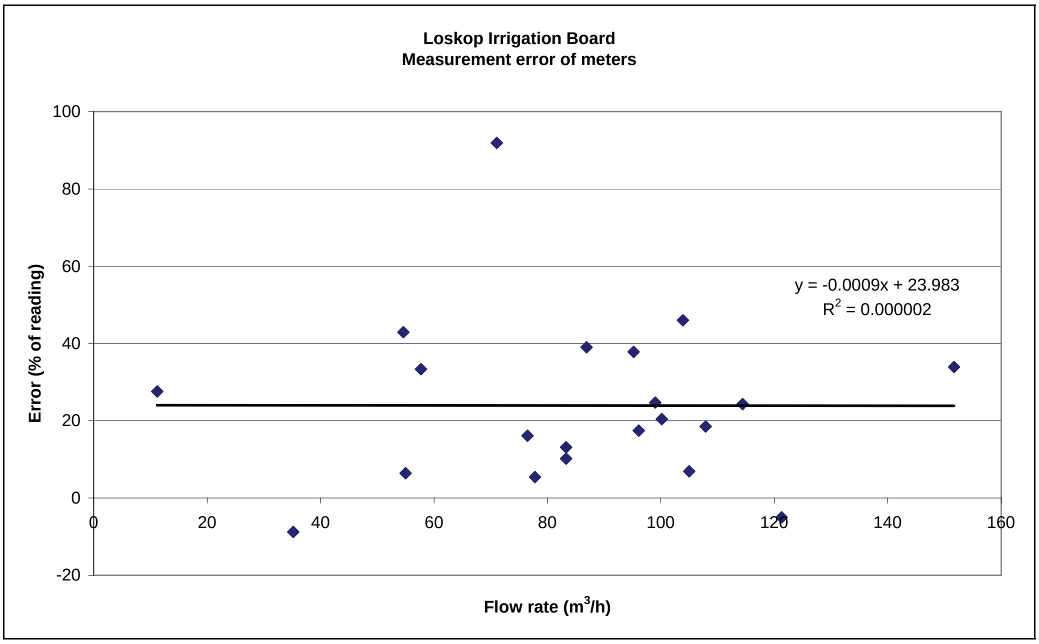


Figure 3.4 Relationship between measurement errors and flow rate

It has been speculated that the removal of the sieves could have contributed to the inaccurate measurements, and to investigate this, the evaluation at site A 223/7 was repeated after replacing the sieve. The results are shown in Table 3.4:

Table 3.4 Comparison of meter readings with and without sieve

	Flow rate, m^3/h	Error, % of reading
Without sieve	103.9	46.0
With sieve	95.2	37.8

During the first evaluation, water was supplied to a center pivot system as well as 5 garden sprinklers. During the second evaluation, the garden sprinklers had been shut down. This caused the difference in flow rates between the two evaluations.

However, although the replacement of the sieve seemed to have caused an improvement in measurement accuracy (from a 46 % error to a 37.8 % error), this error is still greater than the manufacturer's maximum allowed error of ± 5 %.

Since it is unknown whether the meters were in fact accurate when originally installed, this test cannot really determine whether the removal of the sieves had perhaps over time resulted in damage to the metering element. This will only be possible by installing two new meters, one with and one without a sieve, and monitoring their performance over an extended period of time (perhaps one year).

Conclusions and recommendations to the Irrigation Board:

- Despite near ideal installation conditions, the average measurement error of the mechanical meters was found to be 24.8 % of readings, which is in excess of the manufacturer's maximum allowable error of ±5 % of reading.
- Although the removal of the sieves seems to have an effect on the accuracy of the meters, this alone cannot be blamed the high error values recorded. If the sieves had been left in, and clogging occurred as described by water management officials of the Board, it is likely that measurement errors would have occurred in any case.
- The meters cannot be used for effective water management in their present condition, and it is recommended that they be either re-calibrated or replaced.
- If the meters are to be replaced, it would probably be worthwhile to consider other meters than the ones which are currently being used, to find one that will meet the requirements better.
- When the meters have been re-calibrated or replaced, it is recommended that the meters be evaluated in the field after installation to establish benchmark error values for later comparison, if problems should occur.
- It is also recommended that the Irrigation Board develop and implement a metering policy, which can include procedures to be followed for annual maintenance, regular in-field and/or laboratory evaluations, replacement of meters, and dealing with complaints with regard to meter performance. Specifically the in-field verification of meter accuracy at least once a year, but preferable at the beginning of each planting season, is strongly recommended.
- For meter evaluations, the use of a portable ultrasonic flow meter is recommended. This can either be done by either contracting the work out to a service provider, or by the Board itself, if they would be willing to buy a suitable meter. There are a number of different meters available in the market that are suitable for specific applications. For irrigation water applications, the transit time type of ultrasonic meter is the most suitable. Experience have shown that Doppler type ultrasonic meters are more difficult to use for measuring irrigation water flow at an acceptable level of accuracy, although they do cost considerably less than the transit time meters.
- Another option that may be considered is to build a small test bench at the Board's premises, so that mechanical meters can be removed from the field and tested under controlled (ideal) conditions. However, this set up would also require another highly accurate measuring method or device to be installed in the test bench for flow

measurement. Furthermore, this kind of test cannot guarantee that the mechanical meter will also perform at the test bench accuracy in the field.

- The decision of which route is to be followed may be further influenced by what water management methods the Board is planning to apply in future. If more meters are likely to be used, then the cost of a portable ultrasonic meter or test bench may be more easily justified.

3.1.1.4 Worcester East

The site at the Worcester East Water User Association was situated close to the Hex River. The farmer does not abstract directly from the river, but the practice is to dig a shallow well, slightly deeper than the riverbed, near the river. Because the well is deeper than the level of the water table, ground water filters through the porous soil from the river and fills the well.

The WUA actually releases water down the river ordered by farmers that have “legal” abstraction points directly from the river. Abstraction through the wells, however, is not metered, but it influences the river flow, often resulting in water shortages at the bottom end of the WUA’s area, and disputes between the staff and farmers.

The pump at this site (DAB K28/500T) is mounted on a float that floats on the water in the well, and the turbine type meter was installed in the 50 mm delivery side pipe (poly ethylene) from the pump to the side of the well.

The transit time meter was installed on the PE pipe between the pump and the gate valve. The turbine meter was fitted with a pulse counter and digital display to monitor the discharge and readings with both flow meters were taken over a flow range of 4 to 25 m^3/h.

This meter performed well compared to other meters evaluated under field conditions, and possibly because it was installed under near ideal conditions, in a long straight slightly uphill sloping pipe without any disturbances.

The maximum error recorded was -13.3 % of reading at 4.5 m^3/h, with the average of the readings being -11.1 %. The meter reads consistently low, and the data points show a linear relationship between error and discharge with a nearly flat slope (0.1698).

The results are shown graphically in Figure 3.6.

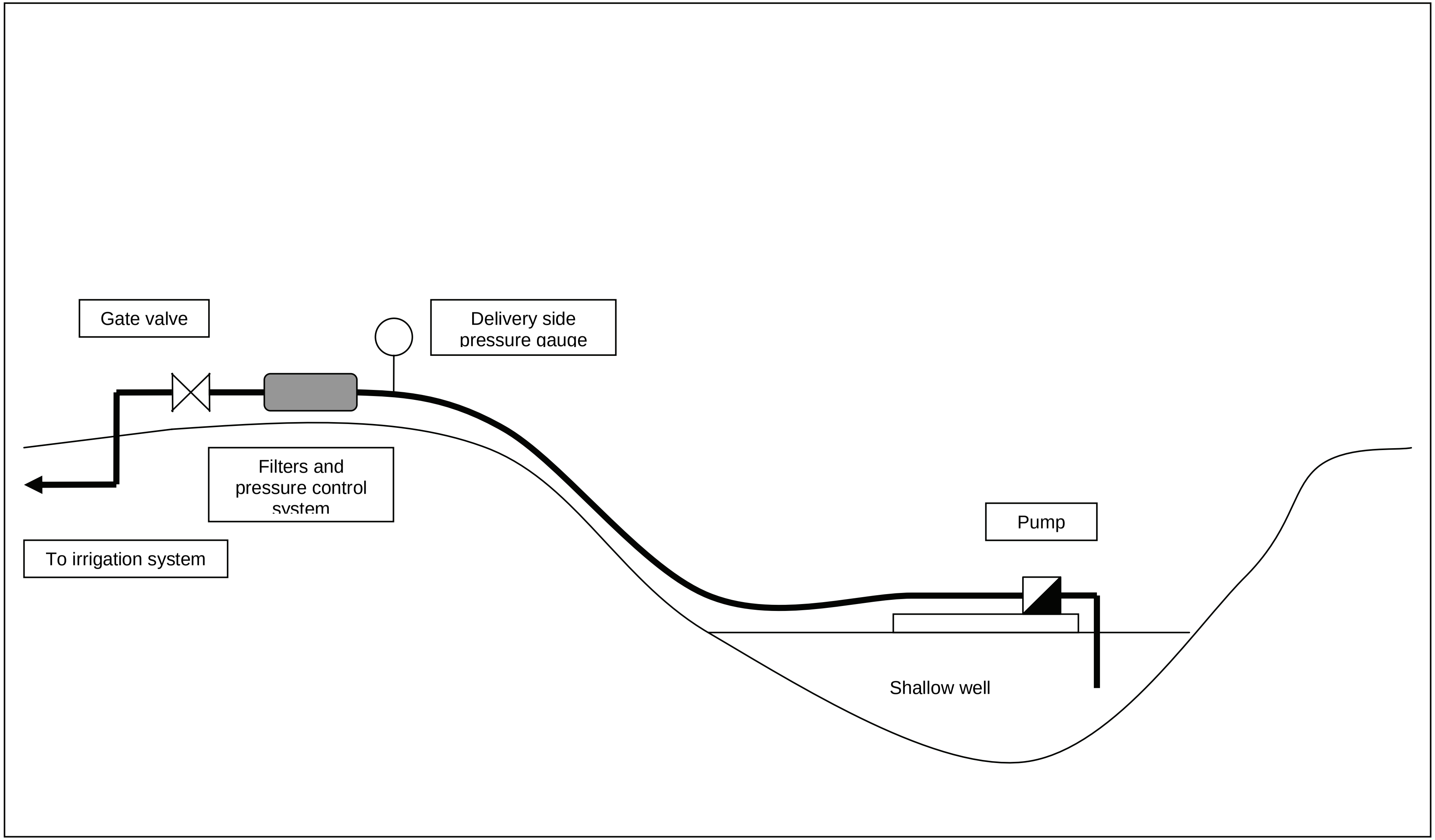


Figure 3.5 Schematic lay-out of the test site at the Worcester East WUA (elevation, not to scale)

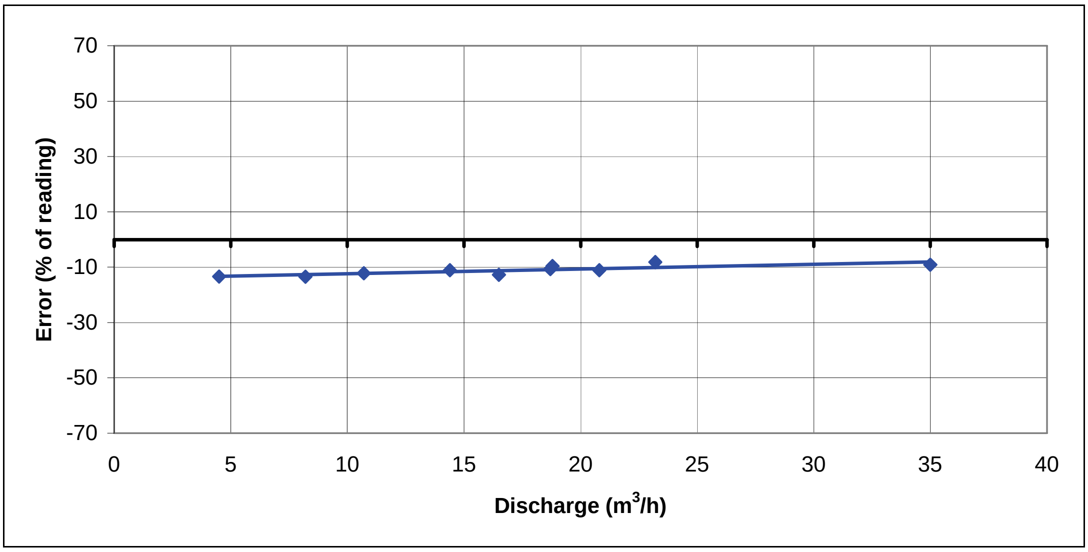


Figure 3.6 Accuracy of the turbine type meter at Worcester East WUA

3.1.2 Electromagnetic meter evaluations

3.1.2.1 Stellenbosch

The Stellenbosch WUA has the longest pipe distribution system of all WUAs in the country, as well as the highest water tariffs. Water is provided to farmers cultivating a total listed irrigated area of approximately 6000 ha at 4000 m^3/ha/year, and to a number of small municipalities. The whole system is piped, and water delivered at a guaranteed discharge and pressure.

The test site is not an individual abstraction point, but a booster pump station operated by the Stellenbosch WUA. It consisted of three Allis-Chalmer 9000 (10x6x22) pumps in parallel and discharge is measured with an electromagnetic flow meter which was installed about 7 years ago. The demand on the system at this stage is low enough so that only one pump is operated at a time. The pump station was designed with future development downstream in mind.

All the pipes at the pump station are steel; the suction side nominal diameter is 400 mm, and the delivery side is 350 mm. Readings were taken over a flow range of 20 to 500 m^3/h.

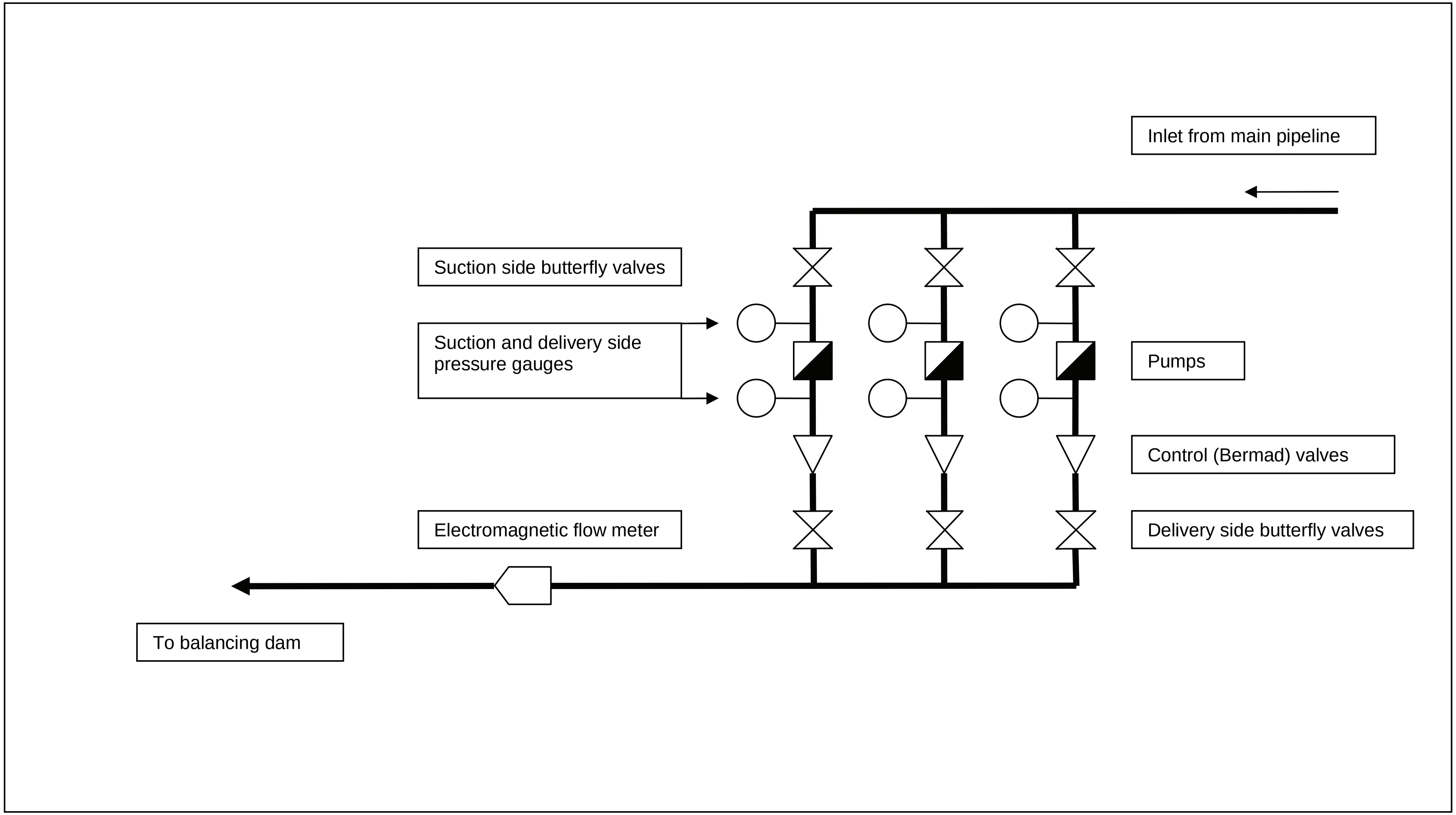


Figure 3.7 Schematic lay-out of the Simonsig pump station at the Stellenbosch WUA (plan, not to scale)

The transit time meter was tried at two positions, one on the suction sided, before the inlet manifold, and at another on the delivery side, after the electromagnetic meter. The second position was found to give the most credible readings. On the suction side, fluctuations in the flow were often detected after adjustments to the valves; it could also be observed on the suction side pressure gauge.

Although this electromagnetic meter's readings were consistently higher than those of the transit time meter, the points are better grouped and less scattered.

The maximum error recorded was 39.4 % at 119 m^3/h, but it is an outlier value and all the other points fall within the ± 30 % error range.

It would seem therefore that this meter could probably benefit from re-calibration (it was seven years old at the time of the tests). The place of installation of the transit time meter, however, was less than ideal and turbulence was caused by the manifolds in the delivery pipe.

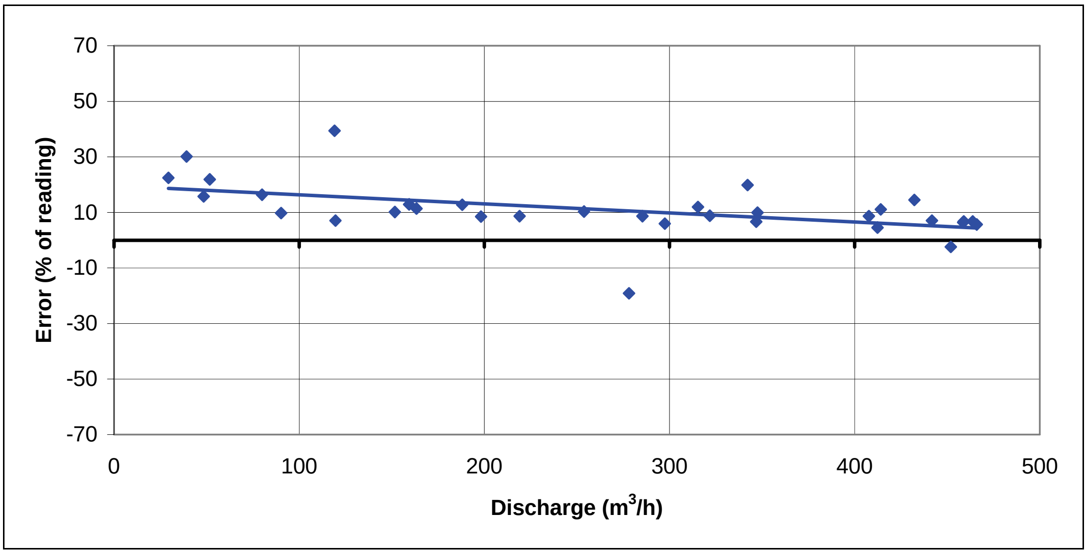


Figure 3.8 Accuracy of the electromagnetic meter at Stellenbosch WUA

3.1.3 Comparative tests at Oranje-Riet Water User Association (ORWUA)

Method

On request of the project steering committee, commercially available meters (an impeller type mechanical meter, a turbine type mechanical meter and an electromagnetic meter) from three manufacturers were tested simultaneously in the field at the Oranje-Riet WUA, who agreed to assist with the installation of meters at two sites in the WUA area.

It was decided that two sites should be used, one at a river off-take and one at a canal off-take on the irrigation scheme, since different problems were encountered at the two type of sites. The meters were installed and their performance monitored over one season, at which stage the meters were removed and returned to the manufacturers for laboratory testing.

Two sites were selected, and in both cases it was necessary to reduce the pipe diameter to 150 mm to suit the typical flow rates in the pipelines. The mechanical meters were fitted with pulse outputs so that the flow could be recorded on a daily basis on the spare channels of the datalogger that forms part of the electromagnetic meter. The manufacturers of the electromagnetic meter also supplied a GSM modem so that the data could be collected from their offices in Durban daily.

Table 3.5 Site information for the comparative meter tests at ORWUA

	Canal site	River site	
Pump	KSB 125-400 45 kW motor 1472 rpm	KSB 125-50/2 75 kW 1475 rpm	
Pipe diameter	200 mm	250 mm	
Meter size: Elster	150 mm	150 mm	
Meter size: Flowmetrix	150 mm	150 mm	
Meter size: Sensus	150 mm	150 mm	
Irrigated area	30 ha	41.5 ha	20 ha
Flow rate	194 m^3/h	241 m^3/h	151 m^3/h
Velocity in original pipe diameter	1.72 m/s	1.36 m/s	0.85 m/s
Velocity in reduced pipe diameter	3.05 m/s	3.79 m/s	2.37 m/s
Additional friction loss if 3 meters are installed	1.16 m	1.46 m	1.08 m

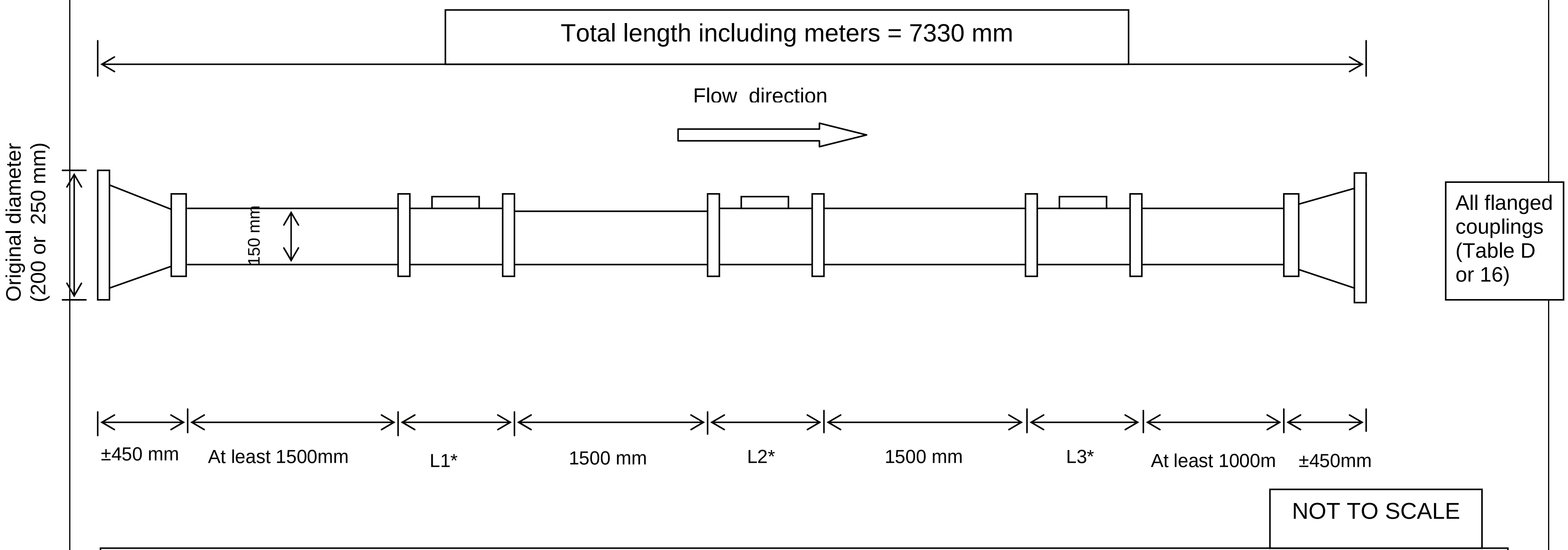
Both pump stations supply water to center pivot irrigation systems and will therefore only be operated at the flow rates shown above. The river pump supplies two center pivot systems but they are never operated simultaneously according to the farmer.

The suggested meter sizes were chosen based on the flow rates, and at both sites this will require a reduction in pipe size to accommodate the meters. The additional friction loss makes provision for losses in the meters (based on information given in the catalogues), the length of pipe of reduced diameter to accommodate the meters, as well as the two reducers. The worst situation will occur at the river pump when supplying the 41.5 ha pivot. The velocity of 3.79 m/s is a bit higher than what is normally encountered in irrigation supply pipes but is still acceptable (less than 5 m/s).

The total length of each site's installation was approximately 7.4 m, including reducers. The sequence of the installed meters was mechanical – electromagnetic – mechanical, in order to reduce the effect the mechanical mechanisms may have on each other. At the one site the turbine meter was first in line and at the other site the impeller meter was first in line. In all cases there were at least 10 straight diameters of pipe in front of every meter.

A schematic representation of the lay-out is shown in figure 3.9.

The installation was completed during August 2004 by the technical team of the Oranje-Riet WUA, and was rather labour-intensive. It required an artisan for cutting and welding the pipes with three assistants to hold the pipes in place as well as an electrician with an assistant to connect the power for the electromagnetic meters and dataloggers.



*Sequence of meters:
Canal site:
- Impeller meter (L1 = 300 mm), Electromagnetic meter (L2 = 420 mm), Turbine meter (L3 = 210 mm)

River site:
- Turbine meter (L1 = 210 mm), Electromagnetic meter (L2 = 420 mm), Impeller meter (L3 = 300 mm)

Figure 3.9 Flow meter installation for comparative tests at Oranje-Riet WUA

Results

Data was collected daily via the telemetric system from 10 August 2004 until both the telemetry units failed. This occurred on 15 October 2004 at the river site after a heavy thunderstorm, and on 20 November 2004 at the canal site due to power supply problems.

The total volumes of water recorded by the meters up to 10 December 2004 according to the registers are shown in Table 3.6. The cumulative volumes as downloaded with the telemetry are shown graphically in Figures 3.10 and 3.11, up to the dates when the telemetry failed. The error values were calculated as a percentage of the electromagnetic meters' totals, since these are considered the most accurate of the three (although the electromagnetic values cannot be guaranteed to be correct).

Table 3.6 Total volumes registered by meters during comparative tests

	Volume of water registered, m^3				
	Electromagnetic meter	Impeller type meter		Turbine type meter	
		m^3	Error %	m^3	Error %
River site	287 122	304 652	+6.10	288 514	+0.48
Canal site	190 125	204 383	+7.50	93 626	-50.76

In general, the results from the river site were the better of the two. The only readings that compared well were the electromagnetic and turbine meters at the river site. At the canal site the turbine meter stopped working completely on 13 November due to a piece of algae that was tangled in the turbine (this was observed after the meters were removed).

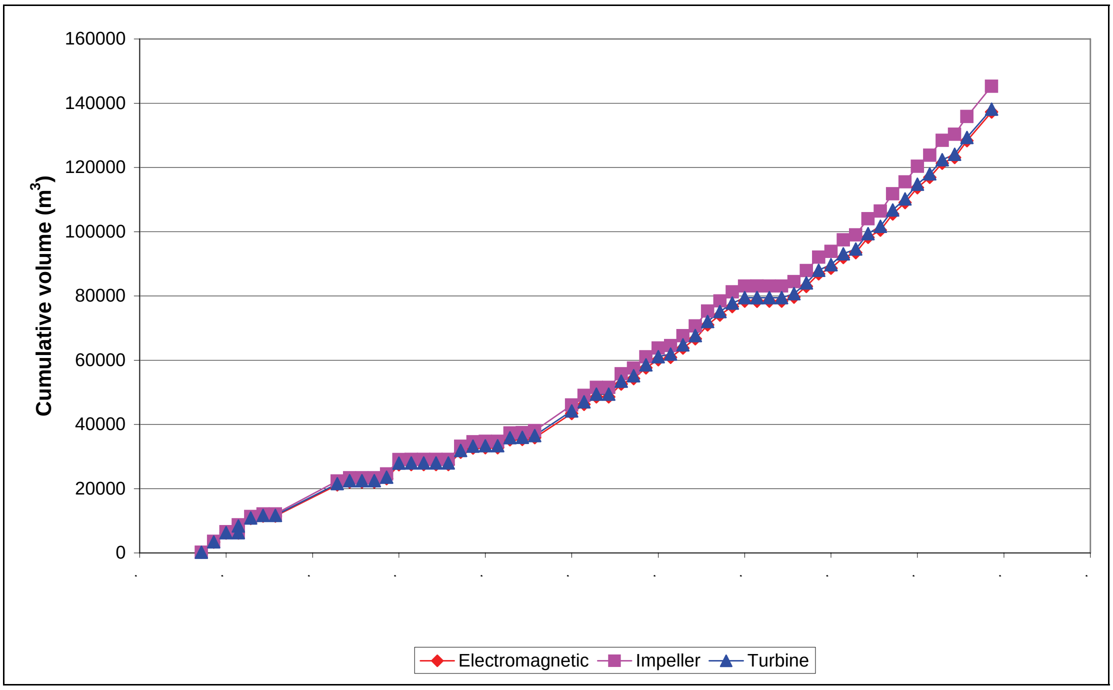


Figure 3.10 Cumulative volumes of water recorded at the river site

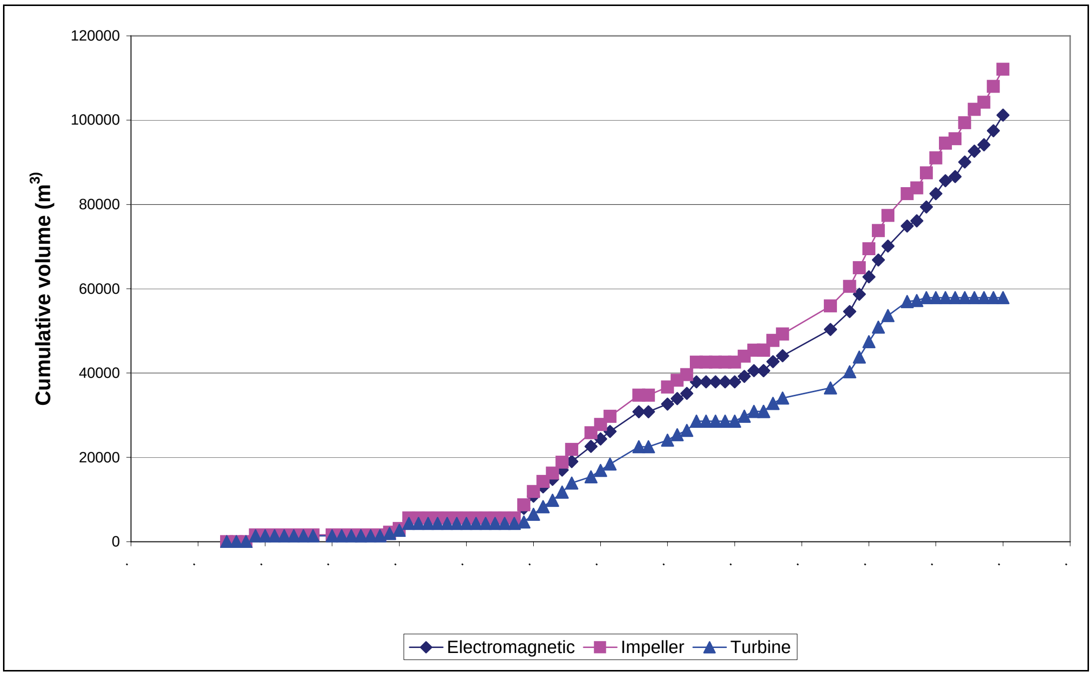


Figure 3.11 Cumulative volumes of water recorded at the canal site

After the meters had been removed the inside of the housings were inspected. It was found that the meters from the canal site were cleaner inside than those from the river site, which were covered with a layer of fine silt. The turbine meter from the canal site, however, had a piece of algae entwined in the mechanism, as said before, which probably caused in to malfunction.

Another factor that may have contributed to the meters' performance was the installation conditions. At the river site the meters were installed more than 100 straight pipe diameters downstream from the pump, while at the canal site only the minimum requirement of 10 straight diameters could be met.

The meters were returned to the manufacturers after removal for laboratory evaluations, and the results are summarized in table 3.7.

Table 3.7 Accuracy of meters used in comparative tests in laboratory tests

	Error of meter, % of reading at 150 m^3/h		
	Electromagnetic meter	**Impeller type meter**	**Turbine type meter**
River site	0.06	0.44	-3.89
Canal site	0.02	0.47	-2.30

The error values recorded in the laboratory differs so far from the field values that the only conclusion that can be made is that installation conditions play a major role in meter performance, and that in-field testing is imperative. Furthermore, turbine meters should not be used if there are any algae in the water.

3.1.4 Portable acoustic meter evaluations

3.1.4.1 Transit time meter in ILI laboratory

Method

A series of tests were performed in the hydraulic laboratory of the ARC Institute for Agricultural Engineering in Pretoria to assess the accuracy and performance of the transit time meter that was purchased with project funds to perform field evaluations of other flow meters.

The pipeline system that was used for the tests was fitted with two pumps that can be connected in either series or parallel, a turbine type flow meter and a flow control valve, before it discharges into a stilling basin with a 90 degree v-notch weir as overflow on the opposite end from the inlet. The overflow discharges into the pump sump. A schematic representation of the lay-out is shown in Figure 3.12 below.

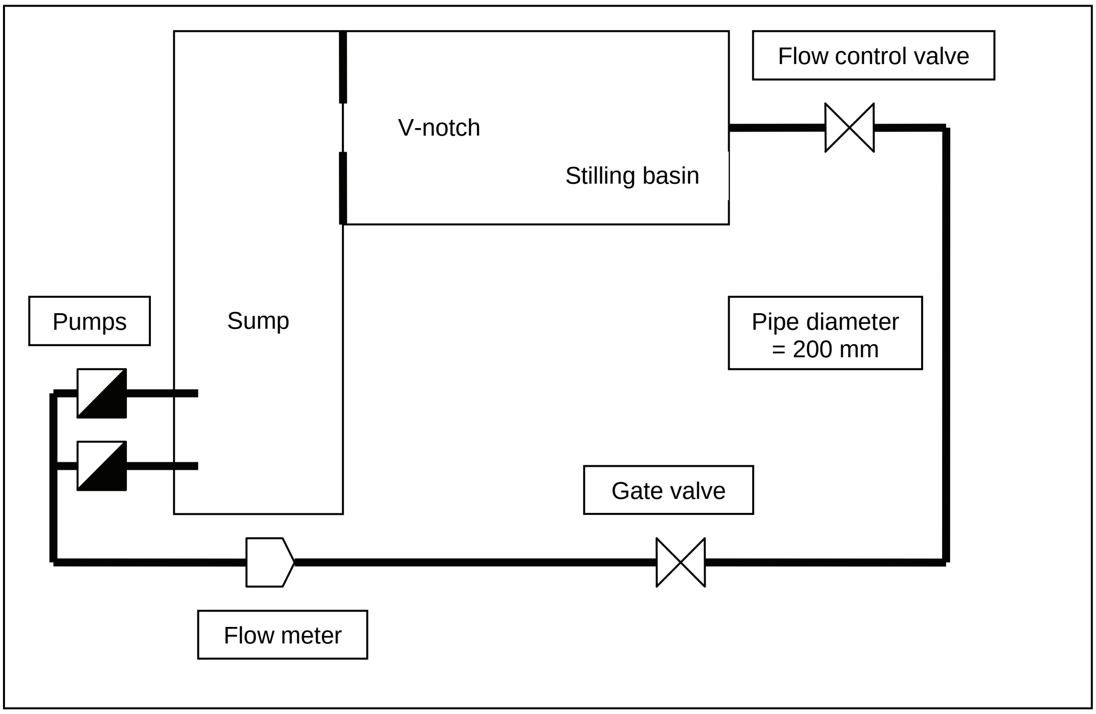


Figure 3.12 Schematic lay-out of the laboratory at ARC-ILI (plan, not to scale)

Three sets of tests were done in the laboratory:

- A comparison of flow rates recorded with the transit time meter and the v-notch weir, with the transit time meter installed according to the manufacturer's specifications of 20 straight pipe diameter lengths upstream, and 10 straight pipe diameter lengths downstream of the meter;
- A comparison of flow rates recorded with the transit time meter and the v-notch weir, with the transit time meter installed only 2 straight pipe diameter lengths upstream and downstream of a gate valve in the open position (2 tests); and
- A comparison of flow rates recorded with the transit time meter and the v-notch weir, with the transit time meter installed only 2 straight pipe diameter lengths upstream and downstream of a 90 degree elbow (2 tests).

The following results were obtained from tests that were done with the meter installed according to the manufacturer's requirements of 10 to 20 straight pipe diameter lengths in front, and 5 to 10 straight pipe diameter lengths after the transducers.

The measurement error as a percentage of the actual flow according to the v-notch weir, is shown in Figure 3.13. Except for the first two readings, taken at discharges less than 50 m^3/h, the meter performed according to the manufacturer's specifications of ± 2% of reading.

Although the first data point indicates an error of 3.1 %, it is actually also within the specifications since the flow velocity is less than 0.3 m/s, meaning that an error of ± 0.01 m/s is allowed. The velocity according to the v-notch measurement is 0.25 m/s and according to the transit time meter, it is 0.26 m/s.

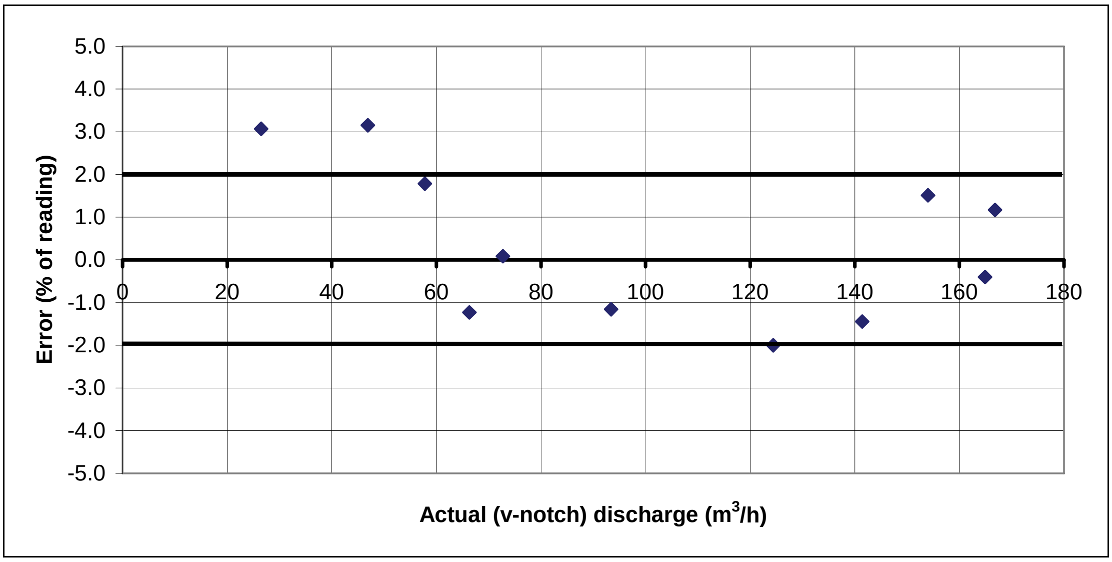


Figure 3.13 Measurement error (% of reading) of the transit time meter

The standard deviation of the errors as a percentage of reading was calculated as 1.83 %, which is also within the ± 2% of reading margin.

The next two sets of test were done to evaluate performance of the transit time meter when the meter's transducers are positioned only 400 mm (2 straight pipe diameter lengths) upstream or downstream from a gate valve and a 90 degree bend.

A summary of the results of the tests are presented through graphs in Figures 3.14 and 3.15. The following observations can be made:

- Measurement errors as a percentage of reading caused by the gate valve were less than ±8 %, while the 90 degree bend caused errors of up to ±26 % of reading
- In both cases, the meter's performance was more affected when the transducers were positioned downstream of the cause of disturbance
- Except for the case where the transit time meter was positioned downstream of the gate valve, the transit time meter registered a smaller than actual discharge
- In all tests, the bigger percentage of reading errors were recorded at lower flow rates

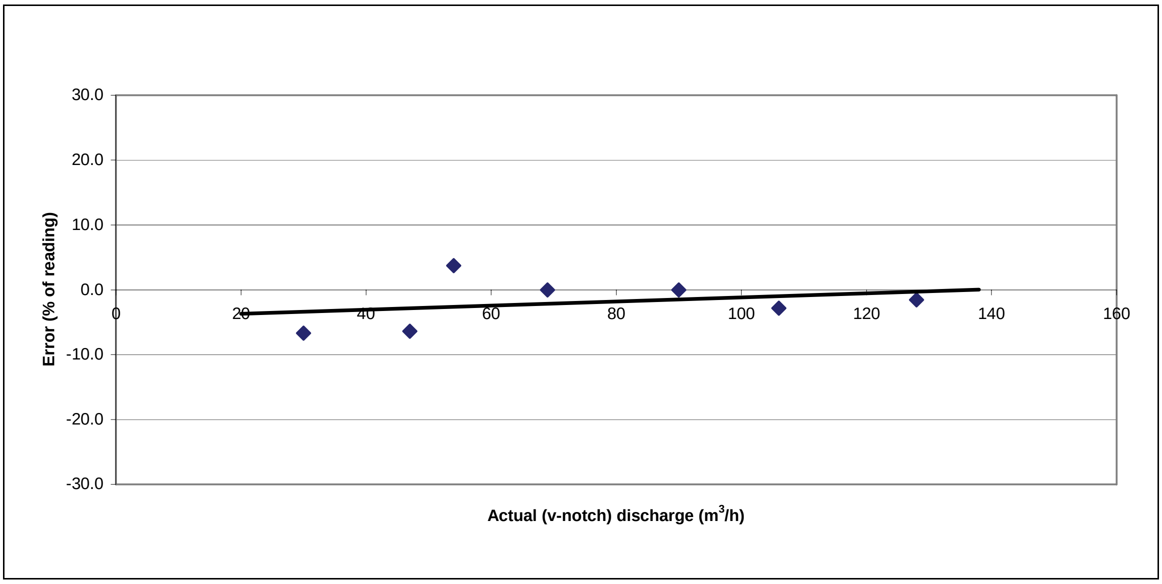


Figure 3.14a Measurement error (% of reading) due to a gate valve positioned 200 mm downstream of the transit time meter

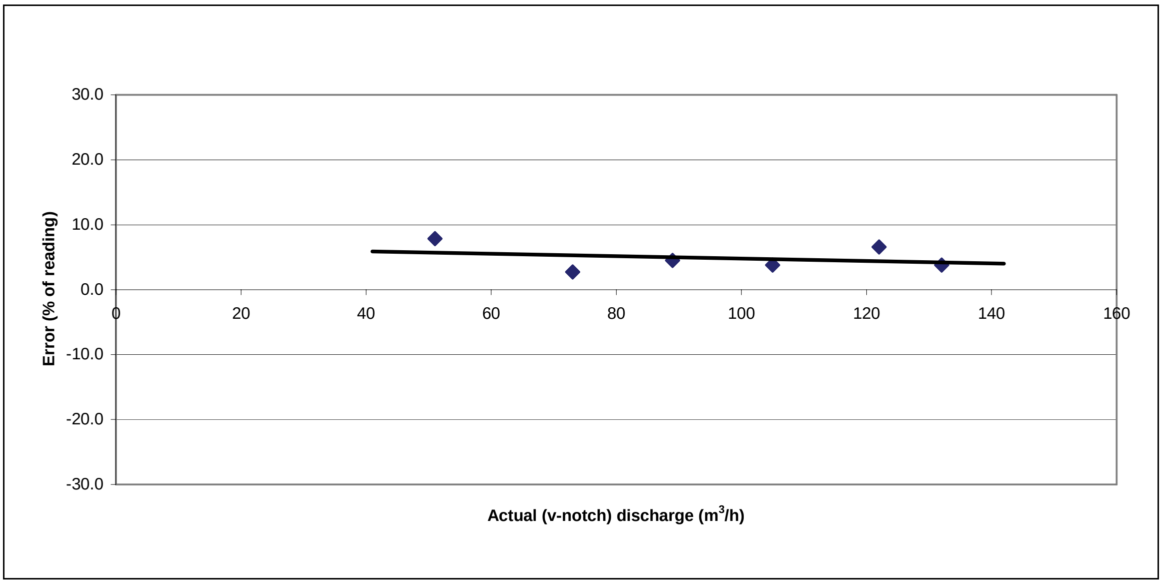


Figure 3.14b Measurement error (% of reading) due to a gate valve positioned 200 mm upstream of the transit time meter

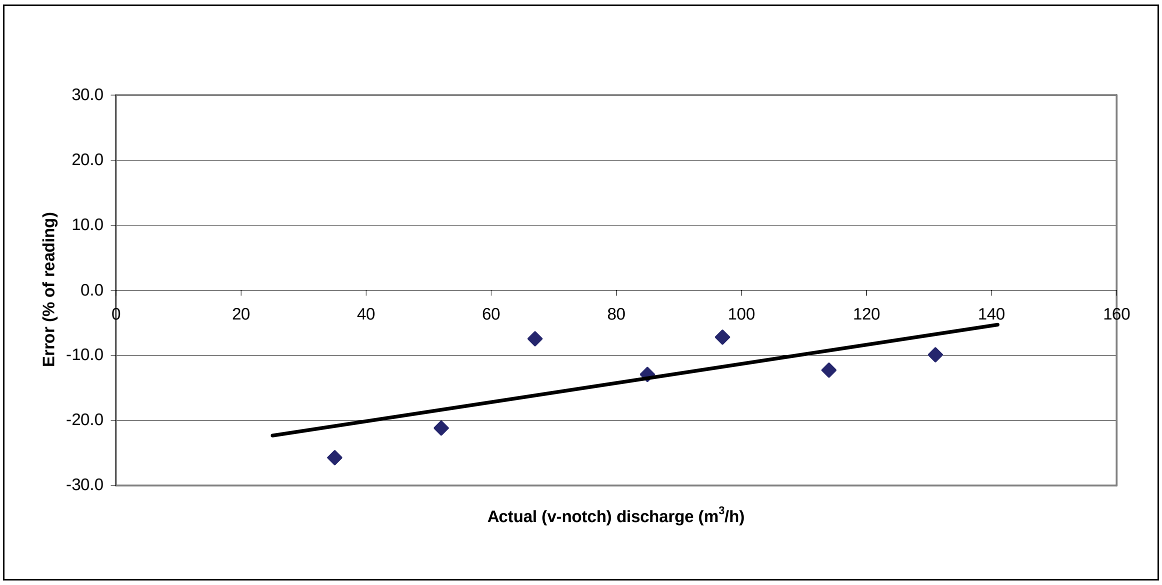


Figure 3.15a Measurement error (% of reading) due to a 90˚ bend positioned 200 mm downstream of the transit time meter

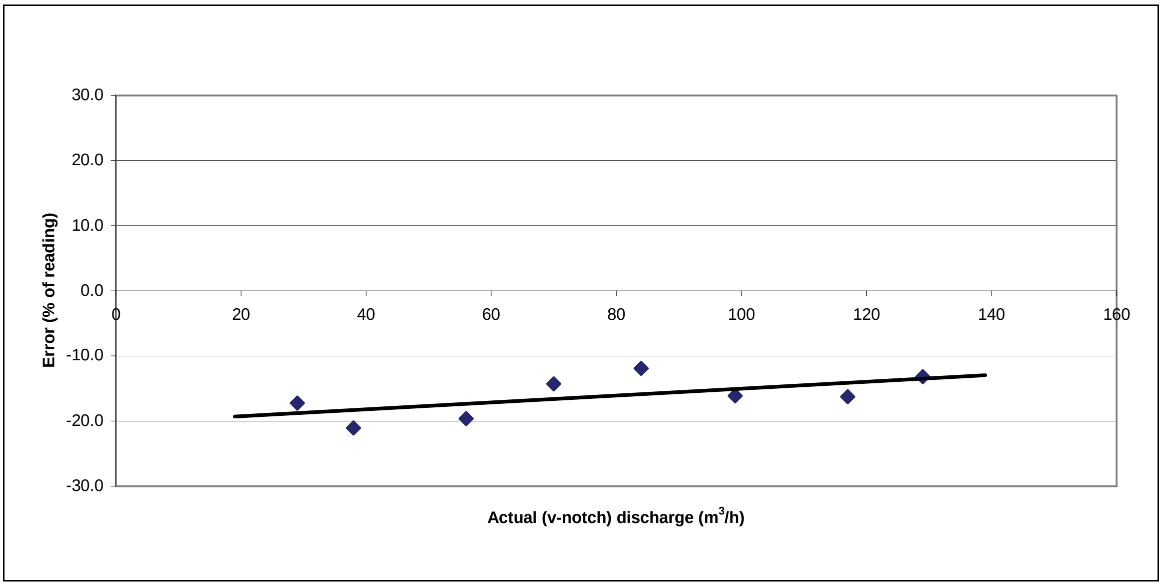


Figure 3.15b Measurement error (% of reading) due to a 90˚ bend positioned 200 mm upstream of the transit time meter

The third observation could probably be explained by the fact that the gate valve causes a slight reduction in the pipe diameter and consequently the velocity of the water at that point increases (a venturi effect). Since the transit time meter measures the velocity and then converts the value to discharge, a higher flow rate is registered.

The last two observations indicate that the error as a discharge value in m^3/h increases as the system discharge increases, although when one only looks at the errors as a percentage of reading, it seems as if the measurement error decreases with an increase in discharge. The flow disturbances do therefore not cause a constant error over the whole flow range.

The tests showed that the manufacturer's recommendations should be followed where the installation of the transit time meter is concerned.

Although the transit time does not have a specified accuracy according to a full scale reading, the measurement error as a percentage of full scale was plotted with the full scale reading taken as the maximum discharge that was recorded with the laboratory system (158.85 m^3/h).

3.1.4.2 Doppler meter in Oranje-Riet Water User Association (ORWUA) laboratory

The Oranje-Riet WUA bought a Doppler type portable flow meter during the early stages of the research project, but found that the meter was not performing to the specified level of accuracy. The meter was evaluated in their flow meter laboratory by comparing readings with the project team's transit time meter on different pipe sizes and various flow rates, but no consistent relationship could be found between the two meters' readings. The variation of accuracy ranged from -7 to 130 % errors compared to the transit time meter.

Initially this problem was attributed to the fact that Doppler technology requires a fair amount of suspended particles in the water for it to function correctly. However, after experimenting with the installation method and some of the set-up functions of the meter, it was found that the average errors could be reduced to within ± 3 % of reading. To achieve this, it was necessary to establish an absolutely airless contact between the meter's transducer and the pipe wall and to maintain this contact while measurements were taken. It was also found that the meter's sensitivity to flow disturbances could be set to match the installation conditions.

3.1.5 Experimental methods

3.1.5.2 Pump differential pressure method

In another collaboration with a WRC project (nr K5/1300), measuring devices were installed at a river pump station of a farmer from the Umlaas Irrigation Board outside Pietermaritzburg. The purpose of the installation was to evaluate an indirect method based on the relationship between flow rate and pump differential pressure, and to investigate the use of telemetry for data collection. The pressures were recorded with pressure transducers and a datalogger provided by Project nr K5/1300, while this project supplied a mechanical meter for reference purposes. The results were also compared with a third measuring method, using hour meters, which is currently used by the Irrigation Board for water account purposes. This method is commonly used in KZN and it provided a valuable opportunity to investigate this method further.

In order to use the pressure measurements for quantitatively determining the water abstraction, the relationship between the flow rate and differential pressure needed to be established. This was done by simultaneously measuring the flow rate and pressures over a period of time to determine typical values on which to base the relationship.

The flow rate was measured with a portable ultrasonic flow meter (Panametrics AT868) which has an accuracy of ± 0.2% of actual reading over the flow velocity range within which measurements were being taken.

The specific pump station where the measurements were taken, is used to pump water to a storage dam, via another booster pump along the pipeline. Since water is always taken from the same suction head (the suction pipe inlet is connected to a float in the river and therefore always at the same depth) and delivered against a constant head (the height of the pipe outlet at the dam which stays the same), the flow rate would always stay more or less constant. (There may be cases where the pump is regularly operated at different duty points such as when it serves different sizes of irrigation blocks or different systems).

Calibration readings were therefore only recorded at one duty point. Statistical analysis showed that flow and pressure values occurred within the following minimum and maximum limits, with average values as shown in table 3.8.

Table 3.8 Interval boundaries for pressure measurement method

	Minimum	**Maximum**	**Average**
Differential pressure, kPa	790	802	796
Flow rate, m^3/h	59	78	66

The data that was to be recorded at short time intervals, could then be evaluated through the following simple logical statement to determine the flow rate (Q, m^3/h) from the recorded pressure values (Δp, kPa):

IF 790 < Δp < 802 THEN Q = 66 ELSE Q = 0

The abstracted volume of water per time interval (Δt, hours) could then be calculated by multiplying the flow rate with the length of the interval, or for a long period of time, t_i, calculated with:

$$V = \sum_{t_0}^{t_i} (Q \times \Delta t) \qquad \text{(3.1)}$$

To apply the statement, data has to be downloaded from the datalogger and processed in a spreadsheet before the abstracted volume for a specific is known.

The pressure-based flow measurements were compared with the readings from a mechanical flow meter that was installed at the pump station specifically for the purpose of verification.

The meter was a 150 mm impeller type irrigation meter which is specified to measure the flow rate within ± 5 % of the actual flow rate. It was fitted with a reed switch to produce a pulse output which could be recorded by the same datalogger used for the pressure readings. The reed switch was installed to produce one pulse per 1 m^3 of water that flowed through the meter.

After the initial problems with the datalogger were solved, data was recorded for the period of 6 November 2003 to 23 February 2004. The data was processed as described in 1.1.6, and the results are displayed graphically in Figure 3.16.

The farmer experienced problems with the pump's motor in the time period between 21 November and 18 December 2003. Up to 21 November 2003, there was a good correlation between the data from the two measuring methods, but it seems that after repairs were done, the two graphs diverted further as time went by.

Due to the changes on the motor, the flow rate – pressure relationship that was established initially was not valid anymore, resulting in a difference of 2179 m^3 of pumped water between the two methods over the nearly four month period. If the mechanical meter output is used as reference measurement, this is equal to a measuring error of –4.09 %, which is acceptable since most irrigation meters are specified to be accurate within ±5 % of reading. Re-calibration could improve the accuracy – visual evaluation of the mechanical meter output showed that the average flow rate was closer to 70 m^3/h than the 66 m^3/h recorded during calibration.

The graph also shows the output from the Irrigation Board's current measuring method where hour meters are used. According to the hour meter fitted at the pump station, water was abstracted for a total of 1469 hours during the four month period, and since the pump is "calibrated" according to their system for 65 m^3/h, this translates into a volume of 95485 m^3 that was supposedly abstracted.

However, the other two measuring methods recorded only 767 hours of pumping over the four month period, or a total volume of 53253 m^3 according to the mechanical flow meter. Although a problem with the specific hour meter was reported and attended to in January 2004, this is a very large discrepancy (+79.30 % error) and may need to be investigated further to ensure that the problem has been solved.

The Irrigation Board is now encouraging farmers to install water meters, and a small number have put in mechanical meters. The cost of the meter and installation however has to be covered by the farmers themselves.

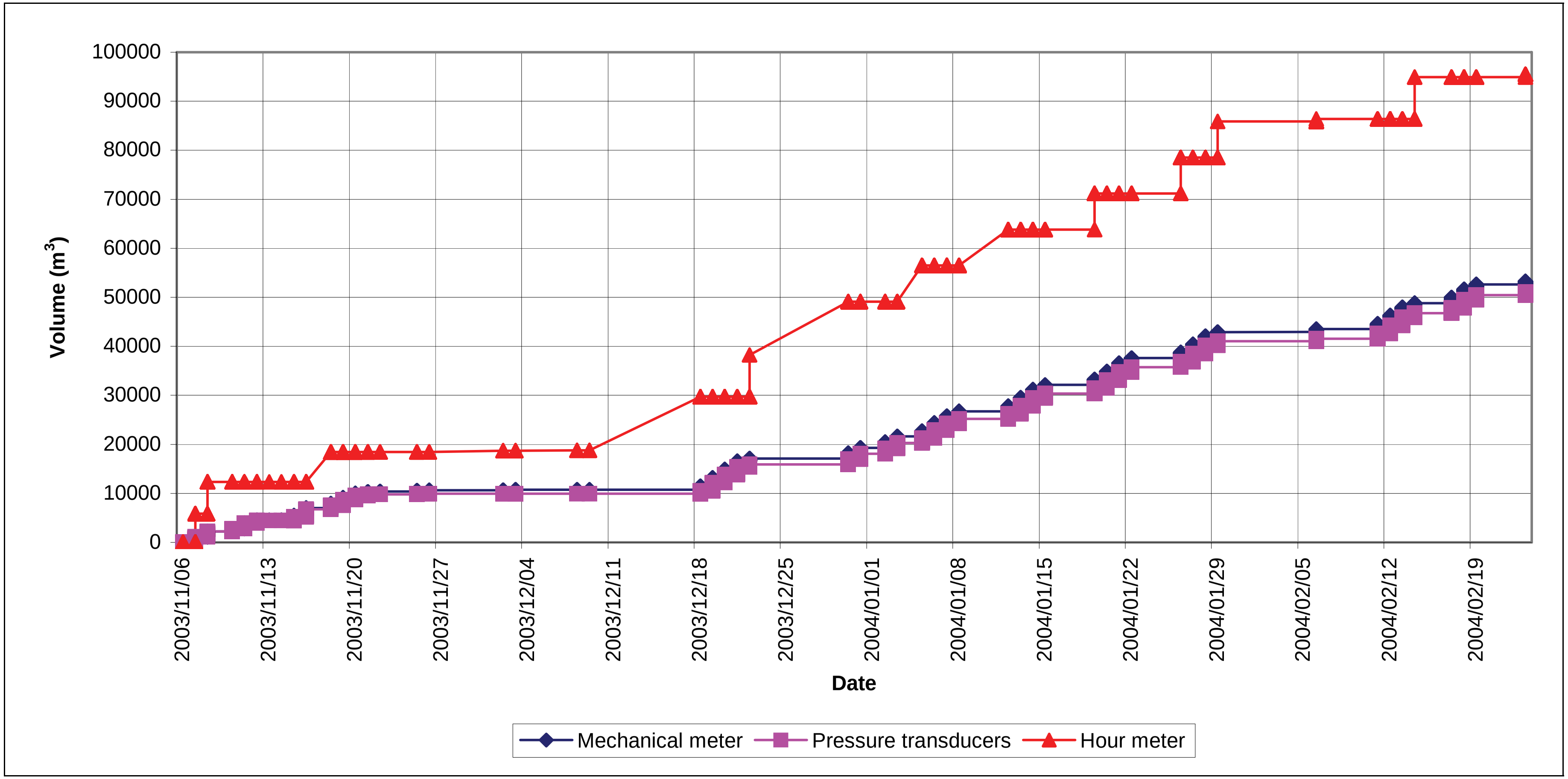


Figure 3.16 Abstraction of water at Umlaas pump station

3.1.6 Depth sensor evaluations

3.1.6.1 Gamtoos WUA

Method

A Water Balance study was proposed over a section of the canal system of the Gamtoos Irrigation Board to determine typical losses from the existing infrastructure. The D canal was identified by the Water Management Plan consultants as the one in which the study can be carried out, for the reason that it is a fairly long canal with most of the measuring infrastructure in place. Furthermore, the Board is in the process of installing new, accurate meters along this length of canal.

A proposal was drawn up to obtain additional funding from the WMP consultants for the above study, which were to broadly consist of the installation of measurement devices at selected locations on the canal, monitoring the performance of the devices over a period of time, periodic data collection and analysis, and development of a water accounting report for the canal.

Not all the positions as indicated in the proposal could be measured due to hydraulic and financial constraints, and the results presented here are for the D canal as a whole. Further studies could help to refine and pinpoint loss figures, but one would have to carefully consider the benefit from this compared to the probable costs of such an exercise.

Figure 3.17 shows all the proposed measurements as envisaged at the beginning of the project. All of these were performed except for the determination of the siphon losses due to lack of suitable measurement locations. The reject at the end of the canal was also not measured since the Irrigation Board informed the consultants that the canal did not return any reject to the river.

As a result, measurements were conducted at four locations along the canal:

- At the Parshall flume at the canal inlet, to determine the total inflow.
- In the canal before the balancing dam to determine the flow into the dam.
- The dam level itself.
- The registered water use by farmers (through the water meter readings).

These four locations are discussed in more detail below.

The Parshall flume

This is an existing measurement structure that was installed when the scheme was built. This type of flume can be used to measure discharge in open channels under both free flow and submerged conditions based on a flow depth reading, and is considered to measure typically within ± 5% of the actual flow. This error can increase if the equipment used to measure the flow depth is inaccurate.

The flume was surveyed by technicians from DWAF at Cradock to determine its actual size and correctness of structure. It was found to be tilted slightly to right (when facing downstream) so that the floor of the flume at the right hand side was 3 mm lower than on the left. This was considered within limits.

The location of the flume relative to the main canal caused greater flow disturbance in the structure. Due to the short distance between the canal inlet and the location of the flume as well as the steep slope, the approach conditions are poor with turbulent flow conditions extending into the flume. This disturbs the velocity pattern, thereby reducing accuracy of measurement in the structure. Approaching flow should be tranquil (laminar), and in an attempt to improve the situation, after consultation with DWAF (Cradock), it was decided to build in some baffles upstream of the flume. This partially reduced the turbulence but did not completely solve the problem. The effect of the turbulence would be difficult to quantify, however.

The record the flow depth in the structure, the WRC project provided a electronic depth sensor, datalogger and telemetric system. The depth sensor is a submersible piezoelectric pressure transducer with a range of 0-5 m water depth at an accuracy of 0.25 % of full scale reading. The datalogger has a capacity of 62 000 data points, and the telemetric system consists of a cell phone modem and antenna. All the components are powered from a 12 v battery charged daily with a 20 W solar panel.

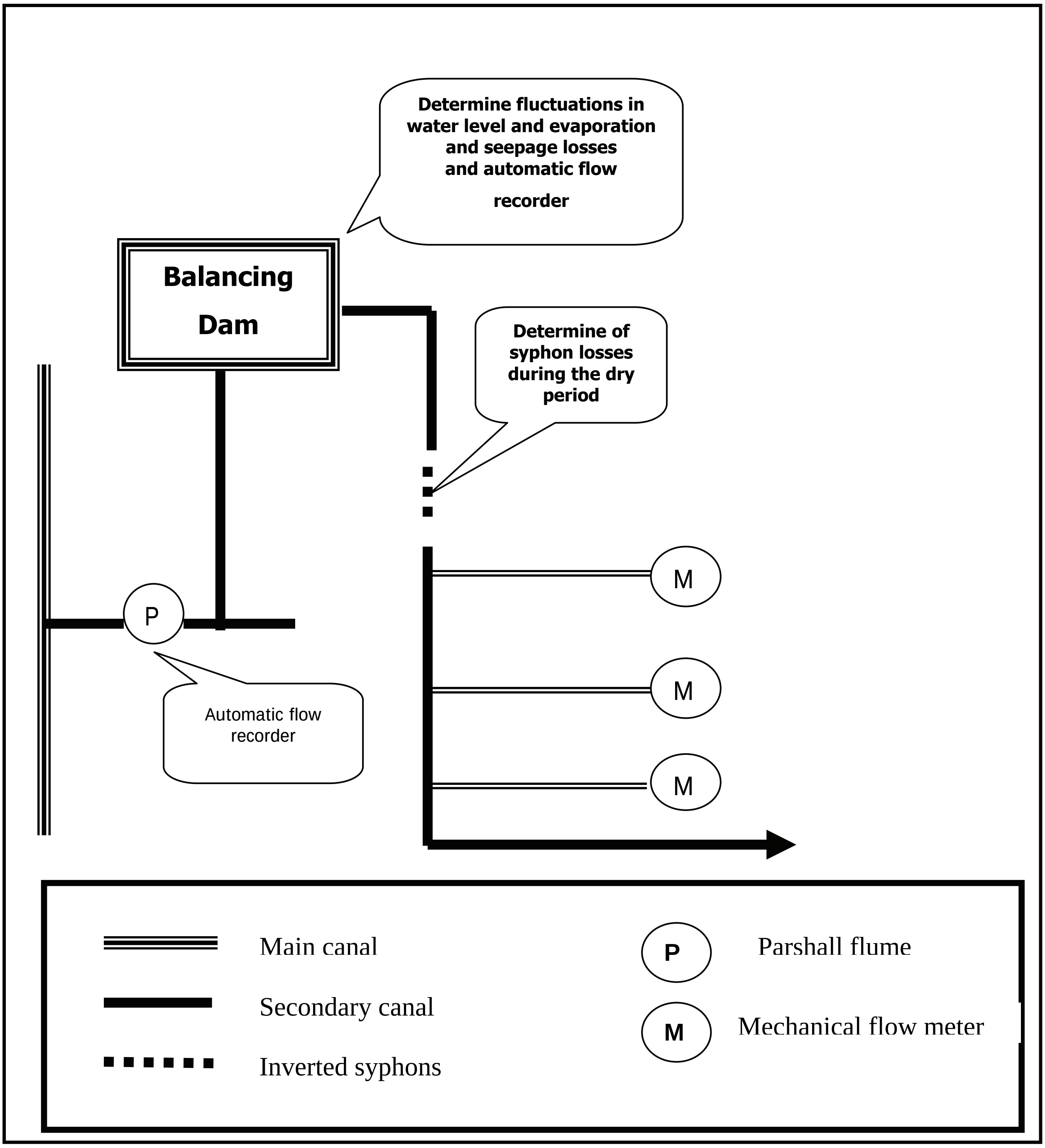
In addition, and as back-up, a mechanical float and counterweight type recorder was also installed. It was provided by DWAF Cradock and installed by their technicians.

The electronic system initially didn't want to work, but this was due to a faulty battery which was subsequently replaced. It worked well from then on, although comparison of the collected data with the mechanical recorder's data showed that there was a calibration error of the pressure transducer. This could however be corrected because of the availability of the other data set.

The mechanical recorder also performed well, except for one period during December 2002, when the pen was not correctly positioned after the graph paper had been replaced.

The flow depth data was logged at 15 minute intervals. The telemetric system makes it possible for data collection from anywhere in South Africa.

Figure 3.17 Lay-out of Gamtoos canal measuring points



Inflow to the balancing dam

An experimental method known as the slope-area method was tried at this site. It consists of using the slope of the water surface in a uniform reach of channel and the average cross-sectional area of that reach to give a rate of discharge from the Manning equation. It was decided to evaluate this method since no measurement structure could be installed at this location. Any flume or weir would result in the water level increasing upstream, leading to possible spillages and damage.

The method requires only the continuous measurement of the flow depth at the two places some distance (ideally 300 m) apart on a straight section of the canal. The depth was recorded with two submersible pressure transducers connected to one logger. The transducers have a range of 0 to 5 m depth and an accuracy of ± 0.15 %. Data was recorded at 15 minute intervals. The one transducer was installed in a stilling basin that was built by the Irrigation Board especially for the canal loss study. The other one was simply installed in a piece of pipe fixed to the canal side and provided acceptable results.

The equipment performed well, but some problems resulted in data loss. This was due the fact that the logger has to be “re-launched” after data collection and this was not done. The other problem encountered was the power supply; the transducer drew very little power, and a small 12 v battery can last up to a month without needing to be recharged. However, it did happen once that it became too flat for the transducers to function. Fortunately the logger has its own internal battery so recorded data was not lost.

Although data was collected successfully, its application was limited due to regular submergence of the measurement site if the balancing dam filled up beyond a certain level. When this happened, the depth could still be recorded but it was impossible to determine whether flow was actually taking place or whether the water was stationary.

The dam level

The level of the balancing dam was recorded to determine the change in storage from one day to the next. It was recorded with a non-contact type ultrasonic transducer and datalogger provided by the WRC project team.

The transducer performed well and was easy to operate. It works on the principle of an emitted beam that is reflected back to the emitter by the water surface. It was installed next to the existing gauge plate on the dam outlet structure, and once calibrated, it shows the reading on a digital display. The datalogger was needed to record readings at 15 minute intervals.

The irrigation board has previously had the dam surveyed to establish a depth vs volume relationship. This relationship could than be used to determine the volumetric content of the dam for a specific depth.

Once again a problem was encountered related to power supply. The transducer requires 24 Volts DC and needed a special transformer. It developed a problem and could not be fixed locally, which means that it had to be brought back to Gauteng, resulting in further delays.

Furthermore, the calibration factor was lost when the laptop computer used for data collection was stolen in December 2002. When the data was downloaded with the new computer, it could be seen that it was incorrect. Re-calibration is required, but meanwhile very little useful data has been retrieved from this point.

The meter readings

The water consumption of the irrigation farmers were recorded with mechanical impeller type flow meters, which on the D-canal has been recently installed. These meters have a low head loss, require no power for operation and are within ± 2 % accuracy over their specific flow range. The meters are read manually by the irrigation board at roughly two-weekly intervals (once in the middle of a calendar month and once at the end of the month). The D-canal is fitted with 91 meters, and readings are in cubic meters.

This measurement meant that the water balance had to be limited to one month units since this was the shortest interval for which these readings were known.

Water balance results

The measurements performed as described in paragraphs 2.1 to 2.4 made it possible to evaluate the canal and dam as a complete system and determine total losses. It did not make it possible for us to say where exactly the losses occur. In order to perform a successful water balance it is necessary to include all the components of the system, even if there is no or little data available. Including these components in the balance will show where possible losses may occur, and also how important it may be to obtain the data.

To do this, Burt (1999) advises that estimates of the confidence interval (CI) for each component should be made. A confidence interval of "10" indicates that one is 95 % certain that the correct value lies between plus or minus 10 % of the stated value. The purpose is to reinforce the fact that we rarely know many values with precision, although we may argue about them as if they are precise!

It is therefore better to include all the components even though their quantities are relatively unknown, rather than to ignore them. In view of this, the balance shown in section 3 of this report makes provision for seepage and evaporation losses although it could not be given at a great accuracy.

Seepage was calculated as 1.2 l/s/1000 m^2 of wetted canal lining based on a literature review for the value, average flow depths as recorded in the canal before for the periods under consideration and the basic canal shape as determined by the DWAF technicians in their survey.

Evaporation was calculated on the bases of the actual measured daily pan evaporation figures recorded by the Irrigation Board.

Losses which were observed but cannot be quantified include canal spills, especially at the balancing dam, and unlawful use, apparently mainly for domestic use of houses close to the canal.

The combined results of the measurements together with estimated confidence intervals for the various components are shown in Table 3.9.

The accuracy with which the possible causes of the losses can be determined, is however considerably less as shown in the confidence intervals. After allocating portions of the losses to evaporation and seepage in the dam and canal, there is still an estimated 11.33 % (442 885 m^3) unaccounted for, which may be due to any of the last three (unquantified) components listed in the table. Considering that the balancing dam has a total volume of approximately 90 000 m^3 when full, even an extreme difference in water levels from one month to the next for all three months will not make up the unaccounted for water.

Table 3.9 Water balance results

	Dec	Jan	Feb	D+J+F	% of inflow	CI	
	m^3	m^3	m^3	m^3	%	%	
						min	max
Inflow	1 261 844	1 487 872	1 158 187	3 907 903		-5	5
Usage	964 380	1 375 510	941 680	3 281 570	84.0%	-3	3
Gross losses	297 464	112 361	216 507	626 333	16.0%	-5	5
Gross losses detail:							
Evaporation (canal)	2 631	2 898	2 149	7 679	0.2%	-15	15
Seepage (canal)	53 120	58 686	53 399	165 206	4.0%	-30	30
Evaporation (dam)	3 502	3 493	2 846	9 842	0.3%	-15	15
Seepage (dam)	248	248	224	720	0.02%	-30	30
Unaccounted	237 961	47 035	157 888	442 885	11.0%	-30	30
Total	297 464	112 361	216 507	626 333	16.0%		
Un-quantified components:							
Change in dam level					?	-3	3
Canal and dam spills					?	-15	15
Unlawful abstractions					?	-20	20

The conveyance efficiency for the combined three month period was calculated as 0.84 (or 84 %), which means that 16 % of the water that flowed into the D-canal did not reach a farm off-take (water meter). Based on the estimated accuracy of the Parshall flume, the depth sensor and water meters it is probable that these results are within ± 5 % of the actual value. According to personal communications with DWAF officials and other water management professionals, an efficiency higher than 80 % is considered acceptable. These results therefore meet these criteria.

This may lead to consider what the magnitude of the remaining two components (spills and unlawful abstractions) may be. It could be a considerable amount, or it could be that the seepage and evaporation values are seriously under estimated.

Conclusion

The study provided the researchers some insight into the problems encountered with open channel measurement. The results of the water balance illustrates clearly the constraints highlighted by the scheme manager, Mr Pierre Joubert, at the discussion forum, namely that losses cannot be determined accurately if the accuracy of the measuring method is unknown or doubtful. This makes it difficult for the WUA to assess the conveyance efficiency at distribution system level, and complicates decision-making on infrastructure upgrades and capital investment. However, in order to obtain more accurate answers, more funds will have to be spend, and it may be difficult for a WUA to justify these costs to their water users if the results of further studies are still inconclusive.

Although a variety of more affordable canal measuring methods were evaluated during this study, there was a clear need identified at the discussion forum for more information on modern methods used internationally. It seemed that even very high cost of equipment is not considered an insurmountable problem at all times. WUAs are interested in solutions and are aware that there will be costs involved.

3.1.7 Zanyokwe Irrigation Scheme

The fair distribution of water on small-scale irrigation schemes in the former homeland areas is probably one of the biggest causes of conflict among their participants. Often conventional water management procedures are inappropriate, or water management infrastructure is vandalized. This makes it almost impossible for anyone on the scheme to irrigate successfully.

In order to obtain more knowledge on the practical aspects of water measurement and management at small-scale irrigation schemes, a post-graduate student from the University of Pretoria conducted research by monitoring measurement practices at Zanyokwe Irrigation Scheme. This did not only involve the evaluation of appropriate technologies but also an investigation of the acceptability and the transfer of improved measurement practices to developing communities.

As a result from an initial visit to Zanyokwe, the project team was approached by the farmers from the Kamma Furrow section of the scheme to assist them in installing water meters. The reason for their request was that they wanted to use the meters to divide the cost of electricity consumed by the pump's motor. Water is pumped from the Keiskamma River into a reservoir, from which nine farmers use it under gravity for their sprinkler irrigation systems. At the moment the two-monthly bill is divided evenly between all nine farmers, but they do not all irrigate the same area (block sizes range from 3 to 9 ha).

It was interesting to observe how quickly the farmers grasped the possibility of using the meters for this specific purpose. It addresses a real problem for them, and the request came from them without any prompting by the project team. It is however an unique situation since the rest of the scheme receives water under gravity from the Sandile Dam and have no electricity accounts to pay. The farmers at Kamma Furrow have already developed to a level where they are taking responsibility for their system by paying the electricity account.

The student's research project had the following objectives:

- To evaluate the water use efficiency at the scheme
- To evaluate how farmers perceive the concept of volumetric water allocations
- The determine how farmers perceive the implementation of water pricing
- To make recommendations for improved water measurement practices at small-scale irrigation schemes

The method to conduct the research include planning and executing the installation of the measuring equipment, monitoring over a period of time, data collection and analysis, and making recommendations on the suitability of the different devices.

Two meters meters supplied by the project team were installed at the scheme, one at the river pump and one at a block off-take (the meters were removed from other project sites where the work had been completed). The Eastern Cape Department of Agriculture initially agreed to supply and install the additional seven meters, a contribution of about R50000, but this never materialized and no further progress was made. By the end of 2004, DWAF had developed and approved a subsidy scheme for small farmers to obtain infrastructure. Some of the project team members are still involved with other projects in the area and it is envisaged that a proposal will be developed to access these subsidies to buy the water meters.

3.2 Survey amongst farmers

As required in Aim 3 of the project proposal, a survey amongst water users had to be completed. This aim was addressed by distributing questionnaires amongst farmers from six areas with different water distribution systems, irrigation systems and farming conditions. The areas covered were the Lower Riet River, Umlaas River, Loskop, Vaalharts, Hartbeespoort and Dendron. A total number of 30 questionnaires were completed, which is a relatively small sample size, and care should be taken when interpreting the results since it cannot necessarily be considered representative of the whole group of irrigation water users found in South Africa.

Except for the Loskop Irrigation Scheme, the questionnaires were completed through personal interviews by the project team with the water users. At Loskop, this was done by the water management staff of the Irrigation Board.

The results are presented graphically below and discussed where necessary. Please note that the y-axis titled "Frequency" in each refers to the number of respondents.

3.2.1 Profile of the water users

The water users included in the survey had a range of background with regard to water distribution systems, annual allocations, abstraction rates and point of delivery, as well as irrigation systems.

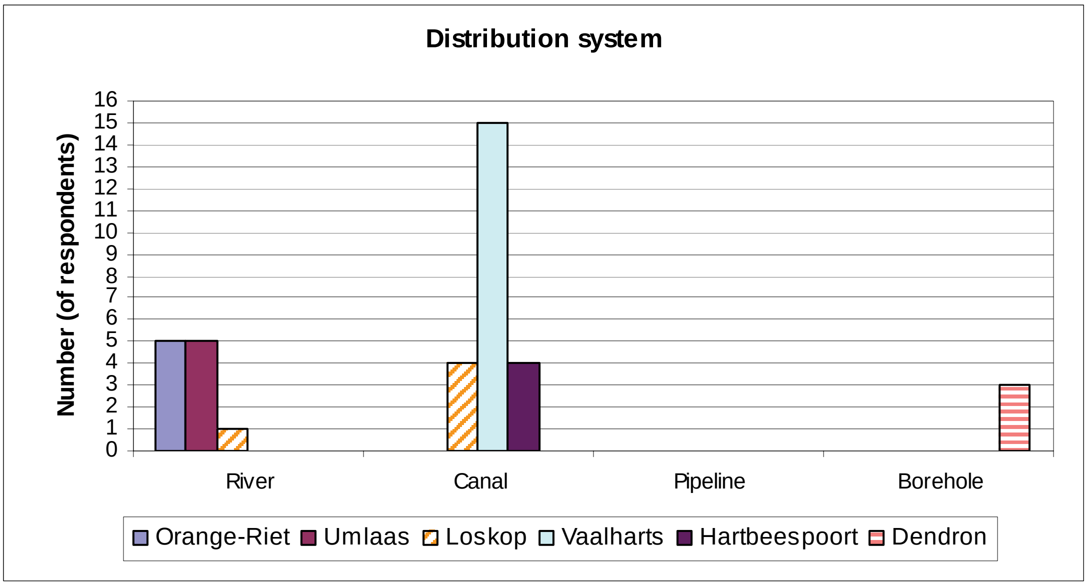


Figure 3.18 Distribution systems covered by survey

River, canal and borehole systems were covered as shown in Figure 3.18. Unfortunately no pipeline schemes were included; it was envisaged to interview farmers from the Hoedspruit area using the new pipeline from the Blyde Dam, but the pipeline is still not being used. The consulting engineers responsible for completing the pipeline indicated that the pipeline should be operational by the end of 2004.

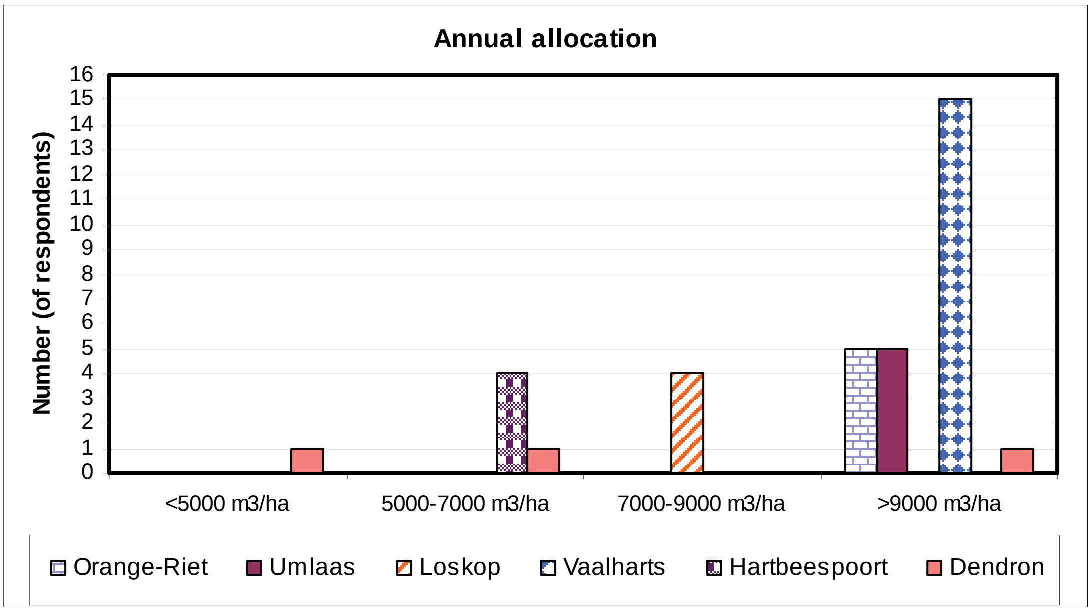


Figure 3.19 Annual allocation of water users

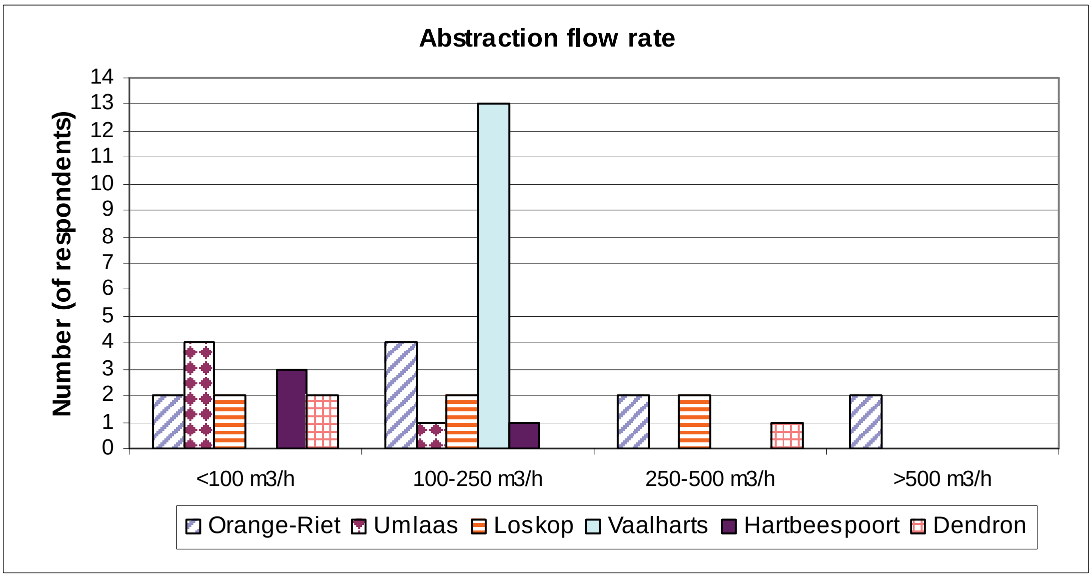


Figure 3.20 Flow rates at the water user abstraction points

The annual allocations of the water users are shown in Figure 3.19. It was interesting to notice how many farmers did not know off-hand what their allocations were, and had to confirm with water management officials, if present.

The range of typical flow rates at which water users abstract water from the distribution system in their areas (such as a river or canal) gives an indication of the sizes of flow meters that is required for irrigation water measurement. Most of the flow rates were below 250 m^3/h. The water users abstracting water at a rate higher than 250 m^3/h were mainly those operating center pivot systems. This is illustrated in Figure 3.20.

The results in Figure 3.21 shows that water is often stored on-farm after abstraction from the distribution system. This may mean that water is pumped more than once (increasing the cost of irrigation) and that there are more opportunities for losses (conveyance losses, and evaporation and seepage losses in storage dams) reducing the overall water use efficiency.

The reasons for on farm storage differ, but is usually related to either the irrigation system (rate of abstraction doesn't match the rate of application), or scheduling (water is not available in the distribution system when it is required by the crop, or vice versa).

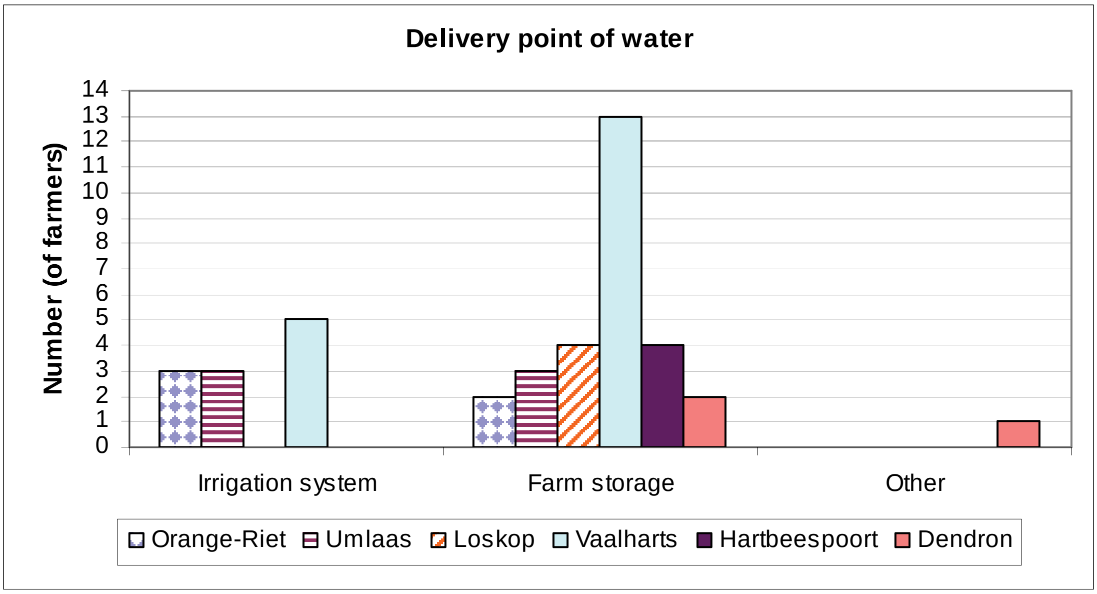


Figure 3.21 Delivery point of water abstracted from the distribution system

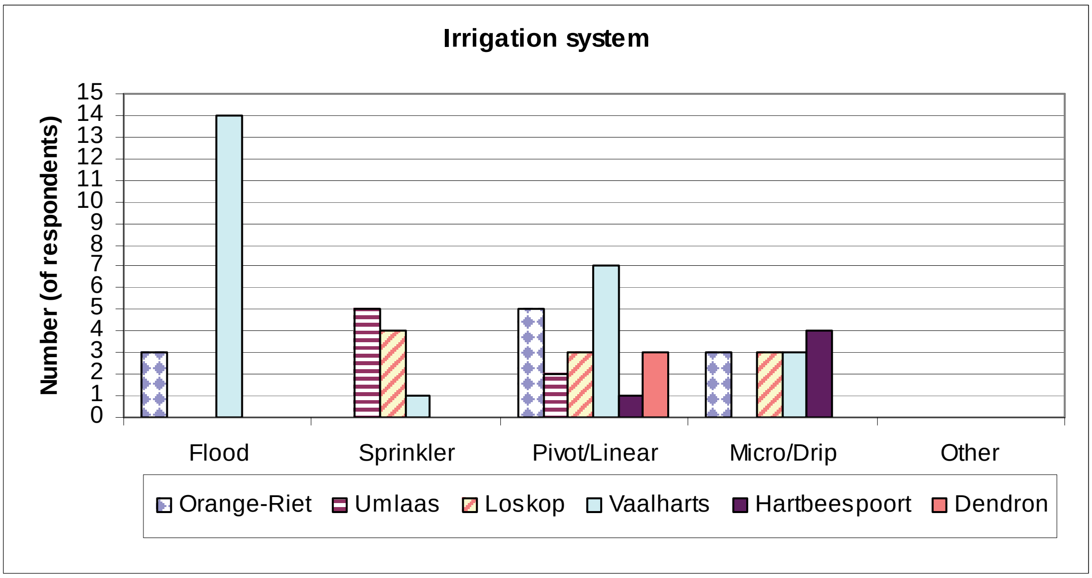


Figure 3.22 Irrigation systems of water users surveyed

Figure 3.22 shows the range of irrigation systems used by water users covered in the surveys, and Figure 3.23 the scheduling methods. The scheduling methods under "Other" included a variety of different soil water instruments such as C-probes, etc.

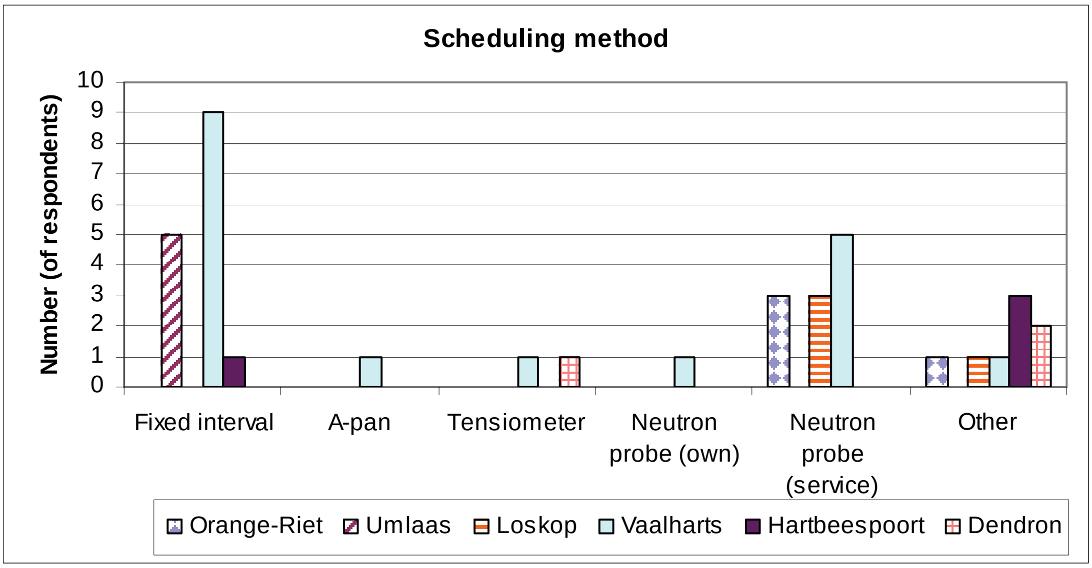


Figure 3.23 Scheduling methods used by water users surveyed

Most of the water users surveyed indicated that they do not have measuring devices on their farms that they installed themselves or use for their own purposes (such as scheduling or recordkeeping), as shown in Figure 3.24.

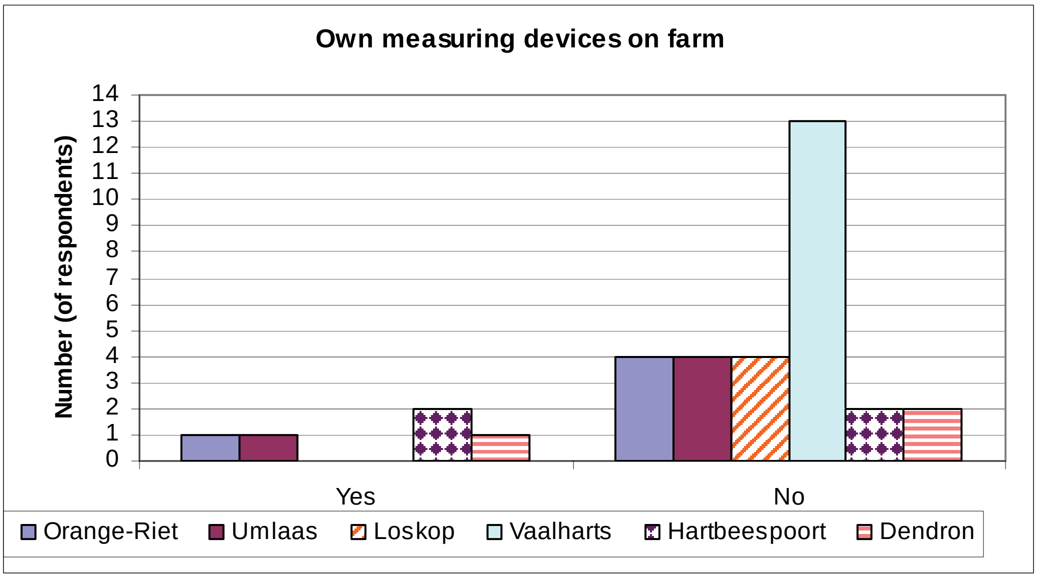


Figure 3.24 Measuring devices owned by water users surveyed

3.2.2 Opinion on current measuring practices

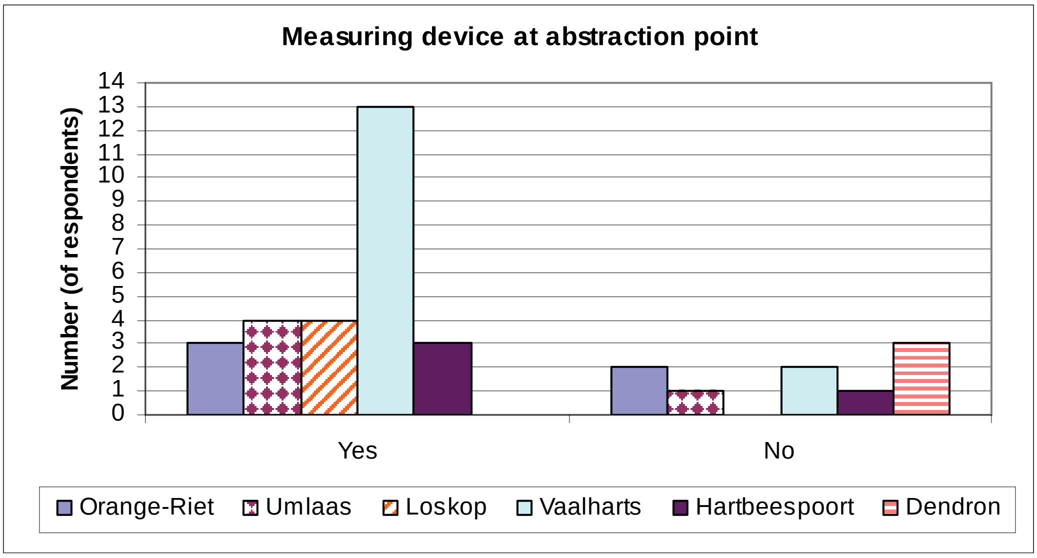


Figure 3.25 Presence of measuring devices at the water users' abstraction points

Most of the respondents indicated that there was a measuring device installed at the point where they abstract water from a distribution system that supplies water to other users, and the majority also reported that the devices were in working order, as shown in figures 3.24 and 3.25.

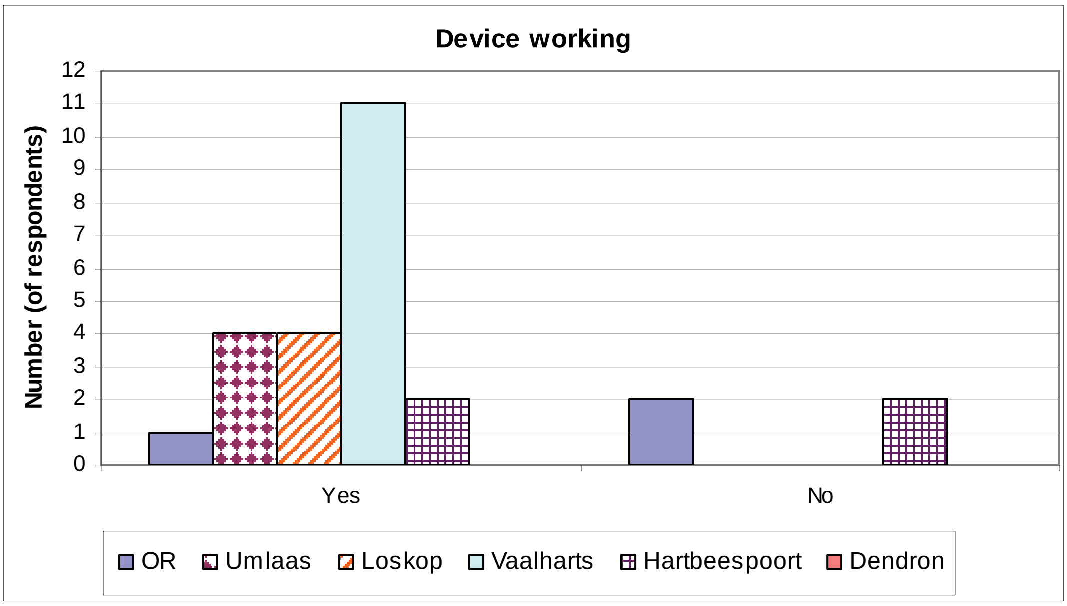


Figure 3.26 Number of installed devices in working order

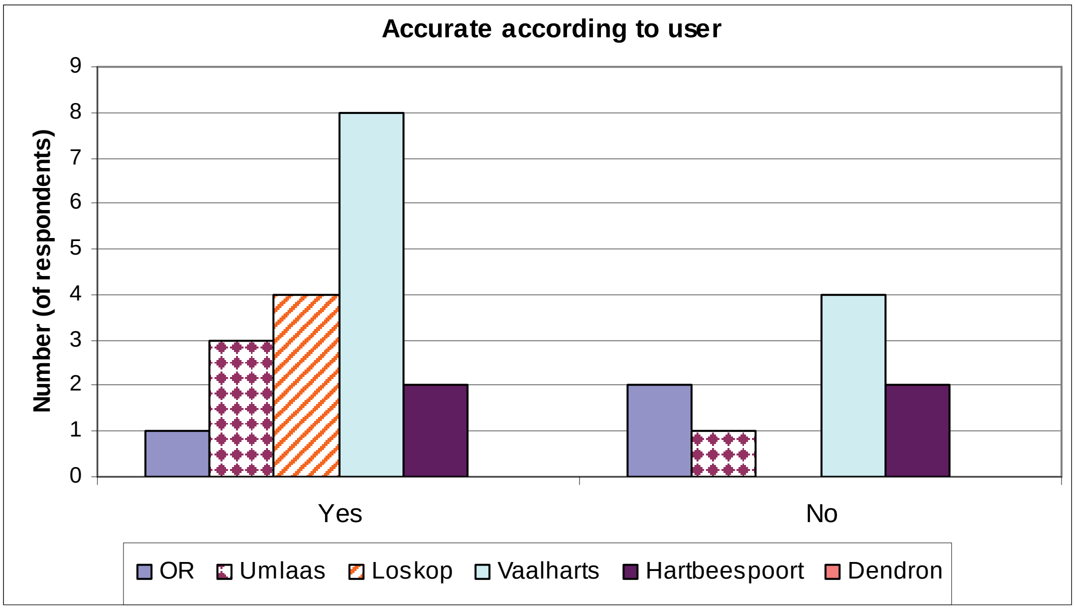


Figure 3.27 Device accuracy according to users

Furthermore, most of the respondents also believed that the devices give an accurate reflection of their water use. Whether this is actually the case, is difficult to determine but probably unlikely since all the respondents indicated that the devices were older than 2 years and most of the respondents indicated that the devices are never calibrated or verified.

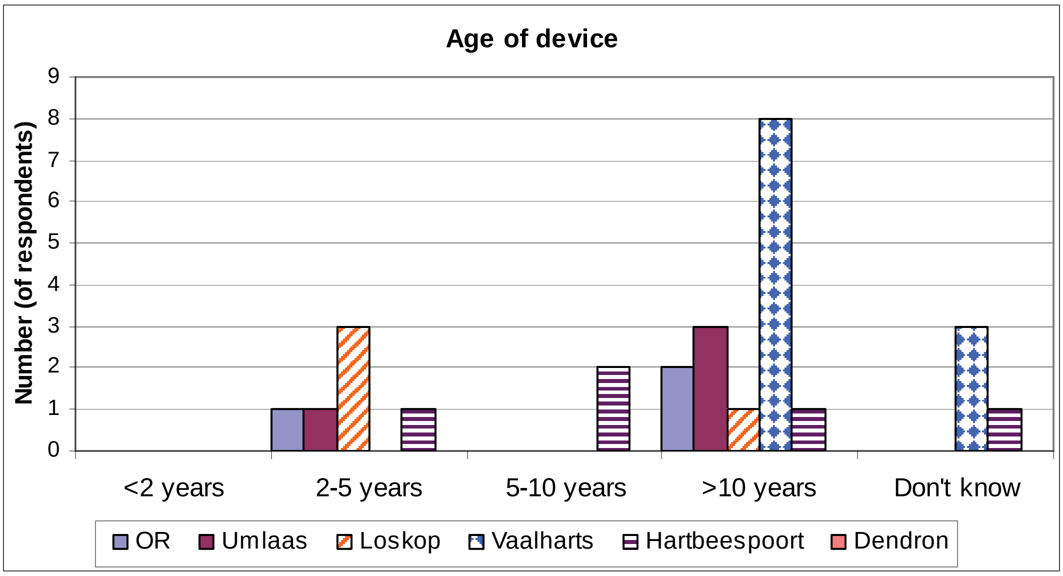


Figure 3.28 Age of measuring devices

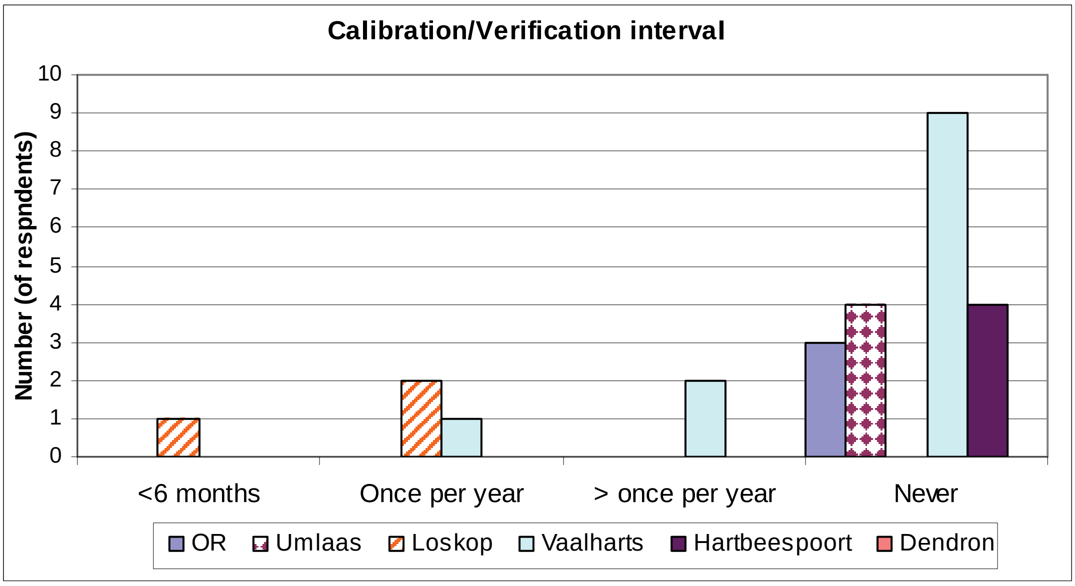


Figure 3.29 Intervals between routine calibration or verification of devices

Despite the lack of routine maintenance, most of the devices seemed to be used for billing purposes by the WUAs. Irrigation Boards, but not by the water users for their own purposes, (such as scheduling or recordkeeping). It could probably have been asked how often the users queried their accounts.

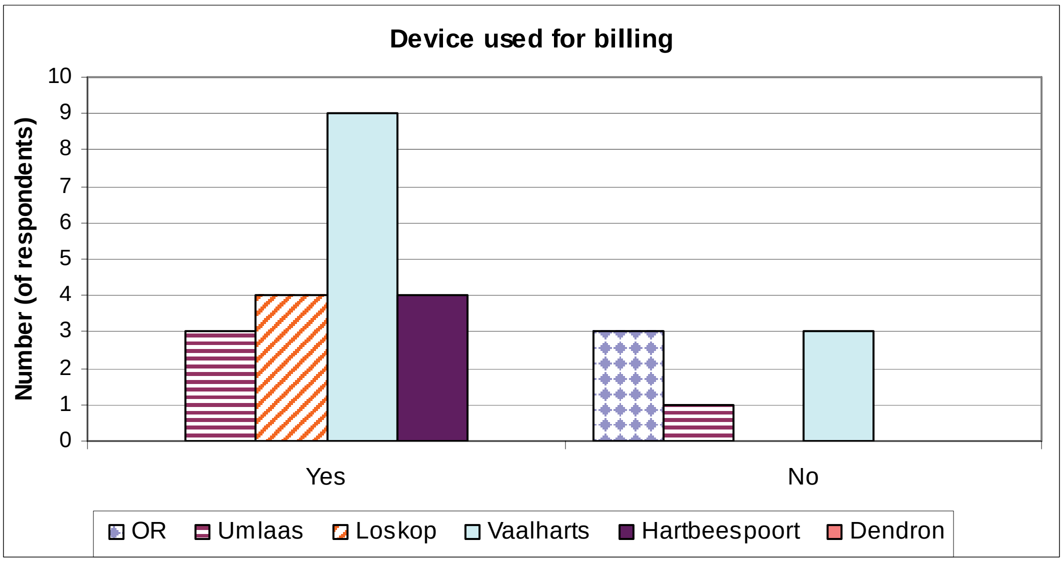


Figure 3.30 Number of devices used for water accounts paid by users

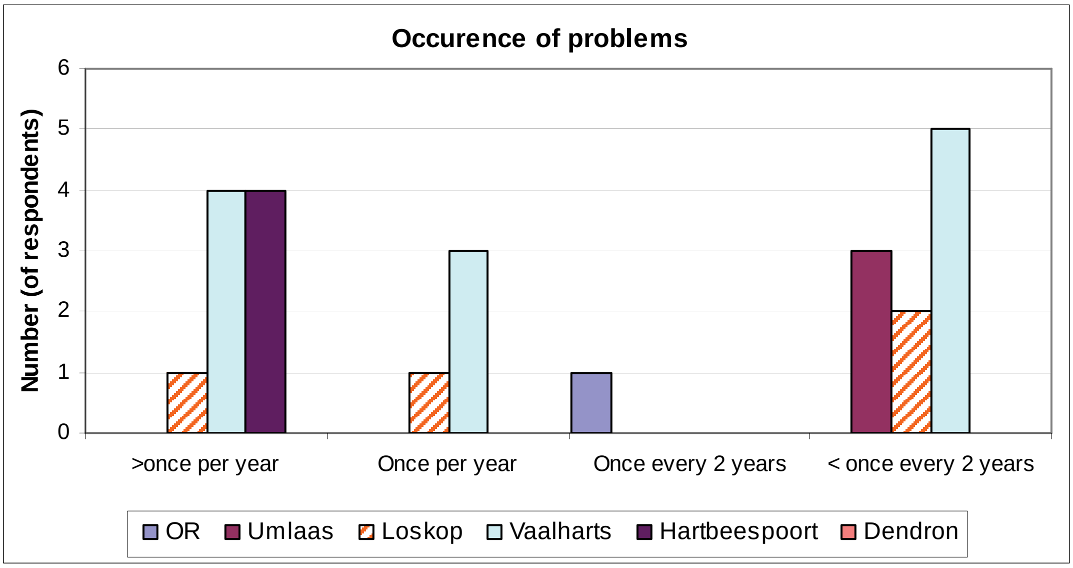


Figure 3.31 Occurrence interval of problems with devices

The water users' perceptions on problems with the measuring devices seemed to be divided. Respondents mostly either indicated that problems occurred regularly (more often than once per year) or seldom (less often than once every two years). From this result, it would seem that opinions are that devices either worked well or not at all, and based on these perceptions the water users approach measuring issues.

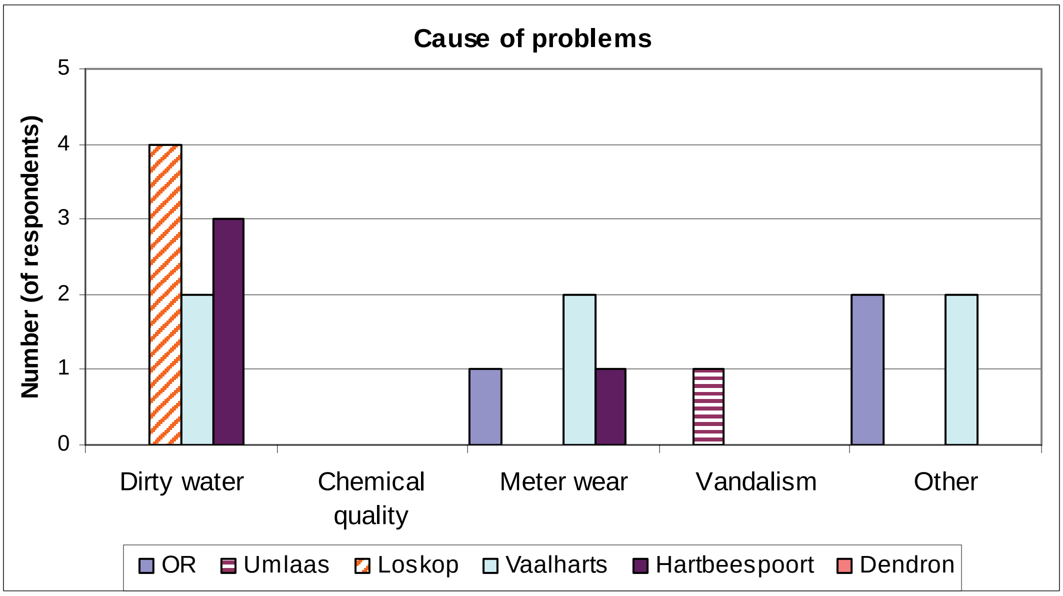


Figure 3.32 Cause of problems with devices

According to the water users, the problems encountered with the meters are usually caused by the physical impurities in the water (such as algae) or meter wear. Other problems reported included damage by floods and the fact that meters are installed but never read.

According to those respondents who did not have a measuring device at the abstraction point from the distribution system, the opinion on whether a device is necessary or not was divided, with almost an equal number saying it is necessary with those that say it is not. However, this result is encouraging since it seems that there are water users who are susceptible to the idea of measurement.

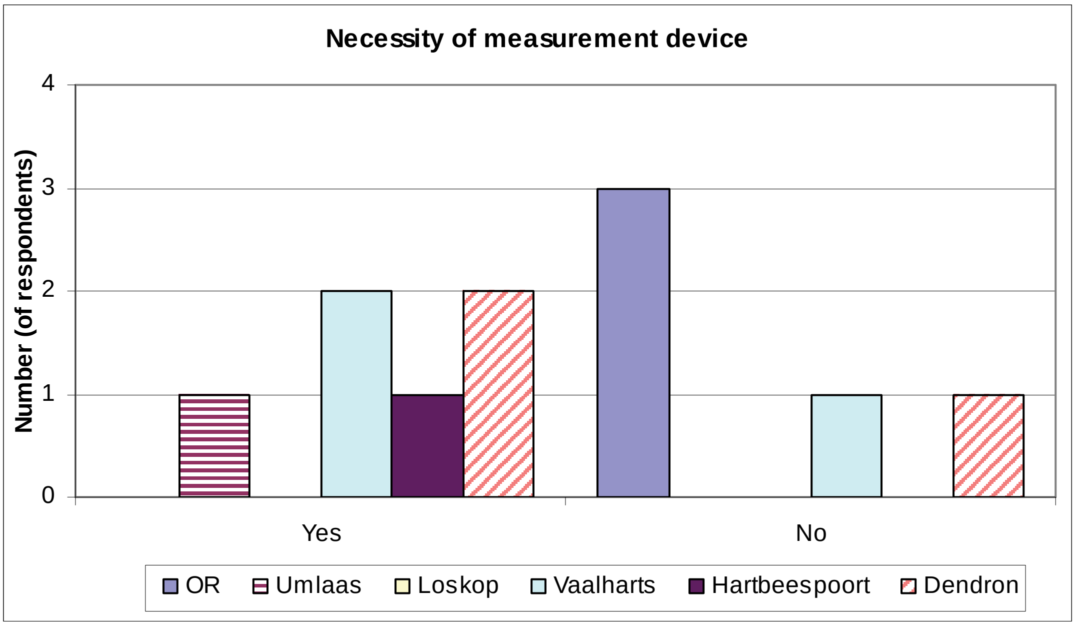


Figure 3.33 Necessity of measuring devices

Since there are no devices in place at these users abstraction points, the survey indicated that most of them pay for the water on a "flat rate" basis, in other words they pay for a certain amount but their actual abstractions are never verified.

Interestingly enough the strongest opinion that devices are unnecessary, came from the Lower Riet River farmers who pay according to their planted areas and the theoretical crop water use.

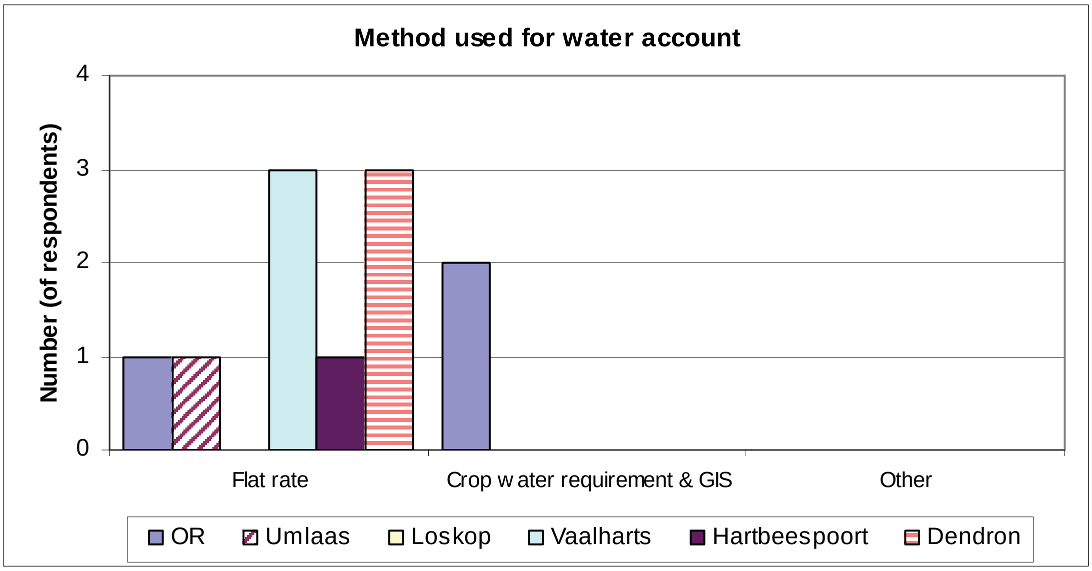


Figure 3.34 Billing method used by users without devices

3.2.3 Measuring needs and requirements

The last section of the questionnaire aimed to investigate what water users' expectations of measuring devices and systems are. The fact that water users want to pay as little as possible (or not at all), but would like devices to be highly accurate, could probably interpreted in a number of ways.

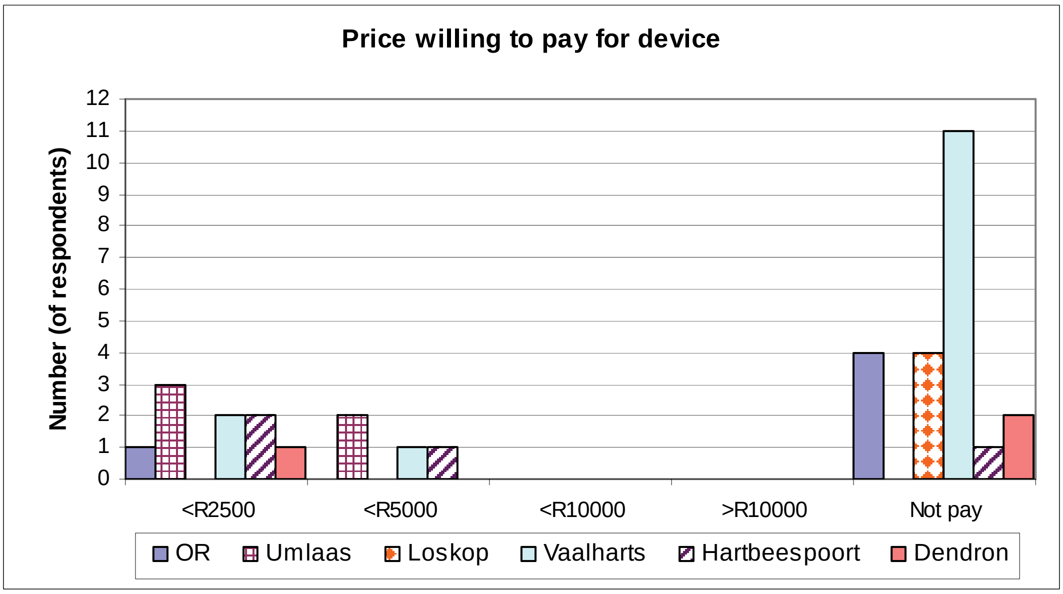


Figure 3.35 Price water users are willing to pay for devices

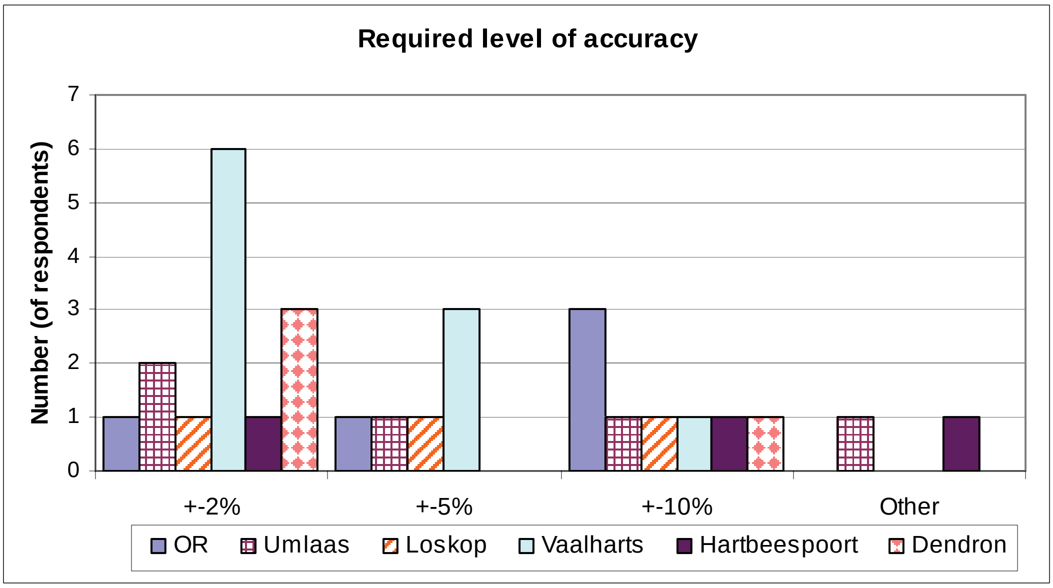


Figure 3.36 Expected level of accuracy of devices

What this does show, however, is that there is a need for greater awareness amongst water users on the benefits and implications of volumetric water measurement. Under certain circumstances, and when the cost can be justified, high accuracy may be required, but in some cases it will not.

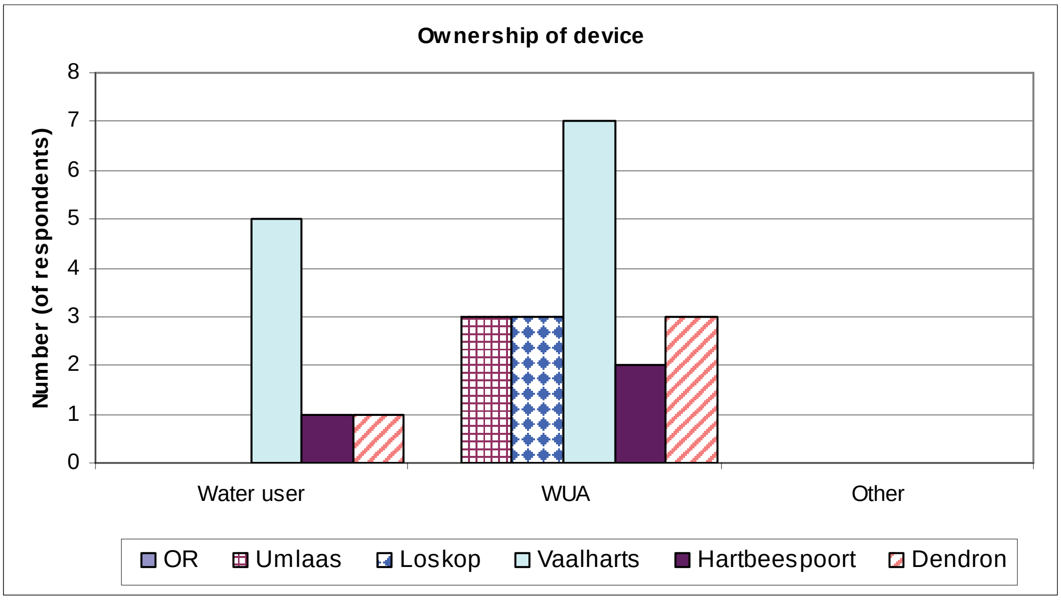


Figure 3.37 Opinions on who should own the device

Most of the respondents indicated that if a device is installed, it should be owned by the WUA rather than the water user. There was also general consensus that devices should be calibrated or reading verified once a year.

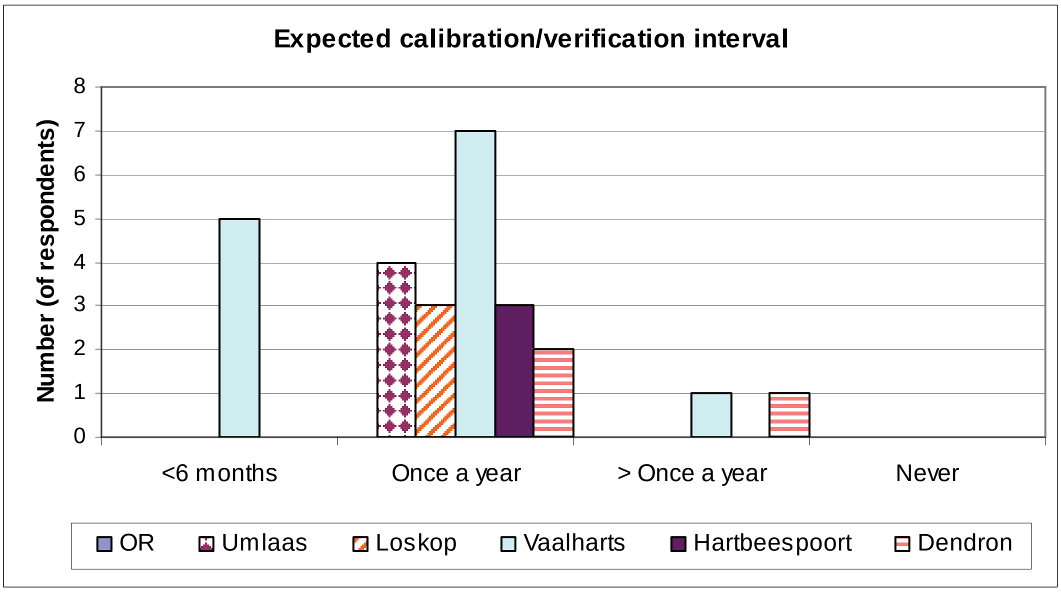


Figure 3.38 Expected calibration interval of devices

There was some support for devices to be able to capture continuous readings, display the flow rate during operation, and be able to send data telemetrically. Other requirements included totalisers for a specific period and easy to clean.

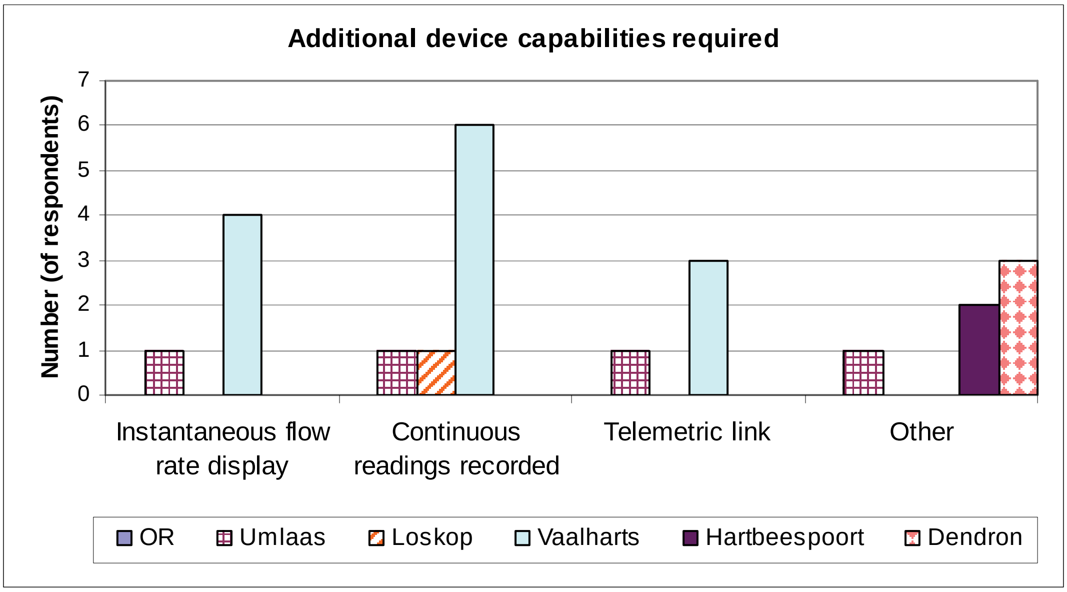


Figure 3.39 Additional functions of devices required

4. CONCLUSION AND RECOMMENDATIONS

4.1 Addressing the project aims

The four project aims were addressed through a wide range of activities that were undertaken in the course of the project. By undertaking these activities, the project team obtained valuable insight into irrigation water measuring practices and problems. A wide network of useful contact was established during the initial field visits and maintained through the field and laboratory evaluations that took place over three years.

A good practical working knowledge of measuring devices was established and information on different devices that are available both locally and internationally was gathered. The first hand experiences of the project team have definitely led to the development of new skills that will hopefully be put to good use in future.

The contact with water management staff and users showed that irrigation water measuring cannot be considered in isolation but is rather one of the tools that can be used by WUAs and of which greater awareness is necessary, especially as far as new technological development is concerned. This, together with the interest that was shown in the Discussion Forum, definitely points to a need for the transfer of information to WUAs and water users.

4.2 Practical implications of irrigation water measurement

Changes that have taken place in South Africa with regard to water legislation, access to information and improved technologies over the past two decades (in other words, since the last water meter committee concluded its work in the 1980s) are making it more likely for irrigation water measurement to be implemented successfully.

Probably one of the most important aspects that needs to be taken into account is that each WUA's situation is unique, in order to identify the relevant measuring requirements, needs to be evaluated as such. No two WUAs can blindly use or apply the same devices or methods.

More suitable, better adapted devices are available, but in order for them to be used successfully, they need be installed correctly, well maintained, and read accurately. In other words, a WUA's water measuring system has to be managed. This approach of managed implementation consists of at least the following components:

- A reason for measuring ("trigger"),
- Acceptance and support by the water users,
- Assessment of the current situation and planning the system,
- Choosing appropriate technologies,
- Correct installation by skilled technicians,
- Sound operation and maintenance policies,
- A system for data retrieval and management,
- Comprehensive financial planning, and
- Procedures for handling disputes and tampering

Suitable technologies are definitely available, and their failure is more often than not linked to incorrect application (unsuitable for specific conditions), installation practices or lack of maintenance. In order to apply this approach successfully, the Guidelines contained in Part B of this report were compiled, and it is hoped that they will be useful to WUAs.

4.3 Recommendations

4.3.1 Measuring guidelines

The fact that South Africa has a new National Water Act (NWA) (Act 36 of 1998) that promotes good water management and conservation practices does not ensure effective water measuring. Water measuring is considered a best management practice according to the Water Conservation and Demand Management Strategy (DWAF, 2000), which now forms part of the National Water Resources Strategy (NWRS) (DWAF, 2004) but there are no clear guidelines from the Department on how it should be implemented. The NWA and the NWRS need to be followed up and supported by sound measuring regulations and procedures to speed up the process of implementation.

There seems to be genuine interest amongst irrigation water users and management staff to understand and implement the most appropriate methods but they are faced with unanswered questions that can ultimately influence decisions regarding water measuring systems. It is therefore strongly recommended that a water measuring policy be drawn up as a matter of urgency to provide a reference for implementation procedures. It is hoped that the information in this report, specifically in Chapter 5, will provide some background to the policy makers on what is required.

4.3.2 Further development

It is believed that measuring is going to be an on-going and ever-changing concern in future. There should be a core group of knowledgeable people to look after the interests of the water users and managers in the long term and maintain the knowledge generated through this project and envisaged follow-up actions. Two recommendations are made in this regard:

It is firstly recommended that a special technical committee be set up for example by SANCID to look after the interest of the irrigation sector in terms of measuring water. Such a committee should consist of representatives of water users (possibly through SAAFWUA), device manufacturers, government departments, and education and research organisations. The purpose of the committee would be to look after policy and institutional issues.

From a more practical point of view, it is secondly recommended that a knowledge center be created at the Department of Civil and Biosystems Engineering at the University of Pretoria, to continue research, prepare and distribute information, train students and provide a field service to WUAs in assisting them with measuring implementation, evaluating devices and trouble-shooting. Some of the equipment bought for the research project could in this way be put to good use and further capacity building will take place. In this regard, funding has already been obtained from the NRF to conduct a two year research project starting in 2005 on acoustic open channel measuring devices. Ideally, external funding and support will be sought continuously to fund the activities at the center.

4.3.3 Technology transfer

The project has lead to the gathering of a large volume of information on different measuring devices and their applications. It is recommended that this information should be made available to the WUAs and their members as widely as possible.

This report was compiled in two parts, of which part B, the Guidelines, can be used as a basis for a training manual on irrigation water measuring. The development of such a manual and other training material will make it possible to distribute this information to interested parties through short courses or seminars. This will add value to the results of the project, but additional funding will be required.

Part B is also supported by the KBS, the Knowledge Base of Measuring Devices, which provide useful written and graphical information on commercially available products in South Africa. However, for the KBS to stay relevant, it will have to be maintained and updated regularly, and it is recommended that a way be found to do this on a website. The responsibility of covering costs for such a venture will have to be finalized first, though.

PART B GUIDELINES FOR THE SELECTION, INSTALLATION & MAINTENANCE OF IRRIGATION WATER MEASURING DEVICES

5. Approach to measurement implementation

Changes that have taken place in South Africa with regard to water legislation, access to information and improved technologies over the past two decades, since the first water meter committee led by CJ Kriek concluded its work in the 1980s, are making it more likely for irrigation water measurement to be implemented successfully.

No two Water User Associations (WUAs) are going to follow the same route, but the approach to be taken should show that the WUA makes progress towards measuring the quantity of inflows and outflows, losses and water supplied to its customers, and towards the use of acceptable measuring devices or techniques, as required by the Water Conservation and Demand Management Strategy (DWAF, 2000). Actual water measurement and even automation of measurements is the goal, however, the use of crop water requirements may be a manageable and achievable intermediate step to estimate water use, particularly as a seasonal planning figure for the WUA's water management.

More suitable, better adapted devices have become available, but in order for them to be used successfully, they need be installed correctly, well maintained, and read accurately. In order to achieve this, a WUA's water measuring system has to be planned and managed. This approach of managed implementation consists of at least the following components (table / flow chart?):

- A reason for measuring ("trigger"),
- Acceptance and support by the water users,
- Assessment of the current situation and planning the system,
- Choosing appropriate technologies,
- Correct installation by skilled technicians,
- Sound operation and maintenance policies,
- A system for data retrieval and management,
- Comprehensive financial planning,
- Procedures for handling disputes and tampering, and
- Monitoring and evaluation.

If this approach is followed, it is more likely that measurement solutions will be found that is acceptable, affordable and sustainable for a specific WUA. It is therefore according to this structure that water measuring implementation will be discussed in this report.

5.1 The reason for measuring

In Australia the term "triggering" has been adopted for the situations and circumstances that make measurement an urgent need. The circumstances are important in determining not only the timing but also the intensity and sophistication of the measuring program as well as the specification and acceptable costs of the measuring devices themselves. The need for measurement devices specifically may not be obvious initially but may follow when a need for improved water management had been identified.

Examples of reasons for measuring to take place in a WUA's command area are:
- Measurement becoming a license requirement
- Pressure on a water source requiring losses to be reduced
- Disputes between water users requiring accurate allocation
- Water trading taking place between different users
- Decreasing operating costs by reducing water management staff

The reason for measuring will determine the **functions** that the measuring device will have to perform as well as the **standard** of the functions, thereby directly influencing the final selection of the measuring device(s), discussed in section 5.4 below. It is therefore important that the reason should be clearly identified and defined at the beginning of the process.

A typical example of an urgent need for measuring in South Africa was where a number of farmers were pumping direct from a river with marginal capacity. Inevitably accurate and verifiable water metering became urgent and facilities were incorporated in the system that automatically shut down a farmers pump if entitlement was exceeded. Under these circumstances the cost of the measuring device and its electronic control system became a secondary consideration.

On the other hand there is the example of a large WUA served by a complex canal system that was upgraded to advanced electronic control with telemetric remote control system that could be monitored and managed via mobile phone from anywhere in the country. Here the chances are good that it will be many years before there is a clamour for individual farm metering. This example, that is not unique, illustrates that there can be sophisticated management without conventional metering.

What these examples illustrate clearly, however, is that when implementing such an approach one needs to take into account that each WUA's situation is unique, and in order to identify the relevant measuring requirements, needs to be evaluated as such.

Checklist:
- ✓ Identify and define the reason for considering measuring devices
- ✓ List the expected results / outcomes to be achieved
- ✓ List the expected constraints to be overcome

5.2 Acceptance by and support from the water users

Once the decision has been made to install measuring devices, it is recommended that a specific person or team should be given the responsibility of driving the process. This could be either existing staff members from the WUA or consultants appointed specifically for the purpose. One of the most important tasks to be undertaken, however, is to obtain the support of the water users by creating awareness of the envisaged plan and its outcomes through written and verbal communication.

The support is crucial in making further steps of measurement implementation possible since information will be required on aspects such as the location and specification of farm off-takes, planted areas, water delivery preferences, etc., and the water users will have to be consulted for this.

Decisions will have to be taken on the ownership and responsibilities involved with new infrastructure, and in this regard their support is also the first step towards preventing vandalism and tampering with equipment to be installed. It is most likely that any infrastructure will be owned and maintained by the WUA with any costs recovered from the water users. This approach, rather than individual ownership, helps to prevent inconsistencies in types of devices installed, installation practices and maintenance levels but requires support from the users at grassroots level.

The costs that will need to be recovered will include the initial capital cost of the equipment as well as running costs for on-going operation and maintenance. The capital cost will have to be recovered over a number of years, which does not exceed the expected life of the devices, while the running costs will have to be revised annually to meet expenses associated with data retrieval, repairs, calibrations, etc. It is important that cost can be justified by the envisaged benefit for the water users as a result from the proposed measuring system. It is therefore recommended that different scenarios be investigated to present the users with a range of options from which they can choose.

Checklist:

- ✓ Appoint a person or team to manage the process
- ✓ List the expected benefits / advantages
- ✓ List the expected drawbacks / disadvantages
- ✓ Inform stakeholders / create awareness

5.3 Assessing the current situation and planning a system

In order to implement measurement effectively at a scheme, the management strategy of the particular scheme has to be understood. Unnecessary measurement is not only expensive, but will also generate a large amount of irrelevant data that has to be processed and stored.

The assessment of the existing circumstances and needs can be done on the basis of existing Rapid Appraisal Process (RAP) and irrigation benchmarking method such as described by Malano & Burton (2001) and Burt (2001), making extensive use of maps, on-site inspections, historical flow data and planting records. If this information is not already kept by the WUA this will also provide an opportunity to gather such information, which will in any case be required in a Water Management Plan (WMP). The following information should at least be gathered:

- Map with lay-out of the scheme infrastructure and irrigated areas indicated (ideally GIS based so that it can be updated regularly)
- Water source and method(s) of water abstraction (into main supply)
- Water delivery infrastructure (type and length of each type, m)
- Type and location of water diversion points, with or without existing control equipment (number, type of control equipment and condition)
- Type and location of water user off-takes, with or without existing flow measurement facilities (number, type and condition / age, accuracy)
- Type of water distribution management (on-demand, rotational, etc.)
- Frequency of abstraction at main supply and farm levels
- Irrigated fields per water user and/or off-take (ha)
- On-farm irrigation systems (types and areas per field)

- Average rainfall per month (mm/month)
- Average reference evapotranspiration per month (mm/month)
- Peak daily reference evapotranspiration (mm/day)
- Crops grown, with typical growing seasons and crop factors (list)
- Any known drainage systems or return flow systems
- Any water quality information available
- Cellular phone network availability at measuring locations

The gathering of this data ensures that a thorough understanding is obtained of the water supply and demand processes of the WUA. The climatic and agronomic data will not be used directly to select appropriate measuring devices but can be used to estimate the total water requirement of the WUA. An analysis of the data should be done to develop a baseline of information for comparison against actual performance in future, as well as a basis for making specific recommendations for modernization and improvement of the water control system, such as where measuring devices are necessary. The importance of local knowledge of the system should not be disregarded; most WUAs have a number of experienced staff members that know the system and its problems, and they can provide very valuable information on modernising the management.

The next step would be to identify the locations where measuring devices are required. At most WUAs, flow measurement is required at either main supply system or farm off-take level (or a combination) to manage distribution, as described in Chapter 2.

Every irrigation scheme has to make use of a unique combination of approaches to manage these two levels. Even in cases where the infrastructure at two schemes is similar, some aspects of the management approaches will differ. However, within each level generic or typical approaches can be taken as discussed in more detail in below.

In most cases, the obvious starting point is the measurement of bulk supply to the WUA and to follow this through down to individual farm level, if necessary. In analysing the situation it is important to concentrate on what needs to be done to achieve effective management. Over simplistic solutions such as insisting that all farmers must in the short term be individually metered can be impractical and expensive.

Once the required measuring locations have been identified, the number of devices likely to be needed at the different levels as well as the flow rates each type would need to handle should be determined. At this stage it may be quite possible that there is more than one possible solution; they can all be investigated further and compared in terms of cost and appropriateness as described in the following sections.

Checklist:

- ✓ Compile background information
- ✓ Identify measuring locations
- ✓ Estimate number of devices needed and typical flow rates
- ✓ Repeat for different options

5.4 Selecting appropriate technologies

The selection of a measuring device for a particular installation will depend on how the characteristics of the available devices satisfy the requirements set by the WUA, as identified during the situation assessment described above. In general, these requirements will make sure the following needs are addressed:

- The device performs certain functions,
- The device performs to a certain standard, and
- The device is the most affordable solution that satisfies the first two needs.

What it comes down to, is that the method for choosing the appropriate device should focus first on what type of information and what level of precision is required by the WUA, and then on choosing the least expensive device that meets the practical needs and any other standards set by the WUA or the CMA or DWAF.

5.4.1 Device functions

In order to decide which devices are required at the different locations and whether existing devices can be used, the required **functions** of the devices should be identified. The measuring device will be required to perform any of the following functions (Queensland Natural Resources and Mines, 2002):

- Measure cumulative flow volume
- Memorise and continuously display cumulative flow volume
- Measure instantaneous flow rate
- Display instantaneous flow rate continuously
- Memorise history of instantaneous flow rate
- Measure depth of flow
- Measure flow velocity

It has to be emphasized at this point that for neither open channel nor piped flow conditions is there an “ultimate” flow measuring device that will be the answer to all problems under all conditions. Each situation is unique and has to be assessed as such, and the specific needs matched to a suitable device. This approach will hopefully lead to the most appropriate solution being found – this may not necessarily be the least expensive, or the most sophisticated option, but the most suitable one for the specific circumstances.

5.4.2 Performance standards

The WUA will have to set **standards** what they think the envisaged measuring devices should meet (and is acceptable to the catchment management agency (CMA) or DWAF) and assess the existing infrastructure accordingly. Standards should be set for all levels, keeping in mind that it may not necessarily be same at all levels. For example, a measurement accuracy (standard) of ± 2 % may be required at farm off-take level because the farmer is billed according to the measurement, but an accuracy of ± 10 % may be good enough at main supply level because it is only required to give an indication of the flow conditions in the system.

Standards usually have to be set for all or some of the following parameters, which are discussed in chapter 6:

- Type of flow and flow conditions
- Water quality

- Flow range
- Pressure head
- Accuracy
- Repeatability
- Installation conditions
- Data output
- Power requirement
- Operating requirements
- Life expectancy
- Maintenance, trouble shooting and repair
- Resistance to tampering
- Environmental protection
- Existing devices and user acceptance of new methods
- Reliability
- Legal constraints
- Impact on the environment
- Cost

The different devices show varying degrees of sensitivity to the parameters listed above, underlining the fact that there is no “ultimate” device that will work under all conditions. The characteristics of the various commercially available devices, including installation and maintenance requirements, advantages and disadvantages are discussed in detail in Chapter 6 of this report. The characteristics should be studied carefully before making a final selection.

5.4.3 Cost comparisons

The issue of cost effectiveness over the life of the device is often the deciding factor when selecting an appropriate device. The total cost of a measuring device depends not only on the actual cost of purchasing the device but also on its installation, management and maintenance requirements.

In order to summarise the cost components and their elements, a framework has been drawn up for use by WUAs to compile budgets for comparison as an aid to selecting the most appropriate solution. See table 5.1 below. The total capital cost of an installation will consist of the measuring device and installation components, and should be recovered from the water user of an agreed number of years not exceeding the expected life time of the device.

The total operation (running) cost consists of components related to the equipment, administration and maintenance required to manage the devices. These costs are annual expenses that will also be recovered from the user by the WUA. For clarification on the elements of these components, see sections 5.5, 5.6 and 5.7 below, where they are discussed in more detail.

The cost of capacity building through training of technicians, data collectors and data processors will also have to be recovered, although these costs may not necessarily occur every year. As mentioned earlier, some of the functions of the WUA can be outsourced to contractors, if this seems to be a more cost-effective way, and the saving passed on to water user in the form of reduced water charges.

The information in Chapters 6, 7, 8 and 9 of this report is aimed at providing WUAs with background to be able to compile such budgets and select appropriate devices and implementation methods.

Table 5.1 Cost framework

Component	Element	Cost
Measuring device	Primary element (standard physical device or structure)	R/installation
	Secondary element (additional data display or read-out, if not part of the primary device, e.g. pulse output)	R/installation
	Data retrieval device (datalogger or telemetry)	R/installation
Installation	Supporting infrastructure (pipes, flanges, reducers, sieves, etc.)	R/installation
	Electricity supply and connection	R/installation
	Security devices (lockable enclosures, tamper-proofing)	R/installation
	Labour cost (technicians, electricians)	R/installation
	Consumables	R/installation
	Traveling	R/installation
	In-field calibration (expenses or contractor)	R/installation
	Specialist installation equipment	R (once-off)
Operation (equipment)	Electricity	R/installation /year
	Telemetry (Cell phone contracts)	R/installation /year
	Additional energy due to increased friction loss	
Operation (administrative)	Data retrieval (staff and expenses, or contractor)	R/installation /year
	Data processing (staff and hardware)	R/year
	Software (for retrieval or processing)	R/year
	Other overhead costs to WUA	R/year
Operation (maintenance)	Routine inspections (staff and traveling, or contractor)	R/installation /year
	Routine servicing (in-field or laboratory, incl. cost of removal if necessary)	R/installation /year
	Re-calibration (equipment and expenses, or contractor)	R/installation /year
	Spare devices for replacement (ex-stock)	R/year
Capacity building	Training of technicians for installation	R
	Training of technicians for maintenance	R/year*
	Training of data collectors (meter reading, etc.)	R/year*
	Training of data processors (software use)	R/year*

* If required.

Checklist:

- ✓ Identify functions expected of each device
- ✓ Set standards for each function
- ✓ Evaluate existing devices according to the set functions and standards
- ✓ Compile a shortlist of most appropriate devices
- ✓ Compare the total cost (capital and running) of the short-listed devices

5.5 Installation and calibration

If the data obtained from any measuring device is to be useful and the expense of purchasing, installing, maintaining and reading a meter is to be justified, it must be installed, calibrated and maintained according to predetermined standards. This is so that the water user can be sure it operates as accurately as possible, that it remains accurate over time, and that a verification system is in place.

This starts with proper installation. Through careful planning the installation process should be kept as simple as possible, with construction and other site work kept to a minimum to reduce costs, yet still complying with the selected device's installation requirements.

Many Water User Associations (WUAs), especially smaller ones, may find it more cost-effective to outsource supply and installation to a knowledgeable contractor. Not only may this save the WUA from buying expensive equipment that may not be used often after the installations have been completed, but another possible advantage is that the contractor may be able to negotiate better prices on measuring devices with the supplier if he buys in bulk.

If this route is followed, it is suggested that it is done through a tender system which will require comprehensive technical documentation and careful management from the WUA to ensure work is completed on time, according to the specifications and within the agreed budget.

The WUA should ensure that each installation is complete and according to the plans before the contractor leaves the sites. This can be done by compiling a database with information on each installation as it is completed, including a photograph of the completed work, global positioning system (GPS) location, a checklist of important information of the installation, and written confirmation by both the WUA, the contractor and the water user that the installation is correct and operating as intended.

In order to ensure that a device is accurate at a specific installation, it is strongly recommended that all measuring devices be checked or calibrated in the field after installation. Experience has shown that even if a device comes with a calibration certificate from the manufacturer it is not guaranteed that the device will perform accordingly in the field. In the case of open channels, handheld current meters, either the mechanical or acoustic type, can be used to measure instantaneous flow rates, with the acoustic type especially producing quick and accurate results. For piped flows, a clamp-on type acoustic meter (preferable the transit time type) can be used for verification.

Checklist:

- ✓ Identify different installation options
- ✓ Draw up technical specifications, time frame and detail budget for each option
- ✓ Choose the most appropriate option
- ✓ Manage the installation process (either in-house or outsourced)
- ✓ Complete in-field verification of measuring devices
- ✓ Confirm completion of installations

5.6 Operation

The purpose for which measuring was implemented initially will usually determine how the devices are operated (read), and when data is collected. For instance, if the devices are used to manage the supply to a number of water users sharing an on-demand type distribution system, the WUA would be interested in real-time data to ensure all users get their fair share. This may necessitate a technologically advanced data collection system based on telemetry. On the other hand, if the WUA is merely interested in monitoring water users' abstractions against their allocations, periodic readings taken manually by WUA officials may be adequate.

Data can therefore be collected either manually, or via remote sensing technology. If the readings are taken manually, it must be ensured that the device is fitted with a suitable display unit that can be easily read, and that the person taking the readings has been trained to do so correctly. This will make mistakes in data collection less likely to occur.

It is also possible to connect most measuring devices to a datalogger which can store data for longer periods and thereby reduce the number of visits required for manual collection. Data from a datalogger can also be transmitted telemetrically. If electronic equipment is used to collect data, the equipment must be properly protected against the elements, since especially lightning and frost can cause serious damage, resulting in data loss. Whichever data collection system is decided on, it will have certain implications for cost and quality of the data.

It is important that only necessary data is collected. The data should as far as possible be made available to the water users, and preferably in user friendly formats such as graphs or tables with short discussions or summaries. Presenting the data in this way can help to create greater awareness amongst water users of their water use, possibly encouraging them to increase efficiency.

The data obtained from the measuring devices should be critically evaluated, and that can only be if there are benchmarks with which it can be compared. This may take on the form of a framework for calculating the water requirements of the WUA for a specific season, based on irrigated areas and gross irrigation requirements of the various crops planted on the areas (the information collected during the initial assessment). A purpose-made module has been developed for the WAS (Water Administration System, WRC Report nr 513/1/97) program to perform these calculations once the necessary data has been captured in the database. The actual measured results can then be compared with the theoretical estimations, making it possible for the WUA to advise the farmers on water use efficiency of, and the cost of water as an input for different crops, as well as identifying inefficiencies and losses in the distribution system. It will also provide useful pointers for the WUA as to where further measurement is necessary.

As in the case of the installation, data collection can be outsourced to consultants. Some manufacturers also offer data collection services, especially when telemetry is used in conjunction with their equipment. The data is usually sent to a dedicated internet address from where it can be accessed by the WUA at any time.

The different data collection methods and their related hardware are discussed in Chapter 9 of this report.

Checklist:

- ✓ Identify data collection options
- ✓ Draw up a data collection schedule
- ✓ Purchase any equipment and software required, if necessary
- ✓ Train staff to collect and process data, or appoint contractor
- ✓ Develop benchmarks and evaluate data
- ✓ Present data to water users

5.7 Maintenance

A maintenance schedule that adheres to the manufacturers specifications, if relevant, should be drawn up and followed to ensure that measuring devices operate effectively for as long as possible. Preventative maintenance includes regular inspection of devices or structures for damage and signs of wear, as well as accuracy verification, which can be performed in the same way as the in-field verification described in section 5.5. Recalibration may be necessary, either due to general wear or due to changes in the distribution system (and therefore flow conditions).

In some cases maintenance may required that the device be removed from the installation. In these cases, maintenance should be planned to take place during periods when there is no irrigation, or a replacement device should be installed. In the case of open channel systems, it is customary to schedule a number of "dry periods" in the year during which general maintenance and repairs can be undertaken, since infrastructure can usually not be removed. As in the case of the installation and data collection, maintenance can be outsourced, but it should however never be made the responsibility of the water user.

The interval between inspections will be determined amongst other by the type of device, its age as well as the quality of the water, but surveys amongst water users as part of this project showed that it should be done at least once a year. An agreed procedure for handling measuring errors should be in place in case faults or failures are encountered. Maintenance procedures have to be evaluated periodically and revised if found to be ineffective.

The maintenance requirements of different devices are discussed in Chapters 7 & 8 of this report.

Checklist:

- ✓ Identify maintenance requirements of all devices
- ✓ Draw up a routine maintenance schedule and procedure
- ✓ Draw up a re-calibration schedule and procedure
- ✓ Develop a procedure for compensation for measuring errors
- ✓ Purchase any equipment required, if necessary
- ✓ Train staff, or appoint contractor

5.8 Disputes and vandalism

5.8.1 Disputes regarding device accuracy

Disputes regarding the accuracy of a meter may occur despite careful installation and maintenance procedures. The procedure that should be in place to handle such a problem should meet at least with the following requirements:

- The water user should report the suspected faulty device, presenting any evidence on which the claim is based.
- If at all possible it should be attempted to verify the device accuracy in situ, since installation conditions can often be the cause of the problem and this will therefore not be picked up if the device is evaluated in a laboratory under ideal flow conditions.

- If no fault is found with the device, the costs involved with verifying the device will be recovered from the complainant.
- If the device if found to be faulty, it will have to be replaced and the historical data assessed in order to determine whether the water user needs to compensated or adjustments made to his/her water use records.

5.8.2 Tampering with devices

If any evidence of tampering is encountered during maintenance or any other inspection of measuring devices, a procedure should be in place to deal with the situation. It is recognized that tampering may or may not have been done by the water user, but in both cases it is a serious situation, more so if it had an effect on the performance of the measuring device. It has to be investigated since it affect the fair allocation of water amongst the users as well as cost recovery. The procedure should provide for the following:

- The case should immediately be reported the WUA.
- If possible, a photograph should be taken, and the effect of the tampering noted on the measuring device.
- The tampering should be corrected / repaired, if possible, or the device replaced as soon as possible.
- The relevant water user should be informed, and allowed to present his argument, if required.
- Provision should be made in the WUA constitution for any disciplinary actions that can be implemented if necessary.

Checklist:
- ✓ Draw up a procedure for handling measuring disputes
- ✓ Draw up a procedure for handling cases of tampering
- ✓ Obtain support from the water users
- ✓ Include procedures in WUA constitution

5.9 Monitoring and Evaluation

An essential element of a sustainable measuring system is an effective monitoring and evaluation programme. Once a system has been designed and implemented, it has to be monitored to assess whether it is actually addressing the needs that were identified. Mechanisms can be built into the process to allow for learning, correction and adjustments to benefit the system as a whole and all parties concerned. This will require the development of a clear set of objectives and performance indicators, linked to the original device functions and standards that were identified, which promote accountability and participation, and which can be monitored and evaluated by the relevant decision-makers.

Checklist:
- ✓ Draw up a monitoring and evaluation plan
- ✓ Implement the plan
- ✓ Give feedback to water users

6. Selection and installation guidelines

6.1 Introduction

The types of devices that can be used for measuring irrigation water in canals, pipes and rivers in South Africa are listed in Table 6.1. The devices function on different principles, mainly dependant on energy conservation laws, and this influences their appropriateness under different installation conditions. The section aims to provide some background of flow measurement in general.

Open channels flow occurs when the water has at least part of its surface exposed to the atmosphere, such as in canals, rivers or partially full pipes. Since the water is not fully enclosed no pressure can be exerted and therefore the water will only flow in the direction in which there is a downward slope of the water surface.

Closed conduit flow occurs when the water is fully enclosed, usually in a pipe, and pressure can be exerted on the water, either due to pipe height changes, or external forces (such as a pump). These influences, together with friction between the water and the pipe wall, leads to pressure differences that will dictate the flow of water. Water in a closed conduit will always flow from high pressure to low pressure locations. The rate at which water will flow between such locations is further influenced by the size of the pipe, the roughness of the pipe wall, and other restrictions such as valves, bends and reducers.

The following publications were used extensively in the chapter and the authors would like to acknowledge their usefulness specifically:

Australian National Committee on Irrigation and Drainage. 2002. Know the Flow Flowmetering Training Manual. ANCID. New South Wales, Australia.

Crabtree, M. 2000. Flow: Mick Crabtree's Flow Handbook (Second edition). Crown Publications. Johannesburg.

Queensland Department of Natural Resources and Mines. 2002. Metering Water Extractions: Interim Policy. Queensland Department of Natural Resources and Mines: Brisbane, Australia.

Queensland Department of Natural Resources and Mines. 2003. Interim Metering Process Manual. Queensland Department of Natural Resources and Mines: Brisbane, Australia.

United States Bureau of Reclamation. 1997. Water Measurement Manual. US Department of the Interior. Denver, Colorado.

Table 6.1 Measuring devices discussed in this report.

The following open channel (canals & rivers) flow measurement devices are discussed in this report:	**The following closed conduit (pipes) flow measuring devices are discussed in this report:**
Hydraulic structures: **Flumes:** Parshall Replogle **Weirs:** Crump Sharp-crested: Rectangular, 90° V-notch, Cipoletti **Orifices:** Pressure regulated sluice gate with long weir Piped orifice outlets with long weir	In-line flow meters: **Mechanical velocity meters** Turbine type Impeller type (small paddle wheel) Propeller type Proportional type **Venturi** with by-pass incorporating a mechanical velocity meter Electromagnetic flow meter **Acoustic meters**: Transit time type (fixed or portable) Doppler type (fixed or portable)
Water level recording devices for hydraulic structures: Measuring plate in stilling basin Float and counterweight level sensors Submersible depth sensors Ultrasonic depth sensor (non contact)	Indirect flow meters: Instantaneous electrical power meter kilowatt-hour meters Differential pressure meters
Open channel velocity meters: Mechanical current meters Acoustic Doppler velocity meters Acoustic transit time velocity meters	Flow meter secondary units: Displays (Registers) Transmitters (Pulse outputs) Converters

6.1.1 Basic measuring principles

In irrigation water measurement, water managers are usually interested in determining either the flow rate in a canal or pipe section, or the volume of water that has passed a certain point during a certain period. In South Africa, the common unit for measuring flow rate, Q, is cubic meters per hour (m^3/h) or per second (m^3/s), and if this is known, the volume of water, V, in m^3 passing a specific point in a specific period of time can be determined by multiplying the flow rate with the time period (t in hours (h), or t in seconds (s)).

The required flow rate can be determined if the flow velocity ("speed" of the water), v, in meters per second (m/s) is known. In some cases, especially in open channels the flow rate is derived from a measurement of head (pressure expressed as a water depth) h in meters, m. This method is actually just an indirect "measurement" of the velocity, since head is a proportional indication of the velocity.

It is therefore always either velocity or head that a measuring device actually measures at a specific location, and by combining this parameter with the cross sectional flow area (basically the flow depth and width in a canal, or the inside size of a pipe) at the same location (area, A, in square meters, m^2), the flow rate can be calculated. Many measuring devices contain built in mechanisms to convert the measured flow parameter to flow rate before it is displayed or transmitted. The process is shown schematically in Figure 6.1:

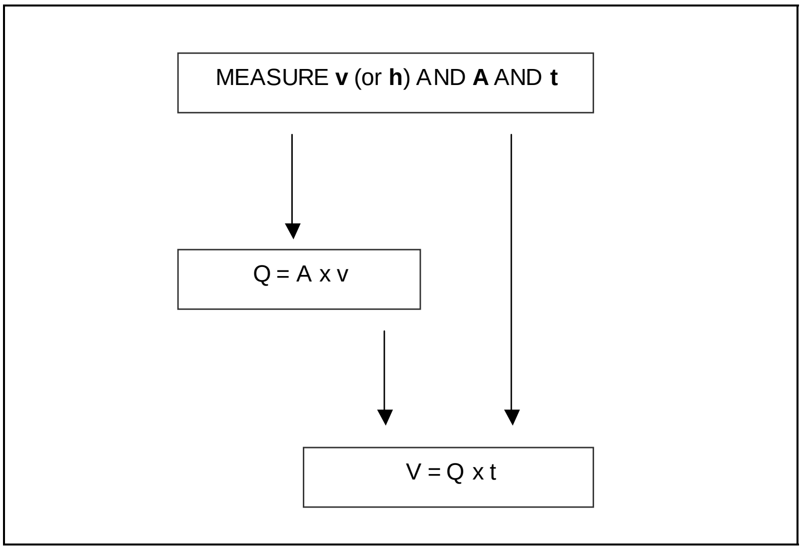


Figure 6.1 Volumetric flow measurement

6.1.2 Velocity profiles

The velocity that is measured and used a basis for calculating the discharge at a specific location should be representative of the velocity over the whole flow cross sectional area. This requires that that certain flow conditions exist at the point of measurement.

Under ideal measuring conditions, the flow should be such that all the water particles are moving at the same velocity in the same direction in parallel paths, without any swirling or lateral movement in the water. Due to the resistance caused by the pipe wall or canal sides to the adjacent water particles, a fully developed laminar flow profile does not have uniform velocities across the whole profile, but the water flows faster in the middle of the pipe or channel, as shown in Figure 6.2.

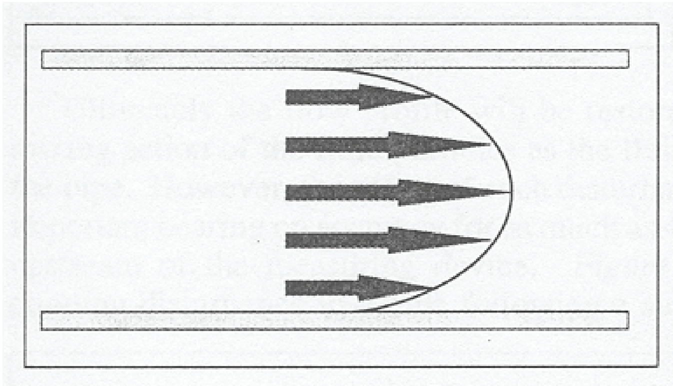


Figure 6.2 A fully developed laminar velocity profile (Crabtree, 2000)

This is the type of profile in which most measuring devices are meant to operate, but it can be quite difficult to ensure that it always occur at all measuring locations. Poor flow conditions, or turbulent flow, are caused by disturbances upstream of the measuring location, such as bends, reducers, sluice gates, pumps, etc. These disturbances can be transmitted for long distances downstream, necessitating the placement of measuring devices to be carefully considered. A graphical representation of an example of flow disturbance is shown in Figure 6.3.

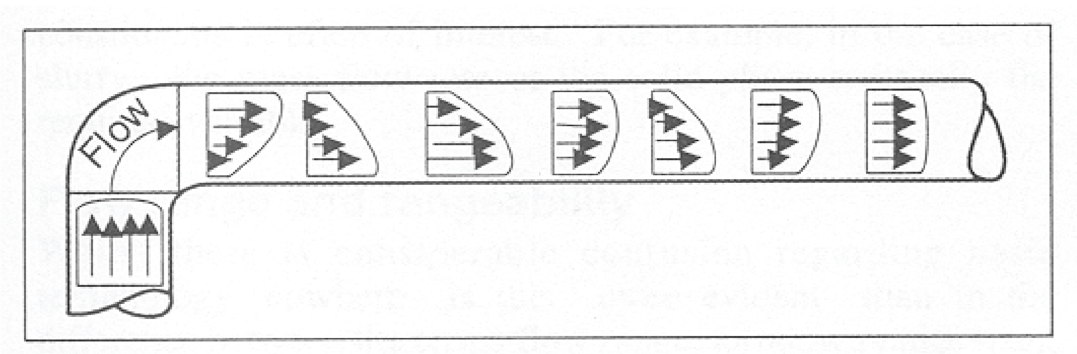


Figure 6.3 Disturbance of the velocity profile by a pipeline bend (Crabtree, 2000)

Most measuring devices therefore require a certain length of straight pipe or canal section upstream of it to ensure a fully developed laminar velocity profile is established and measurements are accurate. Other basic requirements are that full closed conduit flow, the conduit (or pipe) should always flow full, and for open channel flow the water should be discharged freely at the downstream end, as far as possible. These requirements can be met through correct installation, and are discussed further in section 6.3 below.

6.1.3 Definition of a measuring device

All fluid meters consist of two distinct subunits: a primary device that interacts with the fluid and the secondary element that translates the interaction into flow quantities (volumes or weights) or discharge (quantity per unit time) that can be observed and acted on by a human operator or by control equipment (Replogle, Clemmens & Bos in Hoffmann, 1991).

The Instrument Society of America (ISA) gives the following definitions related to flow meters (Miller, 1989):

> *Flow meter:* A device that measures the rate of flow or quantity of a moving fluid in an open or closed conduit. It usually consists of both a primary and secondary device.
>
> *Flow meter primary device:* the device mounted internally or externally to the fluid conduit which produces a signal with a defined relationship to the fluid flow in accordance with known physical laws relating the interaction of the fluid to the presence of the primary device.
>
> *Flow meter secondary device:* the device that responds to the signal of the primary device and converts it to a display or to an output signal that can be translated relative to the discharge or quantity.

Both the primary and secondary devices can consist of one or more elements to perform its specific function.

The Queensland Department of Natural Resources and Mines (2002), however, defines a flow meter for the purposes of their Water Metering Extractions Policy as:

> "a device for measuring, or giving an output signal proportional to, quantities of water passed and / or the rate of flow in a pipe or channel. This policy uses the term metering to include not only water meters but also other measurement tools, for example depth measurement gauges."
>
> And further:
> "For the purpose of determining an estimate of meter installation cost, a meter shall be deemed to include the physical device and any supporting equipment, plus such straight lengths of pipe connecting to the upstream and downstream ends of the meter as specified by the meter manufacturer to be necessary to ensure the required accuracy and / or durability of the meter."

For the purpose of this Water Research Commission (WRC) report however the term "measuring device" will be used to refer to a combination of primary and secondary instruments and / or structures for measuring flow, either as a volume or a rate, in open channels or pipes with the installation costs and infrastructure excluded (to be considered separately). The measuring device will perform certain functions at specified minimum standards.

6.2 Selection

The following factors should be taken into account when setting standards the device should meet:

6.2.1 Type of flow

The most basic decision to be made is whether the measuring device is required for open channel or pipe flow conditions. Irrigation schemes often use a combination of distribution system types so it is quite possible that both types of measuring devices may be required by one WUA. One example is where water on an irrigation scheme is distributed by canals with open channel measuring structures, but the farm off-takes are pipes fitted with flow meters.

6.2.2 Water quality

Water quality is usually determined by the water source, especially in terms of possible physical and chemical impurities that may occur in the water and influence the performance of a measuring device. Acidity and alkalinity in water can corrode metal parts while water contaminants can damage lubricants, protective coatings and plastic parts. Mineral encrustation and biological growth can impair moving parts and plug pressure transmitting ports. Sediment can abrade parts or consolidate tightly in bearing and runner spaces inside devices. If the WUA is not sure that a specific device will meet with the requirements, is recommended that one device be installed and monitored for a period of time. Although this practice may delay the process it can also prevent the wrong devices being bought and possible financial loss by the WUA.

6.2.3 Flow range

All measuring devices have specified minimum and maximum flow rates within which it has to operate in order to work effectively. The ratio of the maximum to the minimum flow is referred to as the turndown ratio. Some devices can handle a wider range of flow rates, and therefore is referred to as having a high turndown ratio. Most devices are manufactured in a range of sizes, with each size most suitable for a specific flow range. Devices should be selected of the basis of the flow range and **not** the size of the existing infrastructure, for example if water is pumped through a 100 mm pipe it doesn't necessarily imply that a 100 mm flow meter will be the correct choice. It is therefore important that the minimum and maximum flow rates to be measured at each location be specified.

6.2.4 Pressure head

The available head should be known so that the effect of measuring devices that causes head loss, can be determined. In the case of open channels, the installation of a measuring structure may cause an increase in flow depth leading to spillages upstream of the structure; in the case of pipe flow, a meter may cause additional friction loss leading to a reduction in the pressure available to an irrigation system that needs it to operate correctly. If a device has to be fitted into an existing system and there is not enough additional head available, a more expensive type of device such as acoustic or electromagnetic technologies may have to be used.

6.2.5 Accuracy

Measurement is at best an approximation and will always have a degree of error. The more accurate the flow needs to be measured, the more expensive the device will be.

Accuracy of measurement relates to the quality of the result and it is the maximum deviation of the meter's indication and the true value of the flow rate or the total flow. Accuracy is reported in percentage of error.

The accuracy of a water measurement device is commonly expressed as an error percentage of either the comparison standard discharge (or the actual discharge), measured with another device of known accuracy, or the upper range value (URV, or also called the full scale value) of the device being tested.
In the first case, the measurement error can be mathematically expressed as:

$$E_{\%CS} = \frac{100(Q_i - Q_{CS})}{Q_{CS}} \qquad (1)$$

where

$E_{\%CS}$ = error in percent comparison standard discharge
Q_i = indicated discharge from device being tested
Q_{CS} = comparison standard discharge as measured with another device of known accuracy

Comparison standard discharge is also sometimes called the actual discharge, but it is an ideal value that can only be approached by using a much more precise and accurate method or device than the one being tested.

The error as a percentage of full scale can be calculated from:

$$E_{\%FS} = \frac{100(Q_i - Q_{CS})}{Q_{FS}} \qquad (2)$$

where

$E_{\%FS}$ = error in percent full scale discharge
Q_{FS} = full scale or maximum discharge of the device being tested

Meter manufacturers usually specify the maximum measurement errors at specific points within the meter's flow range. An example is shown graphically in Figure 6.4.

In this example the manufacturer specifies that the meter's maximum measurement error will be ± 5% of the real value if the meter is operated within the flow range between the transitional discharge, Q_t, and the maximum discharge that the meter can handle, Q_{max}. If the discharge is between the minimum recordable discharge, Q_{min}, and Q_t, the measurement error will be less than ± 10%.

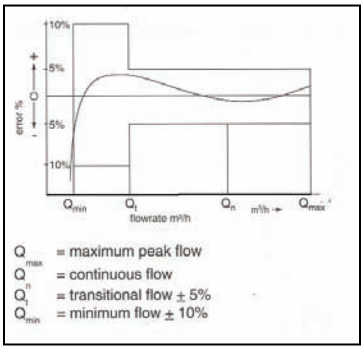


Figure 6.4 Example of a meter accuracy curve (Meinecke Meters, 2001)

The acceptable level of accuracy depends on the situation. Manufacturers test their meters in fully developed flow conditions where laminar flow is achieved. In the field, however, meters are more often than not subject to less-than-perfect conditions, resulting in accuracies lower than the laboratory values. Most of the irrigators interviewed during a survey indicated that they would be satisfied with ± 5% accuracy levels in the field.

Errors may be due to a number of factors, which can be related to the equipment used or the operator (or a combination), including nonlinearity, hysteresis, incorrect calibration, incorrect installation, bias, and reading, recording or computing mistakes.

The total error of importance for manufacturers is the result of the combination of systematic and random errors caused by components of the entire measurement system.

6.2.6 Repeatability

Repeatability relates to the quality of the measuring process and it is the degree of consistency or uniformity of a result. A measurement can be precise, or repeatable, without being accurate. The following example illustrates the difference between accuracy and repeatability.

The left 'target' on Figure 4.6 shows repeatability without accuracy, The right hand 'target' shows the accuracy with high repeatability.

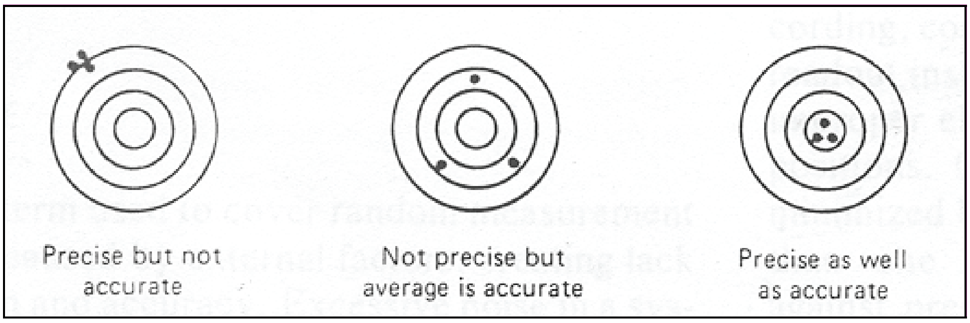


Figure 6.5 Difference between systematic and random errors (Dunnicliff, 1988)

6.2.7 Installation conditions

Installation conditions should be set that are practical and simple, but also create suitable flow conditions for the measuring devices. These conditions may limit the appropriate options, or increase the initial cost of certain devices so that they become uneconomical compared to alternatives. Examples are infrastructural requirements to protect the device or improve the flow conditions, such as long straight pipe sections to overcome sensitivity to turbulent flow conditions, or reduction in pipe size to achieve a certain flow velocity.

The installation is also often influenced by the location of the measuring devices. Remoteness, subjectivity to floods, accessibility for maintenance, etc. can influence the selection. The location may also determine the possibility of vandalism to the equipment.

6.2.8 Data output

The complexity of the functions of the meter always influences the cost, so that more complex and accurate meters are more expensive. Specifications can be set for the format of the data required, for instance as pulse or analog output, or the need for time and event type data recording.

6.2.9 Power requirement

Some measuring devices require electricity to operate, or requires electricity for advanced functions, so availability at the location becomes important. If electricity is not already available at the location, the additional cost should be taken into account or alternatives (such as solar or wind power) considered. This will also necessitate monthly electricity bills. Due to the problems of theft surrounding solar power units, a number of manufacturers have devices available that has internal batteries with very long life expectancy. One example is an ultrasonic flow meter that has a built in battery with a lifetime of 8 years.

6.2.10 Operating requirements

The data can be retrieved in different ways, such as manually at short intervals, with data loggers at longer intervals, or making use of telemetry to convey data to a central point, either periodically or continuously. The cost components (capital and running) of the different retrieval methods should be considered when making a decision. By spending more on the equipment, for instance investing in a telemetric communications system or buying a datalogger with more storage capacity, the running cost of data collection can be reduced considerably since it could eliminate visits to the installation sites, which are often remote and may be inaccessible in bad weather conditions.

6.2.11 Life expectancy

The life expectancy of the device should be enough to present opportunity for cost recovery and should not be subject to excessive and/or expensive maintenance. A minimum life expectancy of 10 years is considered realistic.

Some flow meter suppliers offer an option to lease meters to a WUA at an annual fee instead of selling them. The fee may include some basic maintenance costs, and there may be an option to replace meters if they malfunction or become outdated.

6.2.12 Maintenance, troubleshooting and repair

Since different devices have different maintenance needs, this can also influence the affordability (and therefore the appropriateness) of a specific device. The quality of the water can further affect the maintenance requirements of devices. For example, in the case of a canal system, continuous maintenance may be required to remove algae and other impurities from the water that clogs structures and outlets. Over time, it may prove that it would have been a better decision to have invested in acoustic or electromagnetic type devices that are not affected by impurities in the water, and saved the ongoing expense of cleaning trash screens. Especially smaller WUA may rather opt for low maintenance equipment that costs more initially if they do not employ technicians full-time. This also makes sense with regard to re-calibration and repairs, especially if devices are technologically advanced so that expert knowledge is needed in any case.

6.2.13 Resistance to tampering

Changes that have taken place in South Africa with regard to water legislation, access to information and improved technologies over the past two decades are making it more likely for irrigation water measurement to be implemented successfully. Old perceptions that all farmers steal water, and all water meters are tampered with and therefore unreliable are not valid anymore.

Many water users take a scientific approach to their farming practices and expect technologies to work for them. Many water users actually install water meters themselves as an aid to fertigation and scheduling. More suitable, better adapted devices are available that can operate effectively despite the presence of physical impurities in the water. The data management system can also be planned in such a way that checks and balances can be built in to pinpoint suspected irregularities.

New water legislation also further enables better enforcement since power lies with the WUA as a legal entity at local level to prosecute transgressors, instead of with DWAF. Provision for disciplinary actions, supported by the water users, can therefore be made in the WUA's constitution.

6.2.14 Environmental protection

The WUA will have to decide on the levels of climatic extremes the devices should be able to handle, especially in the case of electronic equipment. For most devices the manufacturers specify conditions such as minimum and maximum allowable operating temperature, humidity, voltage fluctuations / power surges, and vibration. Other conditions that may occur include electrostatic discharge, lightening strikes and electromagnetic susceptibility. Even mechanical devices can be damaged by extreme conditions, such as water freezing in small enclosures causing cracks even in cast iron, or damage from veld grass burning around insufficiently protected devices, melting plastic components.

6.2.15 Existing devices and user acceptance of new methods

In cases where existing devices are installed, these devices can be kept in use if they can perform the functions as identified by the WUA and meet with the required standards. If the devices however have a history of being inconsistent or inaccurate, or are incorrectly installed, the WUA should seriously consider replacing them. The water users are in any case unlikely to have faith in the output from the devices.

If the devices are still performing satisfactorily but are becoming outdated they could still be used while new devices are phased in over a period of time. The new devices should be acceptable to the water users; if there are any functions that the water users could use for their own benefit, these should be accessible so that they can experience any possible benefits. This will decrease the chances of vandalism, or disputes over device output.

6.2.16 Reliability

The chosen device should be reliable so that its output is credible and that water users and water management staff can have faith in it. In the past failure of in particular mechanical flow meters had led to a general perception that meters are unreliable and water user support for measuring was lost at many schemes. Reliability can not be quantified as such but is more a perception formed on the basis of accuracy, repeatability, resistance to tampering and maintenance requirements.

6.2.17 Legal constraints

Although legislation in South Africa has not developed that far yet, in future it may be possible that water measuring regulations are implemented which specify conditions that have to be met by a measuring device. This may limit the devices that can be selected from.

6.2.18 Impact on environment

Consideration should be given to potential environmental impacts of installing measuring devices. This aspect is more relevant where water is measured in a natural waterway and the installation of additional infrastructure may disturb the natural conditions. For example, the installation of a structure in a river causes lower velocities, resulting in sedimentation, or water backing up and flooding production areas alongside the waterway. Acoustic measuring devices offer considerable environmental advantages over structures because there is basically no resistance to flow, although they cost considerably more.

6.2.19 Cost

As discussed in section 5.3, cost is the final deciding factor. The cost of installing measuring devices must be justifiable by the benefits to the WUA. Obviously, the WUA will opt for the most affordable solution that meets its needs.

6.3 Generic installation requirements

6.3.1 General requirements

- The device should be installed in the position and orientation recommended by the manufacturer, supplier or designer, to ensure it operates as intended.
- There should be no air or vapour in the water, since this can cause damage to components or incorrect measurements.
- If the water quality is poor and the selected device will not be able to let the debris past, filtration elements have to be installed upstream of the measuring location to protect the measuring device. These filters should be installed in a way that they do not interfere with the effective operation of the device, and should be easily accessible for maintenance and cleaning.
- Good quality construction materials should be used for the installation, and occupational health and safety procedures followed where necessary.
- There should be enough clearance around the installation for easy maintenance, calibration and removal of the device, if necessary. A concrete slab should be put around the area to stop excessive growth of grass and weeds. This will also protect the device in case of veld fires. In general, the site should be easily accessible.
- If necessary and possible, install connections for in-field calibration or verification permanently so that they are in place when required. These may include pressure tappings, inspection inlets, or positioning guides for current meters.
- If the measuring device is installed in a critical section of the water supply network, providing a bypass will make it possible to remove the device for repairs without stopping the flow.
- Once all the equipment has been installed, a pre-commissioning check should be done to make sure everything is in place, fastened, connected, etc. The device should then be filled with water to see if it is operating correctly and if there are any leaks or faults. In-field calibration to check the accuracy after installation should be done and any corrections made, if necessary.
- After commissioning and calibration, seals should be installed to prevent further adjustments or tampering. Other anti-vandalism devices may also need to be installed.
- A form should be drawn up which must be signed by the WUA, the water user and the contractor, if relevant, after completion of the installation to confirm that all parties involved is satisfied that the device is properly installed and operating correctly.
- The location of the measuring device should be sign-posted so that it can be found and identified in future. It is also good practice take at least one photograph of the completed installation and to find the location's GPS coordinates for future reference.

6.3.2 Closed conduit requirements

- In order for a flow meter to operate correctly, the pipe is fitted in should always be completely full of water. If there is any air or vapour in the pipe, this can not only lead to measuring inaccuracies but also to damage to components. For example, if air is forced through a pipe fitted with a mechanical flow meter, the rush of air can cause the turbine to turn faster than ever intended and damage its mechanisms.

- A meter should preferably be installed in a low horizontal or slightly rising section of pipe, and never in a vertical section where the flow is going downwards, or a horizontal section that is the highest part of the pipeline.
- If varying conditions exist, equipment to protect the meter against pressure pulsations and flow surges should be installed.
- The flow conditions in the pipe should be as close as possible to established laminar flow. To achieve this the following installation guidelines are recommended:
    - The meter should be fitted in a pipe section where upstream of the meter the pipe is straight, without any fittings that can cause disturbances, and with a constant diameter, for a length of at least 10 times the pipe diameter. An absolute minimum of 5 diameters can be used.
    - The meter should be fitted in a pipe section where downstream of the meter the pipe is straight, without any fittings that can cause disturbances, and with a constant diameter, for a length of at least 5 times the pipe diameter. An absolute minimum of 3 diameters can be used.
    - Examples of typical lay-outs as developed by the Queensland Department of Natural Resources and Mines are shown in Figures 6.6 to 6.9.
- If stable flow conditions cannot be achieved through the above guidelines, it is possible to use flow conditioning devices such a straighteners or vanes inside the pipe. This practice however is not recommended for irrigation water since it contains impurities that may cause a blockage at the straightener.
- If impurities in the water are a problem for the selected meter, a filtration element can be installed upstream of the meter, although this is not recommended since the filter may become blocked and will require regular maintenance. It will be better to select another meter that is less sensitive to impurities.
- Make sure that the meter is installed in the right direction, if relevant. Mechanical meters can only measure cumulative flow in one direction and should be installed correctly. Electromagnetic and acoustic meters can often measure bi-directional flow and will then have two totalisers, one showing positive flow and one showing negative flow, in which case is important to know the orientation of the meter.
- If possible any flow control devices such as valves, t-pieces, etc. should be installed downstream of the meter to prevent disturbance of the approach velocity profile.
- It is however necessary to install a control valve the required distance of 10 pipe diameters upstream of the meter in the case of long downhill pipelines, so that the flow in the pipe can be stopped if the meter has to be removed. It is also useful to have drainage plug close to the meter so that the pipe can be drained before removing the meter.
- If the meter is located near a local peak in a pipeline, it is recommended that an air valve is installed.
- If possible use galvanized metal, or otherwise protect the metal against corrosion with suitable paints.
- When cutting or welding near flow meters, make sure that the pipework does not heat up around plastic fittings or components, since they will melt.
- If possible, install an adjustable coupling on one side of the meter. This will allow for expansion of the pipework, as well as easy removal of the meter.
- Standardise to a specific type of flange (for example Table D or Table 16) so that fittings can be universal. When ordering meters attention should be given as to what flanges they are fitted with.
- Gaskets should be used between flanges and bolts torqued correctly to make sure that there are no water leaks and there is no unnecessary strain on the pipe work.

- If the meter is installed above ground, it should be supported on both up and downstream sides to minimize the effect of vibration.
- Avoid strong electromagnetic fields in the vicinity of the meter. This can affect its operation and calibration.
- Any earthing requirements set by meter manufacturers should be adhered to, especially in the case of electromagnetic flow meters.
- Lightning protection should be installed with any electronic equipment.

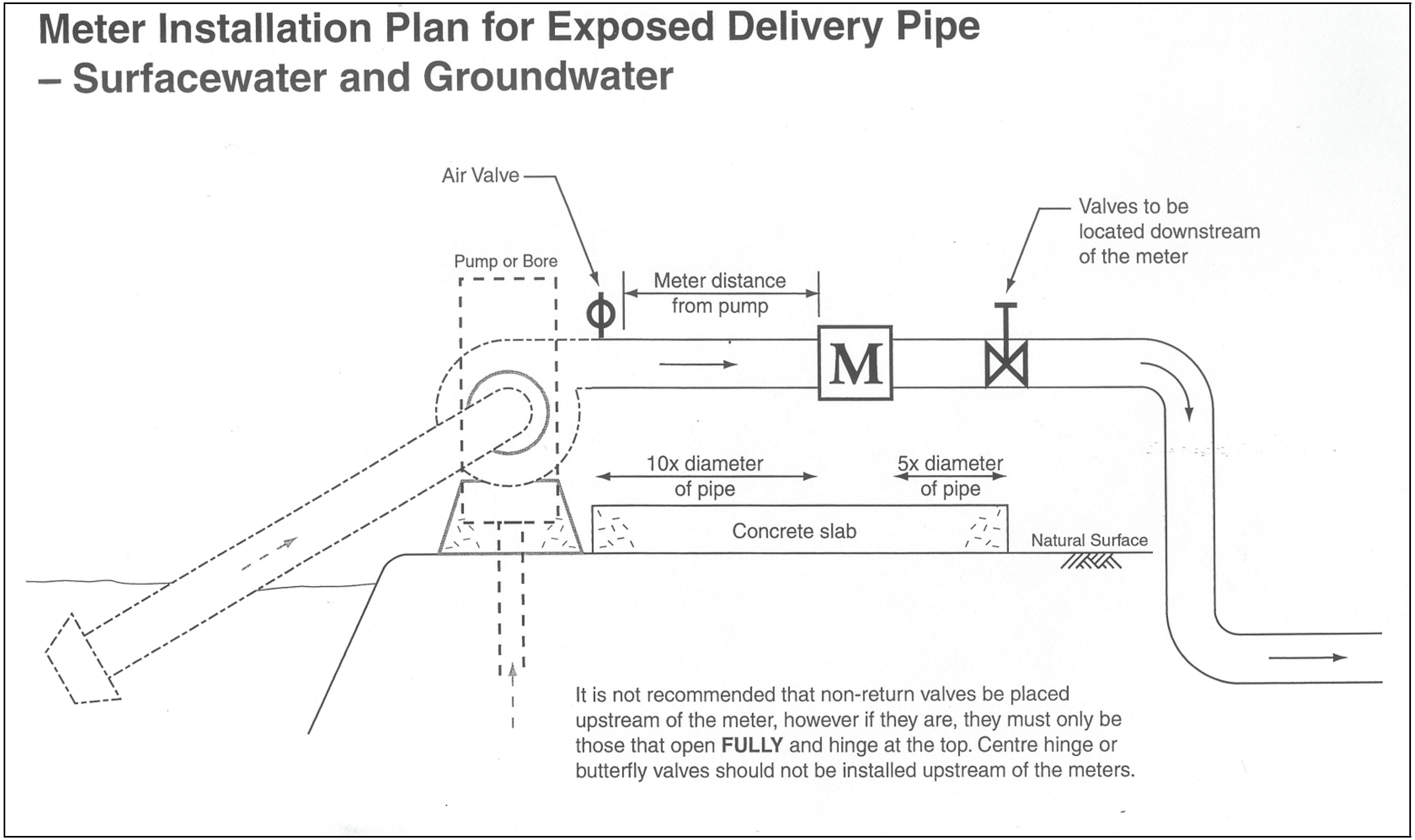


Figure 6.6 Example of meter installation requirements (Queensland Natural Resources and Mines, 2003)

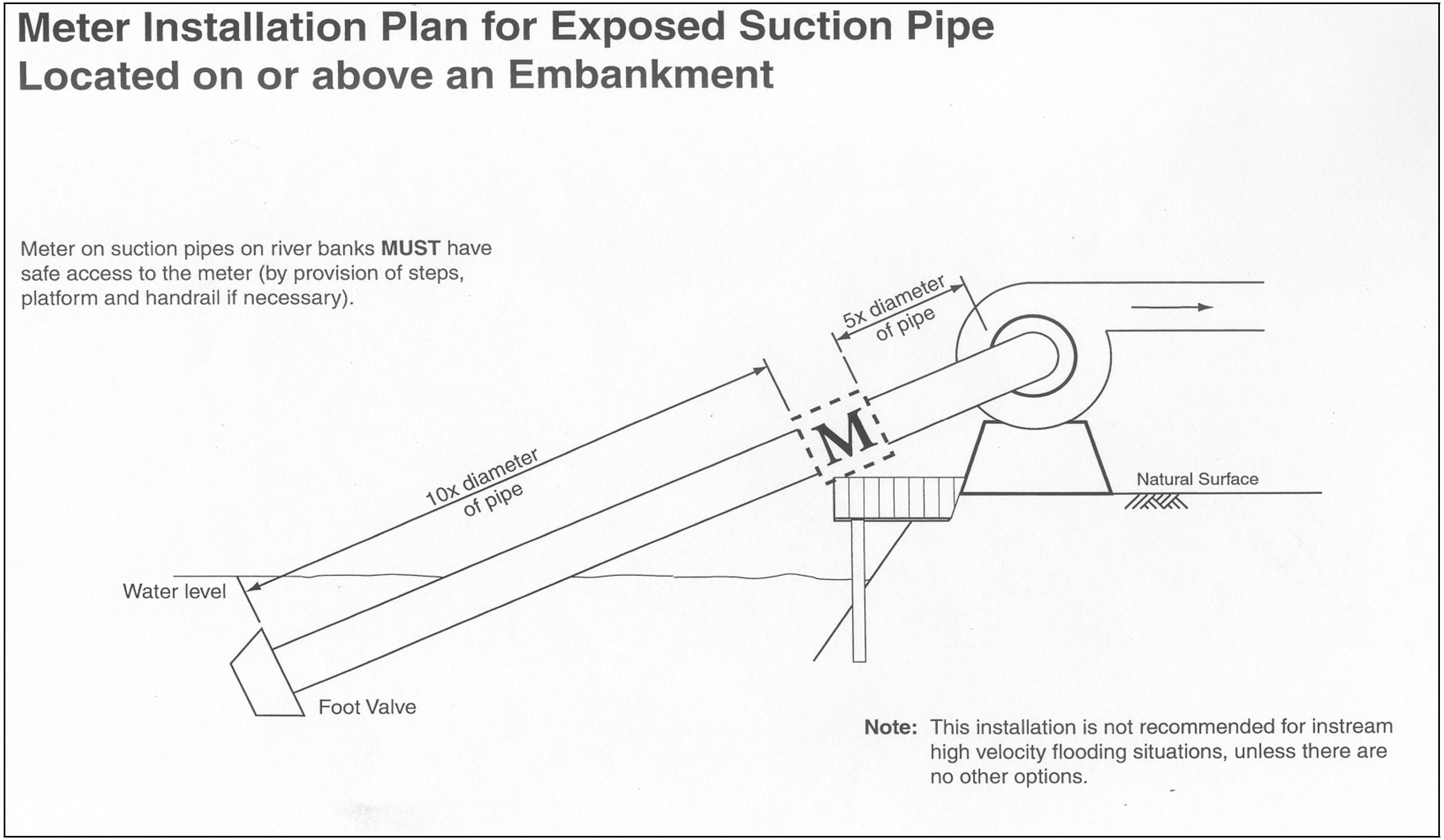


Figure 6.7 Example of meter installation requirements (Queensland Natural Resources and Mines, 2003)

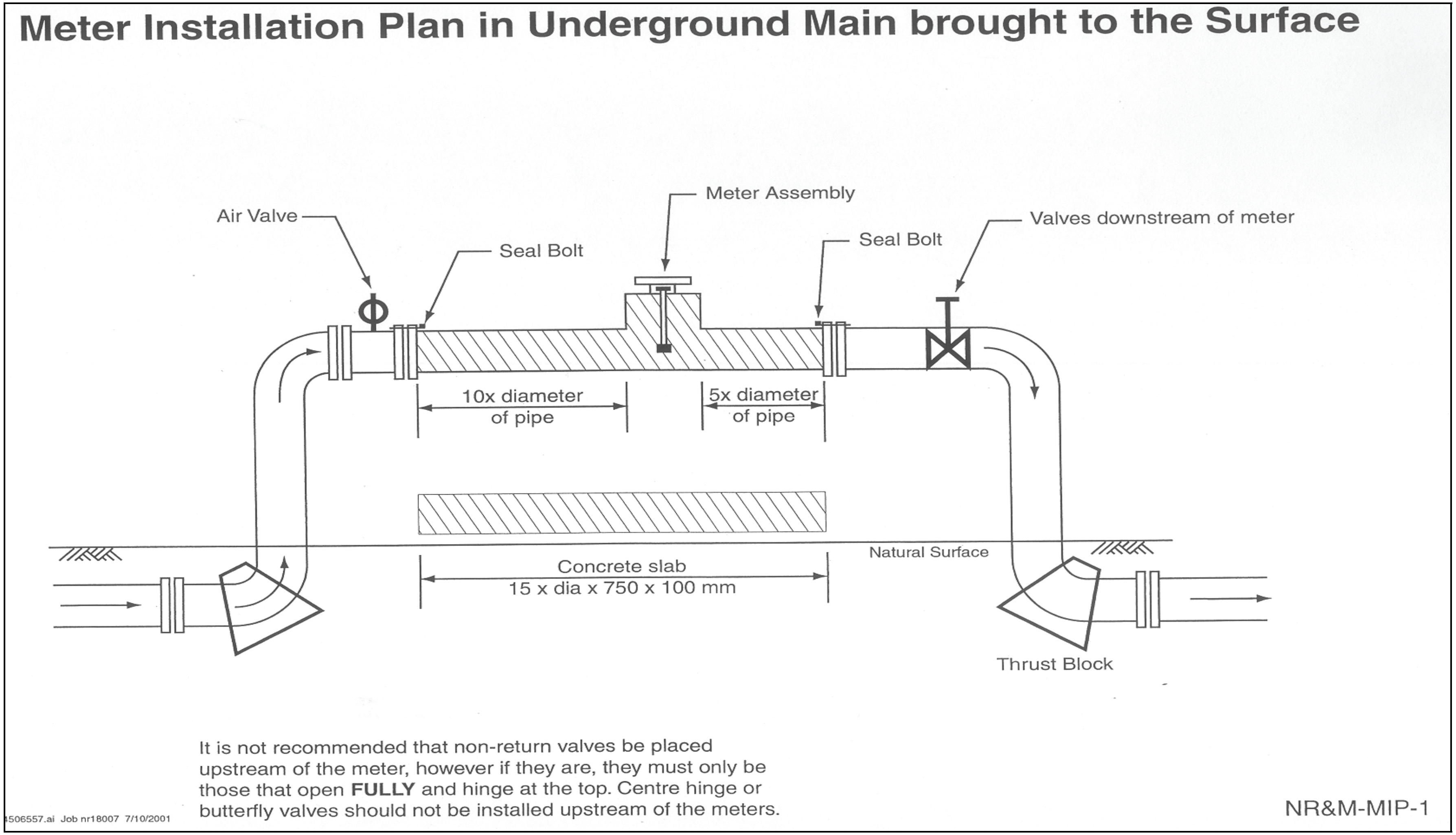


Figure 6.8 Example of meter installation requirements (Queensland Natural Resources and Mines, 2003)

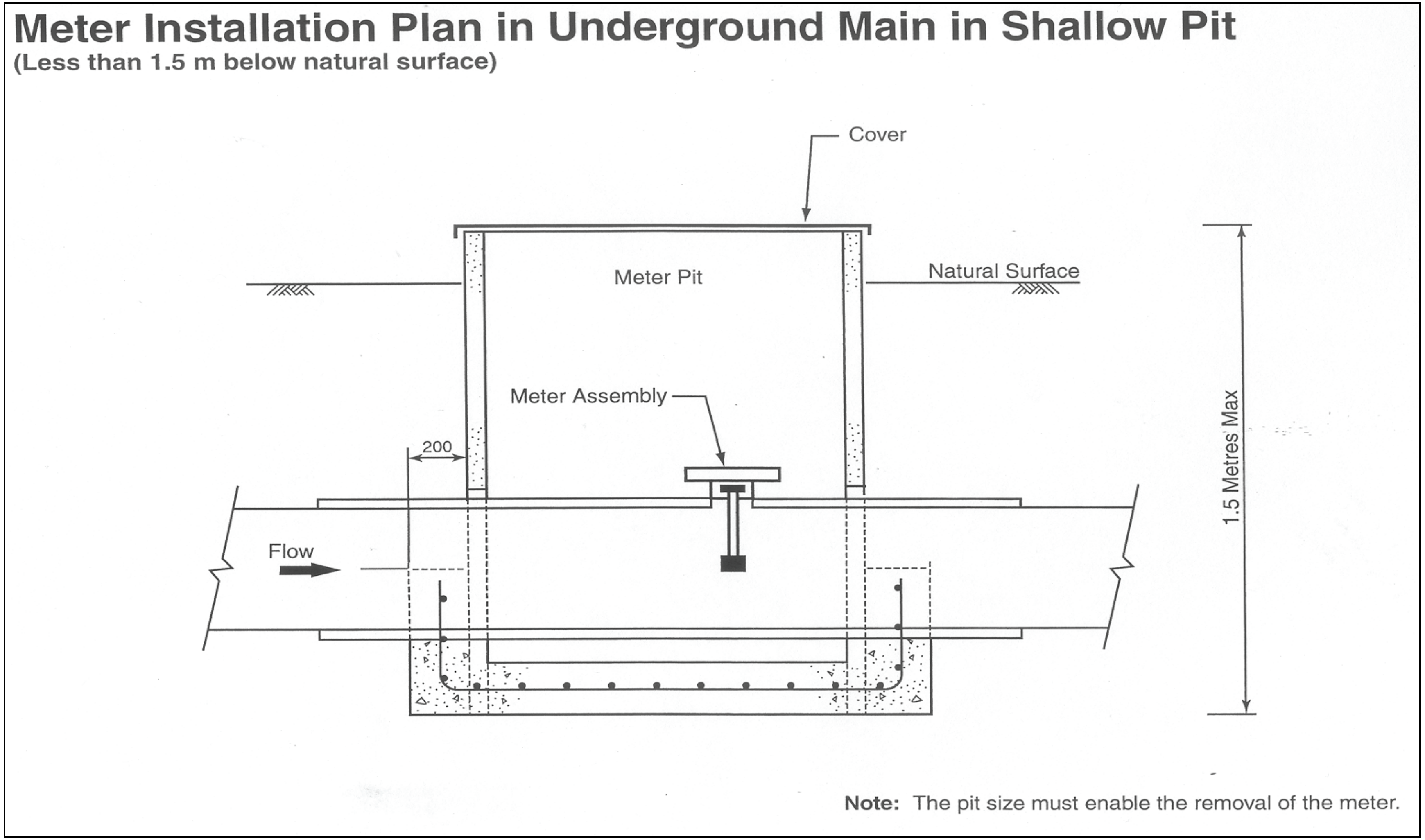


Figure 6.9 Example of meter installation requirements (Queensland Natural Resources and Mines, 2003)

6.3.3 Open channel requirements

- Good approach flow conditions should be created, to prevent turbulence and swirling in the water upstream of the measuring device. Recommendations made by Bosch (1989) according to the USBR (1997) are as follows:

  If the control width (eg. width of a weir) is greater than 50 % of the approach channel width, then 10 average approach flow widths of straight, unobstructed approach are required;

  If the control width is less than 50 % of the approach channel width, then 20 control widths of straight unobstructed approach are required;

  The first two recommendations are valid for sub-critical flow (i.e. generally deep, slow flow conditions). If supercritical flow (i.e. shallow fast flow conditions) occurs, a hydraulic jump should be forced to occur, and a distance greater than 30 measuring heads where straight unobstructed flow occurs allowed for downstream of the jump before measuring takes place;

  If baffles or other wave dampening devices are used to condition the flow, it should be followed a distance of at least 10 measuring heads before measuring takes place.
- If ideal flow conditions are not present, excessive turbulence and swirling can be reduced by installing wave dampening devices such as baffles or floats upstream of the measuring location. It is however better to avoid measuring at locations where poor flow conditions exist, or then at least to use the least sensitive devices available.
- The exit flow conditions should allow as far as possible for free flowing conditions to prevent submergence of structures. The mathematical relationship between flow rate and the measured head at a structure is usually based on the assumption that the structure is not submerged and that the nappe is well ventilated. A clinging nappe will draw down the head upstream of the structure, resulting in incorrect head measurements.
- The water level sensing should take place at the correct position in or before the structure. It is best done in stilling basin constructed adjacent to the structure.
- The measuring structure or device should be well installed and/or constructed. It should be level in all directions, square and plumb, at the correct level relative to the waterway and the expected flow depth, with no leaks, and level sensing devices properly fastened at the correct heights.

6.4 Testing and verification of devices

In order to ensure that a measuring device actually performs according to its specifications, it will be necessary from time to time to evaluate the measuring results against a standard. ANCID (2002) defines “testing” as providing the service of measuring, calibrating, examining, identifying, inspecting or checking a product or system for conformity or against specified standards or requirements. In the case of measuring devices, the requirement is usually the accuracy of the device.

Devices can either be tested under ideal conditions in a laboratory where the installation conditions as described in section 4.3 above can be met, or under field conditions, where the effect of non-ideal installation conditions on device accuracy can be determined. In both cases, however, it means that another measuring method, that is more accurate than the method or device being verified, have to be applied, and some of these methods are discussed further below.

6.4.1 Laboratory testing and classification

Laboratory testing is only applicable to devices that are supplied and installed as complete units, such as flow meters in closed conduits and some of the acoustic devices used in open channels. However, installation conditions can still affect these devices' performance and therefore even if a device performs well in a laboratory test it cannot be guaranteed that the device will perform equally well in the field.

Testing laboratories have to conform to certain standards as set by SANAS. There is only one approved facility in South Africa and that is owned by ESKOM and located in Johannesburg. Other laboratories however can have their verification equipment certified by the SANAS laboratory, and in that way obtain some additional credibility. The accreditation of any laboratory requires that the staff operating the testing facility have be trained to perform the work.

The laboratories rely on calibrated weighing tanks or volumetric tanks with timing equipment, or highly accurate flow meters to perform the reference measurement when testing devices. The testing method usually requires a certain volume of water to pass through the reference meter and the meter being tested for the accuracy to be calculated. This process is repeated at least three times and at different flow rates to get an impression of variation across the meters whole flow range.

The specification to which meters must conform in South Africa should be drawn up by the South African Bureau of Standards (SABS), but currently no such standards for raw water flow meters exist.

Meter manufacturers usually test and calibrate meters at the factory after manufacturing is completed, and a calibration certificate can be provided on request. It is however strongly recommended that the meters be tested in the field, once installed and from then on annually, to verify their performance under the actual operating conditions.

6.4.2 Field testing / Verification

Under field conditions, the effect of the installation is taken into account when evaluating measuring device accuracy and it can therefore be expected that field accuracy will be less than laboratory accuracy values. Furthermore, the reference measuring methods that can be applied in the field are limited, and the available methods may be less accurate than sophisticated laboratory methods. However, despite these limitations, in-field verification can be done in most cases to an acceptable level of accuracy and often provided more useful information than laboratory testing. Especially in the cases of disputes, it may be more effective to evaluate a device on site in the presence of the parties involved with the dispute.

In the case of closed conduits, field testing is best done with a portable acoustic meter. These meters have transducers that are clamped temporarily to the outside of the pipe, and the system is further set up by entering the necessary parameters into a computer programme that controls the meter. Parameters include pipe size and wall thickness, water temperature and pipe material. The transit time type of acoustic meter is preferred for use during field testing because of its high level of accuracy and repeatability but requires skill and experience to install and operate correctly. Portable acoustic meters are discussed in section 8.3.

Open channel measuring devices are less easy to verify due to the disturbance that may be caused by any devices that are inserted into the flow path of the water directly up or downstream of the device being evaluated. The most suitable method that can be recommended is through the use of hand-held acoustic Doppler velocity meters (ADVMs). These meters have recently become available in South Africa but are quite expensive, and instead the older type of mechanical velocity meters (also called current meters) can also be used.

Both type of devices require a number of velocity readings to be taken at different positions in the flow cross sectional area. These readings are then considered to be representative of the total area and used to calculate the flow rate in the channel. Mechanical current meters are more sensitive to flow disturbances and require more calculations. The ADVMs on the other hand collect the velocity data electronically and can calculate and display the flow rate almost instantaneously after the measurements have been collected. These devices are discussed in chapter 7.

There are no standard guidelines for field testing and verification of devices, but in general it is important to install and operate the reference device according to the manufacturer's specifications to obtain good results. It is also good practice to have verifications done by a team consisting of at least two people, and to repeat and verification measurements at least three times to check for repeatability and random errors. Taking photographs and notes of the testing conditions are also important as well as good record-keeping of the data.

6.5 Knowledge base of measuring systems (KBS)

As shown in section 4.2, there are a wide array of factors that have to be taken into account when selecting a suitable device. There are many different devices commercially available that may meet the requirements set by a specific WUA, and in order to make the selection process easier, a database of available equipment, called the KBS, was compiled and will be distributed with this report.

The Knowledge Base System (KBS) is a database that can be used to capture detailed information on any measuring device for open channel flow, closed conduits and boreholes. The information can be filtered on the application of the device (e.g. open channel and closed conduit), method used for measurement (e.g. pressure, mechanical, ultrasonic etc.) and the brand name of the device. Detailed information can be captured for each device on the following:

- Accuracy
- Calibration
- Installation
- Maintenance
- Advantages
- Disadvantages
- Unlimited number of pictures per device including descriptions
- Address list of current installations and suppliers

KBS has extensive searching capabilities. The information can be sorted in a number of ways. A list of keywords can be linked to every measuring device that, if populated correctly, results in a very powerful searching capability. All the information in the database, including pictures can be printed.

The following are some of the benefits of using the KBS:

- Assist in obtaining information about a measuring device
- Centralized database of available measuring devices
- Better knowledge of available devices
- Improve device handling, for instance calibration, installation and maintenance
- Extensive device querying capabilities
- View pictures of different devices

KBS requires at least a 486-PC running Windows 95/98/ME/NT/2000/XP. At least 64Mb random access memory (RAM) is needed to run the program, but 128Mb is recommended.

KBS is written in Delphi and it uses Firebird as the underlying database. Firebird is a relational database management system (RDBMS) that provides rapid transaction processing and data sharing in a single- or multi-user environment.

The KBS main screen consists of a number of speed buttons at the top and a few dropdown boxes that is used to sort and filter the records in the database. The bottom of the screen displays a number of Tabs which is used to edit and display information on the current record (device) selected.

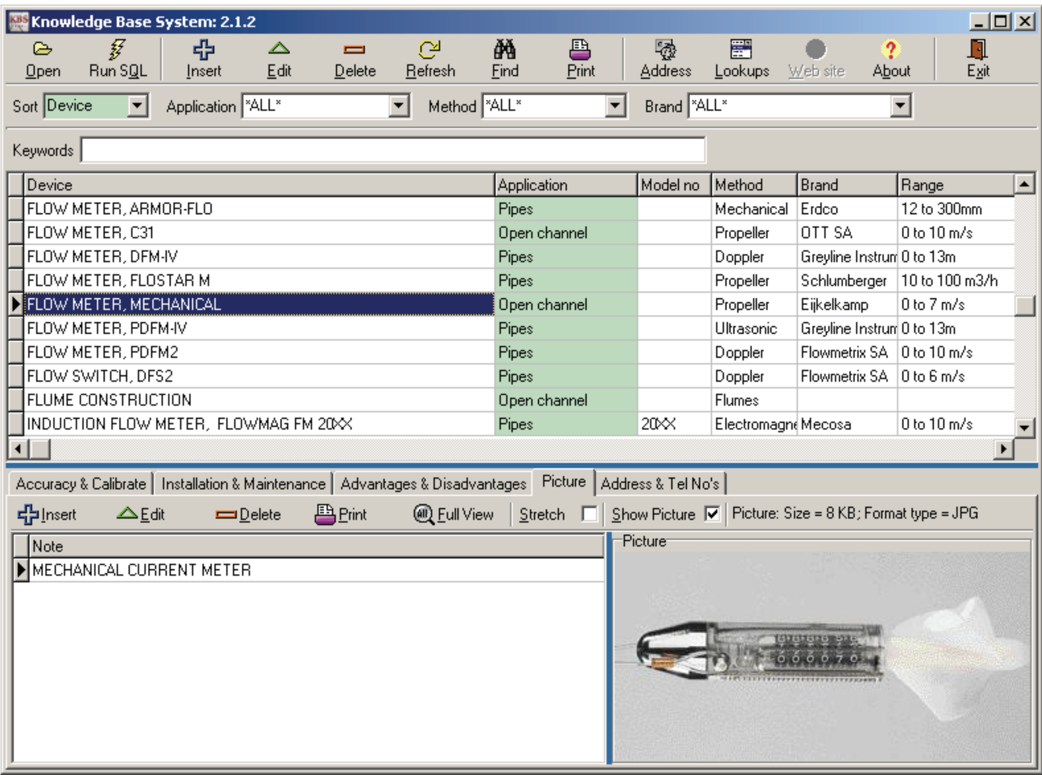


Figure 6.10   KBS main form

The following information is included on each device in the KBS:

- Device: Device description.
- Application: Device application which is selected from a list in a dropdown box. The options are:
  - Open channel
  - Open channel & wells
  - Pipes
- Model no: Device model number.
- Method: Device measuring method which is selected from a list in a dropdown box. The choices are:
  - Flow: Acoustic Doppler
  - Flow: Acoustic Transit Time
  - Flow: Differential Pressure
  - Flow: Electromagnetic
  - Flow: Electronic
  - Flow: Flumes
  - Flow: Impeller
  - Flow: Propeller
  - Flow: Proportional
  - Flow: Turbine
  - Flow: Woltmann
  - Velocity: Doppler
  - Velocity: Mechanical
  - Water level: Acoustic
  - Water level: Bubble
  - Water level: Mechanical
  - Water level: Pressure
- Brand: Device brand name which is selected from a list in a dropdown box. The brand names are user defined and it is maintained under the Lookups button (**Lookups|Brand**).
- Range: Measuring range which is selected from a list in a dropdown box. The measuring range is a user defined string and it is maintained under the Lookups button (**Lookups|Range**).
- Cost: An indication of the cost of the device which is selected from a list in a dropdown box. The cost is a user defined string and it is maintained under the Lookups button (**Lookups|Cost**)
- Web site: The web site address of the current device which can be accessed using the **Web site button** at the top for the form. The Web site button will only be active if a web site address has been captured for the specific device.
- Keywords: A list of keywords which are captured to filter the data according to the specified keyword. The Keywords box at the top of the screen is used as a keyword filter. The number of keywords per device is limited to 1000 characters.
- Accuracy: Used to capture any notes on the accuracy of the specific device. Maximum of 1000 characters.
- Calibrate: Used to capture any notes on the calibration of the specific device. Maximum of 1000 characters.
- Installation: Used to capture any notes on the installation of the specific device. Maximum of 1000 characters.
- Maintenance: Used to capture any notes on the maintenance of the specific device. Maximum of 1000 characters.
- Advantages: Used to capture any notes on the advantages of the specific device. Maximum of 1000 characters.

- Disadvantages: Used to capture any notes on the disadvantages of the specific device. Maximum of 1000 characters.

Different reports can be printed after the KBS has been searched, including detail information on a specific device and lists of devices meeting a set of requirements.

Addresses and contact details of the device suppliers and also clients (existing meter users) are included in the KBS. The different addresses can be linked to specific device information records.

The KBS is currently populated with valid data and available on a compact disc (CD), but it is envisaged that it will be maintained and updated in future, possibly as a website, to ensure data stays relevant and useful. The complete user manual is attached in Appendix B, as well as a printed list of the device suppliers listed in the KBS.

7. OPEN CHANNEL FLOW MEASUREMENT

Open channel flow measurements are normally made by measuring the water depth (head) or average velocity which is then converted to flow rate. The devices commonly used for these measurements are flumes, weirs, gauges and many types of mechanical, electromechanical, and electronic sensors. The three most commonly used types are float-driven sensors, pressure sensors, and ultrasonic sensors. These measuring devices and sensors are discussed in the following paragraphs as they applies to open channel flow. For more commercially oriented information, including costs, the Knowledge Base System (KBS) should be consulted under the application “Open channels”.

7.1 Primary elements for open channel flow measurement

7.1.1 Weirs

7.1.1.1 Introduction

A weir is a low dam or overflow structure built across an open channel. It has a specific size and shape with a unique free-flow, head-discharge relationship. The edge or surface over which the water flows is called the crest. Discharge rates are determined by measuring the vertical distance from the crest to the water surface upstream from the crest.

Weirs can be used for both high flows with the discharge measured using the water level upstream of the weir or for volumetric flows in extremely low flow conditions that are too small to measure with a current meter.

Weirs are one of the oldest structures to measure the flow rate in open channels. Many weirs of different shapes can be used to calculate the flow rate in channels. One of the most commonly used weirs is the sharp-crested weir and specifically the following types:

- Rectangular with no end contractions
- Rectangular with end contractions
- V-notch
- Trapezoidal or Cipolletti

The sharp-crested weirs are most commonly used in smaller irrigation channels and are ideal for water distribution purposes. The V-notch is preferred in cases when very small discharges are measured because of the small cross-sectional area that leads to a greater variation in head.

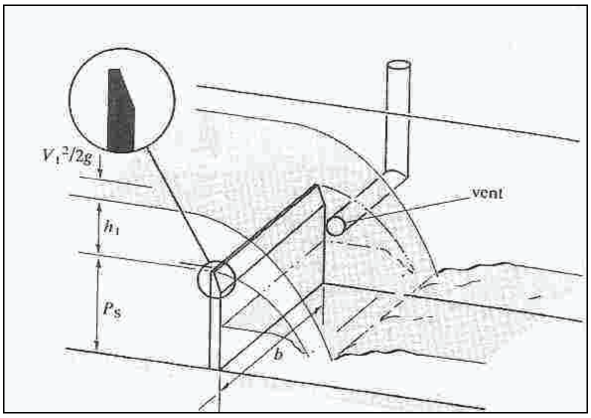


Figure 7.1 Rectangular weir with no end contractions

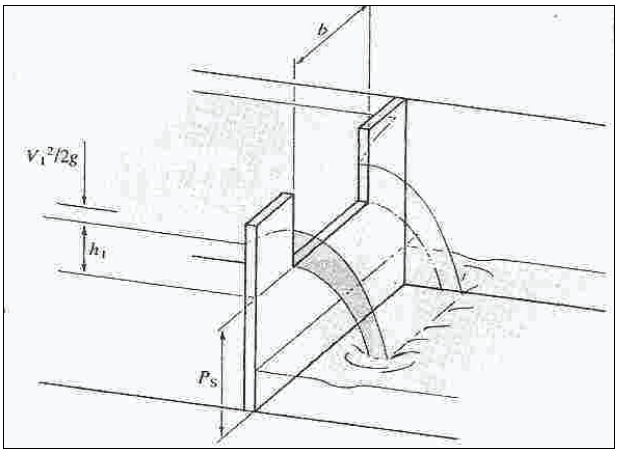


Figure 7.2 Rectangular weir with end contractions

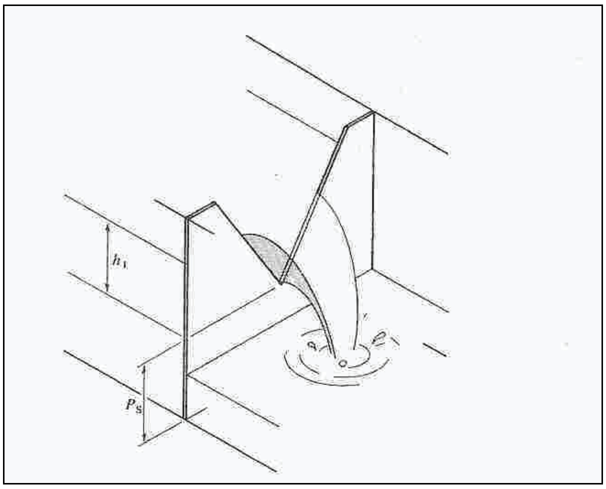


Figure 7.3 V-notch

7.1.1.2 Installation

Approach flow conditions are important in all measuring structures in open channel flow. Poor flow conditions just upstream of measuring structures can cause large errors in the flow measurement. The approaching flow should be sub-critical without any waves. The approaching channel should be straight for a recommended length of 40 times the hydraulic radius.

The following installation requirements are common to all types of sharp crested weirs and must be complied with to ensure the accuracy of these measuring structures:

- The upstream face must be vertical and the crest plates, usually of brass or stainless steel, must be provided with an accurately finished upstream square edge.
- The crest width must not exceed 3 mm and it must have a bevel on the downstream side.
- The measuring plate must be built perpendicular to the flow.

7.1.1.3 Advantages

The main advantages of sharp crested weirs are:

- Accurate.
- Easy to install.
- Not very expensive.
- Handles a range of different flows. The V-notch is very sensitive at low flow conditions.

7.1.1.4 Disadvantages

The main disadvantages of sharp-crested weirs are:

- Sharp crested weirs are slender and lack stability if the structure is getting too large. It is therefore vulnerable to handle debris-laden flood discharges.
- Under continuous operation there is a tendency for the crest to become rounded which effects the calibration.
- Sediment deposition occurs upstream of the weir in sediment laden streams.

7.1.1.5 Maintenance

The approach to the weir crest must be kept free of sediments and deposits.

7.1.1.6 Further reading

Irrigation Design Manual: Chapter 8 Flow measurement (Burger et al., 2003)

7.1.2 Flumes

7.1.2.1 Introduction

"Long-throated flumes and broad-crested weirs are usually the most economical of all structures for accurately measuring open-channel flows, provided that conditions are such that a weir or flume is feasible"

Flumes and weirs are designed to force a transition from sub-critical to super-critical flow. The transition is created with a narrow section (throat) and a drop in the channel bottom. Such a transition causes the flow to pass through critical depth in the flume's throat. At the critical depth, energy is minimized and there is a direct relationship between water depth, velocity and flow rate. The primary function of weirs and flumes is to calculate the flow rate from a measured flow depth (head).

The flume may be operated as a free-flow, single-head measuring device, or operated under submerged-flow conditions where two heads are measured. The head in the converging section and the head near the downstream end of the throat section are measured in stilling wells. Both measurements have their datum at the elevation of the floor of the converging section. Free flow occurs when the ratio of the lower reading to the upper reading is less than 0.6. The discharge under this condition depends only on the length of crest (width of throat section) and depth of water at the upper reading. Submerged flow occurs when the ratio of the lower reading to the upper reading exceeds 0.6. When this occurs, a reduction adjustment to the free-flow rating of the flume is needed. Since the flow velocity is high it is considered self-cleaning in sediment laden streams and deposition of sediments is practically eliminated. A flume that is properly constructed has an accuracy of 2-3 percent under free-flow conditions, but is less accurate during submerged flow.

The two basic classes of flumes are:

Long-Throated Flumes:

Long-throated flumes control discharge rate in a throat that is long enough to cause nearly parallel flow lines in the region of flow control. Parallel flow allows these flumes to be accurately rated by analysis using fluid flow concepts. The energy principle, critical depth relationships, and boundary layer theory are combined to rate flumes and broad-crested weirs by Ackers et al. (1978) and Bos et al. (1991). Thus, the long-throated flumes and modified broad-crested weirs are amenable to computer calibrations. Long-throated flumes can have nearly any desired cross-sectional shape and can be custom fitted into most canal-site geometries. The modified broad-crested weirs (Replogle, 1975; Bos et al., 1991), also called ramp flumes (Dodge, 1983), are styles of long-throated flumes.

Short-Throated Flumes:

Short-throated flumes are considered short because they control flow in a region that produces curvilinear flow. Although they may be termed short throated, the overall specified length of the finished structure, including transitions, may be relatively long. The Parshall flume is the most common example of this type of flume. These flumes would require detailed and accurate knowledge of the individual streamline curvatures for calculated ratings, which is usually considered impractical. Thus, calibrations for short throated flumes are determined empirically by comparison with other more precise and accurate water measuring devices.

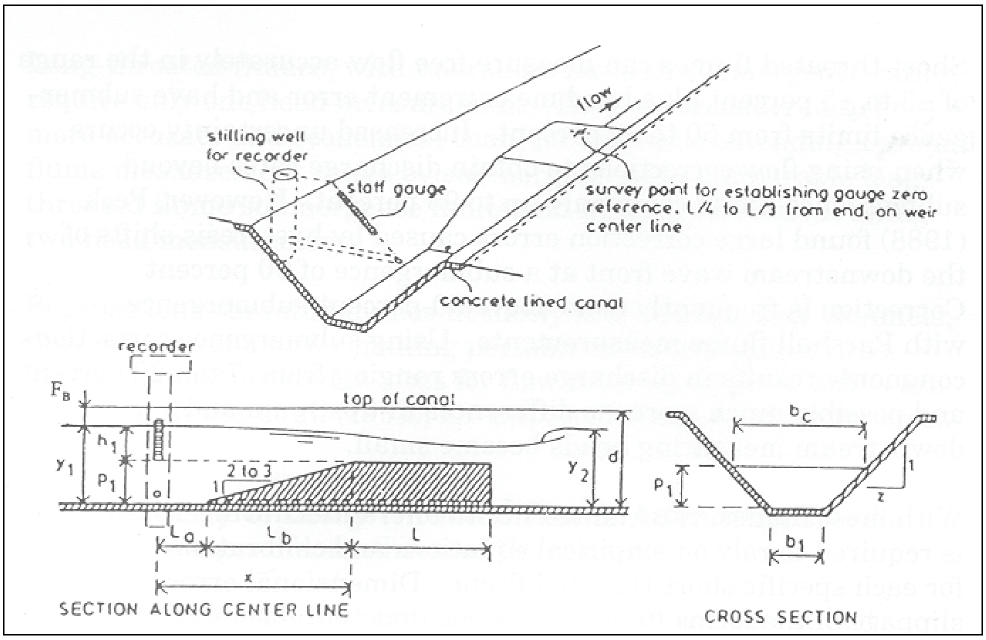


Figure 7.4 Flat-crested long-throated flume in concrete-lined canal.

7.1.2.2 Installation

Proper location of the flume is important from the standpoint of accuracy and ease of operation. For convenience, the flume should be located near the diversion point and near the regulating gates used to control the discharge. Flumes should be readily accessible by vehicle for both installation and maintenance purposes. All structures for measuring or regulating the flow rate should be located in a channel reach where an accurate head can be measured.

Flumes should not be installed too close to turbulent flow, surging or unbalanced flow, or a poorly distributed velocity pattern. Poor flow conditions in the area just upstream from the measuring device can cause large discharge indication errors. In general, the approaching flow should be tranquil. Tranquil flow is defined as fully developed flow in long straight channels with mild slopes, free of curves, projections, and waves.

Studies of approach requirements for closed conduits have led to the acceptance of 10 diameters of straight pipe as sufficient for meters claiming to be accurate to within 0.5 to 1 percent. The hydraulic analogy for open channel flow would require 40 times the hydraulic radius of straight, unobstructed approach channel. These requirements can probably be relaxed because open channel measuring flumes claim accuracy to a wider margin of 2 to 5 percent.

Bos et al. (1991) gives approach length requirements stated in various terms of flow depths, head readings, and widths as follows:

- If the control width is greater than 50 percent of the approach channel, then 10 average approach flow widths of straight unobstructed approach are required.

- If the control width is less than 50 percent, then 20 control widths of straight unobstructed approach are required.
- If upstream flow exceeds critical velocity, a jump should be forced to occur. In this case, 30 measuring heads of straight unobstructed approach after the jump is completed should be provided.
- If baffles are used to correct and smooth approach flow, then 10 measuring heads should be placed between the baffles and the measuring station.

To prevent wave interference of head measurement, the Froude number of the approaching channel flow should be less than 0.5 for the full range of anticipated discharges and should not be exceeded over a distance of at least 30 times the measurement head before the structure.

Flumes require accurate workmanship for satisfactory performance. Short flumes will provide reasonably accurate flow measurements if the standard dimensions are attained during construction. For accurate flow measurement, the flow surfaces must be correctly set or placed at the proper elevation, the crest must be properly leveled, and the walls must be vertical.

The head is usually measured either in the channel itself or in a stilling basin located to one side of the channel. The stilling basin is connected by a small pipe to the channel. Many methods can be used to measure the water surface in the stilling basin or in the channel. Some of the most common methods are:

- A measuring plate attached to the side of a stilling basin.
- A float and counterweight in a stilling basin attached to a shaft encoder which can be linked to an electronic data logger or readout.
- A submersible pressure transducer which can be linked to an electronic data logger or readout.
- An ultrasonic sensor which can be linked to an electronic data logger or readout.

7.1.2.3 Advantages of Long-Throated Flumes

The main advantages of long-throated flumes are:

- Provided that critical flow occurs in the throat (not excessively submerged), a rating table can be calculated with an error less than +2 percent. This calculation can be done for any combination of a prismatic throat and an arbitrarily shaped approach channel.
- Long-throated flumes can have nearly any desired cross-sectional shape and can be custom fitted into most canal-site geometries. The throat cross section can be shaped in such a way that the complete range of discharge can be measured accurately.
- Long-throated flumes can be made into portable devices that fit conveniently into open channels with considerably less complicated construction forming.
- The required head loss over the long-throated flume to obtain a unique relationship between the upstream sill-referenced head and the discharge is small. This head-loss requirement may be estimated with sufficient accuracy for any of these flumes placed in any channel.
- Because of their gradual converging transition, these flumes have few problems with floating debris and sediment. Field observations have shown that the flume can be designed to pass sediment transported by channels with sub critical flow.

- Provided that the throat is horizontal in the direction of flow, a rating table can be produced that is based on post construction dimensions. This horizontal orientation is required to allow an accurate rating table to be made to compensate for deviations from design.
- Under similar hydraulic and other boundary conditions, long-throated flumes are usually the most economical of all structures for accurately measuring flow.
- Long-throated flumes are amenable to selection, design, and calibration by computer techniques.

7.1.2.4 Disadvantages

The short throated flumes like the Parshall flume need to be laboratory-calibrated, because the flow through their control sections is curvilinear. In contrast, the streamlines are essentially parallel in the throat sections of long-throated flumes (broad crested weirs), making it possible to rate them analytically.

The position of the measuring plate can easily be tampered with to give readings lower than the actual head.

7.1.2.5 Maintenance

Make sure the measuring plate is zeroed with the crest of the flume on a regular basis. Seal any cracks that might appear over time. Make sure there is no movement in any part of the structure due to earth movements which might cause inaccurate measurements.

Care must be taken to construct Parshall flumes according to the structural dimensions. This factor becomes more important as size gets smaller.

7.1.2.6 Further reading

Water Measurement Manual (United States Bureau of Reclamation, 1997) or at http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/wmm.html.

Flow Measuring Flumes for Open Channel Systems (Bos et al. 1991).

Water Measurement with Flumes and Weirs (Clemmens et al, 2001).

Submerged Flows in Parshall Flumes (Peck, 1988).

WinFlume — Windows-Based Software for the Design of Long-Throated Measuring Flumes (Wahl et al, 2000) or at www.usbr.gov/pmts/hydraulics_lab/winflume/

7.1.3 Portable flumes

7.1.3.1 Introduction

Portable flumes are mainly designed and used to measure discharges in smaller earth channels or off takes. It may be used in conjunction with a permanent measuring plate to produce a stage/discharge relationship. The portable flume is a simple and reliable instrument which can easily be installed to measure water deliveries to fields.

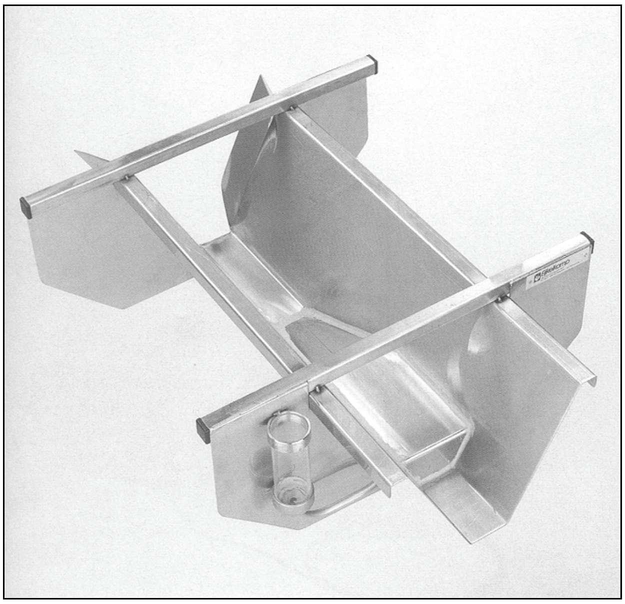


Figure 7.5 Small RBC flume for manual read-out (KBS, 2005)

7.1.3.2 Installation

When installing a portable flume, the crest should be used as an index. Careful leveling is necessary in both the horizontal and vertical directions if standard discharge tables are to be used. Care should be taken to seal the flume on the outside to prevent any water leakage past the flume which will result in inaccurate measurements.

If the flume is used in conjunction with a permanent measuring plate to produce a stage/discharge relationship, the flume must be located in a position that will not affect the water level at the measuring plate while the flume is installed, or after removal.

7.1.3.3 Advantages

- Easy to install.
- Easy to transport.
- Accurate.
- Low cost when compared to a permanent structure.
- Can be used as a temporary measuring station.
- Can be used to verify pressure regulated off takes.

7.1.3.4 Disadvantages

- It is a temporary solution.

7.1.3.5 Maintenance

Make sure there is no movement of the portable flume during the time of usage which might affect the readings. Ensure there is no water leakage past the flume.

7.1.3.6 Further reading

The following website www.eijkelkamp.com can be accessed for more information.

7.1.4 Mechanical velocity meters

7.1.4.1 Introduction

The current meter is a widely used method which is used to measure the water velocity which can be converted to a discharge for a known cross-section and water depth. Current meters are rated by dragging them through tanks of still water at known speeds. The reliability and accuracy of measurement with these meters are easily assessed by checking mechanical parts for damage and using spin-time tests for excess change of bearing friction. A typical measuring range is from 0.025 to 10 m/s.

Although propellers are designed to pass (to some degree) weeds, algae, and other debris, only a limited amount of foreign material can be tolerated in the flow. Even moderate amounts of algae or weeds can influence a propeller unless it is protected by screens.

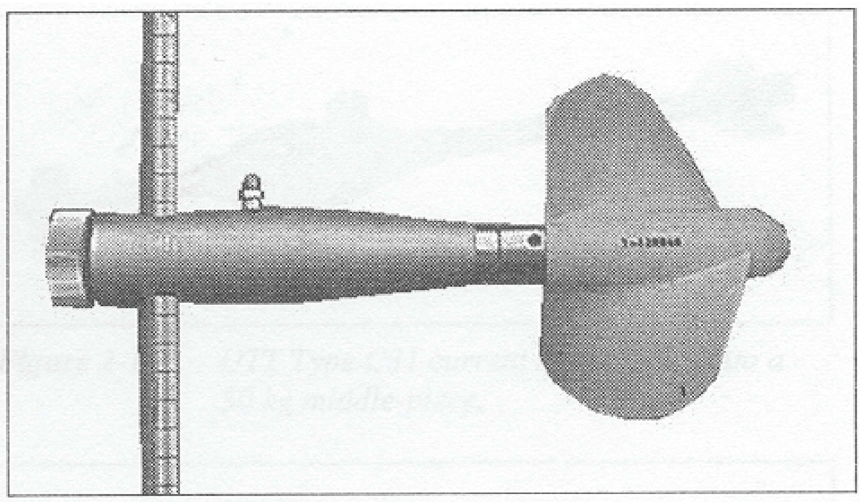


Figure 7.6 Mechanical current meter (Le Roux & Kriel, 1999)

7.1.4.2 Installation

The current meter is a portable device that needs no installation. Care should however be taken in the determination of the average velocity and the depths at which the different velocities should be measured. Detail information is available in the Manual on Conventional Current Gaugings of the Department of Water Affairs and Forestry, and in the Water Measurement Manual from the United Stated Department of the Interior Bureau of Reclamation at the link below.

7.1.4.3 Advantages

- Accurate.
- Easy to operate.
- Can be used in polluted water.

7.1.4.4 Disadvantages

- The current meter is a sensitive instrument and must be kept clean and properly lubricated at all times.
- Good approach conditions are essential at the location of use to ensure representative measurements.

7.1.4.5 Maintenance

Current meters are sensitive instruments and care must be taken during transportation to prevent accidental damage to the meter. The meter should be carefully cleaned and properly lubricated after use.

7.1.4.6 Further reading

Manual on Conventional Current Gaugings (Le Roux & Kriel, 1999)

Water Measurement Manual (United Stated Bureau of Reclamation, 1997) or at http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/wmm.html.

7.1.5 Acoustic Doppler velocity meters

7.1.5.1 Introduction

The acoustic Doppler velocity meter (ADVM) is a proven, accurate solution for high-precision velocity measurements in channels and rivers. ADV meter performance has been shown to compare favorably with laser Doppler systems costing ten times as much. In addition, the ADV is extremely simple to set up and use. Most users are taking high quality data within minutes of receiving the system. Many ADV meters have built in data loggers with an option to use telemetry.

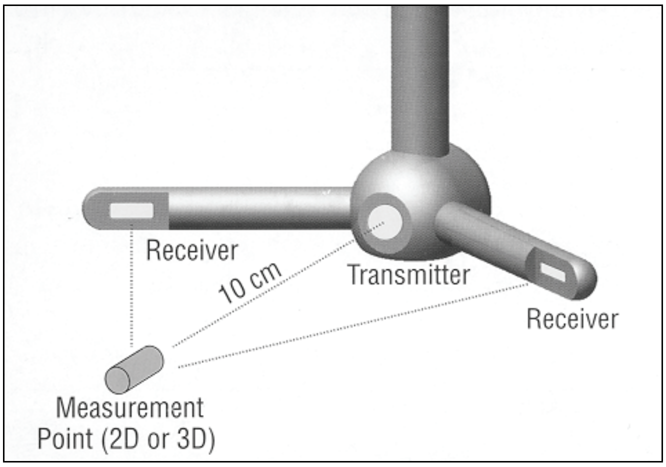


Figure 7.7 Acoustic Doppler velocity meter measuring principle (Sontek, 2004)

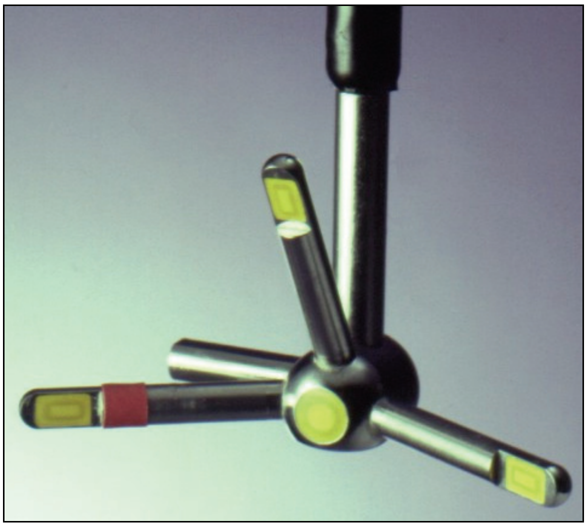


Figure 7.8 Example of ADVM probe (Sontek, 2004)

7.1.5.2 Installation

The installation of this type of measuring device is normally easy. It can either be a fixed installation or a hand held device on a wading rod.

7.1.5.3 Advantages

- Easy to install setup and maintain.
- Never needs calibration.
- Measures from 0.001 m/s up to 5 m/s.
- Easily attaches to wading rods.
- No moving parts.
- Velocity accuracy is not affected by biological growth.

7.1.5.4 Disadvantages

- Relatively expensive compared to other types of velocity meters.

7.1.5.5 Maintenance

Almost no maintenance is needed other than ensuring a constant and reliable power supply.

7.1.5.6 Further reading

KBS
www.sontek.com
www.campbellsci.com/waterlevel.html

7.1.6 Floats

7.1.6.1 Introduction

Floats can be used to estimate the average velocity in irrigation canals which is then used to calculate the discharge using the cross section flow area. This method should be used when other more accurate methods are impractical or impossible. To get the best results floats should be used on straight channel reaches with a uniform cross section and a constant slope.

The method of measuring is as follows:

- Determine the cross sectional area of the channel.
- Determine the water velocity as follows:
  Measure 10m on a straight uniform channel.
  Determine how it takes for a float to cover the 10m distance. Release the float far enough of the starting point to ensure that it reaches the stream velocity.
- Repeat the process at least 5 times at different streamline positions.
- Calculate the average velocity with the following equation:

$$v = C_f . v_f$$

where v = velocity (m/s)
C_f = correction factor
v_f = float speed (m/s)

Table 7.1 Correction factors for float velocities

Average flow depth [m]	0,3	0,6	0,9	1,2	1,5	1,8	2,7	3,7	4,6	≥6,1
$\mathbf{C_f}$	0,66	0,68	0,70	0,72	0,74	0,76	0,77	0,78	0,79	0,8

7.1.6.2 Advantages

- It is a very simple and practical method to use which can give satisfactory results if applied to a uniform channel with a constant slope.

7.1.6.3 Disadvantages

- The method is not very accurate and more than person is needed to take a measurement.

7.1.6.4 Further reading

Irrigation Design Manual: Chapter 8 Flow measurement (Burger et al., 2003)

Water Measurement Manual (United States Bureau of Reclamation, 1997) or at http://www.usbr.gov/pmts/hydraulics_lab/pubs/wmm/wmm.html.

7.1.7 Orifices

7.1.7.1 Introduction

Orifices are commonly used on irrigation schemes for water distribution in open channel networks. Any submerged opening can be used as an orifice but the two popular types are:

- Pipes (standard sizes) which is used to measure water deliveries for household and livestock water use.
- Rectangular or circular pressure regulated sluice off-takes.

Orifices can be operated under free flow or submerged conditions in which case two head (water depth) measurements are needed to calculate the flow using the standard orifice equation.

7.1.7.2 Installation

An orifice used as a measuring device is a well-defined, sharp-edged opening in a vertical structure through which flow occurs. For irrigation use, orifices are commonly circular or rectangular in shape and are generally placed in vertical surfaces.

Standard designs for household and livestock pipe installations exist which will limit the maximum abstraction rate as well as any tampering. The installation normally consists of a two well system which is connected with a standard pipe size to limit the abstraction rate.

Standard designs also exist for pressure regulating sluice off-takes which might be unique for each irrigation scheme. This type of off-take is installed with a long weir in the main channel which is used to keep the head (water depth) behind the sluice gate relatively constant for a varying flow rate. Pressure regulating sluices are normally designed with fixed opening settings that deliver a constant flow rate. The flow rate multiplied by the time period gives the volume delivered through the off-take.

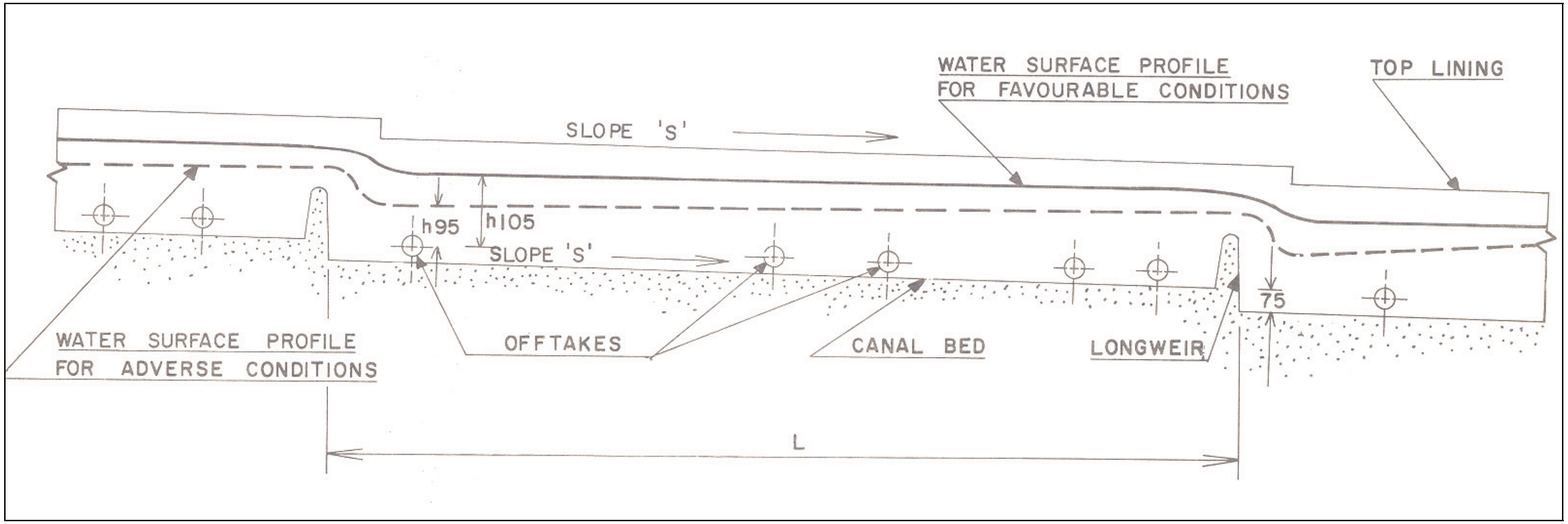


Figure 7.9 Pressure regulating sluice with long weir (DWAF, 1980)

An off-take should not be installed at the inside of a channel bend. Sediment tends to settle on the inside of bends where the velocity is lower and which might lead to blockages.

7.1.7.3 Advantages

- This type of off-take is a simple, practical and a robust method for water delivery measurements. The accuracy is good enough for water billing and channel operation purposes.

7.1.7.4 Disadvantages

- Long weirs tend to fill up with sediment over time which might block the orifice opening.
- Pressure regulating sluices are not tamper proof and various methods have been used to increase the flow rate through it illegally.

7.1.7.5 Maintenance

Remove any built up of sediment from time to time to prevent any blockages. Inspect pressure regulating sluices for any tampering on a regular basis.

7.1.7.6 Further reading

Irrigation Design Manual: Chapter 8 Flow measurement (Burger et al., 2003)

7.2 Secondary elements

7.2.1 Staff gauges (Measuring plates)

7.2.1.1 Introduction

The measuring plate has been in use since the beginning of water distribution in open channel networks. Measuring plates are used to measure water depth in open channels to determine the flow rate at a specific point for a variety of flow measuring techniques.

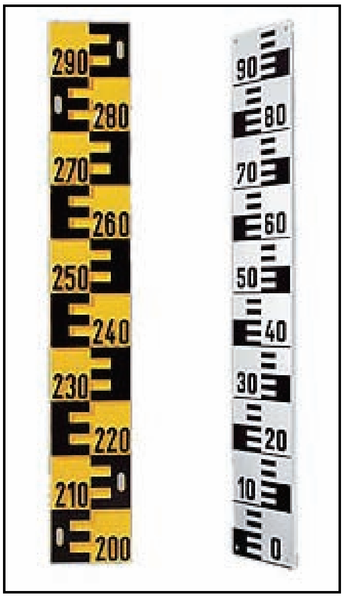


Figure 7.10 Measuring plates

7.2.1.2 Installation

A measuring plate can be installed in different ways. The most common method is to install in a stilling basin which is linked to the canal with a pipe with a small diameter. The main purpose of the stilling well is to damp any surface waves that might occur and which will make accurate readings on the measuring plate difficult. It is also good practice to design the stilling well in such a way that it caters for the installation and use of electronic equipment that might be used if needed.

The following are points that need to be considered when working with measuring plates:

- The stilling well must be deeper than bottom of the canal to prevent that the build up of any sediment interferes with the reading.
- The measuring plate must be zeroed with the crest of the measuring structure.
- The measuring plate must be attached in a way that will prevent any tampering.
- The measuring plate must be placed in a position so that it can easily be read.

7.2.1.3 Advantages

- A measuring plate can be used to check other electronic depth sensors.
- A correctly installed measuring plate will always be available compared to electronic devises that might go down due to a power failure.

7.2.1.4 Disadvantages

- A measuring plate can easily be tampered with by moving it up or down to give incorrect readings.
- A measuring plate has to be read on site if no other depth measuring device is installed.
- Human errors can easily be made during readings.

7.2.1.5 Maintenance

A measuring plate should be cleaned regularly to make it as clear as possible. The position of the measuring plate should be checked on a regular basis to ensure that it is zeroed correctly.

7.2.1.6 Further reading

The following website www.eijkelkamp.com can be accessed for more information.

7.2.2 Float and counterweight sensors

7.2.2.1 Introduction

The mechanical float operated water level recorder (chart recorder), as can be seen in the previous figure, has been in use by various irrigation schemes throughout South-Africa for over 20 years. It is a robust, cost effective and reliable instrument that mechanically draws the water level on a chart over time. The chart needs to be replaced on a weekly basis. The latest developments make it possible to attach a shaft encoder to the chart recorder that can be linked to a data logger which in turn can be connected to an office using telemetry. This is one of the few measuring devises which makes it possible to duplicate measurements that can serve as a back-up if one of the methods should fail.

7.2.2.2 Installation

The chart recorder is installed over a stilling well in a tamper proof enclosure. The stilling well protects the float and dampens the fluctuations in the water surface elevation due to wind and turbulence. The following points should be considered during installation:

- Ensure that the float and counterweight can move free of obstructions for the whole measurement range.
- Ensure that the counterweight don’t get submerged for the measuring range.
- Ensure that the stilling basin is deep enough to allow for any sediment build up.
- Ensure that the counterweight will not be submerged at any time during operation.

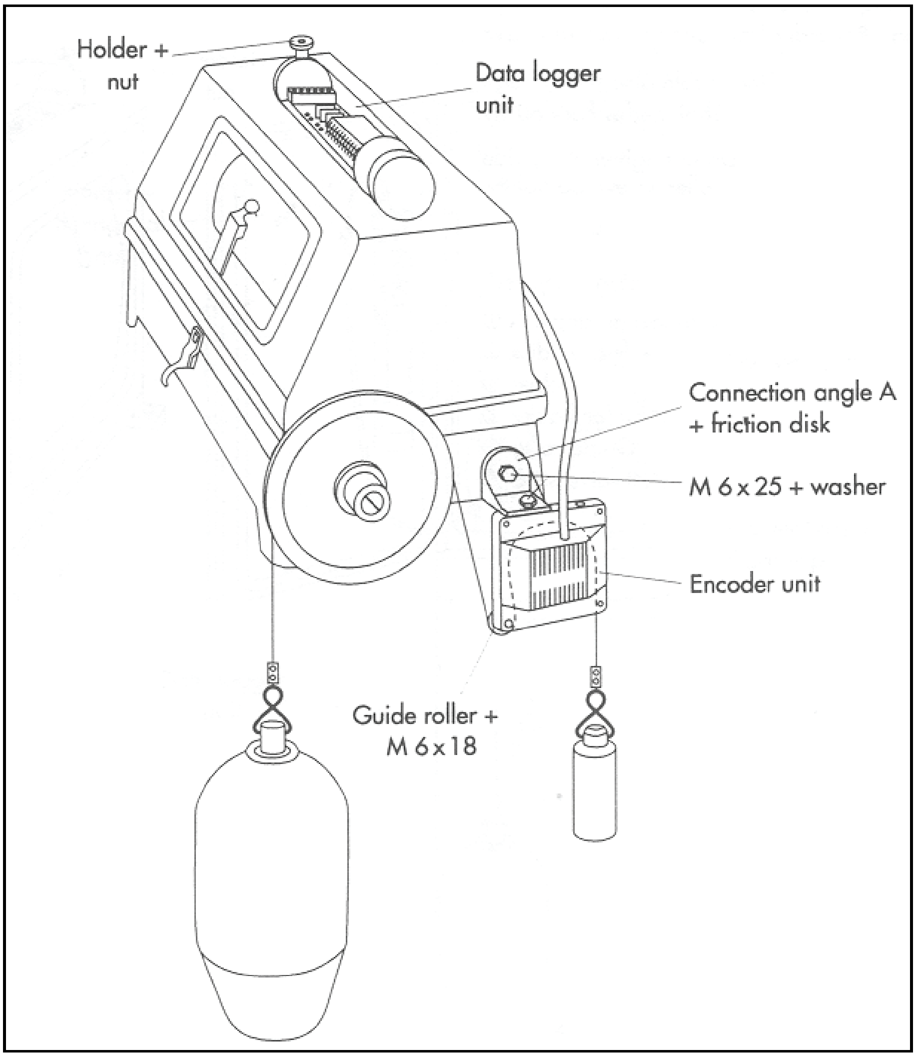


Figure 7.11 Mechanical water level recorder with shaft encoder and datalogger (OTT Hydrometry, in Kriel, 1999)

7.2.2.3 Advantages

- Quick and easy to install.
- The basic mechanical unit is inexpensive and robust.
- Weather resistant.
- No external power supply is needed (the datalogger has internal long-term battery).
- Allows for continuous measurements at various water fluctuations.
- Easy to attach a shaft encoder and data logger without making changes to the current installation. It is a cost effective upgrade from a mechanical system to digital technology.
- In situ comparison between the conventional chart recorder principle and the new digital technology allows for easy training.

7.2.2.4 Disadvantages

- The time cannot be read from the chart accurately (if no datalogger is connected).
- The chart needs to be replaced on a regular basis.
- The initial water level and time need to be set when changing the charts which allow for human errors.
- Data manipulation is difficult if data is not electronically stored.

7.2.2.5 Maintenance

The chart recorder should be cleaned and lubricated on a regular basis to ensure the smooth running of the pulleys. The batteries should be checked and replaced when necessary. Remove any sediment build up which might influence the float or counterweight.

Most errors in measurement when using mechanical float operated water level recorders come from cable slip, float lag and submergence of the counterweight.

7.2.2.6 Further reading

KBS
www.ott-hydrometry.de

7.2.3 Submersible pressure transducers

7.2.3.1 Introduction

Pressure transducers convert pressure forces to electrical signals that can be recorded by a data logger. Pressure transducers measure the water level by means of a pressure measuring cell which measures the hydrostatic pressure of the water column via a capacitive pressure diaphragm and converts this measured value into an electric signal. A data logger is normally connected or integrated with a pressure probe which stores the measured values in pre-set intervals. The accuracy is 0.1% of the measured value depending on the specific sensor.

Configuration and readout of data can normally be made with a PC or laptop and software that is supplied with the instrument.

7.2.3.2 Installation

The installation of a pressure transducer is very simple. The submersible pressure sensor may be placed slightly below the lowest expected water level. When ordering, select the level sensor range that will cover the maximum water level change (this is not necessarily the total depth of water). Selecting the smallest water level range possible will ensure the greatest accuracy. Make sure that a reliable and constant power source is available if the sensor needs an external power source.

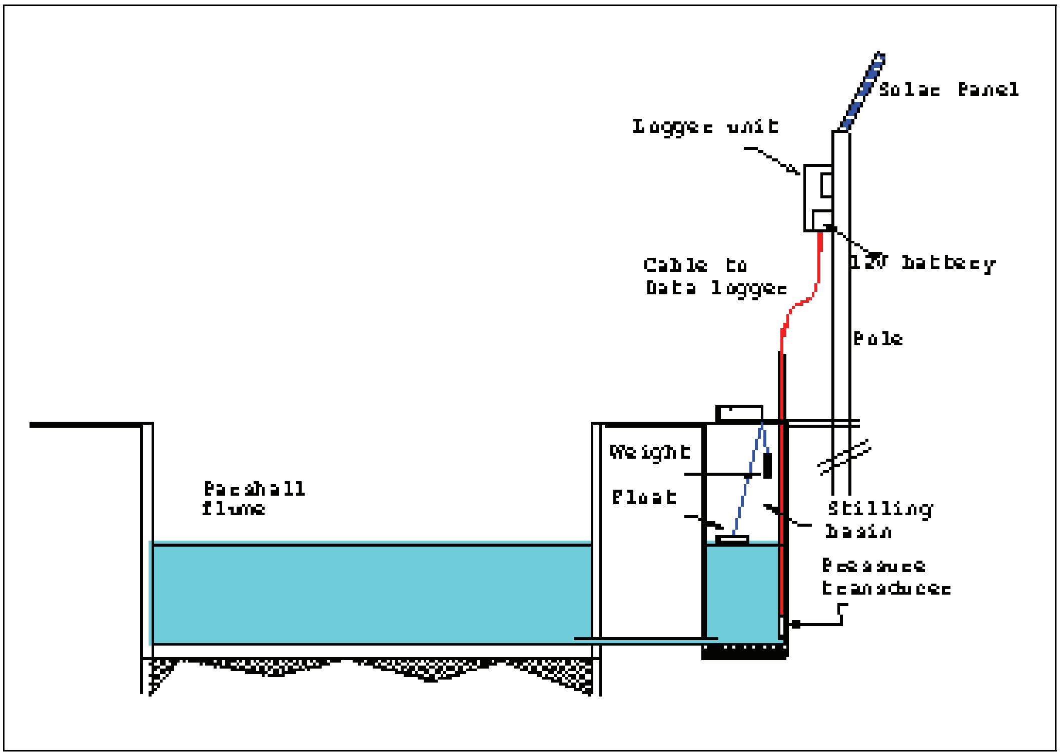


Figure 7.12 Typical installation of a submersible pressure transducer (Hidad, 2000)

7.2.3.3 Advantages

- Out put can be analog or digital depending on model
- Smaller diameter stilling well or pipe can be used for installation.
- A low profile installation site can be achieved using pressure sensors with internal data logging.
- A wide range of sensors is commercially available.
- Most affordable sensor that produces electronic output.
- Easy to install, maintain and calibrate.

7.2.3.4 Disadvantages

- Typically subject to long-term drift and variations with temperatures. However, they are in the water where the temperature is usually fairly stable, so the temperature concern may not be too high. It is good idea to check calibration every 6 months.
- Fouling or corrosion with direct exposure to the water can affect the readings.
- Models are available in a broad pressure range that needs to be known at time of purchases.
- Some models require breather tube in the cable to reference to atmospheric pressure for best accuracy.
- Some models have a sensor head that can be easily damage to human touch or other objects touch.

7.2.3.5 Maintenance

Pressure transducers require less service and maintenance than manometers, are small and compact, and vary greatly in cost, depending on the accuracy and type of sensing technology used. However, care must be taken to protect the transducer diaphragm from pressure beyond its certified limits and other mechanical damage. The transducers should be inspected at least every three months for signs of damage, corrosion, blockage or wiring problems. They should be verified or calibrated at least every 2 years.

7.2.3.6 Further reading

KBS
www.campbellsci.com/waterlevel.html
www.ott-hydrometry.de

7.2.4 Acoustic water level sensors

7.2.4.1 Introduction

This *non contact* ultrasonic sensor (fig. 7.13) is mounted above the water surface and sends acoustic pulses to the water surface that are reflected back to the sensor. The time between the transmission and receipt of the signal is used with the speed of sound in air to compute the distance from the sensor head to the water surface. The range of water levels that can be sensed by most commercial ultrasonic units of this type is approximately 0.3 to 10 m.

Since there are no parts in contact with the water, poor quality water poses no risks to the system, thereby minimizing maintenance requirements. It is possible to measure a wide range of depths with one sensor, and the digital output can be recorded in a datalogger.

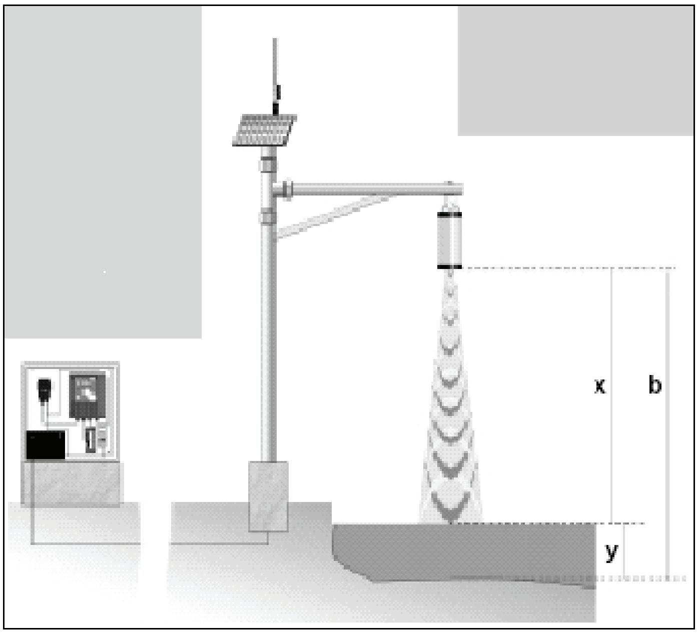


Figure 7.13 Principles of an acoustic level sensor (OTT Hydrometry, 2004)

7.2.4.2 Installation

The sensor should be mounted in an area that is within the temperature range specified and that is suitable to the housing rating and materials of construction. It is advisable to keep the sensor away from high voltage or current runs and contactors.

Locate the sensor so that it will have a clear sound path perpendicular to the water surface. Mount the sensor so that the face of the sensor is the specified height above the highest anticipated water level.

The sensor should preferably be installed over a water surface where there is little disturbance or waves, although some devices have built-in functions that can filter out repetitive disturbances. It is also important that the sensor should be secured firmly in a perpendicular position to the water surface to prevent it from shifting and producing inaccurate readings.

7.2.4.3 Advantages

- No parts in contact with the water.
- The device can be installed and repaired without stopping the flow that is being measured.
- Digital data can be easily recorded by datalogger or telemetry.
- Low power consumption
- Easy to install, maintain and calibrate.

7.2.4.4 Disadvantages

- Some sensitivity to ambient temperature variations has been reported.
- Requires electrical power to function.
- Relatively expensive compared to other types of sensors.
- Should be protected against lightning.

7.2.4.5 Maintenance

Since there are no moving parts or parts in contact with the water, the sensor has relatively low maintenance requirements. It should be ensured that the power supply to the sensor is maintained at all times to prevent data loss. If the measuring location is fitted with a measuring plate, and the sensor has a display unit, it is easy to verify correctness on site and it is good practice to do this every time the device is visited.

7.2.4.6 Further reading

KBS
www.campbellsci.com/waterlevel.html
www.ott-hydrometry.de

7.3 Ultrasonic measuring methods in open channels

7.3.1 Doppler Discharge measurement

7.3.1.1 Introduction

Ultrasonic sensors use acoustic pulses to sense water levels and velocities. The Doppler type sensor (figure 7.14 and 7.15) is mounted below the water surface and transmits acoustic pulses that are reflected back to the sensor by the water surface. The time interval between signal transmission and receipt, and the speed of sound in water, are used to compute the distance from the sensor to the water surface. This data has be combined with the flow depth and the cross sectional area at the measuring location to calculate the discharge.

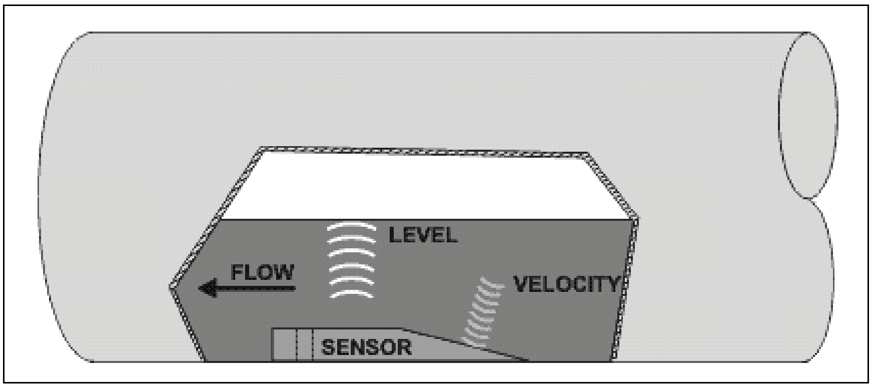


Figure 7.14 Doppler type installation with built-in water level sensor (Greyline Instruments, 2005)

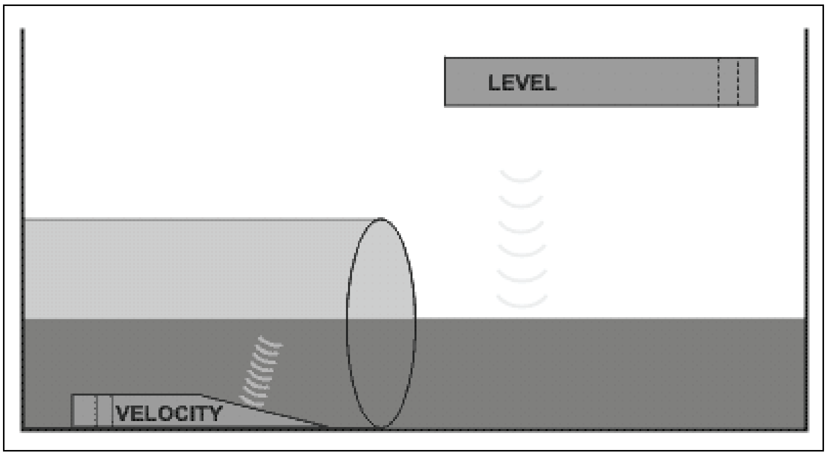


Figure 7.15 Doppler type installation with external water level sensor (Greyline instruments, 2005)

7.3.1.2 Installation

The sensor should be located in a place where silt or deposits are least likely to occur, but the stable approach conditions are preferred so that the flow should be evenly distributed across the channel and relatively free from turbulence. It is recommended that at the flow path should be clear of vertical drops or other disturbances for at least 10 times the average flow depth up and downstream of the measuring location. Most devices do some averaging calculations, however, to reduce the effect of any disturbance.

The sensor should be installed so that the signals are projected perpendicularly to the direction of flow, whether it is installed on the bottom or the side of the channel. The cable connecting it to the datalogger and power supply should be securely fastened to the channel wall.

7.3.1.3 Advantages

- Very robust.
- The installation is inexpensive and easy to do compared to measuring structures.
- The minimum maintenance is necessary.
- No stilling well is necessary.
- Can be linked to various data logging and telemetry equipment.

7.3.1.4 Disadvantages

- The device itself is relatively expensive compared to other sensors.
- The sensor is susceptible to errors caused by high water velocities, air entrainment in the water, and solids suspended in the water. Heavy sediment deposition might cover the sensor and render it useless.

7.3.1.5 Maintenance

Minimum maintenance is necessary. Any sediment deposition should be removed close to the contact sensor.

7.3.1.6 Further reading

KBS
www.greyline.com
www.sontek.com
www.ott-hydrometry.de

7.3.2 Transit time discharge measurement

7.3.2.1 Introduction

Ultrasonic transit time measuring methods are normally used for exact volume metering for the purpose of controlling irrigation channels. It works on a principle where an acoustic signal is transmitted at a defined angle so that it is simultaneously directed both towards and against the main direction of flow. The transit time for the signal transmitted against the main direction of flow is longer than the transit time for the signal transmitted in the main direction of the flow. The resulting time differential is directly proportional to flow velocity v in the measuring path.

7.3.2.2 Installation

Ultrasonic transit time sensors can be installed in different configurations which are used for different applications. The "single-path arrangement" (Figure 7.16) represents the simplest construction. This is the preferred application in waters with a constant angle of flow (also bi-directional, e.g. subject to tidal influence). This configuration provides the largest measurable waterway width of 1 to 300 m.

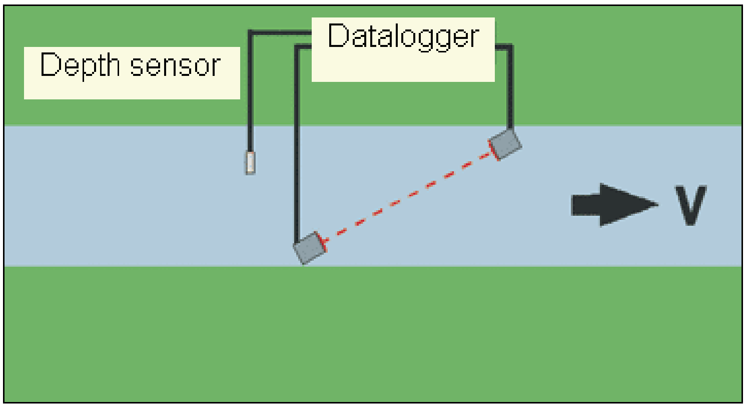


Figure 7.16 Ultrasonic transit time single-path arrangement (OTT Hydrometry, 2005)

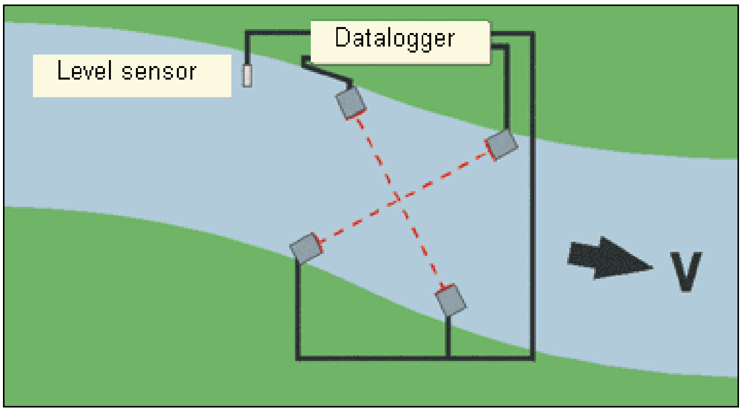


Figure 7.17 Ultrasonic transit time two path cross arrangement (OTT Hydrometry, 2005)

The "two-path cross arrangement" (Figure 7.17) is the arrangement that is most sensitive to changes in flow direction. This is the preferred application for river widths of up to 300 m with unfavorable admission conditions. This configuration is very accurate and can also be used in river bends.

The power supply needed is normally 12 Volt direct current (DC), which makes the operation with a rechargeable battery or solar energy possible. Lightning protection should be provided.

7.3.2.3 Advantages

- Most ultrasonic devices have remote data transmission as an option.
- Suitable for low water levels.
- Easy to install, operate and maintain.
- Compact modular design.

7.3.3.4 Disadvantages

- Need a constant power supply.
- Tampering might be a problem.
- Few local installations if any.

7.3.3.5 Maintenance

Ensure that the facing sensors have a clear path between each other. Ensure that the power supply is reliable.

7.3.3.6 Further reading

KBS
www.ott-hydrometry.de

7.4 Summary of open channel devices

Table 7.2 Summary of open channel devices

Method	Volumetric data output (standard)	Flow rate data output (standard)	Sensitivity to installation conditions (hydraulic)	Needs ext. electric power (standard)	Accuracy (relative)	Sensitivity to dirty water	Additional pressure loss in system	Continuous data recording possible	Relative cost of standard unit (including installation)***
Weir	No	Yes	High	No	Moderate/High	High	High	Yes*	Moderate/Low
Flume	No	Yes	High	No	Moderate/High	Moderate	Moderate/High	Yes*	Moderate/High
Mechanical velocity	No	Yes	Moderate	No	Moderate	High	Low	Yes*	Moderate
Doppler velocity	No	Yes	Moderate/High	Yes	Moderate/High	Moderate/High	Low	Yes*	Moderate/High
Floats	No	Yes	Moderate/Low	No	Low	Low	None/Low	No	Low
Orifices (Pressure controlled sluice gate)	No	Yes	High	No	Moderate	Moderate	Low	No	Moderate
Acoustic Doppler	No	Yes	High	Yes	High	Low	None	Yes**	Low-high****
Acoustic Transit Time	No	Yes	High	Yes	High	Moderate/Low	None	Yes**	Low-high****

* Additional hardware always required

** Additional hardware sometimes required

*** Prices vary widely with size and therefore only relative.

**** Often “one size” device for all flow rates – expensive for small canals but affordable for big canals

8. CLOSED CONDUIT FLOW MEASUREMENT

This chapter presents an overview of the types of flow measuring devices suitable for measuring of irrigation water in pipes. The devices' principles of operation and characteristics are discussed, and some illustrations are included. However, to obtain more commercially oriented information and to see colour photographs this chapter should be read in conjunction with the Knowledge Base System (KBS), where under the application "Closed conduits", different types of devices have been captured including information on cost.

8.1 Primary elements for closed conduits

8.1.1 Mechanical meters

Mechanical meters have rotor-mounted blades in the form of a vaned rotating element which is driven by the water at a speed proportional to the discharge. The number of rotor revolutions is proportional to the total flow through the meter and monitored by either a gear train, or by a magnetic or optical sensor (Crabtree, 2000).

Distinction can be made between turbine, impeller, and propeller meters, based on the orientation of the vaned rotor in relation to the flow direction and the number of vanes. Distinction can also be made on the basis of whether the whole stream of water passes the primary element, or whether only part of the stream is measured, in which case it is referred to as proportional meters.

The velocity of the water flowing in the pipe is determined from the rotor's rotational speed which is registered by means of either a magnet, fitted within the rotor assembly which produces a single pulse per revolution in an externally mounted pick-up coil, or a low friction gear train connecting the axle to the display (register) or totaliser. (Van der Stoep, 2003).

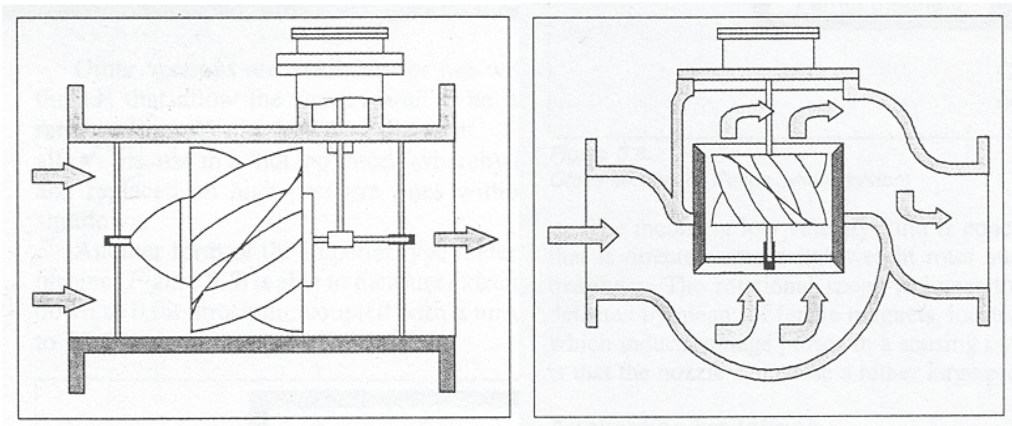
Some innovative design characteristics include elements that can be removed from the housing without removing the housing from the pipeline. This makes it easier to replace malfunctioning elements but fasteners should be secured by means of a seal or other device to prevent tampering.

The following mechanical meter types that are listed, are based on their popularity and use in the South African irrigation industry. A large number of brands are available but care should be taken to choose devices from an established manufacturer with a proper support service and adequate spares available to the Water User Association (WUA).

Turbine meters.

The turbine meter usually comprises of an axially mounted bladed rotor running on bearings or bushes and mounted concentrically within the flow stream by means of support struts.

The axle may be positioned either horizontally or vertically as shown in Figure 8.1. The vertical turbine is said to be subject to less bearing friction and is therefore more sensitive. However, it provides more obstruction to the flow through the meter and is more likely to be affected by the physical impurities often found in irrigation water.



(a) (b)

Figure 8.1 (a) Horizontal and (b) vertical turbine meters (Crabtree, 2000)

Some meters are available in which the turbine is smaller than the pipe diameter so that it only obstructs a section of the flow path, as shown in Figure 8.2. This design makes it easier for debris to pass through the meter and reduces head-loss but accuracy is compromised in the process.

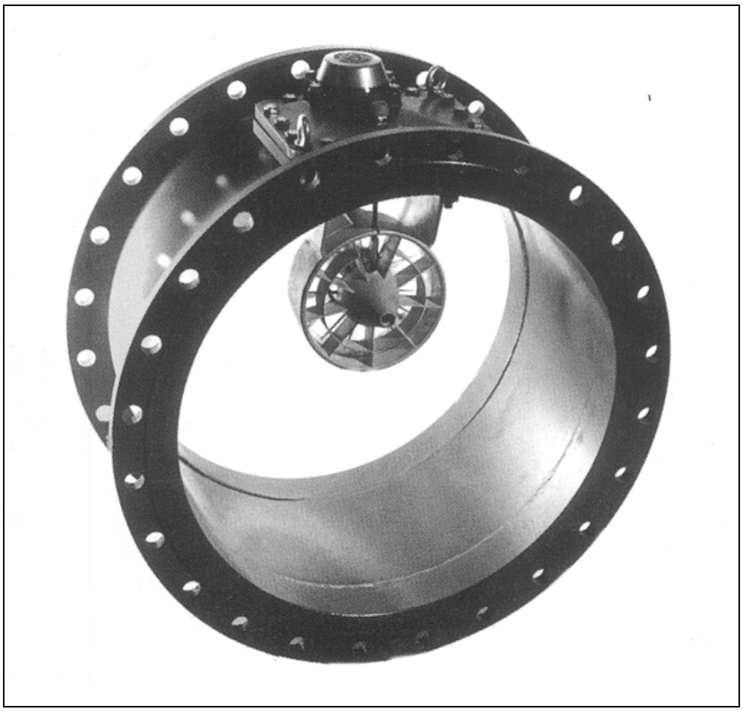


Figure 8.2 Turbine flow meter with smaller measuring element (Meinecke, 2001)

Impeller type meters

These meters are also called the paddlewheel meters. The rotating blades of the impeller meter are perpendicular to the flow, making it inherently less accurate than the turbine meter. At low discharges or flows, it is possible that the water cannot maintain the force needed to overcome bearing friction, impeller mass inertia and drag, and at high flow velocities of more than 10 m/s, cavitation can occur and cause readings that are higher than the actual discharge.

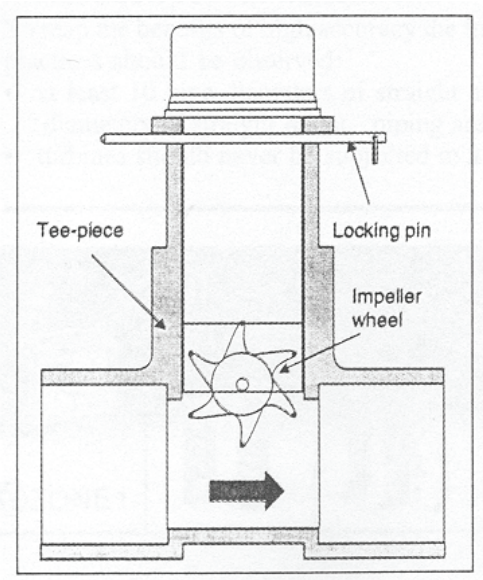


Figure 8.3 Impeller type meter (Crabtree, 2000)

The schematic lay-out of a typical impeller meter is shown in Figure 8.3, with the impeller wheel mounted at the top of the pipe section. Although the meter provides minimal head loss in the system, the top end of the section is also the first place where air can accumulate. An advantage of this type of flow meter is that the measuring unit (secondary element) adheres to “one size fits all” for a specific manufacturer.

Propeller meters

This type of meter incorporates a long axle at the end of which the propeller is mounted, with the body of the meter at the other end of the axle and out of line of the flow stream, as shown in Figure 8.4. The working part of the meter can be removed easily without dismantling the whole installation, and the meter’s performance is usually better than the impeller type meters due to the position of the measuring element relative to the flow profile in the conduit. The use of propellers with large clearances between the blades, enables the particles in suspension to pass with ease. However, it is sensitive to stringy debris in the water, similar to the turbine meter.

With the bearings mounted on the outside of the main flow, the effects of contamination of dirty water are eliminated or reduced to a minimum.. The removal of the primary and secondary parts can be done with-out the removal of the meter casing from the pipeline; some meters are even supplied simply with a saddle (no complete housing) that can simply be fitted by drilling a hole into a suitable pipe section and clamping the saddle to the pipe.

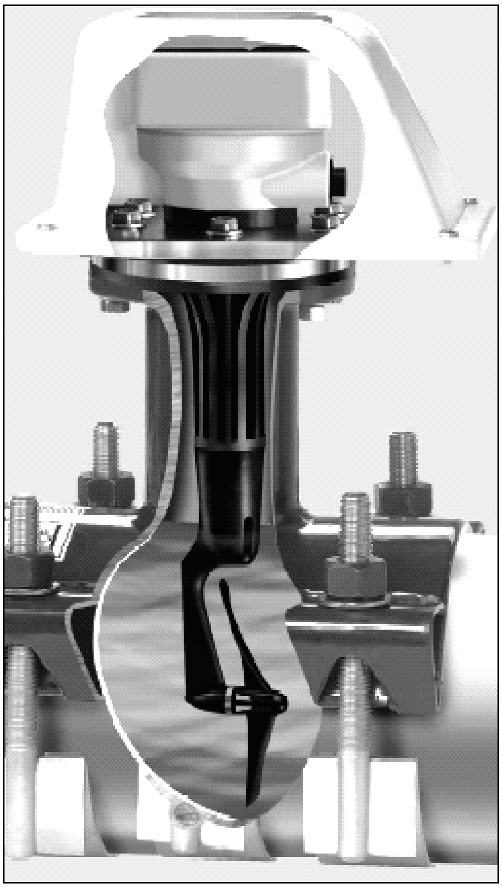


Figure 8.4 Propeller type meter (Mace, 2005)

Proportional meters

These meters are also known as the by-pass flow meters. The basic principle on which these flow meters work, is that only part of the total flow passes by the measuring element and this flow is proportional to the total flow. The by-pass flow is created by an internal reduction in the meter's internal diameter (venturi). This reduction creates a higher pressure at the by pass inlet and a low pressure at the by-pass' outlet. This condition creates a flow through the flow meter with the secondary element or register. The total flow is then displayed on the secondary element or register/display. The reading which is displayed on the register is the total flow and no additional calculations are needed.

The purpose of the lay-out is to protect the measuring element by allowing debris to pass in the main stream flowing through the meter. In practice however it was found that the inlet to the bypass is very sensitive to clogging by either silt or algae due to its small diameter. Even if the inlet to the bypass is protected by a strainer, this meter can still not be recommended for use in raw water. Its use should be limited to borehole water with good chemical quality.

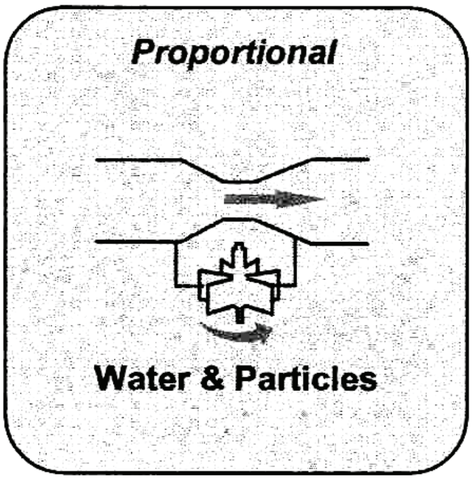


Figure 8.5 Schematic lay-out of a proportional meter (KBS, 2005)

8.1.1.2 Installation

Mechanical meters are available in sizes from 5 to 800 mm internal pipe diameter. They are specified according to nominal diameter with minimum and maximum linear flow rates that are allowed and other specifications that have to be met. It is recommended that the meter is sized for the maximum flow rate of the application, which is 70% to 80% of the maximum flow rate of the meter. If the meter is used at flow rates higher than those specified for extended periods, it may cause damage to the register. If the flow rates are lower than the specifications, it will results in poor accuracy of measurements.

It must be ensured that the pipe where the meter is located is always filled with water. Cavitation may occur when a low pressure region or pressure drop occurs at the surface area of the impeller. This can be avoided by retaining a sufficient back pressure and by keeping the pressure loss through the meter to a minimum. The pressure drop is typically around 20 to 30 kPa at the maximum flow rate and it varies depending on the flow rate and meter. (This pressure loss does not include further losses due to possible reduction in diameter of the meter housing in relation to the nominal supply pipe line diameter). High velocity air movement in the pipe can also cause damage to the measuring element, especially turbines.

Water quality is a very important consideration. Especially if any algae. water grass or gravel has to pass through the pipeline, turbine, propeller or bypass meters should NOT be considered at all. The installation of strainers under these conditions are not a solution to the problem either since the strainers will have to be cleaned often (sometimes more than once a day), adding additional cost to the management of the meters.

8.1.1.3 Advantages

- They need no electric power, which give them the capability to be installed at remote sites.
- Available for a wide flow range.
- Robust and easy of use.
- Low capital cost.

8.1.1.4 Disadvantages

- These meters are susceptible to blocking by larger physical impurities (impeller meters to a lesser degree).
- Relatively low accuracy (within ± 10 % in practice) if the installation conditions are anything less than ideal.
- If these meters are used outside of their recommended ranges, inaccurate readings will occur. Their accuracy can also deteriorate over time due to wear.
- Difficult to install in existing pipelines, since it has to meet the straight pipe requirements and may require cutting of pipes and welding of flanges on site.
- If flanged connections are used they can be difficult to remove from fixed (buried) pipelines for repairs.
- If the diameter of the meter is smaller than the pipeline diameter, excessive additional friction loss may occur (bypass meters especially).
- If the meter is installed in a low part of the pipeline to ensure the pipe stays full, it may become submerged during rain.
- These meters may need additional tampering protection in certain cases.

8.1.1.5 Maintenance

Care should be taken to prevent the occasional entry of any debris or foreign material into the pipeline. If strainers are installed, they should be cleaned regularly.

The entry of any moisture into the secondary elements or gear trains should be prevented and if it occurred, it should be rectified promptly. It is recommended that meter performance is verified once a year in-field, typically with a clamp-on type ultrasonic meter, and any problems be rectified as soon as they are detected. Depending on water quality, the meter will have to be removed periodically for inspection to the measuring element and condition of the housing, which may need to be re-painted. It is recommended that this be done every second year, although some manufacturers recommend only every 6 years.

8.1.1.6 Further reading

KBS

Mick Crabtree's Flow Handbook (Crabtree, 2000)

Know the flow training manual (Australian National Committee on Irrigation and Drainage, 2002).

8.1.2 Electromagnetic meters

8.1.2.1 Introduction

Electromagnetic meters, also known as "Magflows" or "Magmeters", have been in widespread use for more than 40 years. This was the first meter type that had no moving parts and caused no additional headloss in the system.

The principle of operation of the meter is based on Faraday's law of induction. In the electromagnetic flow meter, a magnetic field is produced across a cross-section of the pipe, with the water forming the conductor. Two sensing electrodes set at right angles to the magnetic field, are used to detect the voltage which is generated across the flowing water. The strength of the magnetic field is directly proportional to the velocity (discharge) in the pipe. A schematic lay-out of the meter's components and operating principles is shown in Figure 8.6.

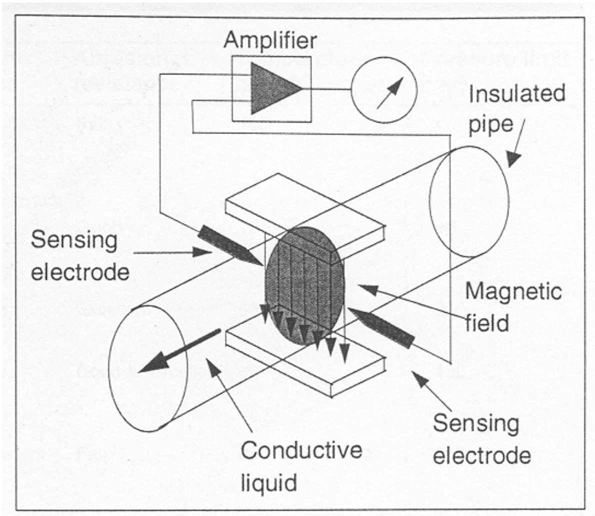


Figure 8.6 Components of an electromagnetic flow meter (Crabtree, 2000)

Two types of electromagnetic flow meters are available for permanent installation, namely the in-line and the insertion type meter. Examples are illustrated in Figures 8.7 and 8.8. The inline type offers greater accuracy but the insertion type is easier to install and more affordable.

The electromagnetic meter's characteristic that makes it ideal for irrigation water measurement, is the fact that the meter causes no or little obstruction in the flow path of the water. Furthermore, it has no moving parts, is relatively insensitive to flow profile changes (in-line type), and can record discharge readings with errors less than ± 0.5% of reading (in-line type) and ± 2% of reading (insertion type).

The inline type meter is also relatively expensive (approximately 5 – 10 times the cost of a similar sized mechanical meter), and it requires electricity to record readings. The insertion type is more affordable and requires less power, so that battery operation is possible. It is also easier to handle and to install than the in-line type.

The meter can usually display flow rate in digital format as well as cumulative volume of water measured. The electronic output of the meter also makes it easy to connect to a datalogger for collection of continuous readings at a set interval.

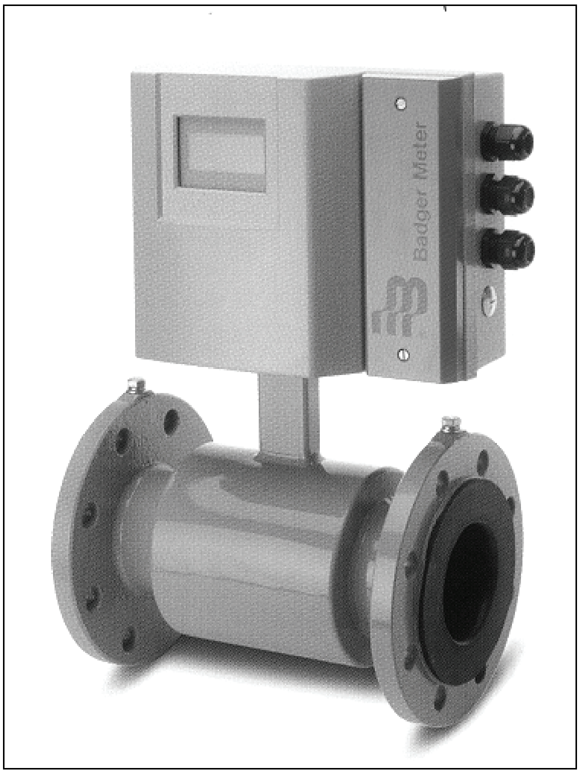
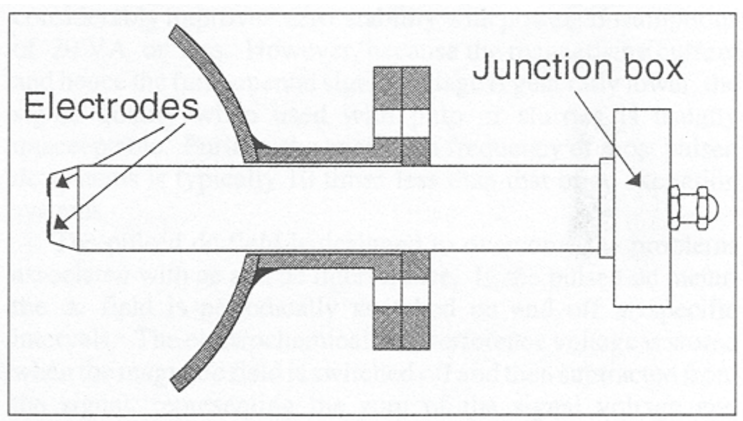
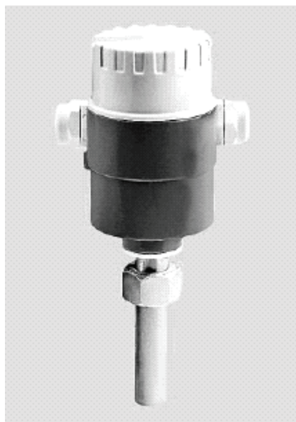


Figure 8.7 Example of an in-line type electromagnetic flow meter (Badger Meter, 2004)





(a) **(b)**

Figure 8.8 (a) Fitting and (b) example of an insertion type meter (Crabtree, 2000, and Endress & Hauser, 2004).

8.1.2.2 Installation

To achieve the levels of accuracy mentioned above, a minimum flow velocity of 2 m/s is recommended, and in the case of water containing solids, a minimum of 3 m/s is recommended to prevent deposition in the pipe. Most irrigation supply pipelines are designed for velocities less than 1.5 m/s for economic reasons, and the installation of an electromagnetic meter may therefore require a reduction in pipe size that will lead to additional friction loss in the system.

This may be critical in some irrigation systems since a reduction in available pressure to the system will results in lower irrigation efficiencies.

Care should be taken that the meter and pipeline are properly earthed and also protected against lightning. Protection of the connecting electricity and data cables as well any digital display units against vandalism and UV rays (sun) should be provided

8.1.2.3 Advantages

- No pressure drop (no flow obstruction)
- Short inlet / outlet sections (5D / 2D) for stable flow
- No moving parts
- High accuracy
- Wide flow range
- Robust with only minimal routine maintenance
- Relatively insensitive to flow profile disturbances
- Can be buried (vandalism proof)
- Difficult to tamper with, without detection
- Causes no obstruction in water flow path. (the insertion type has minor obstruction in the flow path)

8.1.2.4 Disadvantages

- Relatively expensive (in-line type)
- Inaccurate at low flow velocities (requires at least 2 m/s in pipe)
- Power supply required
- Larger sizes are difficult to handle due to weight
- Electronic components vulnerable to lightning damage
- Sensitive to electromagnetic interference
- Repairs require skilled technicians and specialised equipment
- Pipeline must be full
- The formation of chemical coatings, or even organic material, will depend on the characteristics of the water and developments of depositions should be monitored, especially on the insertion electrodes.

8.1.2.5 Maintenance

Since these meters do not have any moving parts and are of robust construction, no or only minor routine maintenance is necessary. It is recommended that the lining, earthing and electrodes be inspected annually, and verification performed when necessary but preferable at least every 5 years.

8.1.2.6 Further reading

KBS

Mick Crabtree’s Flow Handbook (Crabtree, 2000)

Know the flow training manual (Australian National Committee on Irrigation and Drainage, 2002).

8.1.3 Acoustic (ultrasonic) flow meters

8.1.3.1 Introduction

Similar to the electromagnetic meters, ultrasonic flow meters are non-intrusive devices that can measure flow at high accuracies (± 2% of reading), but are slightly more expensive. The biggest application of these meters in irrigation water measurement therefore is the use of portable clamp-on models for in-field verification of other installed meters or temporary measuring of flow at different points in a pipe distribution system.

Ultrasonic signals are transmitted through the wall of the pipe and works on most pipe materials found in the irrigation field, so that no installation equipment, changes to pipe work or disruption of flow is necessary. The operation can however be influenced by pipe vibration (if installed too close to a pump) or excessive rust inside the pipe. The meters are also relatively sensitive to upstream flow disturbances, thereby requiring long straight pipe section upstream of the measurement locations (as much as 40 diameters in the case of an upstream pump). Another aspect that make the meters more suitable for temporary use, is the fact that measurements are temperature sensitive.

There are two types of ultrasonic meters commonly used that each operates on a different principle for measurement:, ie. the Doppler method, and the Transit Time (time of flight) method.

The Doppler method

This type of meter operate on the basis of the Doppler effect, which is the change in frequency that occurs in a sound wave when the source and receiver of the wave move either away or towards each other.

The meter transmits an ultrasonic signal with a frequency in the order of 1 to 5 MHz at an angle into the water flowing in the pipe. Some of the energy of the signal is reflected back to the transmitter by particles (impurities) that are suspended in the water and the reflections are detected by the receiver. The transmitter and receiver are usually combined in one sensor unit. Since the particles are moving towards and past the meter, the reflected signal has a different frequency than the original one, and the frequency difference (Doppler shift) is directly proportional to the velocity of the particles. A schematic representation of the principle of operation is shown in Figure 8.9.

This meter was originally designed for the water treatment industry, and the water has to contain reflective particles of a diameter that is at least one tenth of the wavelength of the signal in concentrations of at least 75 parts per million (ppm) in the water, other wise it cannot be detected by the meter. This type of acoustic meter is more affordable than the transit time type, which is discussed below, but in the majority of instances irrigation water is to 'clean' or do not have enough silt or particles in it for effective measurement.

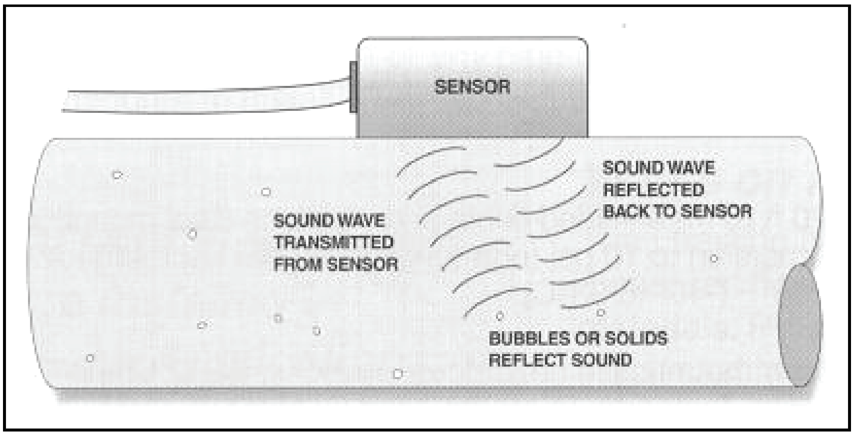


Figure 8.9 Doppler meter principles of operation (KBS, 2005)

Since it is possible that the particles are not always moving at the same velocity as the water, the Doppler meter's can produce measurement errors of ± 10%, which is considered relatively high, especially when one considers the relatively high cost of the meter. This type of meter is seldom considered for permanent installations since there are more accurate meters available at a lower cost. Its use is therefore limited to portable applications where the water carries a high impurity load.

The transit time (time of flight) method

The principle of the transit time meter is that the flowing water will reduce the propagation speed of an ultrasonic signal traveling against the direction of flow, and increase the propagation speed of a signal traveling in the same direction as the water flow. It is more accurate than the Doppler type meter (usually within ± 2 % of reading), does not rely on the presence of particles in the fluid and is therefore considered more suitable for irrigation water measurement. It is however, also more expensive than Doppler meters.

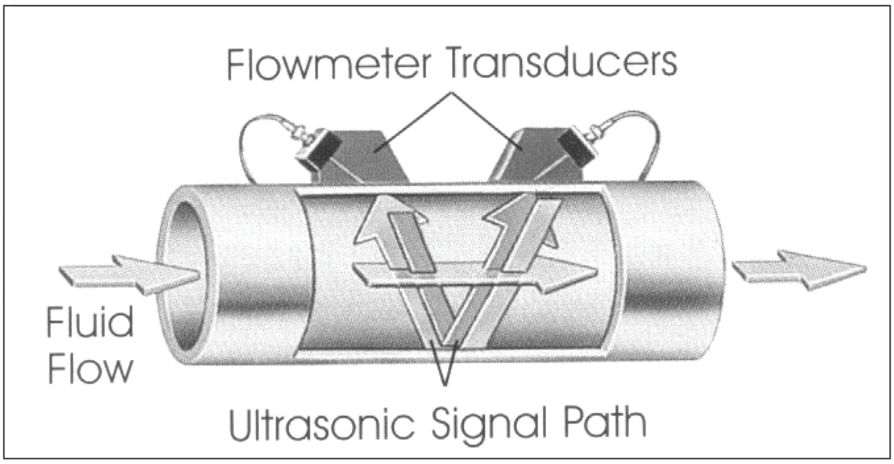


Figure 8.10 Schematic illustration of the signal path and transducer positions of a transit time flow meter (Panametrics Inc., 2002).

The meter comprises of two transducers mounted at an angle to the flow and each acting as a transmitter and receiver. The transit time of the signal is measured in both directions between the transducers and then compared. The flow velocity is directly proportional to the difference in transit time in the two directions. Transducers can be installed in-line with each other, transmitting the signal directly across the pipe diameter, or next to each other, in which case the signal s have to reflect off the inside pipe wall. The distance that the signal travels from one transducer to the next is called the path length.

The meter is suitable for a wide range of pipe diameters (50 mm to >3 m), with the only limitation being in the case of the small pipe diameters when the path length becomes short and the transit time differences are very small. This problem can be overcome by allowing the signal to traverse the pipe more than once, thereby increasing the path length, as shown in Figure 8.11, and improving the measurement accuracy.

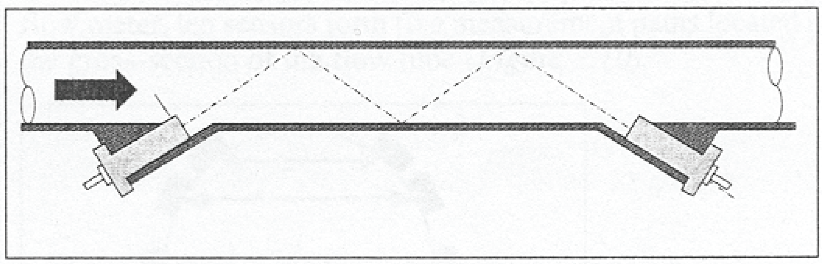


Figure 8.11 Increased path length through multiple traverses (Crabtree, 2000)

8.1.3.2 Installation

The meter installation basically comprises of the installation of the transducer(s). In the case of Doppler meters, there is usually only one transducer, and the manufacturer's guidelines should be followed when attaching it to the pipe. For transit time meters, the transducer spacing has to be calculated (mostly using software supplied by the meter manufacturer) and this depends on aspects such as water temperature and quality, and pipe wall material and thickness in the case of temporary installations.

In the case of temporary installations for both kinds of meters, it is imperative that a good contact between the transducers and the pipe wall is established and maintained during measurements. There should be no air between the transducers and the water, not inside or outside the pipe since this will weaken the signal strength. For this reason, too, should the transducers never be mounted on top of a horizontal pipe since this is where air will accumulate. They should also not be mounted on the underside of the pipe because this is where debris will be deposited most likely.

In order to function correctly ultrasonic meters require a fully developed flow profile, and is therefore sensitive to disturbances to the flow upstream of the measuring location. Typical manufacturer's recommendations with regard to installation are shown in Figure 8.12.

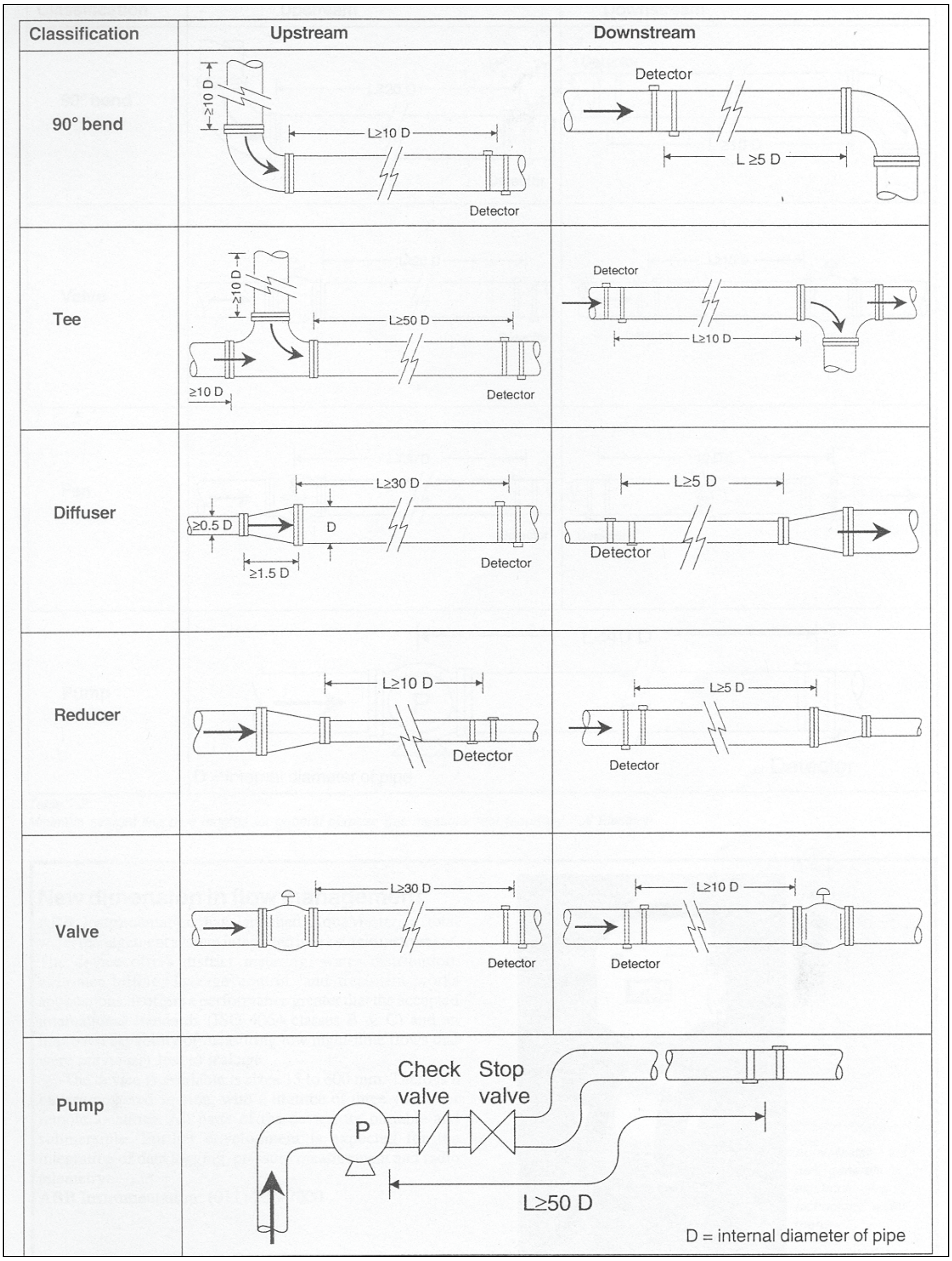


Figure 8.12 Installation guidelines for ultrasonic flow meters (Crabtree, 2000)

For permanent installations, transit time meters that is factory fitted in a flanged housing is available. These meters have a typical accuracy of within ± 1 % of reading and costs are comparable with those of electromagnetic meters. See the websites of manufacturers under paragraph **8.1.3.6 Further reading** below.

8.1.3.3 Advantages

- No contact between the transducers and the water required.
- Easy installation for temporary use.
- Wide range of flows can be measured with the same meter.
- No moving parts
- No additional head loss in the pipe line
- One size meter for all pipe sizes.
- Portable models are generally robust.
- Wide range of flow data is captured (velocity, flow rate, volume, energy, etc.)
- Empty pipe can be detected.

8.1.3.4 Disadvantages

- The low accuracy of the Doppler meter (+-10%) makes its application in certain irrigation schemes a little doubtful.
- The Doppler meter requires minimum size and concentrations of particles in the water being measured.
- Both meter types are very sensitive to flow profile variations.
- Requires external power if used for extended periods (portable models usually have built-in rechargeable batteries).
- High cost, especially good quality transit time meters.
- Repairs require skilled technical staff with specialised equipment.

8.1.3.5 Maintenance

No routine maintenance is required, but wires and batteries may need replacement periodically. Supporting software may need to be upgraded occasionally to fit in with Personal computer (PC) operating system changes (eg, previously DOS to Windows, etc.).

8.1.3.6 Further reading

KBS

Mick Crabtree's Flow Handbook (Crabtree, 2000)

Know the flow training manual (Australian National Committee on Irrigation and Drainage, 2002).

www.mace.com.au/agprod.htm

www.us.water.danfoss.com/produc.html

8.2 Alternative measuring methods

8.2.1 Introduction

The indirect measuring methods are those where flow measurements are based on the measurement of variable inputs into a pumping system. For example, the energy or electricity use of a pump motor (set) is monitored and from this, together with the specific pump's characteristics, the flow rate is calculated. Three different indirect methods are discussed namely the kilowatt-hour -, the hour meter - and the electric power supply measurement methods.

8.2.2 Kilowatt-hour meters

8.2.2.1 Introduction

It is a common practice in Kwa-Zulu-Natal for WUAs to determine farmers' water abstractions made with electrical motor driven pumps on the basis of their electricity accounts (Van der Stoep et al, 2002). The method usually entails a once-off "calibration" procedure where a flow meter is temporarily installed at a specific pump station, and electricity consumption (in kWh) and the discharge be measured simultaneously for a short period of time. A calibration factor is determined that describes the relationship between electricity consumption and the volume of water pumped. The flow meter is then removed, and water usage is calculated on the basis of the electricity account received from the national electricity supplier (ESKOM) and the calibration factor.

Although the method gives some indication of usage, it cannot be considered an accurate measurement method. Investigation by MBB Consulting Engineers (1997) at the Thee-waterskloof Dam in the Western Cape showed that measurement errors between ± 25 to 50% of the real usage can be made. The method is limited to pumped abstractions where electric motors are used and cannot be recommended for use due to the low accuracy.

8.2.2.2 Installation

No additional equipment is needed because the existing electricity supplier's meters are used.

8.2.2.3 Advantages

- No additional equipment is required since the kilowatt hour reading from the electricity supplier is used.
- Low cost.

8.2.2.4 Disadvantages

- Very inaccurate (errors of up to ± 50 % is possible)

- An initial calibration of this kWh-meter, to link it with the pump set at a typical flow rate , is needed. This however cannot make provision for the the pump being operated at different duty points.
- Annual recalibration of the measured pumps will be necessary to minimize the effect of wear and thereby help improve the "accuracy" of this method.

8.2.2.5 Maintenance

The maintenance will include the re-calibration of the pump set to the kilowatt hour (kWh) meter on at least a yearly basis. The maintenance of the kWh meter is the responsibility of the electricity supplier.

8.2.3 Hour meter

This method is similar to the kilowatt hour method described above, but in this case it is simply based on the time for which a pump set is used or the number of hours usage during a cropping season. This number of hours is then multiplied with the specific pump's flow rate, as determined during a once-off "calibration". This calculation provides an estimate of the volume of water which was pumped during a certain time span. The pumps' flow rate can also be estimated from its characteristic pump curve if a portable flow meter is not available.

During a field study in Kwa-Zulu-Natal in 2002, it was determined that the measurement error at one specific location was 79 %. As in the case of the kilowatt hour meter method, this method cannot be recommended for use.

8.2.4 Electric power supply measurement

8.2.4.1 Introduction

This measuring method is based primarily on the assumption that the efficiency of the motor and pump combination is constant for a specific flow-rate of the pump, and that this efficiency does not change significantly over time. The efficiency of the pumping action is a product of the efficiencies of the motor, the coupling and the pump.

This meter measures a number of electric variables and from this the flow rate and cumulative flow of the water can be established. This meter is thus not in direct contact with the water, but only measures the power inputs to a specific the pump unit/set.

Results from the tests showed that the meters had a higher accuracy than available mechanical meters. The installation of this meter and its calibration on site is quite simple and does not involve any pipe cutting, but only electric power supply connections. The capital cost of this meter promises to be lower than conventional mechanical meters. The size of the meter does not vary with the pump's delivery pipe size.

It is foreseen that the re-calibration for this meter type will have to take place every few years, depending on the wear of the pump and electric motor.

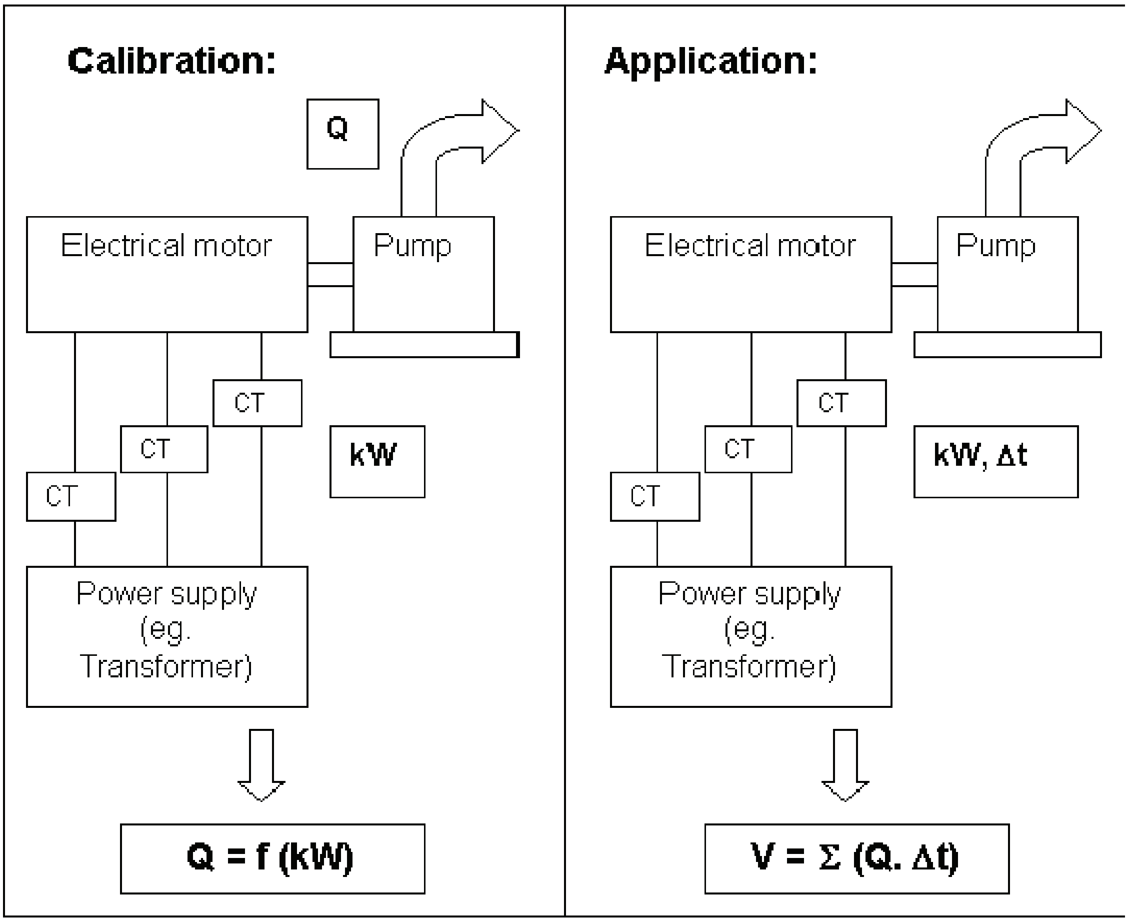


Figure 8.13 Principles of the electric power measurement method

8.2.4.2 Installation

The installation of the meter is normally in the existing box which houses the electric switchgear, without any wiring to the pump set. The installation should be done by a trained person. With installation, the calibration of the pump should also take place. For this an accurate portable flow meter is required. For smaller pump sets it can also be done volumetrically, using a calibrated container.

8.2.4.3 Advantages

- The estimated low price of the meter
- The absence of any moving parts or intruding parts in the water
- Ease of installation
- No head-loss due to meter
- Very low maintenance
- The meter also has features that can protect the electric motor, pump and main lines.

8.2.4.4 Disadvantages

- The calibration of this meter and the re-calibration to make provision for wear on the pump are the main disadvantages. However, the calibration results will be useful, as it will indicate to the user in what condition his pump system is.

8.2.4.5 Maintenance

The meters vulnerability to lightning is foreseen, and on-going attention will have to be paid to proper functioning of the surge breakers installed with the meter. The absence of any moving parts makes this meter nearly maintenance free. Maintenance will have to be done by skilled people with the necessary equipment.

8.2.4.6 Further reading

Water Research Commission (WRC) report no. 1190/1/04 Electric power supply measurement as an alternative to measure flow-rates of hydraulic pumps.

8.2.5 The pump differential head measurement method

8.2.5.1 Introduction

A possible alternative method that could overcome some of the constraints which conventional meters are subject to, is based on the unique relationship between the discharge and differential pressure of a specific pump. The pump differential pressure is the increase in pressure that takes place between the suction and the discharge branches of the pump (SIHI Group, 1985).

For a centrifugal pump driven at a constant speed, the pump head, H, as well as the power, efficiency (ŋ) and Nett Positive Suction Height (NPSH), are functions of the pump discharge, Q. These relationships are represented by characteristic pump curves, resulting from pump tests.

By performing a pump test where the discharge or flow rate (Q) and differential pressure (Δp) can be measured simultaneously, the data which is obtained can be used to determine the discharge – differential pressure relationship for a specific pump for a range of operating conditions (but for specific installation conditions, such as the positioning of the pressure transducers). If this relationship can be described by a mathematical function where the discharge is a function of the differential pressure, the function can be used to calculate the discharge from a differential pressure measurement. The volume of water discharged by the pump over a period of time can then be determined by integrating the calculated discharge over time. A schematic representation of the calibration and measuring principle is illustrated in Figure 8.14

This was an experimental method and its is not currently available in industry. The hardware for infield application still needs to be developed. This measuring method shows potential, but refinement and development is still required.

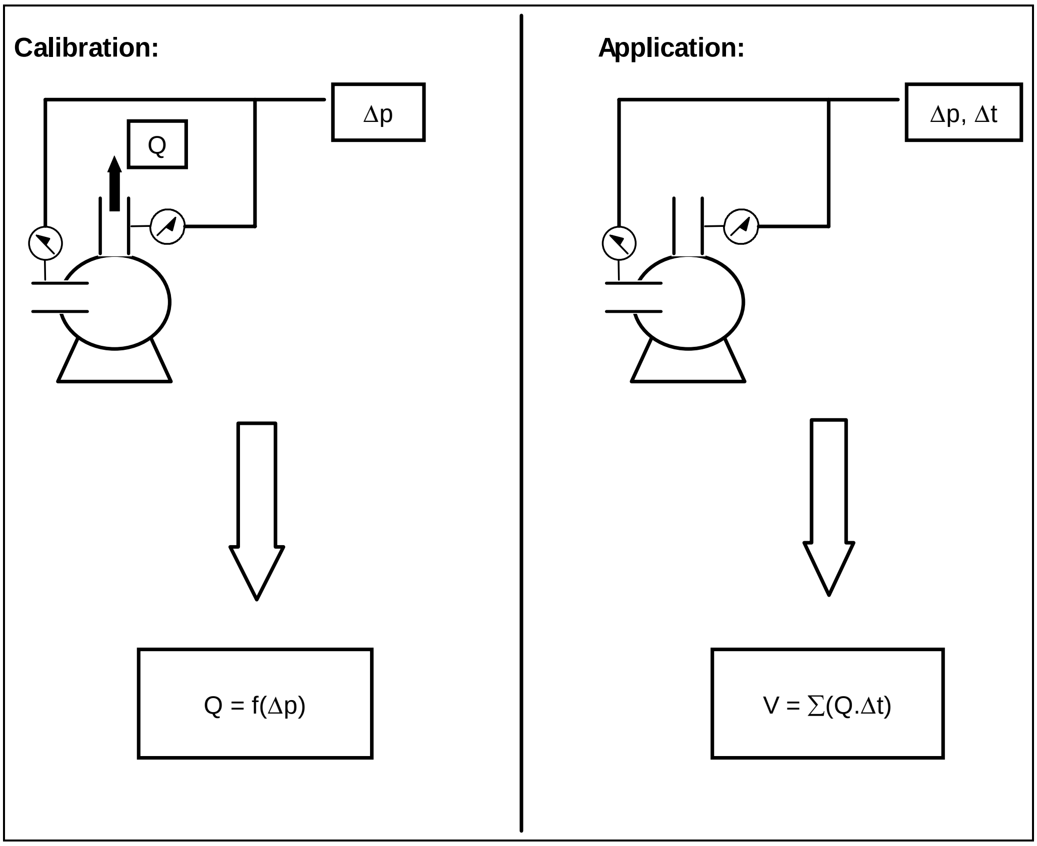


Figure 8.14 Principles of the pump differential head method

8.2.5.2 Installation

The installation is quite simple and only two measuring points are needed, one on the inlet and one on the outlet side of the pump. This can be drilled and tapped or welded onto the different positions.

8.2.5.3 Advantages

- Relatively low capital cost
- Simplicity of installation and operation.
- No moving parts are present and no intrusive elements are used.

8.2.5.4 Disadvantages

- The method has not been commercialised yet.
- Potential vulnerability of the electronic equipment to lightning damage is a disadvantage.

8.2.5.5 Maintenance
Limited maintenance is foreseen and this is due to the absence of moving parts and the simplicity of the elements.

8.2.5.6 Further reading
Evaluation of an indirect method for measuring irrigation water abstracted with centrifugal pumps (Van der Stoep, 2004)

8.2.6 Elbow meters

8.2.6.1 Introduction
If cost is a factor and additional pressure loss from an orifice is not permitted, a pipe elbow can be used as a differential pressure primary device. Elbow taps or take-off's (pressure measuring points) are a given on almost all pressurised water systems. The use of an existing elbow prevents additional pressure drop and additional costs.

Differential pressure meters encompass a wide variety of meter types which includes: orifice plates, venturi tubes, nozzles and variable area meters. The use of differential pressure, for flow measurement, is still the most widely applied technology. (Crabtree 2000)

One of the features of the differential flow meter is that flow can be accurately determined from the differential pressure, the dimensions of the device and the properties of the fluid. From this it can be seen that they do not always require direct flow calibration. They offer excellent reliability, reasonable performance and modest capital cost.

Some factors that influence the pressure difference are:
- Force of the flow onto the outer tapping
- Turbulence generated due to cross-axial flow at the bend
- Different flow velocities at the inner and outer radii of flow
- Internal pipe texture
- Relationship between elbow radius and pipe diameter

Generally the elbow meter is more suitable for higher velocities when typical measuring errors of only ± 5% can be achieved. On-site calibration can however produce more accurate results. This meter type is not commonly used, but it costs little and is easy to install. Unlike the previous three methods described, its application is not only limited to pumped applications – it can be used in any pipeline as long as the pipe is completely filled with water.

The accuracy of the specific elbow flow meter can only be established on site. Therefore a general accuracy indication cannot be provided. Laboratory tests at the Water Resources Research Laboratory, Bureau of Reclamation, Nebraska evaluated a number of elbow flow meters. The meters were made from available irrigation equipment. Accuracies varied within the 10% of the flow ranges.

8.2.6.2 Installation

There are no known suppliers in South Africa, and therefore all meters should be custom made, although available data-loggers can be used. The on site manufacturing (positioning and welding of the measuring points) will be the cheapest and more desirable option for existing in situ elbows.

It is recommended that the elbow meter be installed with 25 pipe diameters of straight pipe upstream and at least 10 diameters of straight pipe downstream of it.

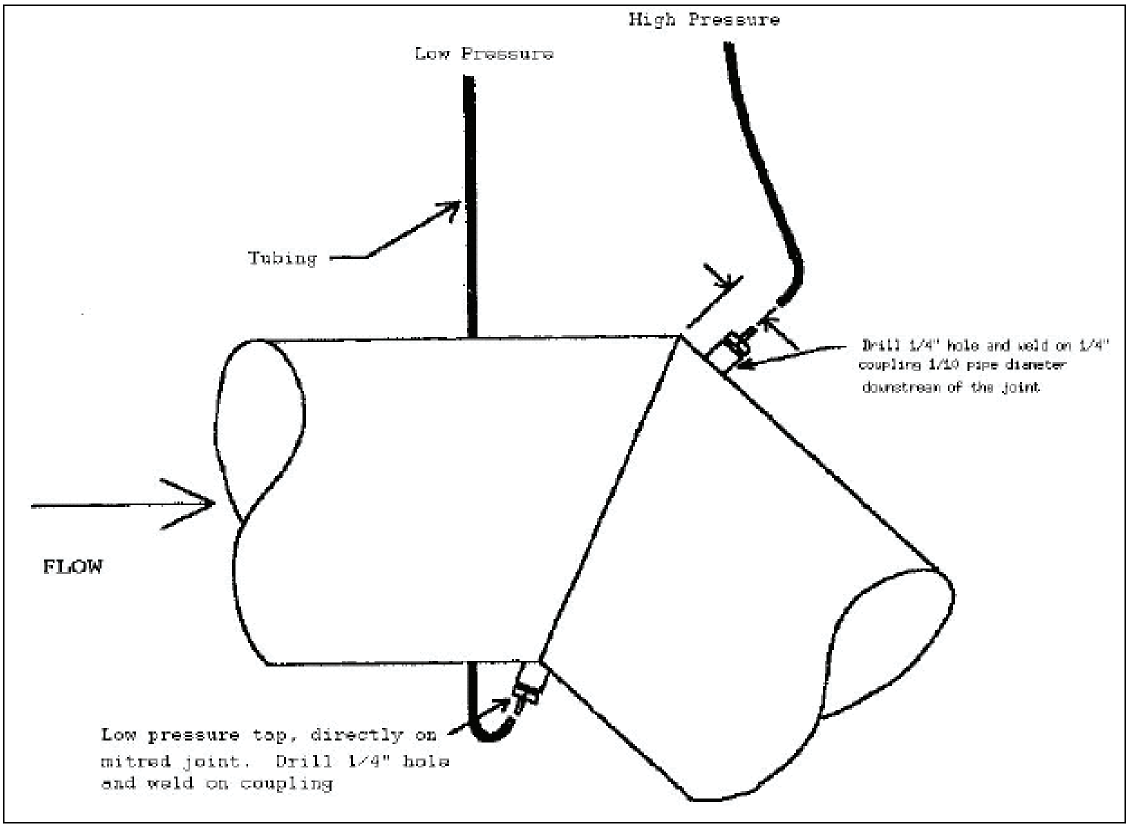


Figure 8.15 Typical lay-out of elbow meters (Wahl, Clemmens, Replogle & Bos, 2002)

8.2.6.3 Advantages

- No obstruction in the flow path, therefore no additional head-loss.
- The cost for this meter is low, since only pressure gauges or pressure transducers as well as a converter are needed if electronic data collection is needed.

- The use of pressure gauges only together with manual calculation of the flow can be done as well to reduce costs.
- Easy installation with no major changes to existing pipe work required.

8.2.6.4 Disadvantages

- The relative low accuracy can limit its application, that is if in-accuracies of less than 10% is required.
- Sensitive to flow profile disturbances.
- Not commercially available and therefore limited technical support available.

8.2.6.5 Maintenance

No additional maintenance should be required, except on the pressure gauges and electronic data collection equipment.

8.2.6.6 Further reading

Einhellig, R. et al. Proc Spec Conf. HMEM

8.3 Secondary elements for closed conduits

In order for useful information to be obtained from the primary measuring device, the measured parameter has to be conveyed to the meter operator. The output of the primary device can be transmitted as an analogue or digital signal, either in visual format that can be observed by the operator, or in electronic format that can be automatically recorded and / or converted by equipment.

This section presents an overview of typical secondary devices that are used in conjunction with closed conduit measuring devices to produce useful output. The processing and handling of the output itself is discussed in Chapter 9.

8.3.1 Displays

8.3.1.1 Introduction.

The revolutions of the rotor of a mechanical meter is usually is registered by means of either a low friction gear train connecting the axle to the display or totaliser, or a magnet, fitted within the rotor assembly which produces a single pulse per revolution in an externally mounted pick-up coil. The output can then be displayed as an analogue or digital output in either mechanical or electronic format.

Mechanical registers

The simplest form of mechanical register only displays the volume of flow (typically in m^3 or kiloliters) that had passed through the meter since its installation on a totaliser that may consist of a row of rotating numbers and / or a set of small dials. Care should be taken when reading this kind of totaliser since the value that is displayed sometimes has to be multiplied by 10 or 100 to obtain the correct units. An example is shown in Figure 8.16. To read this register, the number in the blocks multiplied by 100 has to be added to the reading on the big dial multiplied by 10 and to the reading on the small dial, so in this case the volume in cubic meters will be:

$$(101 \times 100) + (0 \times 10) + 0 = 10100 \text{ m}^3$$

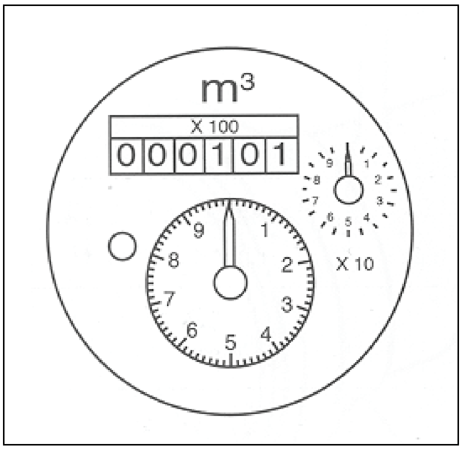


Figure 8.16 Example of a mechanical register (Meinecke, 2001)

Some manufacturers combine the totaliser with a flow rate indicator, similar to an analogue revolution counter in a car, as shown in Figure 8.17. The flow rate indicator, however, only gives an approximation of flow rate and is not highly accurate.

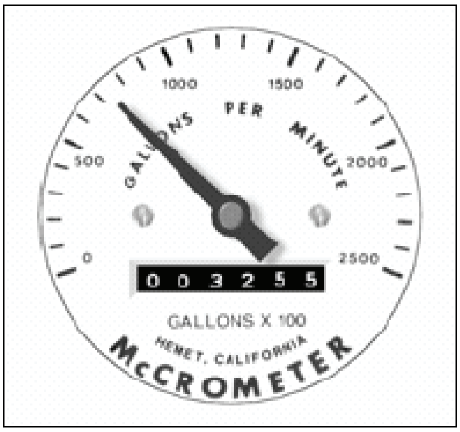


Figure 8.17 Totaliser combined with flow rate indicator (McCrometer, 2005)

In both of these cases, no continuous datalogging can take place and data can only collected by visiting the site and taking the reading manually. In order to collect readings at shorter intervals, and / or automatically, some mechanical registers can be fitted with a pulse output device that can be connected to a datalogger or electronic converter to receive a digital signal. The pulse output device or probe can be either factory fitted or be supplied separately for fitting after meter installation.

The pulse is usually generated by a magnet fitted on one of the gears which rotates inside the register. In the case of the magnet, a normally open reed switch (relay) is fitted outside the enclosure at a specific position and every time the magnet passes or triggers the switch, it changes state (closes) and each switch closure then represents a certain volume of water that has passed through the meter (eg.1 m^3). The number of switch closures recorded within a certain time period therefore represents a corresponding volume of water. If time stamps are also recorded, average flow rates can also be calculated. Optical switches using an infrared light source are also available from some manufacturers.

Some registers can produce analogue outputs (eg. 4-20 milli-Ampere or 1-5 Volt) directly proportional to the flow rate of the meter. This kind of signal can also be recorded by most dataloggers, and if combined with time stamps be used to calculate the volume of water that had passed through the meter.

Typical examples of pulse output probes are shown in Figure 8.18. Pulse outputs are typically available in one pulse per 0.1 or 1 m^3 (100 or 1000 liters) and are also useful for farmers practicing fertigation with a dosing pump (where fertilizer is applied through the irrigation system). The pulse output can be used to regulate the concentration of fertilizer being mixed into the irrigation water.

The dials are sometimes filled with glycerin to improve visibility and act as lubrication for gears, but cases of vandalism to meters to remove the glycerin have been reported in South Africa.

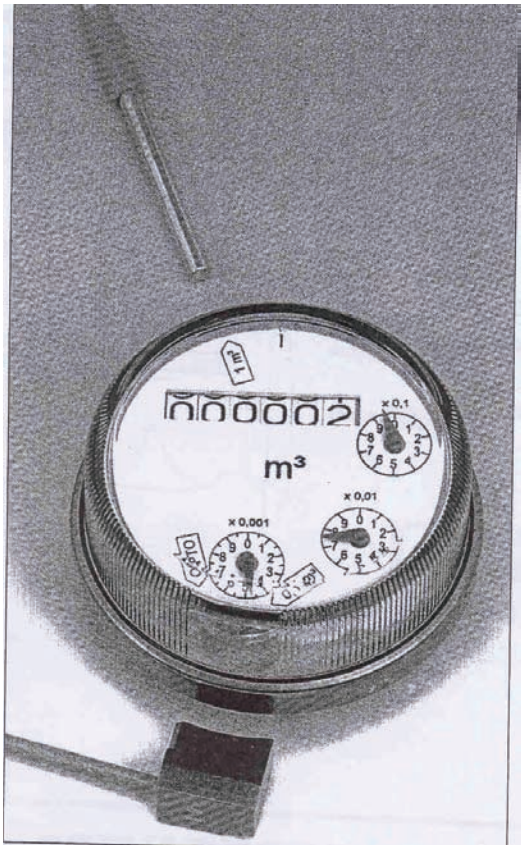


Figure 8.19 Mechanical display with two types of pulse output probes (KBS, 2005)

Electronic displays

If a meter produces an electronic output, such as in the case of mechanical meters with pulse outputs or electromagnetic and acoustic meters, the output can be converted and flow rate and / or volume displayed in digital format on Liquid crystal display (LCD) or Light emitting diode (LED) – based displays. These displays offer the advantage of better readability than the mechanical displays thereby reducing the possibility of human error. It also makes it possible to display more than one parameter if the display can toggle between different screens, and other built –in functions include the possibility of resetting totalisers. Any programmable function on an electronic display should be password protected to prevent tampering. On the other hand, electronic displays are more sensitive to environmental damage from lightning and Ultra-violet (UV) radiation. LCD especially screens should be protected from direct sunlight.

An example of the LED display on a converter is shown in Figure 8.20, and the LCD type in Figure 8.21.

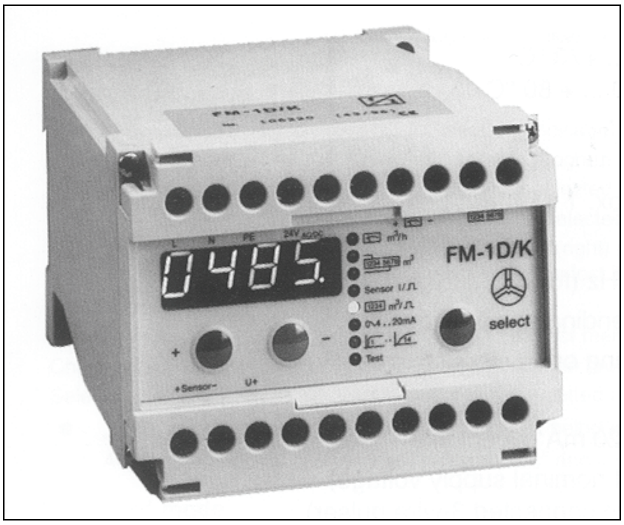


Figure 8.20 Example of an LED display (Meinecke, 2001)

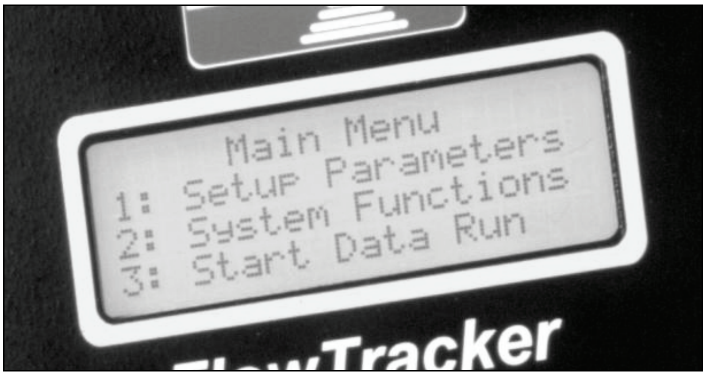


Figure 8.21 Example of a LCD type display (Sontek, 2004)

8.3.1.2 Installation

The installation of the displays will depend on the application of the specific flow meter. In the case of mechanical flow meters, the displays are an integral part of the flow meter. In cases where the displays are in remote or distant positions in relation to the meters or primary elements, installation should be for easy access. The installation should be according to the suppliers' recommendations. This usually entails the supply of electricity, protection against lightning damage and protection against the elements and direct sunlight.

8.3.1.3 Advantages

Mechanical displays

- Robust
- No need for electric power
- Not affected by lightning

Electronic displays

- Versatile – can display many parameters
- Easy to read
- Data can be collected automatically or telemetrically
- Provides interface for on-site programming of converters
- Pulse outputs can be linked to fertigation system

8.3.1.4 Disadvantages

Mechanical displays

- Limited output
- Not always precise
- Mechanical parts wears out over time
- Vulnerable to damage if filled with glycerin
- Has to be read manually – cannot be linked to telemetry
- Difficult to read – mistakes can easily be made

Electronic displays

- Requires electric power
- Sensitive to lightning
- Sensitive to UV radiation
- Data easily lost of the device malfunctions

8.3.1.5 Maintenance

The maintenance needs are to be performed by trained people with the necessary equipment. Mechanical outputs will have to be checked regularly for signs of wear; electronic systems have to be ensured of a reliable power supply. Displays should be kept in good condition so that they can be easily read. Wiring should be checked regularly where applicable.

8.3.1.6 Further reading.

KBS
Manufacturers' technical brochures

8.4 Summary of closed conduit devices

Table 8.1 Summary of closed conduit devices

Method	**Volumetric data output (standard)**	**Flow rate data output (standard)**	**Sensitivity to installation conditions (hydraulic)**	**Needs ext. electric power (standard)**	**Accuracy (relative)**	**Sensitivity to dirty water**	**Additional pressure loss in system**	**Continuous data recording possible**	**Typical cost of standard unit (including installation)**
Turbine	Yes	No	High	No	Moderate	High	Low	Yes*	<R5000
Impeller	Yes	No	High	No	Moderate	Moderate	Low	Yes*	<R5000
Propeller	Yes	No	High	No	Moderate	High	Low	Yes*	<R5000
Bypass	Yes	No	High	No	Moderate/Low	High	Moderate	Yes*	<R5000
Electromagnetic (inline)	Yes	Yes	Moderate	Yes	High	Low	None/Low	Yes*	R10000 – R25000
Electromagnetic (insert)	Yes	Yes	High	Yes	Moderate	Moderate/Low	None/Low	Yes*	R6000 – R12000
Acoustic Doppler	Yes	Yes	High	Yes	High	Low	None	Yes**	R15000 – R40000
Acoustic Transit Time	Yes	Yes	High	Yes	High	Low	None	Yes**	R15000 – R90000
Electric power	Yes	Yes	Low	No	Moderate/High	Low	None	Yes*	<R8000
Pump differential pressure	Yes	Yes	Low	Yes	Moderate	Moderate/Low	None	Yes	<R8000
Elbow	No	Yes	Low	Yes	Moderate	Moderate/Low	None	Yes	<R8000
kiloWatt-hour	Yes	No	Low	No	Low	Low	None	No	<R1500
Hour meters	Yes	No	Low	No	Low	Low	None	No	<R500

* Additional hardware always required

** Additional hardware sometimes required

9. SYSTEM OPERATION

System operation entails the retrieval of operational data, analysis and possible archiving of such data, the formation of decisions based on the analysis and the subsequent execution of resultant control strategies (Wolhuter, 2004).

The secondary measuring devices discussed in Chapters 5 and 6 all produce outputs that can be transmitted for further analysis or processing. These outputs are in either analogue or digital format and can be transmitted to various devices, ranging from simple mechanical registers, to sophisticated data loggers. The data that has been recorded or captured then needs to be retrieved by the Water User Association (WUA). This can take place manually or telemetrically, depending on the situational requirements, and the retrieved data is then processed for presentation to the water management staff or water user. The retrieved data may further necessitate an action to take place, such as an adjustment to a valve or sluice gate, and it is also possible to automate this process.

9.1 Data recording

Depending on the purpose of the measuring system, the data that is needed from a measuring device may only have to reflect the flow rate or accumulated flow for a specific period at the time of measuring, or it may be necessary to record data regularly at short intervals for analysis, for instance to identify trends and usage patterns. The form of data output varies from one device to the next and it is discussed in Chapter 5 and 6.

9.1.1 Displays

Meters fitted with displays, or measuring structures fitted with gauging plates can be read at any time but requires a visit to the measuring location. To reduce the number of visits to a measuring location and to provide time / event historical data of flow at a specific location, the measuring device output can be recorded with a data logger.

9.1.2 Data loggers

A data logger can be defined as a low power device designed to collect readings from a variety of outputs at unattended locations, at specific times. It therefore usually consists of input modules (analogue, digital, pulse), a central processing unit, memory modules for data storage, and communication ports for data output.

The data logger can be programmed using appropriate software from a Personal Computer (PC) via the communication port, to collect data at selected time intervals, and sometimes to perform certain basic processing functions such as averaging. The amount and quality of data that can be stored depends on the capacity of the memory module and processing unit. Care should be taken when programming the logger since there are often options that make it possible to overwrite data stored previously if the logger's memory is full.

The data logger requires power to perform its functions; this power may be provided by a built in battery with a long life time that needs to be replaced periodically, or from an external power source that needs to be supplied constantly. In general, the more powerful and sophisticated the logger, the more power it requires. Sometimes the secondary measuring devices also draw their power from the logger (for example some level sensors), and this can add to the required current drain on the power supply.

The logger should be selected according to the required functions it has to perform. These include:

- The number and type of signals it will receive from measuring devices
- Processing requirements of inputs
- Buffering or storage required
- Format of the outputs

Care should be taken that the data logger is installed correctly, and the output should be checked for correctness during a trial period after installation. There should also be some way of monitoring the power supply levels during data collection, especially in the case where batteries have to be replaced periodically.

Data loggers should be protected against the elements, especially rain, lightning and extreme temperatures since this could result in malfunction and data loss. The power supply unit of a data logger is also very vulnerable, particularly when it is a portable direct current type with widespread other possible applications. It should therefore be secured at all times.

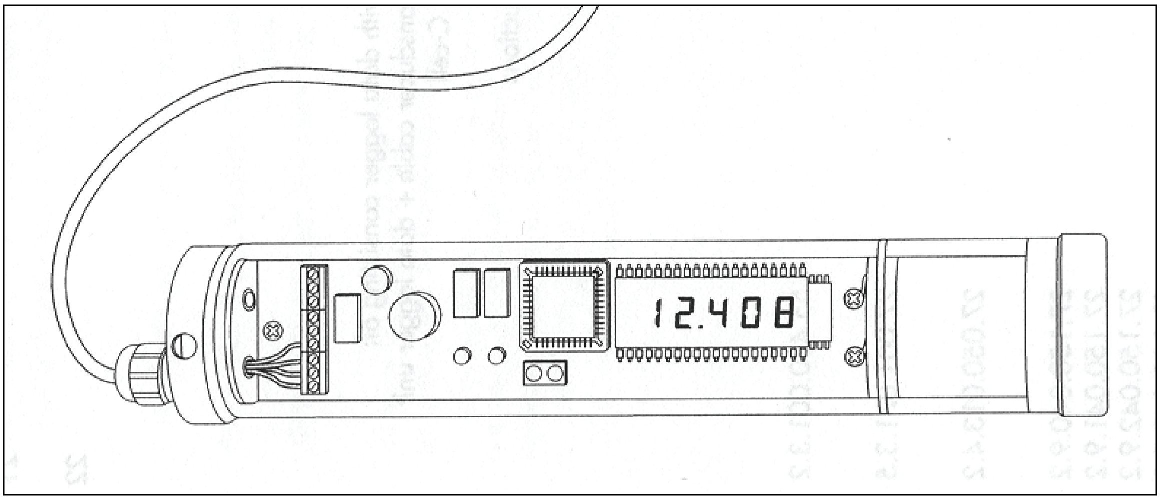


Figure 9.1 Example of a datalogger (OTT Hydrometry, 2004)

9.2 Data retrieval

The data from the measuring device can be collected basically in two ways: either manually through visits to each measuring location, or telemetrically, through remote interrogation of the secondary device or data logger.

9.2.1 Manual collection

Although manual collection is probably the less accurate of the two ways of collecting data, it is still practised widely due to the cost involved with the alternative method. The following important points should be kept in mind when developing a meter reading procedure:

- A schedule should be drawn up for when readings are required
- The measuring device s should always be identified according to the same parameter, for example a number or Global Positioning System (GPS) location, etc., to make sure the correct device is being read
- The reading should be taken down correctly, with attention given to the position of the decimal or any factors that need to taken into consideration
- The reading should preferably be compared with the previous reading taken to make sure the reading is realistic (equal to or greater than the previous reading)
- Any signs of tampering or malfunction should be noted
- If the readings are taken down on paper they will need to be entered into a computer for processing, and this should be done correctly.

Some measuring device readings can be collected with a handheld recorder (not a laptop computer) that picks up a signal from the device when the recorder is activated in the vicinity of the device (inductive), or when connected via a cable. The data from a number of devices can be collected before being downloaded to a computer at the office. This kind of system reduces the likelihood of errors occurring during manual collection. When collecting data from a data logger in this way, the handheld device often also clears the logger's memory and gives an indication of the level of the power supply. A laptop computer can also be used but is more cumbersome because of its size and own power requirements.

Although manual collection is more time consuming and expensive in terms of man-hours than telemetric collection, it offers the advantage that measuring devices are visited periodically and can therefore be inspected for damage or vandalism.

9.2.2 Telemetric collection

Advances in the industrial and process engineering fields have led to the development of automatic monitoring and control systems. This technology makes it possible for an industrial plant to be supervised and operated by programmed electronic controllers, reducing the need for 24 hour human monitoring. If these functions are performed from a central point some distance from the infrastructure that is being managed, it is referred to as remote sensing and / or control systems.

Automatic monitoring and control systems are well adapted for use in irrigation water supply and distribution applications, and some basic information on the typical system lay-out and components are presented here.

Other terms that are often used to refer to automatic monitoring and control systems are telemetry, Supervisory Control and Data Acquisition (SCADA) and Automatic Meter Reading (AMR).

Telemetry can be defined as the remote recording or indication of measurements and signals from plant or supply infrastructure, by means of telecommunication, as well as the remote control and management of such infrastructure via the same means (Wolhuter, 2004).

Supervisory Control and Data Acquisition (SCADA) refers to a system whereby computers are used to collect real-time data from plant machinery to provide central monitoring, control and process visualisation of the plant and its facilities. A SCADA system is built around programmable logic controllers (PLC's) receiving inputs from measuring devices, and specialised PC-based software as the interface (Adroit Technologies (Pty) Ltd, 2000).

Automatic Meter Reading (AMR) refers to systems that collect the data from flow meters automatically, usually consisting of a combination of telemetry and datalogging technology. Two examples of sophisticated yet useful AMR systems are “walk-by” and “drive-by” systems. A walk-by system utilises a meter interface unit which automatically transmits the meter reading to a handheld computer. All the meter reader has to do is to walk by within a certain distance of the meters and the readings will automatically be picked up when the handheld device is within range of a meter interface unit. Drive-by systems are similar, except that a data collection unit is fitted inside a vehicle which is then driven past meters fitted with interface units. The technologies’ obvious advantages are the reduced amount of time required to collect readings as well as easier collection from meters in hard to reach places.

Telemetry is a specialised field of electrical engineering and it is advised that knowledgeable and experienced consultants are approached to assist the WUA in planning a telemetric system. The information presented here is therefore only aimed at providing a WUA with some insight into the basic composition and possible functions of a telemetry system.

The process of selecting suitable data retrieval technologies is similar to the one outlined for selection of the measuring devices. The intended purpose of the system should be defined, as well as a range of design considerations, for example (Wolhuter, 2004):

- Number and type of inputs from measuring devices
- Data arrival rate
- Single or multi channel communications
- Required and / or available bandwidths
- The existing (if any) and ultimately required network topology
- Communications medium to be used
- Physical infrastructure at the different areas of intended installation (power, security, etc.)
- Standard of service required (reliability and accuracy)

Due to the specialist nature of the systems, only the communication medium, network topology and generic system components are discussed here.

9.2.2.1 Communications medium

There are basically two types of communication mediums to select from, i.e. cable-based or wireless, with a number of options under each type. The distance across which data must be transmitted is usually the first determining consideration when selecting a type.

Cable-based communication

For shorter distances over which data must be sent, cable based systems offer advantages such as lower cost and no dependency on networks and service providers. In the irrigation sector, cable based communication is mostly used at farm level only, for instance to connect soil water sensors to a datalogger for scheduling purposes, and has therefore limited application at WUA level.

There are two main types of cables used for communications:

Copper cable

Traditionally, all non-radio based communications were carried by copper conductors, and although it is now being replaced by optical fibres and microwave systems, it is still widely in use due to the low cost and convenience of the systems.

Twisted pair type copper cable are typically used for landline type telephone communications or local area networks (LANs) inside buildings, and can transmit both analogue and digital signals at a capacity of 10 Mb/s over distances of a few kilometres. Coaxial copper cables are used for baseband signal transmission, as well as broadband type networks for long distance analogue transmission, such a s cable TV in some countries (Wolhuter, 2004).

Fibre optics cable

Fibre optics systems offers advantages of increased distances that can be covered and almost infinite bandwidth over copper cable based systems. Current technology allows single-mode transmissions at a few Giga-bytes per second (Gb/s), for distances of up to 30 km without repeaters. Modulation is commonly achieved by pulsing a light source along a glass fibre cable.

A number of fibre cable types and formats exist, ranging from steel armoured, PVC jacketed, or some even with straining wire for overhead installation. The earth conductor on HV lines nowadays has an embedded fibre for telecommunications or control purposes. The selection of the specific type will depend on the data throughput requirements, distance, installation conditions and cost sensitivity of the particular application (Wolhuter, 2004).

Wireless (radio-based or cell phone (GSM)) communication

Wireless communication mediums are developing and improving rapidly. They offer the advantages of increased range and easier installation than cable-based systems, but are more expensive to purchase and to maintain.

Radio frequency

Appropriate radio frequencies (RF) include UHF, VHF (single channel narrow band) and spread spectrum that can be used to retrieve data. The main advantage of RF over GSM is that there are no “call” costs – the connection is always available and only limited by power supply to the equipment. An RF communication system will therefore be less expensive to use for monitoring water supply infrastructure where short but regular communication is necessary (for instance, to check flow depth at a structure) than a GSM system where every communication is charged for by the service provider.

Spread spectrum use requires no license, there is a low on-going cost and data transfer rates up to 115 200 baud is possible. The communication must be line of sight but with special antennas distances of up to 85 km can be covered. Repeater stations can also be used to extend the reach.

UHF and VHF usage requires a license, offers lower data transfer rates (up to 1200 baud) and has higher power consumption. However, it can transfer data over much longer distances and the lower frequency bands can handle uneven topography and obstacles better.

Cell Phone (GSM)
GSM technology (what is used for cellular phone communication) is a reliable system, with networks being maintained well by the service providers, and with an acceptable data transfer rate of 9600 baud. Another advantage is the fact that a GSM connection makes it possible to contact a remote datalogger from any cellular phone at any time to obtain real time information.

The disadvantages include limited network coverage, especially in rural areas, as well as high initial and on-going costs, and high power consumption. GSM communication is therefore more useful where periodic (long interval) data collecting functions are required over long distances, and not for continuous operation monitoring.

9.2.2.2 System components

A typical telemetric data collection system would consist of the following components:

- Digital, pulse or analogue inputs from the measuring devices being monitored
- Remote terminal units (RTUs) receiving the inputs and transmitting it onwards
- A master station (MS) at a central point to receive the data from the RTUs
- Communication hardware for transmitting between the RTUs and MS
- Operating software to program and manage the system

Remote Terminal Unit (RTU)
The RTU usually consist of a datalogger (Central Processing Unit (CPU) controller) with its various input and output modules, power supply and a radio or modem (depending on whether RF or GSM communication is used). A schematic representation of a typical RTU lay-out is shown in Figure 9.2.

In practice, every measuring location has be equipped with an RTU, which can handle inputs from a number of measuring devices (it will depend on the datalogger being used). It is absolutely essential that the RTU be protected against lightning (or other voltage surges in the case of Alternating Current (AC) power), that it is earthed properly and that all the equipment is housed securely in a protective enclosure.

Master Station (MS)
The master station is usually based at a central location, such as the WUA offices, and basically consists of a computer and a radio or modem. Data is received from the RTUs either on-demand or according to set intervals, and stored for further processing.

The computer should have enough capacity to handle large volumes of data, regular back-ups should be made of the data received, and the MS should be fitted with an uninterruptible power supply (UPS) unit so that data can be received even when mains power is down.

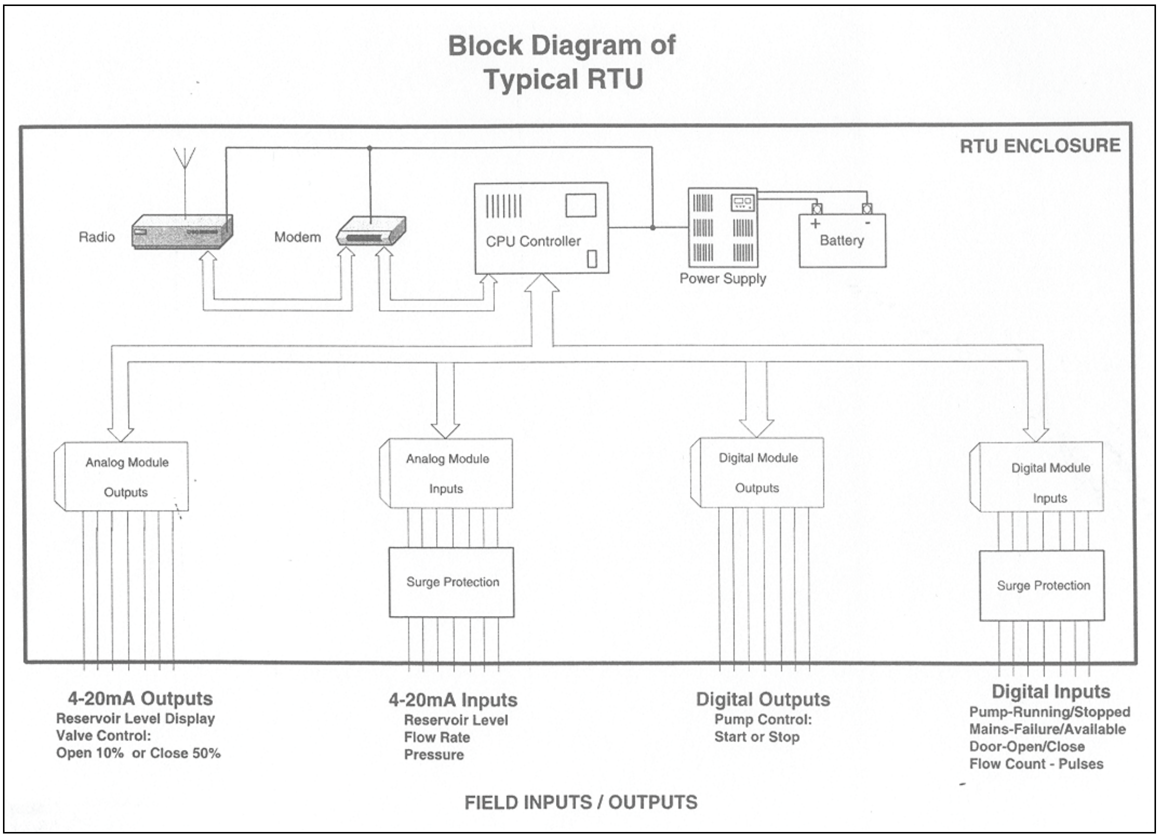


Figure 9.2 Typical RTU lay-out showing components (Wolhuter, 2004)

9.2.2.3 Typical network lay-outs

Two examples of typical telemetric systems are shown in Figures 9.3 and 9.4.

Figure 9.3 shows two types of radio frequency systems; in the simplex system the radio at the MS communicates directly with the radios at the RTUs, but in the duplex system the signals pass through an RF repeater to increase the range.

Figure 9.4 shows the typical GSM system lay-out. Another aspect that can be added to this example, is the fact that either the MS or any of the RTUs can be programmed to communicate with a cellular phone via Short Message System (SMS.)

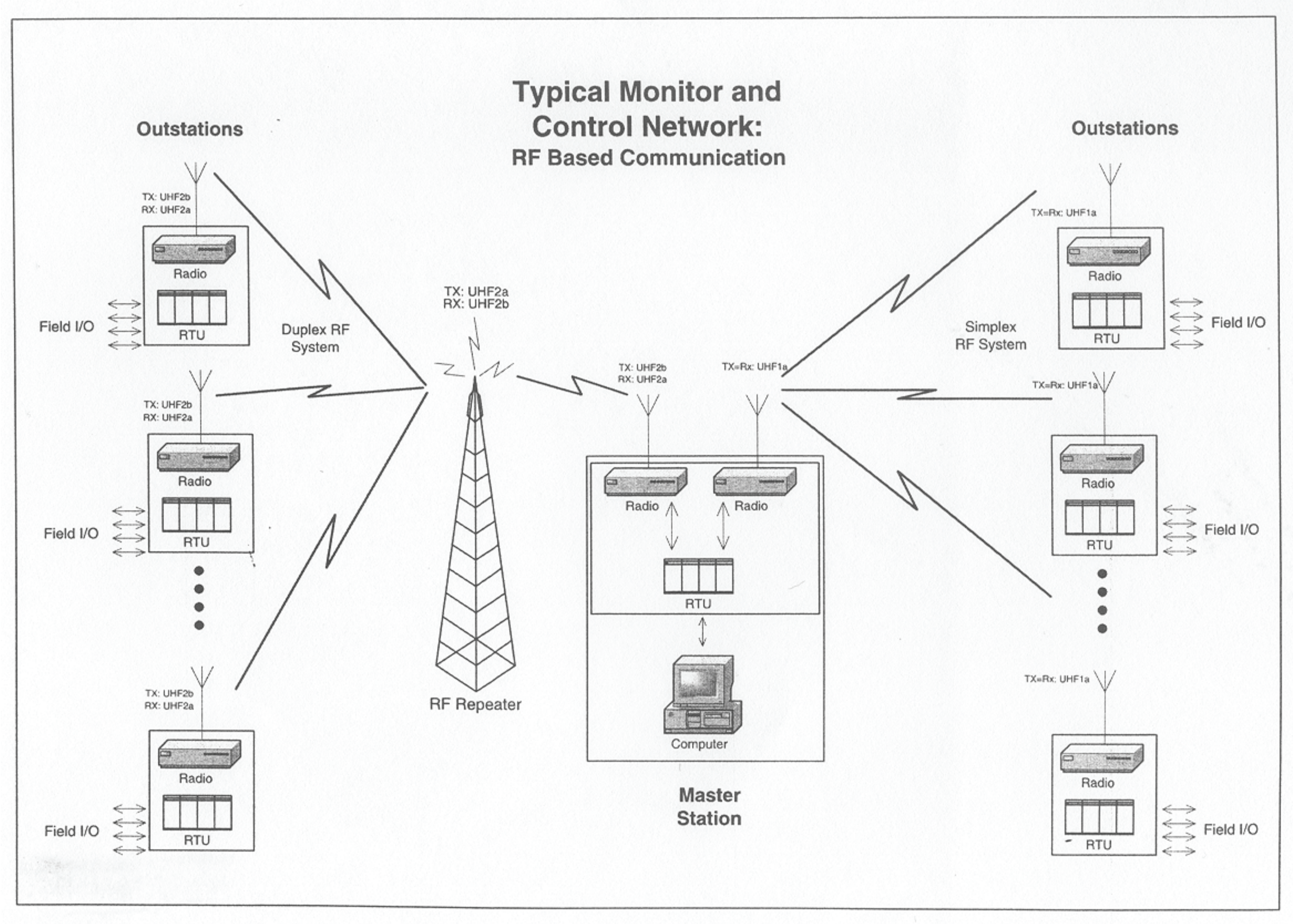


Figure 9.3 Schematic lay-out of a radio frequency based telemetry system (Wolhuter, 2004)

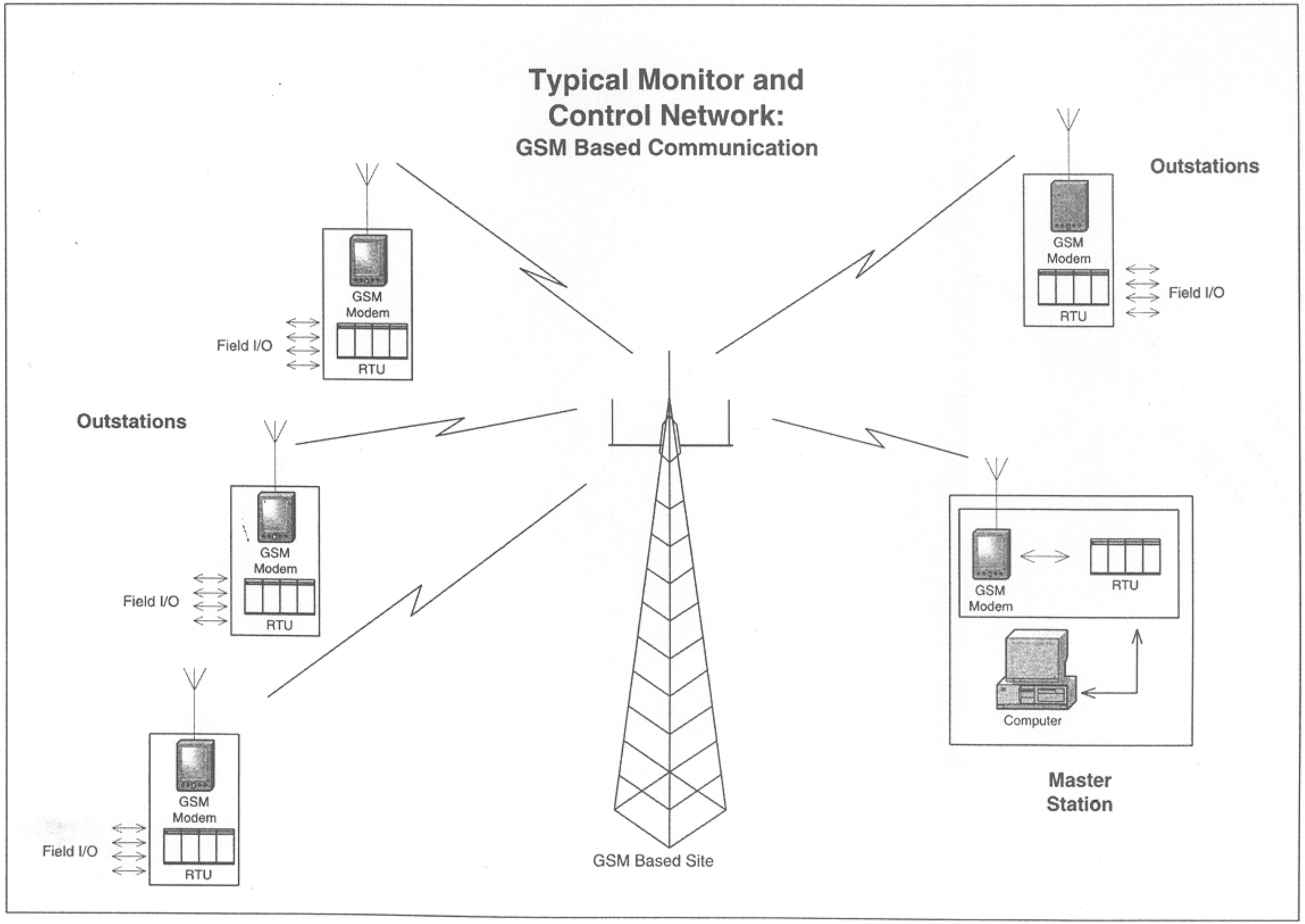


Figure 9.4 Schematic lay-out of a GSM based telemetry system (Wolhuter, 2004)

9.2.3 Software

The primary interface between the monitoring system and the operator is usually a computer based software program that can be used to program and control the datalogger, or in the case of telemetric data collection, RTUs.

Depending on the specific data logger that is selected, the software may require that the operator have certain skills or basic knowledge of the system and its components. Some software programs are more user friendly than other, prompting the operator on which inputs are required and what process must be followed to program the datalogger correctly. More complex data loggers may require specialist programming skills for correct operation.

The process of programming or setting up a data logger or telemetric system usually entails a process setting the necessary parameters in the software program (which channels are receiving inputs, the interval between reading the inputs, the locations where the measurements must be stored, etc.), storing the settings on the PC, and then transferring the stored settings to the datalogger. In some cases this process needs to be done through a cable connection between the PC with the software and the datalogger, and some systems allow this to be done telemetrically. An example of a settings screen is shown in figure 9.5

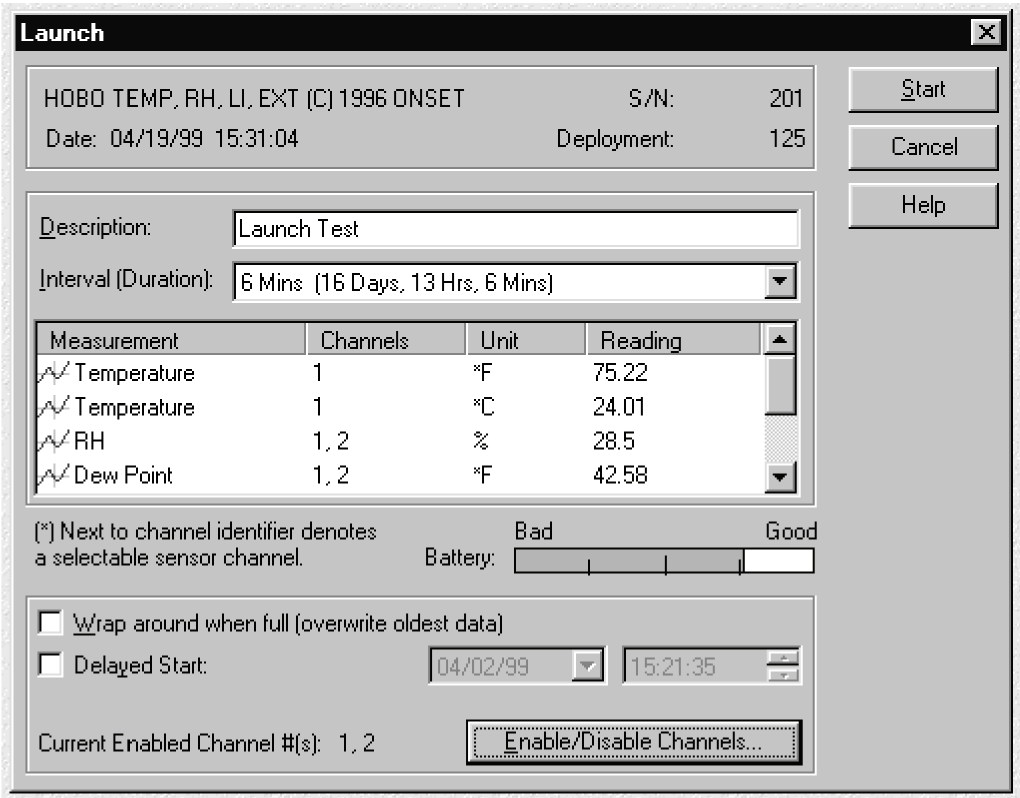


Figure 9.5 Example of screen where datalogger setting can be entered (Onset Computer Corp, 2004)

The process of collecting the data would entail a connection to be established between the datalogger and the MS, either at a specified time or on request of the MS, and then for the data to be transferred at a rate determined by the telemetric system.

Once the data has been received by the MS, the software can be used to store and or display the data to the operator in the form of text files, spreadsheets or graphs. An example of graphed output is shown in Figure 9.6.

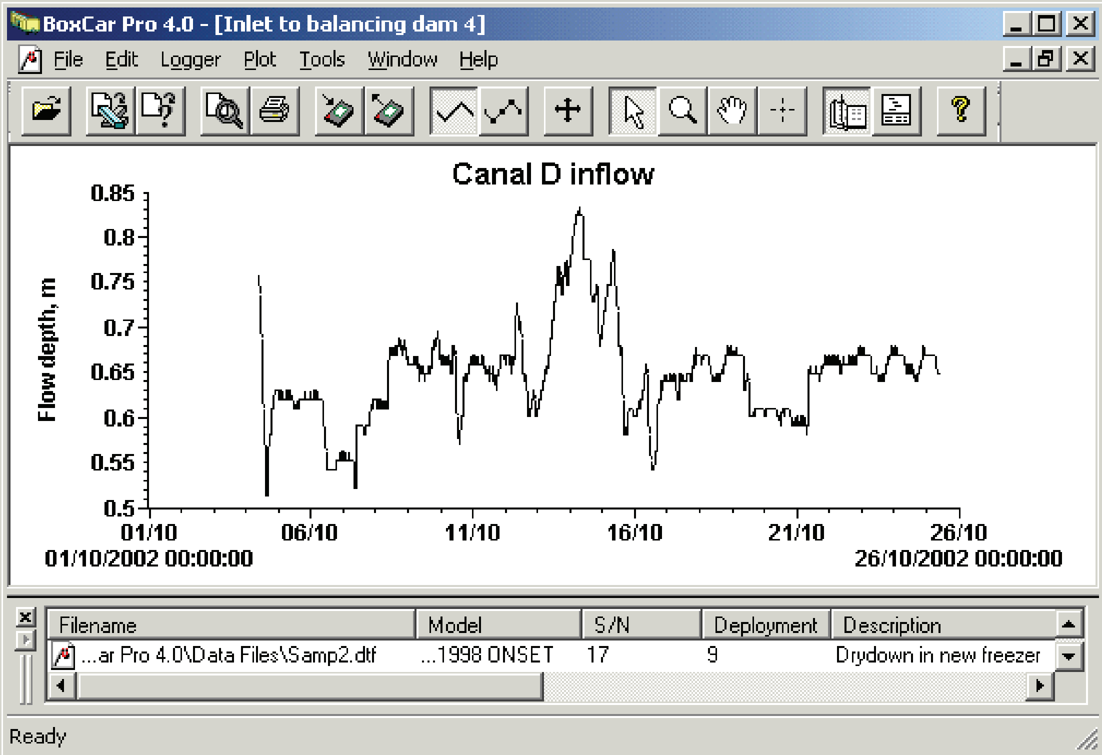


Figure 9.6 Example of graphed output from a data logger (OTT Hydrometry, 2004)

In most programs it is possible to view the data in different formats, by changing the scales of the graph, viewing different series of data together or filtering the data.

9.3 Evaluation and feedback

It is important that the data be processed correctly and presented to the water users in a user-friendly format. This is the point where the water user actually sees the output of the measuring device that he had helped to select in the first place, and with a bit of innovative thinking the users' perceptions of the benefits of the system can be enhanced.

9.3.1 Data Analysis

Data will need to be analysed so that it can be verified in some way, for instance by checking it against benchmarks. For example, the raw data (for instance flow depth measured at an open channel structure) will have to be converted to useful information (the flow rate at the structure) and then used to calculate cumulative volumetric flow (the number of cubic meters of water that passed the structure in a specific time period).

The result can then be compared to a theoretically calculated irrigation water requirement of the crops planted where the water was abstracted. Through the whole process one should constantly verify the results by asking questions such as "is the measured flow depth realistic?", "is the calculated flow rate within the capacity of the structure?", or " could the cumulative volume of water have been abstracted in the specific time period?". This process will reduce the likelihood of errors creeping in.

Further analyses that need to take place include a comparison of the amount of water abstracted by a user against his allocation. By tracking the actual usage throughout the season, the WUA will be able to ensure that a user does not exceed his allocation, or be able to give him ample warning to explore other water sources to supplement his allocation if the crop is at risk. This practice should go together with proper planning by the WUA at the beginning of the season, when farmers can be advised on the maximum areas that they can plant under a specific crop with the water allocated to them.

At supply system level, the WUA can analyse the data to calculate distribution efficiencies and operational losses. This may help to identify parts of the system where excessive losses are occurring and plan infrastructure maintenance to reduce these losses.

9.3.2 Data presentation

The data that is presented should be correct and as accurate as possible. The user should receive the data of his take-off points so that he can evaluate his water situation at any time during the season. Some WUAs have found it useful to present the data to the users in a graphical format of actual usage against expected usage, on for instance a monthly basis.

The water users should also be encouraged to analyse the information for farm level water management. Analysis may for instance show that excessive losses occur from a farm dam, and that lining the dam may make it possible for the farmer to plant (and therefore irrigate) bigger areas. In this way farm level water use efficiency could be improved, or at least some awareness created.

Any feedback or queries received from the water users should be investigated as it may point to problems with the system management or data collection even, and should not necessarily be seen as a dispute in a negative light.

9.4 Automatic control systems

If a telemetric system is used for collecting data, it is possible to expand the system by adding control functions to operate water control infrastructure. What this means is there will be a two way flow of data – the measuring device will supply information on the status of flow at a location, eg. Flow depth, to the MS via the RTU, and this information will be interpreted either by a human operator or an electronic logic controller. The interpretation will create a signal that is returned to the RTU which can create an output (instruction) to a control device, such as an actuator, to open or close a sluice gate and thereby change the flow depth.

The installation of the required equipment is relatively expensive but may be justified if compared to the long-term cost of communicating to and employing a person to manually operate equipment at a remote location.

It is also possible set the system up to monitor for certain unallowable conditions, such as high pressures in pipeline. If a GSM based system is used, an "alarm" can be sounded via an SMS to the responsible person's cellular phone.

9.4.1 Open channels

Some examples of open channel applications are:

- Monitoring and control of flow depth in a canal to prevent spills or maintain water delivery. This necessitates the automation of gates so that they can be opened or closed by an electric motor when a signal is received from the RTU.
- Water release control. By programming the required settings of an inlet sluice, as for instance calculated by the WAS program, into the RTU, it will then automatically adjust the sluice at the required times.
- Automatic reservoir level control. The depth can be monitored and inflow stopped if the reservoir is full.
- Water quality monitoring. Flow through a sieve could be monitored and an alarm sounded if the sieve becomes blocked.
- Automisation of farm off-takes. Although such a system would be expensive to implement, it is possible to automatically open and close sluice gates, and monitor flow depth at each location if the necessary actuators and depth sensors are installed.

9.4.2 Closed conduits

Examples of closed conduit applications are:

- Pressure control. By monitoring the pressure in a pipeline, a system can be designed that start additional pumps if the demand on the system increases, or by shutting down pumps in case of a pipe burst.
- Pressure monitoring. Display pressure profiles along pipelines to ensure all off-takes have adequate pressure.
- Flow monitoring and control. The data from flow meters at farm off-takes can be collected and checked against total allowable abstraction, or and abstraction rate. If the maximum value is exceeded, a valve can be closed automatically.

9.4.3 SCADA software

Most software used to operate advanced PC based monitoring and control or SCADA systems includes a graphical display of the system lay-out and devices that are linked to the MS. This graphical display can be viewed on the PC screen and when the MS is communicating to the RTUs, the status of the different devices are presented graphically and updated continuously. Each device could be represented by an icon of what the device would typically look like. An example of a graphical displays are shown in Figure 9.7 and 9.8. Values from the measuring devices can be displayed next to the icons, and control equipment in the field can be adjusted by clicking on the icons on the computer screen, if applicable.

The idea is that the operator can obtain an overall view of the whole system in a meaningful manner, as opposed to a panel full of indicating lights and pushbuttons. All this information can be displayed on any number of computers, from the technical operator’s to the general manager’s of the WUA.

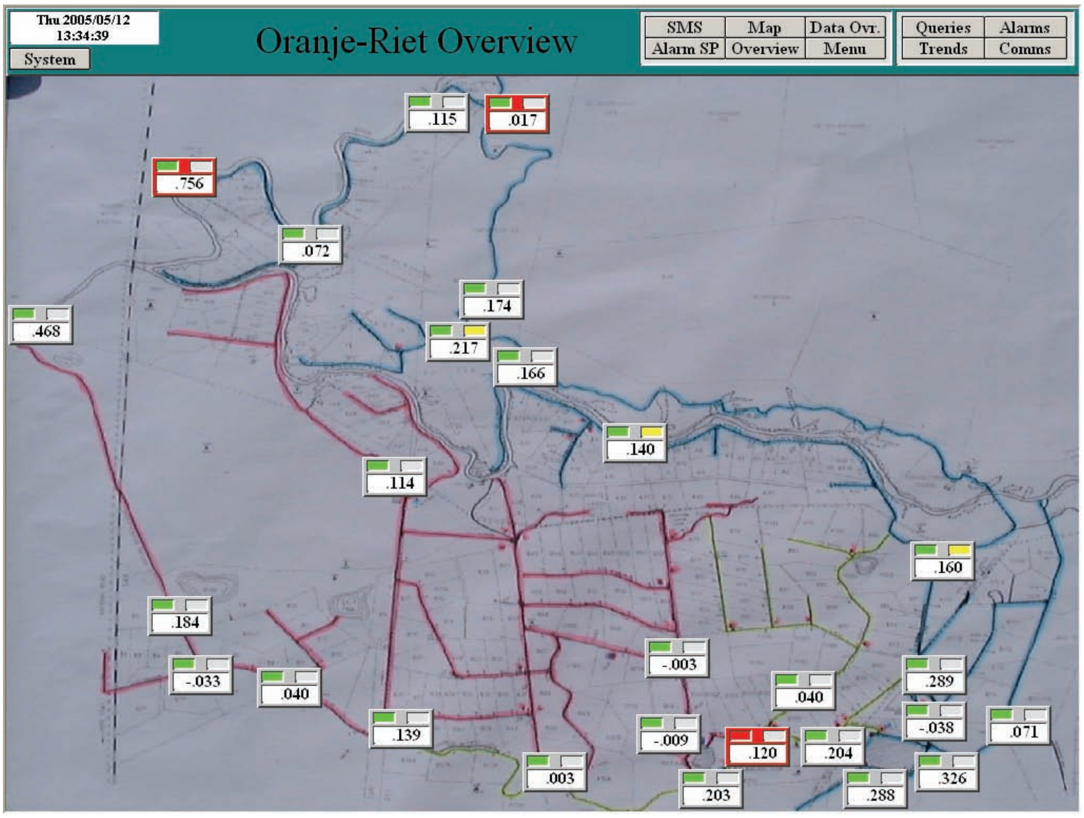


Figure 9.7 Example of a SCADA control screen (ORWUA, 2005)

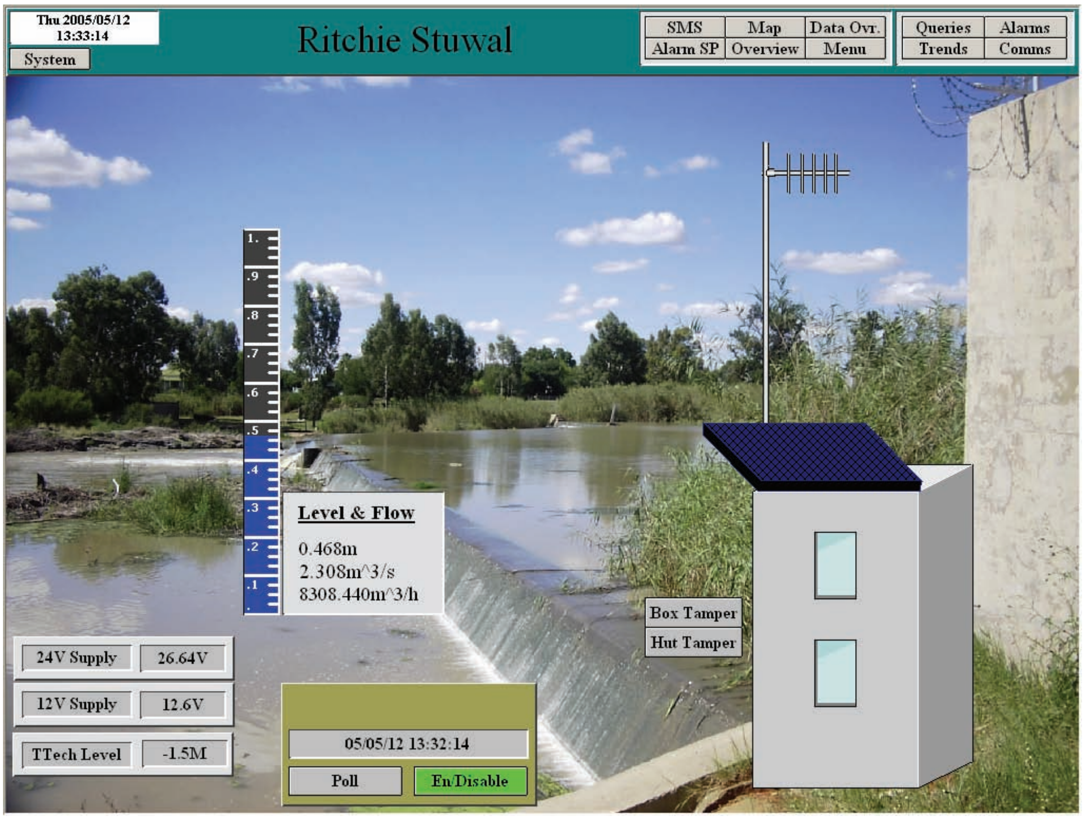


Figure 9.8 Example of a SCADA device screen (ORWUA, 2005)

9.5 Maintenance

Any data collecting system will require maintenance, especially if it is an automatic system, to prevent breakdowns and loss of data (or possible control functions).

Computers and software are continually being improved and upgraded, and in order to ensure that support is available for the system being used, the WUA should keep up to date with new developments. The system should be dynamic, and make provision for envisaged changes that may take place.

In order to ensure continuity and good service to the water users, it is important that the system operators are properly trained, and their training is kept up to date. All procedures should also be properly documented, and data archived in a systematic way so that the knowledge and skills don't get lost if an operator leaves the employment of the WUA.

9.6 Further reading.

http://www.prodesign.co.za
http://www.sse.co.za

10. GUIDELINES SUMMARY

The following figure presents an overview and summary of the contents of chapters 5 to 9.

IMPLEMENTATION GUIDELINES

Information:
- Map
- Water source and supply
- Delivery infrastructure
- Diversion points
- Water user off-takes
- Management system
- Frequency of supply
- Irrigated area per off-take
- In-field irrigation systems
- Mean monthly rainfall
- Average monthly ET_0
- Peak daily ET_0
- Crop information
- Drainage systems
- Water quality
- Cell phone reception

1. Identify the purpose of measurement

2. Obtain stakeholder support

3. Assess the current situation and plan the measuring system

Supporting tools: SAPWAT, WAS

Identify required device functions:

Measure/Display/Record:
- Cumulative volume of water measured
- Real time flow rate
- Flow depth
- Flow velocity

Set performance standards:
- Flow type
- Water quality
- Flow range
- Pressure loss
- Accuracy
- Repeatability
- Installation
- Data output
- Power need
- Operation
- Maintenance
- Life expectancy
- Tamperproof
- Environmental protection
- User acceptance
- Reliability
- Legal issues
- Environmental impact

Set cost limits:
- Device cost
- Installation
- Operation
- Maintenance
- Administration
- Training

4. Choose appropriate devices

Supporting tool: KBS

Open channels:
- Flumes:
  - Parshall
  - Replogle
- Weirs:
  - Crump
  - Sharp-crested
- Orifices
  - Sluice gate
  - Piped outlets
- Water depth sensors
  - Mechanical
  - Acoustic
- Velocity meters
  - Mechanical
  - Acoustic

Closed conduits:
- Mechanical flow meters
  - Turbine
  - Paddle wheel
  - Propeller
  - Proportional
- Electromagnetic meters
- Acoustic meters
- Indirect methods
- Displays, converters and transmitters

Data collection:
- Telemetric:
  - Cable based
  - Wireless
- Manual

Control systems

5. Install selected devices and calibrate / perform in-field verification

6. Operate the system and collect data

Supporting tool: WAS

7. Perform maintenance

8. Monitor and evaluate the effectiveness of the measuring system

Checklist:
- Identify and define the reason for considering measuring devices
- List the expected outcomes
- List the expected constraints
- Appoint a person or person / team to manage the process
- List the expected benefits
- List the expected drawbacks
- Create awareness amongst stakeholders
- Compile background information
- Identify measuring locations
- Estimate the number of devices needed and typical flow rates
- Repeat process for different options
- Identify functions required in each device
- Set standards for each function
- Evaluate existing devices' characteristics against requirements
- Compile a shortlist of most appropriate devices
- Compare the total cost of the shortlisted devices
- Identify the different installation options
- Draw up specifications, time frame and detail budget for each option
- Choose the most appropriate option and implement
- Conduct in-field verification of device performance
- Confirm completion of installations
- Identify data collection options
- Draw up a data collection schedule
- Purchase equipment and software required
- Train staff or appoint contractor
- Develop benchmarks and evaluate data
- Present data to water users
- Draw up a procedure for handling disputes
- Draw up a procedure for handling cases of tampering
- Obtain support from the water users
- Include procedures in the WUA constitution
- Identify maintenance requirements of all devices
- Draw up a routine maintenance schedule and procedure
- Draw up a re-calibration schedule and procedure
- Develop a procedure for compensation for measuring errors
- Purchase equipment required
- Train staff / appoint contractor
- Draw up a monitoring and evaluation plan
- Implement and report back to water users

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Appendix A

Glossary

Accuracy

The maximum deviation of the measurement device's reading from the true value of the flow rate or the total flow. Accuracy is usually reported in percentage error of reading or percentage error of full scale (see: Error).

Acoustic measurement method

Flow measuring method in which a pulse or wave travelling at the speed of sound is used. Doppler and Transit Time devices are types of acoustic devices. Synonym for Ultrasonic measurement device.

Differential pressure

The difference in pressure before and after a physical component (elbow, pump, structure, etc.) in a water distribution system.

Discharge

The rate at which water is conveyed in a pipe or channel, expressed as a volume per time unit, for example litres per second. Synonym, especially in USA, for flow rate.

Doppler measuring method

Acoustic measuring method based on the Doppler effect – the change of frequency that occurs when a sound source and receiver move towards or away from each other.

Electromagnetic measuring method

Method based on Faraday's law of induction which states that if a conductor is moved through a magnetic field, a voltage that is proportional in size to the velocity of the conductor will be induced in it. The flowing water acts as the moving conductor.

Error (Measurement error)

The indicator used to quantify accuracy. The accuracy of a water measurement device is commonly expressed as an error percentage of either the comparison standard discharge (or the actual discharge), measured with another device of known accuracy, or the upper range value (URV or also called the full scale value) of the device being tested. Other terms include percentage error of reading and percentage error of full scale.

Flow

The volume of water that has been conveyed past a specific point in a distribution system, typically in litres (ℓ), cubic meters (m^3) or mega-litres (Mℓ).

Flow rate

The rate at which water is conveyed in a pipe or channel expressed as a volume per time unit, for example litres per second. Synonym for discharge.

SCADA

Supervisory **C**ontrol **A**nd **D**ata **A**cquisition. A system whereby computers are used to collect real-time data from plant machinery to provide central monitoring, control and process visualisation of the plant and its facilities.

Telemetry

The remote recording or indication of measurements and signals from plant or supply infrastructure, by means of telecommunication, as well as the remote control and management of such infrastructure via the same means.

Transit time measuring method

Acoustic measuring method based on the fact that the velocity of the water in a pipe or channel will reduce the propagation speed of an ultrasonic pulse travelling against the flow direction of the water.

Ultrasonic measuring method

Synonym for acoustic measuring method, such as Doppler or Transit time.

Appendix B

KBS

User's Manual

Author: Nico Benade
Date: February 2005

Table of contents

List of Figures

1. Introduction

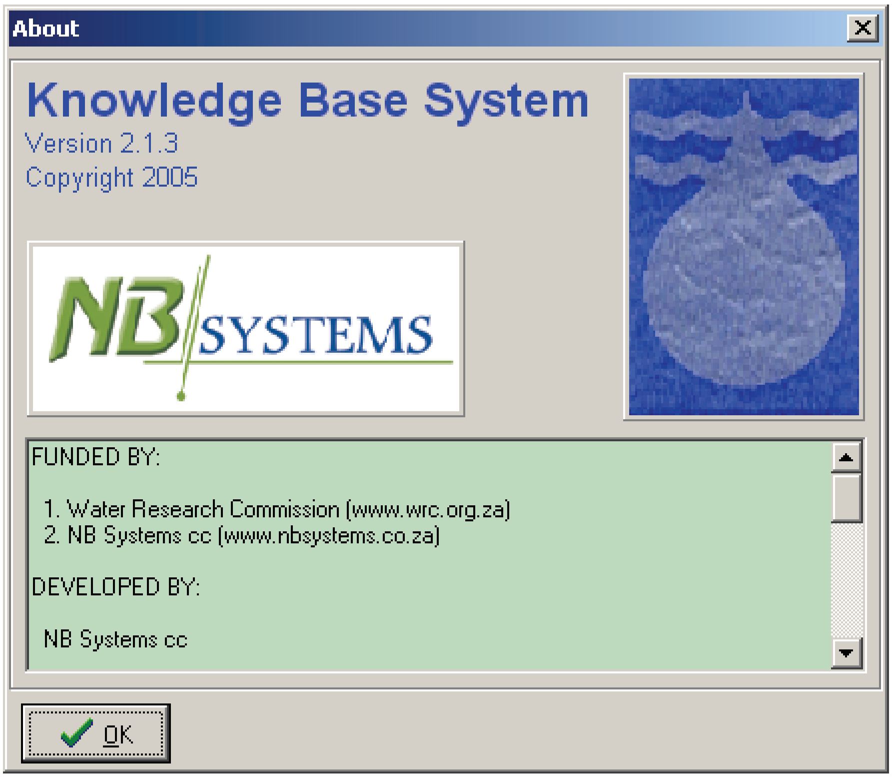


Figure 1: KBS About form

1.1. Purpose

The Knowledge Base System (KBS) is a database that can be used to capture detailed information on any measuring device for open channel flow, closed conduits and boreholes. The information can be filtered on the application of the device (e.g. open channel and closed conduit), method used for measurement (e.g. pressure, mechanical, ultrasonic etc.) and the brand name of the device. Detailed information can be captured for each device on the following:

- Accuracy
- Calibration
- Installation
- Maintenance
- Advantages
- Disadvantages
- Unlimited number of pictures per device including descriptions
- Address list of current installations and suppliers

KBS has extensive searching capabilities. The information can be sorted in a number of ways. A list of keywords can be linked to every measuring device that, if populated correctly, results in a very powerful searching capability. All the information in the database, including pictures can be printed.

1.2. Benefits

The following are some of the benefits of using the KBS:

- Assist in obtaining information about a measuring device
- Centralized database of available measuring devices
- Better knowledge of available devices
- Improve device handling, for instance calibration, installation and maintenance
- Extensive device querying capabilities
- View pictures of different devices

1.3. User requirements

KBS requires at least a 486-PC running Windows 95/98/ME/NT/2000/XP. At least 64Mb random access memory (RAM) is needed to run the program, but 128Mb is recommended.

KBS is written in Delphi and it uses Firebird as the underlying database. Firebird is a relational database management system (RDBMS) that provides rapid transaction processing and data sharing in a single- or multi-user environment.

2. KBS installation

KBS is distributed on a CD. Two files are needed to install KBS:

- Firebird-1.0.3.972-Win32.exe
- SetupKBS.exe

Firebird for Windows must be installed on your computer before you will be able to run KBS. If you have other applications that already use Firebird you don't have to install it again. Firebird is an open source SQL database that is used by KBS.

2.1. Install Firebird

Run Firebird-1.0.3.972-Win32.exe and follow the instructions (Use the default settings).

2.2. Install KBS

Run the SetupKBS.exe file. The following installation form will open.

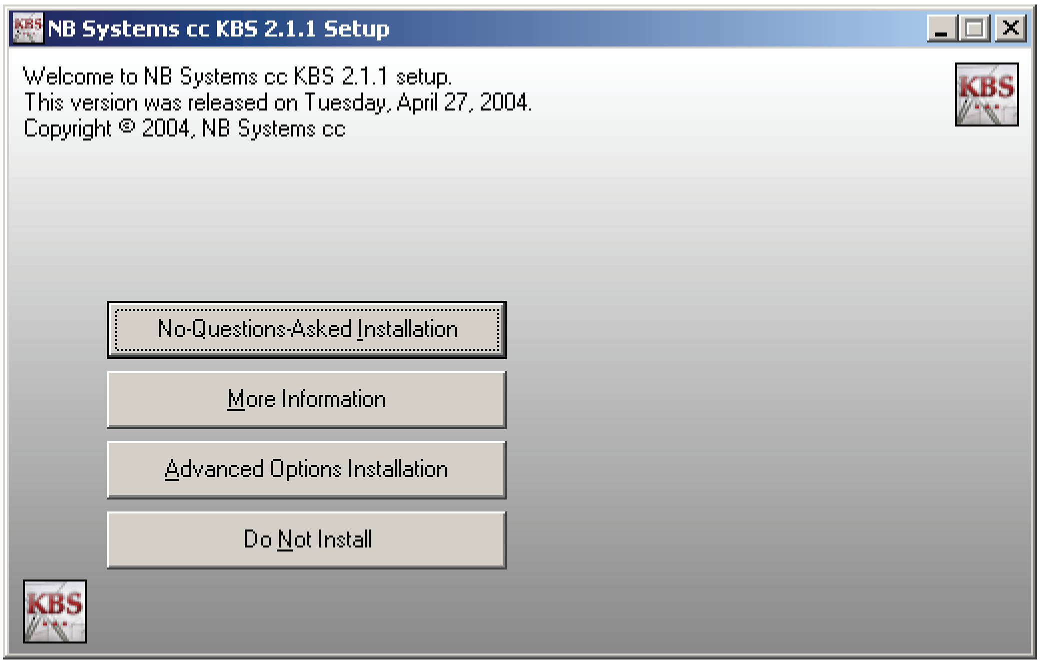


Figure 2: KBS installation form

There are four buttons on the installation form which is used to do the following:

This button is used to install KBS to the default folder (c:\KBS) without asking any questions.

Use this button to open a document which displays information that might be useful before installing KBS.

Use this button if you want to change the default installation folder c:\KBS to something else.

This button is used to quit the installation without making any changes to your system.

The following KBS shortcut will be created on the Desktop during installation.
.

2.3. Support contact information

Any queries can be directed to:

NB Systems: KBS
PO Box 15102
Sinoville
0129

Tel: (012) 548 1005
Fax: (012) 548 3509
E-mail: nicob@mweb.co.za

3. KBS main screen

The KBS main screen consists of a number of speed buttons at the top and a few dropdown boxes that is used to sort and filter the records in the database. The bottom of the screen displays a number of Tabs which is used to edit and display information on the current record (device) selected.

The caption of the main screen **Knowledge Base System: 2.1.2** includes the KBS version number.

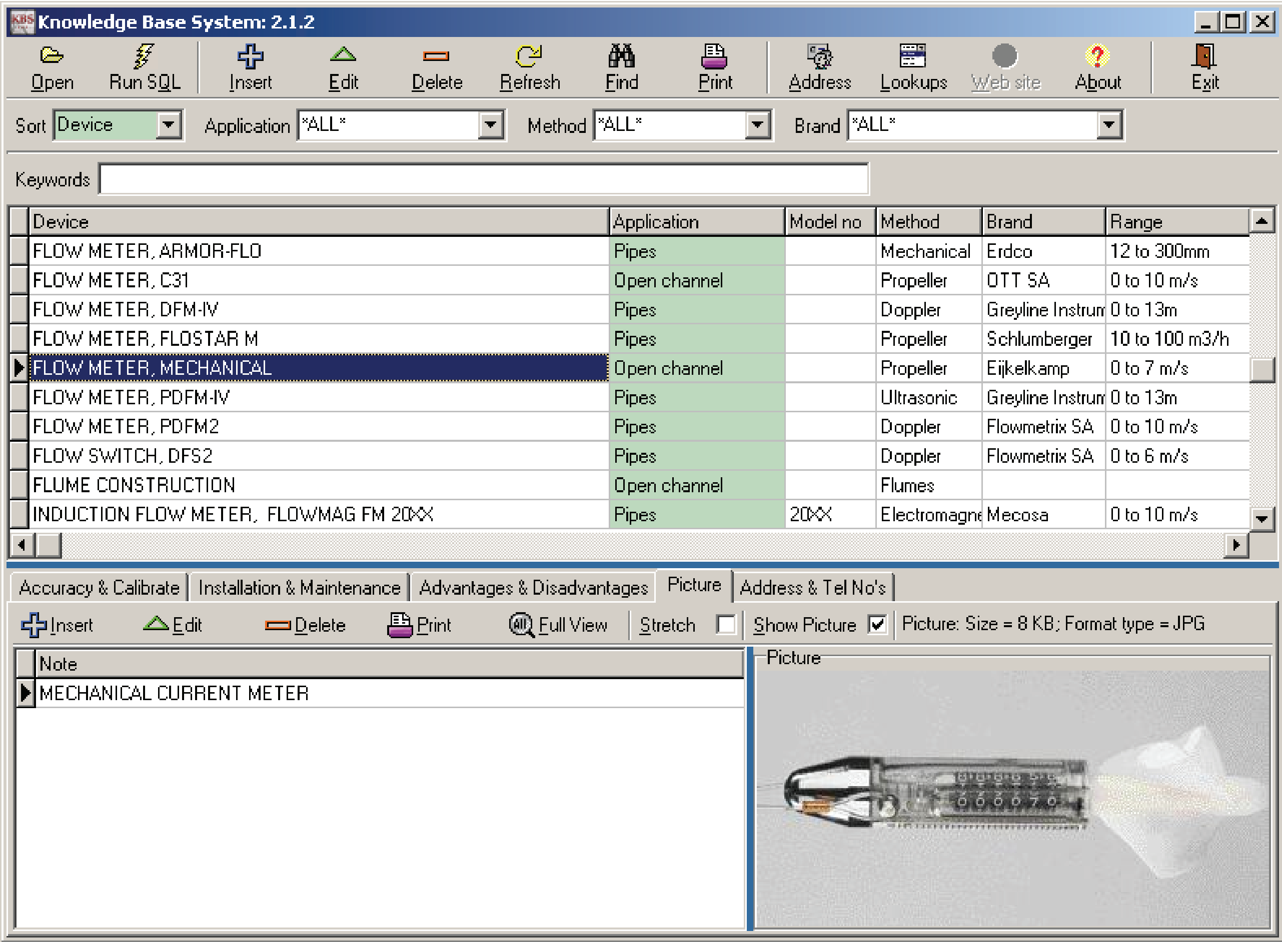


Figure 3: KBS main form

The different menu options are described in detail in the following paragraphs.

Use the **Open button** to open the KBS database. The default database is c:\kbs\KBS.gdb. KBS opens with the previous database selected.

When new versions or updates are made available it might be necessary to update the KBS database. This is done with the **Run SQL database button**.

The **Insert button** opens the device Insert form which is used to insert a device record. The following fields are captured on the device Insert form:

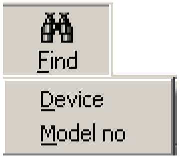
- Device: Device description.
- Application: Device application which is selected from a list in a dropdown box. The options are:
  - Open channel
  - Pipes
- Model no: Device model number.

- Method: Device measuring method which is selected from a list in a dropdown box. The choices are:
  Flow: Acoustic Doppler
  Flow: Acoustic Transit Time
  Flow: Differential Pressure
  Flow: Electromagnetic
  Flow: Electronic
  Flow: Flumes
  Flow: Impeller
  Flow: Propeller
  Flow: Proportional
  Flow: Turbine
  Flow: Woltmann
  Velocity: Doppler
  Velocity: Mechanical
  Water level: Acoustic
  Water level: Bubble
  Water level: Mechanical
  Water level: Pressure
- Brand: Device brand name which is selected from a list in a dropdown box. The brand names are user defined and it is maintained under the Lookups button (**Lookups|Brand**).
- Range: Measuring range which is selected from a list in a dropdown box. The measuring range is a user defined string and it is maintained under the Lookups button (**Lookups|Range**).
- Cost: An indication of the cost of the device which is selected from a list in a dropdown box. The cost is a user defined string and it is maintained under the Lookups button (**Lookups|Cost**)
- Web site: The web site address of the current device which can be accessed using the **Web site button** at the top for the form. The Web site button will only be active if a web site address has been captured for the specific device.
- Keywords: A list of keywords which are captured to filter the data according to the specified keyword. The Keywords box at the top of the screen is used as a keyword filter. The number of keywords per device is limited to 1000 characters.
- Accuracy: Used to capture any notes on the accuracy of the specific device. Maximum of 1000 characters.
- Calibrate: Used to capture any notes on the calibration of the specific device. Maximum of 1000 characters.
- Installation: Used to capture any notes on the installation of the specific device. Maximum of 1000 characters.
- Maintenance: Used to capture any notes on the maintenance of the specific device. Maximum of 1000 characters.
- Advantages: Used to capture any notes on the advantages of the specific device. Maximum of 1000 characters.
- Disadvantages: Used to capture any notes on the disadvantages of the specific device. Maximum of 1000 characters.

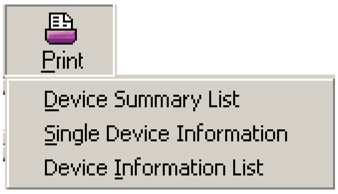
The **Edit button** is used to edit the information captured on the current device record. The fields that can be edited are the same as for the Insert button which is described in the previous paragraph.

The **Delete button** is used to delete the current device record. The user is prompted for a conformation before the record is deleted.

The **Refresh button** is used to refresh the data that is displayed when KBS is used over a network.



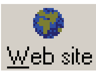
The **Find button** is used to find device records using the *Device* or *Model* no information. Only a partial string needs to be specified.



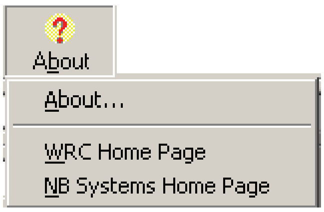
The **Print button** opens a dropdown menu which is used to print different reports as described in the menu.

The **Address button** opens the Address & Tel No's form which is used to capture the supplier and client address information. The different addresses can be linked to specific device information records. A detailed description is given in paragraph ????

The **Lookups button** opens a dropdown menu with options which are used to capture and maintain the different lookups that is used in KBS.



The **Web site button** is used to link to the web site of the manufacturer or supplier of the current device, if any.



The **About button** opens a dropdown menu with options which are used to open the KBS About form and website links to the Water research commission and NB systems home pages.

The **Exit button** is used to exit/close KBS.

3.1. Capturing images

Images are captured using the **Insert**, **Edit** and **Delete** buttons on the Image tab. The following graphic formats are supported: *.jpeg, *.jpg, *.bmp, *.emf and *.wmf. An unlimited number of images can be linked to a specific device. The image can be stretched to fill the total image display area. The image can be printed and if the image is to big for the image display area it can be displayed in a the Full view from which has scrollable sidebars.

It is important not to capture images at maximum resolution because of the huge amount of space an image can take up. It is recommended to keep the image size as small as possible without loosing image definition. Most of the images in KBS were captured with a size of 100 KB or smaller.

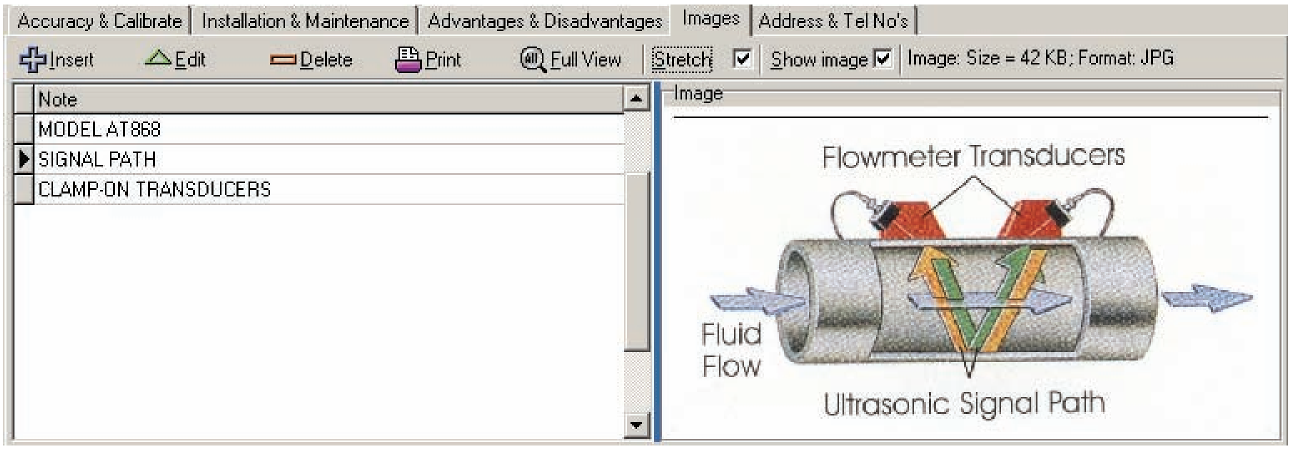


Figure 4: Images tab

The **Insert button** opens the image Insert form which is used to load an image from a file and to add a note to the specific image. The following graphic formats are supported: *.jpeg, *.jpg, *.bmp, *.emf and *.wmf.

The **Edit button** opens the Edit form which is used to edit the current image and corresponding note.

Use the **Delete button** to delete the current image record.

The **Print button** is used to print the current image.

The **Full view button** is used to display the current image in the Full view form with scrollable borders ff the current image is to big for the image display area.

Use the **Stretch checkbox** to stretch the current image to the full image display area. The image might be warped depending on the X and Y aspect ratios.

The **Show image checkbox** is used to enable or disable the display of images. Disabling the displaying of images will improve the scrolling speed between device records.

The **Image info string** displays the image size and format.

4. Address information

The Address & Tel No's form is used to capture all the relevant supplier and client contact information. An unlimited number of contacts can be linked to a specific device. Website links can be captured which is directly accessible form KBS.

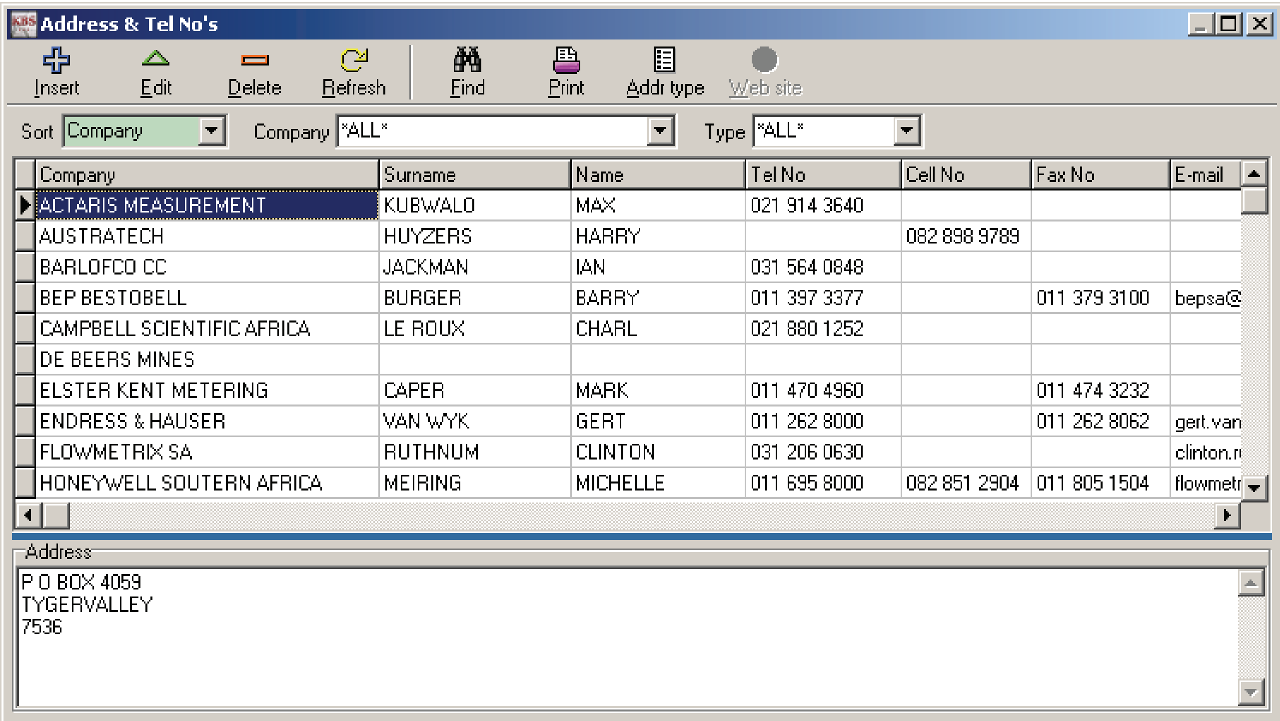
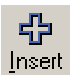


Figure 5: Address information form



The **Insert button** opens the device Insert form which is used to insert a contact. The following fields are captured on the Contact Insert form:

- Company: Company name.
- Surname
- Name
- Tel no
- Cell no
- Fax no
- E-mail
- Address type: An address type can either be a supplier or a client.
- Website
- Print: A print flag which is used to mark the current record for printing.

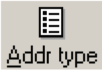
The **Edit button** is used to edit an address record.

The **Delete button** is used to delete the current address record. The user is prompted for a conformation before the record is deleted.

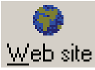
The **Refresh button** is used to refresh the data that is displayed when KBS is used over a network.

The **Find button** is used to find an address record by specifying the company name.

The **Print button** is used to print the current address record.



The **Address button** opens the address type lookup form which can be used to add additional address types if needed.



The **Web site button** is used to link to the web site of the current address, if any.

Appendix C

Capacity building report

1. Individuals

Individual capacity building took place through the development of students of the University of Pretoria, members and staff from WUAs and project team members.

1.1 Students

A number of post-graduate students from the Department of Civil and Biosystems Engineering of the University of Pretoria were actively involved with the project during the four years.

Ms Angel Khumalo completed a mini-dissertation as partial fulfillment for her Masters degree in Rural Engineering Technology based on interviews and field visits conducted as part of the project. The title of the report was "Allocation and Management of Water on Small-Scale Irrigation Schemes in South Africa". Ms Khumalo will be graduating in 2003 and is currently employed by the CSIR in their internship programme.

After Ms Khumalo completed her studies, the remaining post-graduate students in agricultural engineering at the University of Pretoria were all citizens of other SADC countries. However, the University has to accommodate these students, and as a result, five foreign students from SADC countries assisted in some of the project activities, although they did not receive any remuneration from the project funds. It is believed that although these students are not South African nationals, the subcontinent will benefit from the skills they obtained during the project work. The names of the students and the titles of the reports they compiled as partial fulfillment for masters degrees are as follows:

- SB Ghezehei: Comparison and performance testing of selected flow meters in-field and at a hydraulic laboratory
- FH Hidad: Measurement of irrigation water losses from Canal D of the Gamtoos Irrigation Scheme
- AJ Komakech: Categorization and quantification of water losses in a lined canal and balancing dam at the Gamtoos Irrigation Scheme
- YA Tsehaye: Comparison of irrigation water measuring methods at the Umlaas Irrigation Board

These students had all completed their studies successfully by the end of the project.

For the work at the Zanyokwe Irrigation Scheme, it was felt that it is important that a South African student be involved, and this caused the delay in activities. Ms Mokovhe Nthai was identified as a suitable student. Ms Nthai had some opportunity to develop skills in working with communities, broadening her technical knowledge of irrigation schemes and systems, as well as improving report writing skills. Unfortunately due to the lack of funding for meters from the Department of Agriculture, the work could not be completed and she was transferred to another WRC project.

1.2 Discussion Forum participants

A total of 58 participants attended the Discussion Forum on Reliable Water Measuring Methods that took place in Bloemfontein on 29 April 2004. Information on the project, commercially available water measuring devices and water management issues were provided, and discussions took place on water measurement issues. The participants were from a wide range of background, including Water User Associations, government departments, research orginasations, consulting firms and industry (meter manufacturers).

1.3 Team members

Ms van der Stoep successfully completed her masters' dissertation on part of the project and received her Master's Degree in Agricultural Engineering in September 2004..

Dr Benadé attended the USCID workshop in Arizona where he was exposed to new trends in open channel measurement. The workshop has opened up some possibilities that need to be explored further.

2. Communities

The farmers of the Kamma Furrow section of the Zanyokwe Irrigation Scheme have benefited from the exposure to the project by identifying a possible solution to their current problem of dividing the electricity account amongst themselves. Further work that needs to be conducted there will also provide them with water management skills such as meter reading, record keeping and water accounting.

3. Organisations

3.1 Oranje-Riet Water User Association

The staff of the Orange-Riet Water User Association benefited from the project activities, but largely through their own initiative supported by the project team. In their search for measuring solutions, they have explored various options and set an example to other WUAs in this regard. The project team members have assisted them with the calibration of the prototype power-based meters purchased by the WUA, and learnt valuable lessons themselves in the process.

3.2 Gamtoos Irrigation Board

Through the field work conducted at this scheme, the water management staff was exposed to various measuring methods and devices. They supported the project team through assistance with data collection and maintenance to equipment. Mr Xolisa Ngwadla of MBB Consulting Engineers in the Eastern Cape has also benefited from the project through his involvement with the Gamtoos field tests. Mr Ngwadla is an agronomist by training, and although he has had no technical background, he successfully assisted the project team in managing the equipment at the scheme. He has obtained experience in telemetry systems, datalogger programming and operation, and been involved with measurements done by the DWAF Hydrometry staff.

3.3 Umlaas Irrigation Board

The water bailiff from this Irrigation Board, Mr Owen Odell, was also actively involved with the field evaluations that took place at a river pump station. As a result of the evaluations, the Irrigation Board became aware that their method of measuring is in need of serious attention and that large errors are being made during measurement.

Appendix D

Archiving of data

a. Documentation

It is proposed that all documentation, including literature studies and progress reports be archived at the Department of Civil and Biosystems Engineering of the University of Pretoria.

b. KBS

It is proposed that the program code of the KBS remains with the programmer, Dr N Benadé of NB Systems.

Appendix E

List of technology transfer actions taken during the project and those which are envisaged for the future

a. Activities undertaken during the project period:

- A discussion forum on reliable measuring methods was held in Bloemfontein in April 2004. The purpose of the discussion forum was to provide an opportunity for stakeholders in irrigation water use and management to provide inputs into the final phases of the research project. The Forum took place on 29 April 2004 in Bloemfontein, and a total of 58 participants attended from different groups of stakeholders as follows:
  - Water User Associations: 22
  - Government departments: 14
  - Researchers (project team and other WRC projects): 11
  - Consultants: 7
  - Meter manufacturers: 4

- A paper on the project was presented at a conference on Hydraulic Measurement and Experimental Methods organized by the American Society of Civil Engineers and the International Association for Hydraulic Research in Colorado, USA in August 2002
- A presentation on the project was presented in Moama, Australia, at a workshop organized by the Australian National Committee on Irrigation and Drainage (ANCID) on "In-field verification of flow meters".
- A paper was presented on some of the preliminary findings of the project at a congress of the South African Irrigation Institute (SABI) in July 2003 at Goudini Spa, Western Cape.
- A workshop organized by the United States Committee on Irrigation and Drainage (USCID) on water measurement in open channels was attended by one of the project team members in February 2004 in Arizona, USA
- A paper was presented on some of the field work results at a conference organized by the South African National Committee on Irrigation and Drainage (SANCID), held at the Fish River Sun, Eastern Cape from 17 to 19 November 2004.
- Collaboration took place with the Department of Water Affairs and Forestry in their pilot studies on the implementation of the Water Conservation and Demand Management Strategy for the Agricultural Sector
- Collaboration took place with the Department of Agriculture in a number small-scale farmer rehabilitation initiatives in the Northern Province and Eastern Cape

b. Envisaged activities:

- A knowledge center should be created at the Department of Civil and Biosystems Engineering at the University of Pretoria, to continue research, prepare and distribute information, train students and provide a field service to WUAs in assisting them with measuring implementation, evaluating devices and trouble-shooting.
- Based on the Guidelines included in the report, a training manual on irrigation water measuring should be developed to distribute the information gathered during this project to interested parties through short courses or seminars. This will add value to the results of the project, but additional funding will be required.

- For the KBS to stay relevant, it will have to be maintained and updated regularly, and it is recommended that a way be found to do this on a website. The responsibility of covering costs for such a venture will have to be finalized first, though.