ELECTRIC POWER SUPPLY MEASUREMENT AS AN ALTERNATIVE TO MEASURE FLOW-RATES OF HYDRAULIC PUMPS

by

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EXECUTIVE SUMMARY

1. INTRODUCTION

Increasing demands on the water resources of Southern Africa requires improved management of this commodity. Water metering is generally accepted as one of the most important vehicles in appropriate management of water, and is widely applied in practice, usually by means of mechanical flow meters.

The agricultural industry's inadequate implementation of water measurement could be ascribed to a number of factors, and this project's aim is to investigate an alternative to existing methods of implementation.

2. PROJECT OBJECTIVES

The objective of this project is to develop a procedure, or method, by which water pumped with an electrically driven pump, can be metered indirectly.

3. BACKGROUND

3.1 What does the Water Act say?

The National Water Act (Act 36 of 1998) specifies that the government, as the public trustee of the nation's water resources, must ensure that water is protected, used, developed, conserved, managed and controlled in an equitable and sustainable manner for the benefit of all people.

Reliable data on discharges and water uses cannot be obtained without the measurement of flow at various points in the system with a pre-determined degree of accuracy. The measurement itself is not the end product, but only becomes meaningful in the context of overall water management.

3.2 What is really happening in practice?

Although policies that give guidelines for water measurement have been developed, limited implementation was seen since the proclamation of the Act in 1998. Except for the efforts at the WMP pilot study sites, very few irrigation boards (or WUAs) are making a concerted effort to implement measurement, and then usually because they have encountered management problems that cannot be overcome by any alternative other than direct measurement.

3.3 Problems experienced with conventional water metering

Mainly two types of flow meters are currently used for measuring river abstractions on irrigation schemes, i.e. mechanical rotor type meters and electromagnetic meters.
Factors which complicate the installation and management of devices for the measurement of water abstraction at remote points, has mainly to do with maintenance and reliability, the cost of the measuring device and the installation thereof as well as practical difficulties with the installation thereof.

3.4 Theoretical principles of proposed measurement procedure

The possible practical procedure to indirectly determine the volume of water pumped by measuring the power consumption of the pump has a firm theoretical basis.

The proposed 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 (η_T) is a product of the efficiencies of the motor (η_E), the coupling (η_C) and the pump η_P, i.e. $\eta_T=\eta_E \times \eta_C \times \eta_P$. Variation of the η-value for pumps will occur over time, but this is not a rapid change, provided good management and operational principles are followed.

3.5 Pilot studies

During 1997 MBB did a project for DWAF on possible monitoring methods applicable on irrigation by means of pumping-stations from the Theewaterskloof Dam. The study showed that water metering through electrical power measurement has great potential.

During April 1998 MBB submitted a proposal to the Water Research Commission (WRC) for a project to this effect, and in April 1999 they commissioned MBB to carry out a preliminary investigation.

The results of this investigation showed that there is a well-defined relationship between the flow-rate of the pump and the electrical power supplied to the system. It further showed that it is practical to measure the appropriate parameters in the field.

4. METHODOLOGY

4.1 General

The three-year project term can briefly be divided into two phases:

a) A first phase of doing various measurements in the field and in the laboratory (pre-proto-type phase).
b) The second phase, the proto-type phase, during which proto-type meters were built, installed and monitored at a number of pumping stations.

4.2 Pre-proto-type meter phase

Various alternative procedures were tried at the beginning of this phase. Existing testing facilities were also visited. Eventually most of the work for this phase was done in the laboratory of the Cape Technikon, using pumping equipment made available by the Department of Agriculture, Western Cape.

4.3 Proto-type meter phase

Five test sites were identified for field tests. These were done in conjunction with the project team of WRC project K5/1265/4, who are researching the application of flow-meters in irrigation water management.

The proto-type meters were installed, calibrated and monitored at these five sites. Without compromising on the accuracy and usefulness of the results, calibration procedures were altered and made simpler during the course of the phase.

5. LITERATURE STUDY

In the search for relevant work related to this project, several Internet searches were conducted, at some stage with the assistance of a patent attorney. Little literature of particular value could be found.

6. DISCUSSION OF TEST FINDINGS

The findings of the different phases of the project are discussed under four headings. For the research situation the emphasis was different than what it would be for non-research situations (referred to as normal use installation). The main differences between requirements for the research and for a normal use installation are highlighted.

6.1 Suitability of sites

A substantial amount of energy was spent on identifying suitable sites for monitoring work. Reasons are given why this has been a fairly difficult operation, and why the normal use installation will be much easier.

6.2 Installation of meters

The installation of the meters for research purposes involved a large number of activities not required for normal use installations. Several visits to the site were necessary, which will not be necessary for normal use installations. An estimate of time and costs is given for normal use installations.

6.3 Calibration of meters and verification of readings

The research calibration procedure started off with a very broad approach. The procedure was refined to become much simpler during the monitoring process, without loosing accuracy of the readings. Reasons are given for this, as well as an estimate of *the time to do the calibration.*

6.4 Meter performance

From the readings of all the tests done (laboratory and field tests) it is evident that there is a good correlation between power used by the pump and the flow-rate of the pump. What is more important is that this correlation is measurable and also that repetitive measurements give similar results.

These findings enabled the project team to design the first proto-type meter. The monitoring done with the proto-type meter proved that the design meets the basic requirements for its application.

The failures experienced with some of the instruments will have to be eliminated in order to make a meter available with acceptable accuracy and reliability for water management and billing purposes.

7. THE PROTO-TYPE METER

7.1 Introduction

The objective of the meter, which is basically an energy meter, is to measure and store the total quantity of water pumped by an electrically driven pump. An internal mathematical equation and calibrated internal look-up tables convert the electric power used by the pump into a flow-rate, and also record the accumulative water quantity.

The meter is installed in the electric supply to the motor. The data is stored in non-volatile memory, and will not be lost even if the backup battery should fail.

7.2 Description

A description of the meter components is given, and the specifications thereof are listed. The installation - , calibration -, and the operating procedures are explained.

Exhaustive tests have been done on the correct operation and procedures, and the *project team is confident that the present format of the meter is well suited for the purpose it was developed for.*

7.3 Financial aspects

The financial implications involved in the electronic water metering procedure are broken down to four levels. These are namely the cost of the meter itself, the cost of installation and calibration, and the cost of maintenance.

The estimated total cost of the meter is summarised in Table 8.2.

7.4 Tampering issues

Potential tampering aspects with the meter are highlighted, and possible ways to deal with it are given.

7.5 Safety and quality issues

The components sourced for the prototype meters are of a good quality, and should meet the standards (safety and quality) required by industry.

It is recommended that a qualified person do the installation.

7.6 Legal issues

The opinion of knowledgeable people in this field is that no major problems are foreseen. It is suggested that the legal issue be included among those issues to be addressed in the way forward for this project.

7.7 Comparative position

Based on the findings of this research project a comparison was made between the electronic water meter and other conventional methods. This comparison appears in Table 8.3. The remarks as it appears in the table reflect how the electronic meter compares with other conventional methods.

7.8 Issues related to feasibility and acceptance

Preliminary results show that this procedure can be accepted as a practical method to measure the volume of water used with an acceptable level of accuracy.

The fact that the meter must be recalibrated periodically is not necessarily a disadvantage, since these actions serve as a useful preventative pump maintenance operation, which would otherwise probably be neglected by management.

7.9 Possible improvements

A list of relatively small changes to the proto-type meter (mainly programming) is given. Apart from these issues, other useful aspects to investigate for implementation are also given.

8. CONCLUSIONS

The success of the project can be measured by comparing the results / findings against the project objectives. The objective of this project was namely to develop a certain measuring procedure, or method. In order for this procedure to be practical and acceptable by the industry (users of water), four criteria were specified. These criteria had to be kept in mind in developing the procedure.

The project team is of the opinion that the project objectives, as well as the criteria for accuracy and acceptability have been met. The method that was developed may well be accepted in the future as a practical alternative to measure water consumption at electrically driven pumping installations.

9. THE WAY FORWARD

The way forward will to a great extent be determined by the opinion of the steering committee of this project, as well as the WRC. A number of aspects to be considered in the way forward are listed and motivated.

10. CAPACITY BUILDING

During the more than three years that the project lasted, capacity building occurred, and mainly centered on personnel and students of the CT. The most important actions in this regard are described. Capacity building also occurred through regular contact with farmers and personnel of WUAs during the monitoring process.

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Electric power supply measurement as an alternative to measure flow-rates of hydraulic pumps

The Steering Committee responsible for this project consisted of the following persons:

Mr DS van der Merwe	*Water Research Commission - Retired Chairman*
Dr SS Mkhize	*Water Research Commission - Chairman*
Mr JF Taljaard	*Water Research Commission - Committee Secretary*
Mr JN Bhagwan	*Water Research Commission*
Ms I van der Stoep	*University of Pretoria*
Mr AS Roux	*Western Cape - Dept of Agriculture*
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Mr N Baard	*Breede River WUA*
Mr DF de Wet	*Oranje-Riet WUA*

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ABBREVIATIONS

AC	*Alternative current*
CMAs	*Catchment Management Agencies*
CT	*Cape Technikon*
CTr's	*Current Transformers*
DC	*Direct current*
DWAF	*Department of Water Affairs and Forestry*
kW	*Kilowatt*
kWh	*Kilowatt-hour*
NWRS	*National Water Resources*
SABS	*South African Bureau of Standards*
US	*University of Stellenbosch*
WAMS	*Water Allocation Management System*
WC/WDM	*Water Conservation and Demand Management*
WMA	*Water Management Areas*
WRC	*Water Research Commission*
WUAs	*Water User Associations*

TABLE OF CONTENTS

1. INTRODUCTION

Increasing demands on the water resources of Southern Africa requires improved management of this commodity. Water metering is generally accepted as one of the most important vehicles in appropriate management of water, and is widely applied in practice, usually by means of mechanical flow meters.

However, in the agricultural industry, one of the major water consumers in South Africa, water metering is poorly implemented. In fact, research provides sufficient evidence that inadequate water metering at the water source is one of the major reasons for ineffective scheduling practices.

The agricultural industry's inadequate implementation of water measurement could be ascribed to a number of factors, and this project's aim is to investigate an alternative to existing methods of implementation.

2. PROJECT OBJECTIVES

The objective of this project is to develop a procedure, or method, by which water pumped with an electrically driven pump can be metered indirectly. In order for the procedure to be acceptable, the following criteria were specified:

- The accuracy of the meter must be acceptable
- The meter must be tamper-proof
- The installation of the meter in an existing system must be simple
- The cost of the meter must be lower than that of conventional water meters

Results from a pilot project, which preceded this research project (February 1999 to July 1999), showed that water metering through electrical power measurement has potential. The accuracy obtainable through this method, as well as costs, compared well with those of existing water meters. Further important potential advantages of this method are easier installation and lower maintenance cost.

3. BACKGROUND

3.1 What does the Water Act say

In 1998 the previous water act (Act 54 of 1956) was replaced by the National Water Act (Act 36 of 1998), which is to be implemented through the National Water Resources Strategy (NWRS), which incorporates, amongst others, the Water Conservation and Demand Management Strategy (WC/WDM Strategy) for the Agricultural Sector, and Catchment Management Strategies of each of the 19 Water Management Areas (Department of Water Affairs and Forestry (DWAF), 2002).

The National Water Act (Act 36 of 1998) specifies that the government, as the public trustee of the nation's water resources, must ensure that water is protected, used, developed, conserved, managed and controlled in an equitable and sustainable manner for the benefit of all people. The framework for implementation of the Act is planned through the National Water Resources Strategy that has to be established by the Minister of Water Affairs and Forestry (DWAF, 2002).

To achieve the objectives of the Act, it is recognised that water resources need to be managed in an integrated manner. Integrated water resources management is an evolving, iterative process for the coordinated planning and management of water, land and environmental resources (DWAF, 2002). For water resources, integrated catchment management aims to take the different sources and users of water in a catchment into account when planning and managing the resource on a regional level.

The institutional framework being developed as required by the Act, makes provision for 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.

Provisions for monitoring and information systems for water resources, and responsibilities for providing water-related information, are provided in Paragraph 14 of the National Water 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 (DWAF, 2002).

Reliable data on discharges and water uses cannot be obtained without the flow at various points in the system being measured with a pre-determined degree of accuracy. The measurement itself is not the end product, but only becomes meaningful in the context of overall water management.

3.2 What is really happening in practice

3.2.1 On government level

Although policies that give guidelines for water measurement have been developed, very little implementation has occurred since the proclamation of the Act in 1998.

DWAF recognises that this will especially be a problem when the Government Irrigation Schemes are privatised as WUAs, when the raw water pricing strategy is to be implemented, and demand management introduced. As a result, a workshop was held in August 2000 by the water resources managers of the Directorate: Water Utilisation to address the lack of measuring structures and instrumentation (Bosman, 2001).

During the workshop it was identified that structures and instrumentation to the value of R25.4 million is required on schemes across the country. These include at least 11 river structures, 315 canal structures, 140 sets of instruments and numerous meters. To date, implementation by the DWAF regional office has been lackluster and a country-wide implementation drive is planned for the next 15 months (Bosman, 2003).

In 2002 it was indicated in the NWRS that the number of operational flow monitoring points in rivers would need to be increased from 625 to between 1500 and 2000 over the next 20-25 years to meet international best practice standards. The capital expenditure required may be up to R1300 million, but possible sources are still unknown, since this far exceeds DWAF's capabilities (DWAF, 2002).

The NWRS also indicated that the groundwater monitoring points need to be increased from 150 to 460, and a web-based National Groundwater archive is currently being developed to facilitate data management. The estimated costs are included in the R1300 million mentioned above.

3.2.2 On WUA level

As part of the first steps of implementation of the National Water Act, the past three years have seen the conversion of government water schemes and irrigation boards to WUAs. This is an ongoing process, which is expected to eventually bring the total number of WUAs to between 500 and 600 (Bosman, 2001).

According to the Act, WUAs will be required to draw up water management plans for submission to their CMA and/or to DWAF, outlining aspects such as their objectives, strategies, policies, services and standards with regard to their principle functions, which include the following:

- Regulate the flow of water course
- Investigate and record quantities of water
- Supervise and regulate the distribution and use of water from a water resource.

Furthermore, the Act makes provision for measurement to be enforced by a CMA by *"requiring the monitoring and analysis of and reporting on every water use and imposing a duty to measure and record every aspect of water use, specifying measuring and recording devices to be used"* as a condition for the granting of general authorisation or a license (DWAF, 2000). Measurement is therefore needed at both distribution system level (for supply management purposes) and at individual abstraction point level (for billing purposes).

The strategy and implementation guidelines are currently being tested through three pilot studies on the development of water management plans for the Gamtoos, Orange-Riet and Orange-Vaal WUAs. The Water Management Plans that will be the result of the project should reflect the current and expected future 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 farmers as well as water management staff.

Except for the efforts at the WMP pilot study sites, very few irrigation boards (or WUAs) are making a concerted effort to implement measurement, and then usually because they have encountered management problems that cannot be overcome by any other alternative than direct measurement.

For example, in Mpumalanga on the Komati River, the WUAs have appointed a consultant to develop and install a sophisticated monitoring and control system at the river pumps owned and operated by the farmers. Called WAMS (Water Allocation Management System), the system consists of the water abstraction control on the Komati River Irrigation Board for 96 river pump stations along some 60km of river from Swaziland up to Komatipoort. The first system was commissioned in 1996. This system has subsequently been replaced by a new upgraded system after the flood damage of Feb 2000. It includes the following units:

- Magflow / Safmag electronic water meters on each delivery pipe from the river (110 meters in total, sizes 100 to 800mm dia).

- WAMS control unit: This unit picks up a signal from the water meter, totalises and adds to other abstraction meters under the same water allocation and compares to the allocated water total that is sent by radio signal to all pump stations from the control station computer. The WAMS unit receives an allocated amount by radio signal on a weekly basis and down counts to zero according to the actual rate of abstraction from the river; when zero is reached the WAMS unit sends a signal to the motor's electrical contactors to switch off the electrical supply to the motor. The owner cannot switch the pump on again until a new water allocation is received by the unit. The unit is designed to be tamper- proof as far as possible and the data is encoded until final report printing. The unit is electronically design to detect any tampering as far as possible.

- Base computer: This unit is programmed to manage all the member's data information and allocations with real-time updating of the water used on his individual total allocation.

- Administration and diagrams for each pump station: A documentation system was developed to ensure the pipe work, pumps, meters and any other equipment installed is not tampered with without the approval of the Irrigation Board management.

- The water levels on the river weirs will also be monitored real time by 12 depth sensors on the weirs all along the river. This data is also sent to the base station for management purposes and water restrictions evaluation.

A system such as this, however, is very expensive and not affordable for any WUA. Most of the former irrigation boards and government water schemes have and still use mechanical type water meters which are cheaper, but due to ageing, poor quality water and intentional damage, the accuracy of the meters are often mistrusted by both the farmers and the water management staff. (These problems are discussed in more detail in paragraph 3.3)

In an effort to overcome these problems, the Orange-Vaal WUA has developed a monitoring system based on the actual irrigated areas, identified through satellite imagery, and site specific crop water requirements. This information is used to estimate the amount of water that should be used by each farmer, and these figures are used for billing purposes. Since most of the farmers in the area use the same scheduling service, the method works fairly well, but since measurement is not direct, the actual water use is not known.

Another type of scheme where direct measurement is a necessity is pipe distribution schemes, where farmers receive water “on demand”. Since there is no water ordering system, or setting of sluices, flow meters are needed to monitor abstractions.

3.2.3 On farm level

Farmers often use water from more than one source. It may be received from a scheme where water is distributed by canals, a river or pipeline; it may be pumped from a privately owned borehole; it may be run-off stored in a farm dam. For integrated catchment management principle to be applied, the discharge from all possible sources needs to be measured.

When metering is required for billing purposes, meters are usually supplied, installed and maintained by the WUA. However, farmers do sometimes install meters themselves, but usually for specific on-farm water management purposes. Farmers progressing toward more scientific methods of irrigation through scheduling, automation and fertigation often need meters as part of the control system for the specific purpose, since flow-rates and applied volumes of water have to be measured.

3.3 Problems experienced with conventional water metering

Mainly two types of meters are currently used for measuring river abstractions on irrigation schemes, i.e. mechanical rotor type meters and electromagnetic flow meters. Table 3.1 summarises some of the characteristics of conventional water meters.

Table 3.1 Conventional water meters: some characteristics

Method	Obstruction in flow path	Requires electricity	Typical error, %	Sensitive to dirty water	Cost (excluding installation)
Inferential	Yes	No	5-10	Yes	< R5000
Electromagnetic	No	Yes	< 5	No	R10000 - R30000
Acoustic	No	Yes	< 5	No	> R20000
Kilowatt-hour	No	Yes	>10	No	< R2500

The mechanical rotor type (also called ‘inferential’) meters are widely used on irrigation schemes, being the most affordable option and not requiring electricity for operation. However, they are easily affected by physical obstructions, accidentally or intentionally. The two most commonly encountered meters were manufactured by Sparling and SA Liquid Meters in the 1980s, but neither are in production any longer and spare parts are unavailable.

Electromagnetic meters are probably the most ideally suited for irrigation water measurement, with no moving parts that can wear out and no obstructions in the flow path of the water. However, these meters require electricity to operate and can cost up to 10 times as much as a mechanical meter.

Other meters used to a limited extent include acoustic meters, and kilowatt-hour meters.

Factors which complicate the installation and management of devices for the measurement of water abstraction at remote points (rivers, dams, boreholes, etc), can be summarised as follows:

- Maintenance and reliability

  One of the constraints mentioned most often by water management staff of the WUAs, are 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, as it may cause precipitation and chemical reactions in the meter.

- Cost of the measuring device and installation

  In all discussions with water users or management staff on water meters, the issue of cost is raised. A major concern is the initial cost of the meter and installation; although a commercially available meter can be bought and installed for less than

R5000 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. For example, the average number of pumps operated per farmer in the Orange-Vaal WUA region is four. The total number of pumps above the Douglas weir is 400 bringing the total estimated initial cost of installing meters to R 2 million. Since the meters will be considered the property of the WUA, they will have to carry the initial cost through a loan, and then recover this from the water users.

Although this cost could be distributed over a number of years to make it more affordable, the 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 envisage 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. Measurement of the bulk water abstracted for the WUA as a whole catchment management purpose was considered to be a more sensible investment.

If meters were to be installed at individual pumps, it would also require regular maintenance and calibration, which would mean further costs to the WUA.

- Remoteness of the sites

Pumps at individual abstraction points are usually located at fairly remote sites. Pumps are often not enclosed in a pump house that can be locked, and electrical connections and wiring are often substandard. These conditions increase the risk of vandalism or damage to measurement devices, making the installation of expensive equipment even less appealing.

- Installation difficulties

Most of the meter installations required in WUAs will be at existing pumping systems. In order for the meter to operate correctly, most flow meters require a straight section of pipeline of at least 5 (preferably 10) times the diameter of the pipe in front of the meter, and at least 3 (preferably 5) times the diameter after the meter to ensure a fully developed turbulent flow profile in the meter. At most pipeline systems these requirements cannot be met without major changes in the existing pipeline and the pump station.

The installation of a flow meter increases the head loss in the system, and 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. It may be that the pump cannot meet the additional pressure head requirements, in which case the installation will influence the efficiency of the irrigation system.

3.4 Identification of need for alternative measure methods

In an effort to overcome the above-mentioned constraints and other limitations, water management staff at WUAs have developed methods to determine water use by measuring a parameter that is related to the pumping system and deriving the discharge from a predetermined or calibrated relationship between the system discharge and the measured parameter.

The most common application of this method is where the WUA monitors the hour or kilowatt-hour meters on the pumps' motors. The power-discharge relationship is determined by measuring discharge with a portable flow meter (typically an acoustic transit time meter) and simultaneously measuring the power consumption of the motor. This method is however not very accurate, since the relationship may vary at a single pump, depending on the water level on the suction side of the pump, the discharge rate, the head loss in the system, etc. Due to all the variables that are not taken into account, previous investigations by MBB Consulting Engineers (1997) have shown that errors of up to 50 % can occur.

One type of indirect measurement method is through differential pressure measurement across a component of the pipeline system, for example an orifice plate or 90 ° bend. The relationship between the differential pressure and discharge in the pipeline is then used to determine the discharge through the system.

These indirect measurement methods are usually non-intrusive, therefore not causing any obstruction in the flow path, and can more easily be added to an existing system without major construction or alteration to the pipeline. However, disadvantages include the fact that the devices are electrically operated and still not 100 % tamper-proof.

3.5 Theoretical principles of proposed measurement procedure

The possible practical procedure to indirectly determine the volume of water pumped by measuring the power consumption of the pump, has a firm theoretical basis.

Of great importance is the question of how accurate the procedure is, and the effect on accuracy of changing external conditions over time.

The proposed 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 (η_T) is a product of the efficiencies of the motor (η_E), the coupling (η_C) and the pump η_P, i.e. $\eta_T=\eta_E \times \eta_C \times \eta_P$.

These three efficiencies are discussed individually in the following paragraphs.

3.5.1 The electric motor

Typical direct current (DC) and alternative current (AC) motors encountered in the industry are:

- DC: Series, shunt and compound machines
- AC Single phase: Universal, shaded pole, synchronous, capacitor, hysteresis and stepper motors
- AC Three phase: Squirrel cage-, slip ring-, reluctance-and permanent magnet motors

The most common three phase induction motor used on pumps is the squirrel cage induction motor, because of its robustness and economy.

3.5.1.1 Efficiency and load

The efficiency of an electric motor, for the same machine, differs according to the workload. In other words, if the load demand changes, so will the efficiency.

Normally one finds that the bigger the motor (in kW) , the better the efficiency .

The aim should be to run the machine at the highest efficiency possible, as this implies lower losses, therefore lower temperature rise, and therefore less wear on the motor.

3.5.1.2 Power factor and input power

It is necessary to very briefly say something about power factor and power factor correction on electric motors.

Input power is given as $\sqrt{3}$ V I $\cos\varphi$ (3-phase) and V I $\cos\varphi$ (single phase). The power factor indicates how much of the apparent power drawn from the supply is real power. This is the power that in conjunction with the speed of the motor determines the torque. The power factor, as in the case of efficiency, changes with load demand.

The aim of power factor correction is to reduce the reactive power (φ) taken by a motor from the electrical supply. If this is done correctly, the consumer of electricity can expect a reduction in the monthly energy bill. Power factor correction is applied by using a correctly sized capacitor bank to compensate for the inductive reactance of the motor.

There are two ways of applying power factor correction (Q). Firstly, for constant real power (P) and secondly for constant apparent power (S). The powers are related to each other according to $S = P + jQ$. In other words P and Q are the components of S. If S is supposed to be constant, then P has to change if Q is compensated. If P remains constant, S changes consequently. For single-phase motors the compensation is always done for constant real power, because the motor has to deliver the same torque.

3.5.1.3 Something about speed and slip

Slip (s) is the technical term for the fact that the mechanical rotor speed (n) of squirrel cage and slip ring motors can never reach synchronous speed (n_s), because the principle of induction fails at synchronous speed. The definition is given by $s = (n_s – n)/ n_s$ from which it can be seen that the higher the mechanical load, the less the speed and therefore the bigger the slip.

The real power drawn from the supply is split up into two main parts inside the motor, namely the copper loss (which heats up the machine) and the mechanical power (which produces the torque). The slip is an indication of how much of each component is obtained for a given input, e.g. at starting ($s = 1$) no mechanical power exists and all power is converted into heat, while at synchronous speed there would be theoretically no losses and all power is turned into mechanical power. Above the speed of maximum torque the machine is in good approximation linear which is not at all true for speeds below it.

3.5.1.4 Ambient temperature and efficiency

Motors are designed to work according to a specified temperature rise above ambient temperature. This temperature rise is characteristic for the machine and is not a function of the ambient temperature. If the machine is designed for a maximum temperature rise of 80 degrees above room temperature (25 degrees, say) then 105 degrees may not be exceeded. If the ambient temperature is 40 degrees, the machine can therefore not be loaded to its rated point, and the efficiency therefore drops.

Table 3.2 gives an indication of the reduction in allowable load for different ambient temperatures for typical electric motors.

Table 3.2 Reduction of allowable power loads according to ambient temperatures above 40 degrees C

Ambient temperature [°C]	Allowable power load [%]
40	100
45	95
50	89
55	83
60	67
70	64

3.5.1.5 Efficiency above sea level

If the ambient temperature remains constant as elevation above sea level increases, the efficiency of the electric motor will drop, the reason being that as the air gets thinner, the cooling fan of the motor (running at the same speed) can not reduce the heat as efficiently, which means that the motor gets hotter. This decreases the efficiency of the electric motor.

However, for a certain installation this elevation remains fixed, and the potential variation in efficiency is therefore not relevant.

Table 3.3 shows the reduction in allowable power load for different elevations.

Table 3.3 Reduction in allowable power demand according to height above sea level

Height above sea level [m]	Allowable power load [%]	Allowable ambient temperature [°C]
0 tot 1000	100	40
1000 tot 2000	92	32
2000 tot 3000	83	24
3000 tot 4000	74	16

3.5.1.6 Other factors influencing the efficiency of the motor

If the efficiency of an electric motor changes over a period of time, it will always be a decrease in efficiency. Because the output is demanded by the load (which stays approximately constant) a decrease in efficiency means an increase in losses of the motor. Some factors responsible for this are:

- Worn out insulation (due to temperature variation) can create leakage currents between the windings.
- Loose bolts and nuts in the stator (due to the permanent vibrations) can damage the insulation between the laminations.
- Dirt settlements on cooling ducts keep more heat inside the machine.
- Wear and tear of bearings increases mechanical friction.
- Constant over voltages and frequency changes increase the losses. Permanent mechanical overload might damage shaft and bearings, resulting in an uneven air gap.
- A transformer in good condition, no matter what age, will not have an effect on the performance of the motor. If the transformer ages in such a manner that its insulation deteriorates, leading to inter turn faults, the output voltage will drop and the output power and torque of the motor will do likewise. This will lead to mechanical overload of the motor, which in turn increases the losses.

3.5.1.7 Closing remarks

A motor that receives attention at regular maintenance intervals has a service life expectancy of about 20 years, during which the efficiency should not drop significantly. If it does, other factors (mentioned above) are probably responsible, and this should be attended to as a measure of healthy design and maintenance procedures.

3.5.2 The coupling between motor and pump

There are three types of couplings, i.e. directly on the shaft of the electric motor, by means of a flexible coupling between the motor and pump, and by means of pulleys and V belts.

Direct couplings are 100 % efficient. These type of couplings, however, is used only on relatively small pumps, e.g. smaller than 7.5 kW.

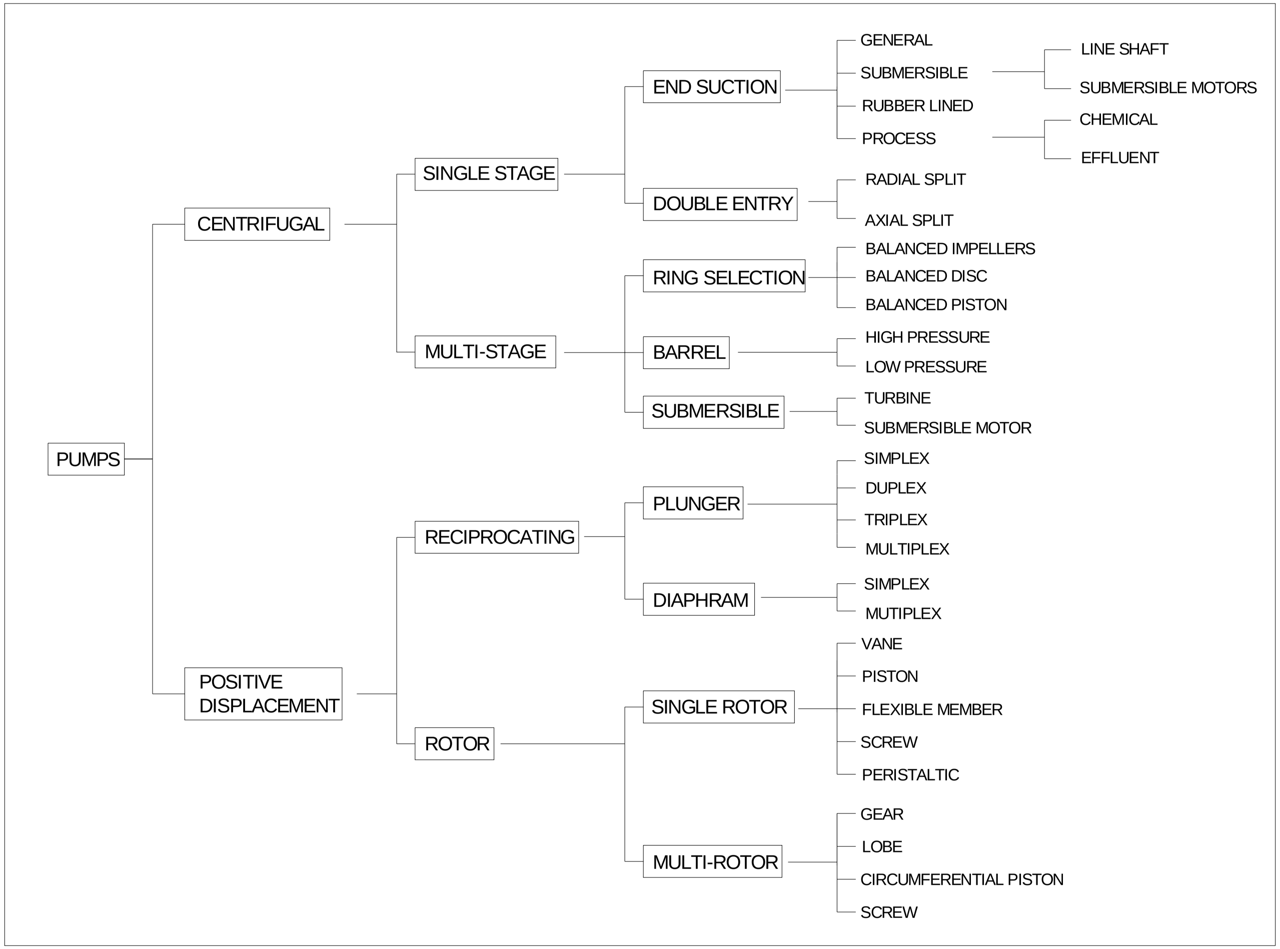
Flexible couplings are the most common type used. When installed correctly, the efficiency is very close to 100 %.

Pulley and belt driven couplings are currently seldom found on electric driven pumps, the reason being that most pumps are designed for ideal duty points running at speeds of 1450 r.p.m. or 2900 r.p.m. , which are the speeds of 4-pole and 2-pole electric motors respectively. For this type of couplings the assumption can be made that its efficiency will vary for different power loads (typically 85%), but that it will remain a constant for the particular load over a reasonable period of time (say 3 to 4 years).

3.5.3 The pump

There are many different types of pumps used in the agricultural sector. Figure 3.1 shows a summary of these.

Figure 3.1 Schematic summary of different types of pumps



Centrifugal pumps are by far the pumps most used in agriculture. This type of pump also covers the submersible multistage pumps for boreholes.

The power demand of a pump at a certain duty point can be expressed by the following equation:

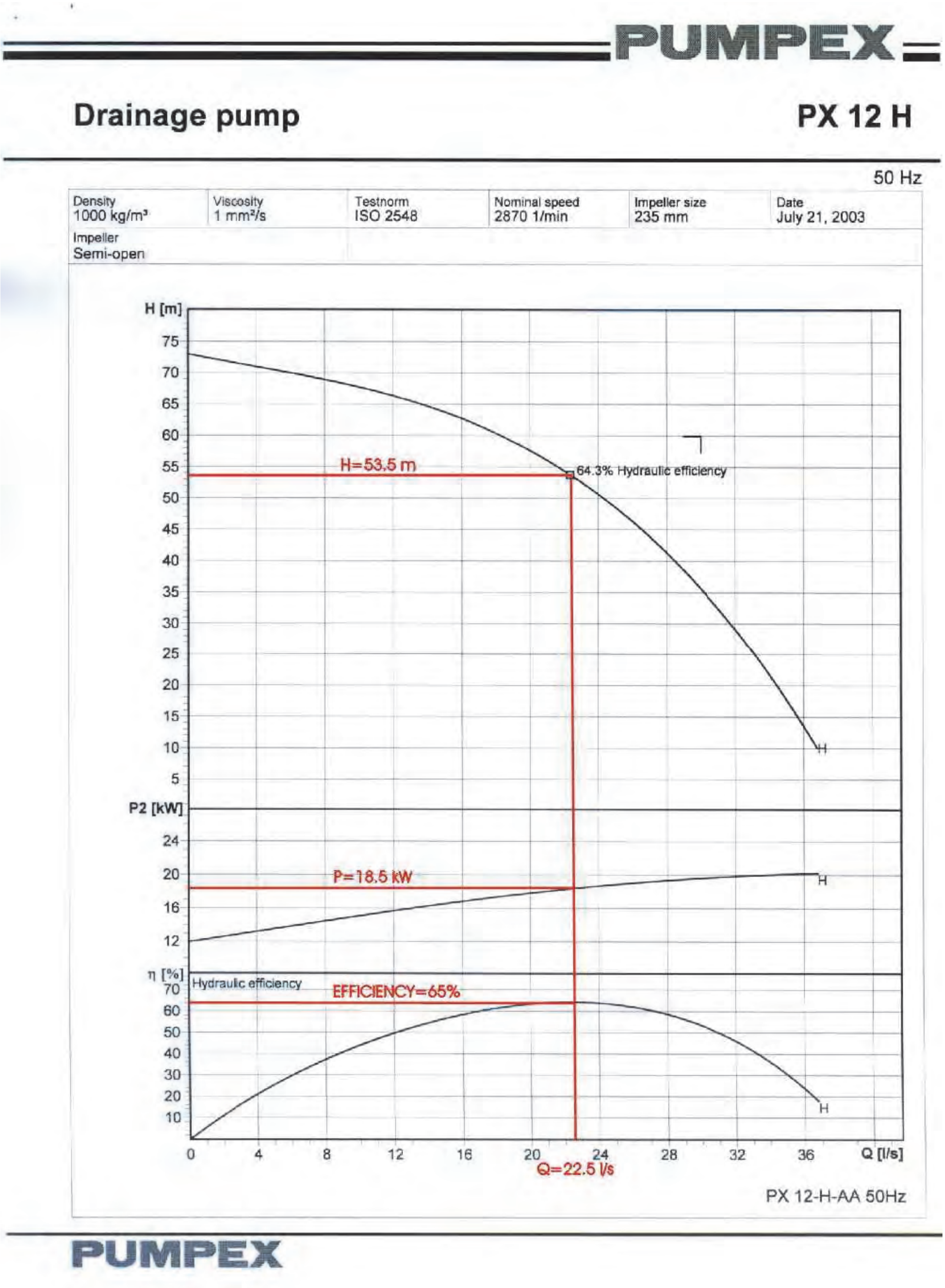
$$P = \frac{\rho \; \gamma \, H \, Q}{36\,000 \; \eta}$$

where P = power required [kW]
ρ = density of water [kg/m³]
γ = gravity [m/s²]
H = pump head at duty point [m]
Q = pump flow-rate at duty point [m³/h]
η = pump efficiency at duty point [%]

For a specific fluid at a certain fixed physical location the only variables in the above equation is the pump head (H), the flow-rate (Q) and the pump efficiency η. If these values are known, the power demand can be calculated.

Consider now a typical pump curve for centrifugal pumps, shown in Figure 3.2.

Figure 3.2 Typical centrifugal pump curve



This pump curve illustrates that for a certain power demand, there can be only one unique H and one unique Q value generated by the pump. H includes both the suction and the delivery head. Q cannot be "destroyed"; what goes through the pump must be discharged somewhere in the hydraulic system on the discharge side of the pump. However, the value of H is changing all the time form the moment the pump discharges the water in the hydraulic system on the delivery side of the pump. Normally the pressure at the end of the hydraulic system is zero when the water is discharged into the atmosphere, e.g. a sprinkler or a dripper. It can also have a positive value, e.g. of the system discharges into a pressure vessel. The difference between the pump discharge pressure and the end pressure will be consumed along the way by friction and static head differences (neglecting the relative small kinematic head differences).

The pump will not sense whether the generated H is a system requirement (useful) or whether it is deliberately destroyed, e.g. the throttling of a valve. Because of the fixed relationship between Q and H, H can be eliminated as an unknown variable. The elimination of H therefore also implies that suction head can be excluded from the relationship, whether it's fluctuating, both positively and negatively. Varying surface levels from which water will be pumped, as well as varying water levels in boreholes, will therefore be irrelevant.

The equation above can now be re-written to the following:

$$P = f(\rho, g, Q, \eta)$$

or

$$Q = f(P, \rho, g, \eta)$$

From the pump curve it is also evident that there is a unique relationship between P and η. If this relationship can be determined, the value of Q can be calculated.

Variation of the η-value will occur over time, always decreasing. This is not expected to be a rapid change, provided good management and operational principles are followed. If this would not be the case, one would very often find pumps not being able to supply in the demand it was designed for, and irrigation systems will fail. Irrigation designers do allow for some reduction in efficiency, but this is normally marginal. It is the practical experience that, with normal maintenance to pumping equipment, the designed requirements can be met over the normal lifespan of the pump, which should be at least 12 years.

There are exceptions to the typical pump curve as shown in Figure 3.4. The difference is namely that, for the same pumping head, there can be two alternative flow-rates. However, normally also for these type of pumps the relationship between power and pump efficiency is unique. Nevertheless care must be taken to ensure that this unique relationship exist if electronic water metering is considered.

3.6 Pilot study

3.6.1 Background

During 1997 MBB did a project for DWAF on possible monitoring methods applicable on irrigation by means of pumping-stations from the Theewaterskloof Dam.

For the mentioned study, a number of metering methods were investigated by means of a desk study of the subject, but based on the actual pumping positions at the dam.

Some of the results from this study appear in Table 3.4.

The study showed that water metering through electrical power measurement has great potential. The likely accuracy obtainable through this method, as well as the anticipated costs, compares well with those of existing water meters. Further important advantages of this method were found to be easier installation and maintenance.

Table 3.4: Estimated cost for different monitoring methods and expected accuracies of the methods (1997)

Monitoring method	Estimated cost			Estimated accuracy (± %)
	Initial (R)	Annual (R)	Total* (R)	
Theoretical irrigation requirement calculation	800	980	7 475	35
Theoretical modeling of irrigation network	2 400	1 120	10 028	30
Measuring of pump operating time	780	1 120	8 408	25
Measuring of electricity used (kWh)	480	1 120	8 108	25
Measuring of electrical power - anticipated (kW)	2 840	1 280	11 558	12
Measuring of electrical power (kW) – telemetric	9 900	480	13 169	12
Measuring with a water meter - ± 5 % rotor type	2 600	1 000	9 411	5
Measuring with a water meter - ± 5 % rotor type telemetric	9 600	200	10 962	5
Measuring with a water meter - ± 2 % rotor type	2 800	1 300	11 654	2
Measuring with a water meter - ± 2 % rotor type telemetric	9 800	500	13 205	2
Measuring with a water meter - ± 0.5 % magnetic type	10 500	850	16 289	0.5
Measuring with a water meter ± 0.5 % magnetic type telemetric	17 500	50	17 841	0.5

*Annual cost is discounted @ 12 % over 15 years

3.6.2 WRC Pilot Project

During April 1998 MBB submitted a proposal to the Water Research Commission (WRC) for a project to investigate the accuracy of flow-rate determinations when use is made of measuring the power supply to electrically driven pumps. Although the project proposal was not approved, the WRC recognised its merit and in April 1999 commissioned MBB to carry out a preliminary investigation before considering the project proposal again.

For the initial field tests it was decided that a handheld electrical supply meter would be used, capable of taking readings for one of the three phases of the power supply to the electric motor. It was considered adequate, since the three phases of the supply to an electric motor are fairly well balanced in practice.

Reliable relationships between flow and power supplied were not that clear during these tests, mainly due to the accuracy of the metering equipment. From the readings obtained it was also evident that the assumption that the three phases of an electric motor is well balanced is not correct, and even though the differences are small, the overall influence may be fairly significant.

A further fact which became clear during the field tests, is that the time lapse between the first electrical parameter reading for a certain duty point (flow-rate) of the pump and the last reading for the same point can be significant. Better relationships between different electric parameters were also observed where more accurate flow meters were used.

During analysis of these results, therefore, it became clear that certain changes to procedures used would have to be made in order to come to more sound conclusions. A decision was taken to run more tests, improving on the following:

- Use an electrical meter which reads more decimals (more accurate)
- Use an electrical meter capable of reading all three phases of the electrical supply simultaneously
- Improve on flow meter readings (instead of calculating flow according to pressure)

Analyses on the results of further tests showed that there is a well-defined relationship between the flow-rate of the pump and the electrical power supplied to the system. It further showed that it is practical to measure the appropriate parameters in the field, provided the right equipment is used.

4. METHODOLOGY

4.1 General

In the original project program it was foreseen that, after field tests at appropriate pump stations had been completed and the relationship between flow-rate and power used had been determined for these pumps, a proto-type meter would be built and moved from one pump station to the other.

In this original program it was foreseen that approximately eight pump stations would be identified, field measurements done and data analised for a proto-type measurement. This would take place over a period of four months. During the next two months a proto-type meter would be built, followed by a period of 12 months of monitoring the pump stations with the meter, moving the meter among the stations.

Due to a number of reasons this procedure did not work well in practice, and an alternative procedure had to be developed. The most significant in this regard was the realisation that research work under laboratory conditions would be necessary. This was mainly due to the fact that problems were experienced to adequately vary the operating conditions of the pumps during the field tests in order to measure the different parameters.

The procedures were changed and a new work program was submitted and approved to provide for this “defect” in the planned program.

The three-year project term can briefly be divided into two phases:

a) A first phase of doing various measurements in the field and in the laboratory. This can be referred to as the pre-proto-type phase.

b) The second phase, the proto-type phase, during which proto-type meters were built, installed and monitored at a number of pumping stations.

In this new program it was envisaged that approximately three months would be needed for tests in a suitable laboratory, with suitable equipment. Two and a half months would be needed to complete the proto-type meter, and then a period of 12 months would follow of monitoring pump stations.

Field measurements were restricted by the seasonal nature of irrigation, and towards the end of the project term the project team felt that more readings were desirable. Extension of time was granted for this reason.

Additional work to establish reasons for failure of prototype meters at two sites

The final project meeting was held in August 2003. The draft final report included a number of recommendations with regards to proposed follow-up work to the concept that was researched (Chapter 10). Amongst these was further research to establish the reason why two of the prototype meters failed at two of the sites.

The WRC agreed that the project team proceeds with this work, and then to include their findings in the final project report. Appendix D contains a description of the additional work done and the findings of this work.

The original contents of the report as submitted for the final project meeting has not been changed to accommodate the findings of the additional work. However, where there is some relevance between the original research and the extended work, footnotes with a prefix of "D" were added in the report with the necessary references to related sections in Appendix D.

The activities during the different phases of the project are discussed in more detail in the following paragraphs.

4.2 Pre-proto-type meter phase

4.2.1 Initial laboratory test

As suggested during the inaugural meeting of this project, a suitable laboratory was to be identified where an initial test would be performed under controlled conditions. The investigation included testing facilities of pump manufacturers/suppliers, the Cape Technikon (CT) and the University of Stellenbosch (US). None of these were ideal, but the civil engineering laboratory of the US was found to be the most suitable.

Tests were carried out on an old centrifugal pump which is part of a system to lift water from tanks below the hydraulic laboratory. Flow measurement was done by means of an orifice plate and a manometer. For very low flows a V-notch was used. The size of the electric motor was 22 kW. Apart from the electrical parameters that were logged, pressures, flows and motor speed were also captured.

Due to a number of problems experienced, the actual readings received from this test were not of significant value. The problems had mainly to do with an initial limited understanding of the measuring equipment, data that were lost due to backups not made properly, communication problems due to different measuring points far apart, and on different floor levels. However, the experience gained during this test indeed proved the value of fine-tuning the measurement procedure, and the project team had a much better idea of how to prepare themselves for the field tests.

4.2.2 Identification of potential sites, and field tests

A number of irrigation schemes were considered for inclusion in the field tests. However, the reliability of the existing water meters were of concern. One of the pump stations of the Cogmanskloof Irrigation Board was identified as suitable. The particular pump was driven by a 150 kW 4-pole electric motor and designed to deliver 350 m^3/h at a head of 100 meter.

At the occasion of the field test, the agent of the metering equipment was also asked to be present, in view of the problems previously experienced. Problems were again experienced, this time mainly due to logging of the data. At the end of the test it was the general opinion that some of the data collected was suspect, and that more trials would be needed to improve the team's procedures for data collection.

A spin-off from the test at this site was that it was established that a power factor correction capacitor on the electric motor was not performing correctly. The manager of the scheme consequently attended to this problem, and it is believed that there is a significant saving in the electricity cost at this pump station after it was repaired.

With the knowledge gained up to this stage the project team felt the need to check their procedures and discuss the problems experienced. A very successful workshop was arranged with senior academics of the electrical and mechanical departments of the CT in November 2000. The general consensus at this meeting was that the team should return to laboratory conditions to refine the testing procedures, before further field tests were to be carried out.

4.2.3 Visits to existing testing facilities

As suggested at the inaugural meeting, the project team made contact with the DWAF in connection with the efficiency tests that they do on some of their bigger pumping stations. The team subsequently attended such a test at Standerton in November 2000. The persons carrying out the tests experienced quite substantial problems with their testing apparatus, probably due to a considerable time period since executing previous tests.

Although no useful readings could be obtained during the test, the opportunity to attend the test was of value to the project team. The principle applied in the tests done by DWAF is, however, quite different from those under investigation in this project. They are namely performing a thermodynamic method to determine the pump efficiency. This method results from the application of the principle of a transfer of energy between water and machine through which it is flowing (first law of thermodynamics). All energy lost in the pump as a result of inefficiency is converted to heat, which is carried away by the water flowing through the pump, increasing the temperature of the water. This temperature differential is measured with very sensitive probes (1mK), and the pump efficiency is calculated.

The testing facilities of the South African Bureau of Standards (SABS) were also visited during the same period to discuss their pump testing procedures. These tests are applied to determine pump performance. The power supplied to the pump is measured with a torque meter on the pump shaft, between the power source and the pump.

The mentioned procedures had only a slight resemblance to this research project, and although useful to observe, did not really influence the course of the project.

4.2.4 Further laboratory tests

In view of the outcome of the CT meeting mentioned in paragraph 4.2.2, various alternatives for further laboratory testing were investigated. These alternatives included the venue as well as equipment to be used. It was realised that a suitable laboratory with the appropriate equipment already in place, would not be easily found. After attempting several cumbersome routes to obtain pumping equipment, the Department of Agriculture, Western Cape, generously made available the major part of the equipment. These equipment, which included pump, electric motor, switch gear and a water meter, were brand new equipment, kept in stock for a planned project. Part of the agreement was that the testing facilities would be available to the Department for demonstrations or training of their personnel.

The CT agreed to have the testing facilities installed in their thermodynamic laboratory. They welcomed the opportunity it provided to several mechanical and electrical students who assisted with the building of these facilities. In fact, all the work was done on site by personnel and students of the CT.

Since the facilities were commissioned in April 2001, four comprehensive tests were done in the laboratory. For each additional test, certain improvements were made to the equipment, and additional measuring devices were added. A good procedure was eventually developed, and the decision to do further laboratory testing proved to be the right one.

As an extension of the tests in the laboratory, one field test was added. This served the purpose of checking the developed procedure.

The first version of the proto-type meter has already been developed at this stage, and during the last three laboratory tests readings were obtained from it. For the field test, however, it was discovered that single-phase power was not available at the site and it could not be used.

4.3 Proto-type meter phase

4.3.1 Identification of proto-type meter test sites and field tests

The most important aspects required in a potential field test site were the following:

- Electrically driven pump station
- A cooperative farmer
- Within reach of the project team for regular monitoring
- The pump must be used frequently
- A facility must exist to monitor the proto-type meter. A reliable (existing) water meter was therefore necessary.

At that stage another WRC project also dealing with water meters was getting under way. The title of this project is: Project K5/1265/4: **The application of flow-meters in irrigation water management**. The electronic method of the measurement of irrigation water was recognised by the project team as an alternative procedure. At a steering committee meeting during 2002 it was suggested that the two project teams should consider monitoring, if practically possible, at the same sites, for at least one or two of the test sites.

With these factors in mind, as well as with the knowledge of the previous sites seen, a number of different schemes were visited. It was evident that it is very difficult to find an existing facility where the proto-type meter can simply be added, in other words where a reliable water meter is present. It also became evident that to install a new meter correctly in the existing pipe work of a pump station is in most cases a difficult and costly exercise.

Five sites were eventually identified as suitable, and the details of each of the pump stations appear in Table 4.1.

Table 4.1: Proto-type meter pumping sites

Site number	Location	Date installed	Date removed	Pump type	Motor size (kW)	Existing meter or new meter	Source of water
1	Jacobsdal	2002-09-11	-	KSB 125/315	30	New	Canal
2	Modderrivier	2002-09-20	2003-05-30	Loewe FD120A	7,5	New	River
3	Koelenhof	2002-12-09	-	Allis Chalmers 9000 (10x6x22)	160	Existing	Booster in pipeline
4	De Wet	2002-09-27	2003-03-28	DAB K28/500T	4	New	Open Well
5	Franschhoek	2003-05-16	-	NM32-160	4	Existing	River

After the original visit to identify the site, further visits were necessary, i.e. to install water meters, and to determine the power / flow relationship.

As shown in Table 4.1, only two of the sites were equipped with a flow meter. For the remaining three sites new meters were made available by the project team of the mentioned K5/1265/4 WRC project. They also coordinated its installation, and made sure that the meters were installed according to manufacturer's specifications.

4.3.2 Manufacturing of proto-type meter

As mentioned in paragraph 4.2.4, a proto-type meter was assembled and readings were taken with it during the laboratory-testing phase. The main purpose of this exercise was to check the basic components and software. A number of aspects were identified for changes to both the hard - and the software, and these alterations were made.

It became clear during identification of the sites that the original idea to build one meter and monitor different sites with it by moving it among them, would not be practical. This was mainly from a logistical and time availability point of view. The decision was therefore taken that several meters would be necessary for the monitoring.

Details of the meter are given in Paragraph 8. Suffice to mention at this stage that the meters for different sites are exactly the same, except for the number of windings through the Current Transformers (CTr's). The number of windings is determined by the maximum power that is required by the electric motor.

For the five monitoring sites, four different meters were necessary due to the different power demands. These meters were built at the CT by one of the team members.

4.3.3 Installation and calibration of proto-type water meter

The planned procedure for the installation and commissioning of a proto-type water meter is as follows:

- Portable ultrasonic water-meter to be set up (K5/1265/4 project team).
- Dranetz Power Platform 4300 to be set up (CT student(s)).
- Installation of proto-type meter in the pump house by a qualified electrician.
- Performance of the calibration test. The valve on the discharge side of the pump is used to operate the pump at various flow-rates. Should conditions allow, the flow-rates should vary from zero (closed valve) to discharging into the atmosphere (valve fully open). The readings to be taken for each setting are the following:
  - Flow-rate registered by mechanical flow-meter.
  - Flow-rate registered by ultrasonic flow-meter.
  - Power consumption of the electric motor registered by Dranetz.
- Compare flow-meter readings of the mechanical and ultrasonic flow-meters. Since the mechanical meters are new, big differences were not envisaged.
- Determine the flow-rate / power used relationship for the pump, making use of the ultrasonic meter and Dranetz readings.
- Program the proto-type meter, also providing for the calibration correction factor. This factor is used to calibrate the readings of the CTr's (to change factory setting to a value which corresponds with the highly accurate Dranetz values).
- Run the system again for a number of operating conditions, but also adding the flow-

rate and power demand as recorded by the proto-type meter to the previously mentioned readings.

- Reprogram proto-type meter if necessary, and when satisfied that the meter is functioning correctly, the ultrasonic meter and the Dranetz can be removed.

In paragraph 7 of this report the findings / results of the different aspects of the meter and its installation are discussed. For reasons mentioned in paragraph 7, it was established that, without compromising the accuracy and usefulness of the results, for the purpose of this project there is no need to take readings with the ultrasonic meter and the Dranetz.

The procedures were altered accordingly and meters were installed at the first four sites as per Table 4.1. The meter from site 4 was later removed and installed at site 5.

5. LITERATURE STUDY

In the search for relevant work related to this project, several Internet searches were conducted, at some stage with the assistance of a patent attorney. Little literature of particular value could be found.

A number of researchers have evaluated alternative methods in order to overcome some of the problems encountered with irrigation water measurement using conventional measurement devices. These methods generally involve the measurement of another parameter in the pumped fluid system, and depend on a previously established relationship between the known parameter and the system discharge to calculate the volume pumped through the system.

This principle has been applied in the medical field for the development of a method to measure the amount of blood pumped by a blood pump during heart surgery. Qian, Zeng, Ru, Yuan, Feng & Li (2000) developed a measurement method based on the driving motor's power.

Another application of the principle is reported by Kouidri, Bakir & Rey (2002) who developed a method to measure two-phase flows through slurry pumps removing rubble from a tunnel boring machine. The method used the power consumption of the engines driving the pumps to determine the flow-rate.

6 TEST RESULTS AND ANALYSES

6.1 Initial field tests

Due to the problems experienced during these tests referred to in paragraph 4.2.2, the actual data collected were not of much value, although a fairly good relationship was found between power and flow-rate. The biggest value of the tests was the improvement of testing procedures and measuring equipment.

The data collected during these tests are not included in this report, but is kept with the rest of the test data.

6.2 Laboratory tests

The data collected during the four tests in the laboratory of the CT, as well as the single field test (to check the developed procedures) appear in Appendix A. Although the tables contain a huge amount of data, only limited data is relevant for the project team's requirement.

Photographs in Appendix B show the layout of the laboratory testing facility. The main components of the layout are the following:

- The electric motor and pump, directly coupled.
- A 5 000 liter storage tank. Both the suction and delivery pipes are connected to this tank.
- Two flow meters; a mechanical meter for high flows, and a magnetic meter for low flows.
- Pressure gauging equipment on both the suction and delivery side of the pump.
- Valves on both the suction and delivery side of the pump.

Other equipment installed and used during the tests were:

- The Dranetz Power Platform
- An ultrasonic water meter made available to the project team by the Breede River WUA
- Pressure transducer with multimeter to read output
- Meter to read the speed of the pump

The valves on the pump enabled the project team to simulate a very wide range of field conditions. Perhaps the most important of these were the simulation of different suction heights. The normal condition for the installation was for a positive suction height of approximately two meters. By controlling the two valves of the pump, this head could be reduced to a negative suction height of as high as eight meters, without cavitation of the pump taking place.

The data tables in Appendix A consist of two parts. The first 14 columns indicate results recorded by the Dranetz system, while the rest of the table are manually recorded readings.

Graphs were then produced to show relationships between certain data sets, i.e. flow-rate and power used.

Figures 6.1 to 6.4 were developed from data produced by the four tests performed in the laboratory. In each test it is evident that a good correlation exists between flow-rate and power used. For these graphs a linear trend line was accepted, and the lowest regression coefficient obtained was 0.986 for the first test.

The differences between the results of the alternative tests can be explained. After each test certain changes were made to procedures and measuring equipment to make readings more accurate. For instance, readings from the mechanical meter were initially taken by means of a stopwatch. Recording instruments were later added to the meter so that the flow-rate could be read digitally.

Figure 6.1 Test results for laboratory test 1

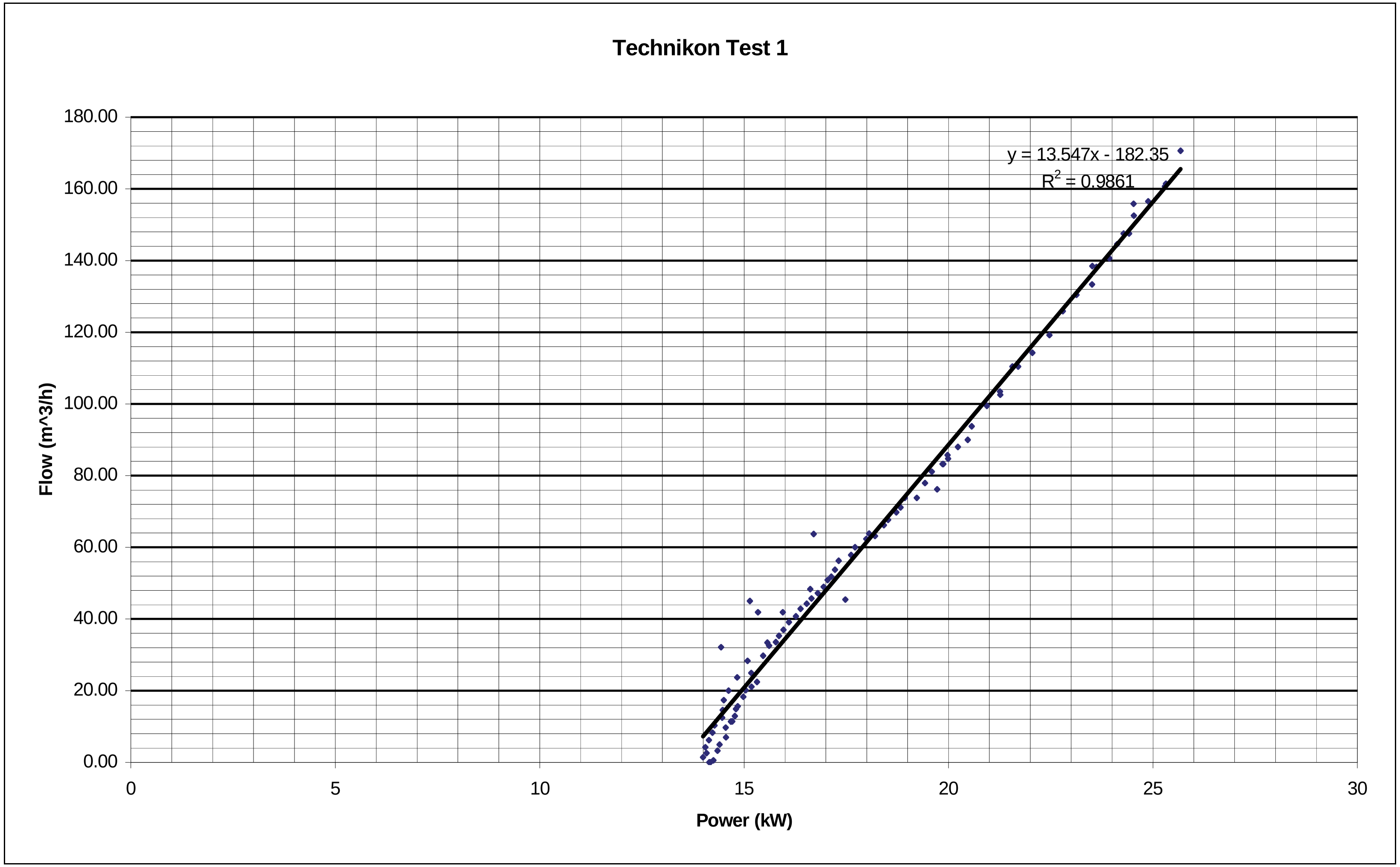


Figure 6.2 Test results for laboratory test 2

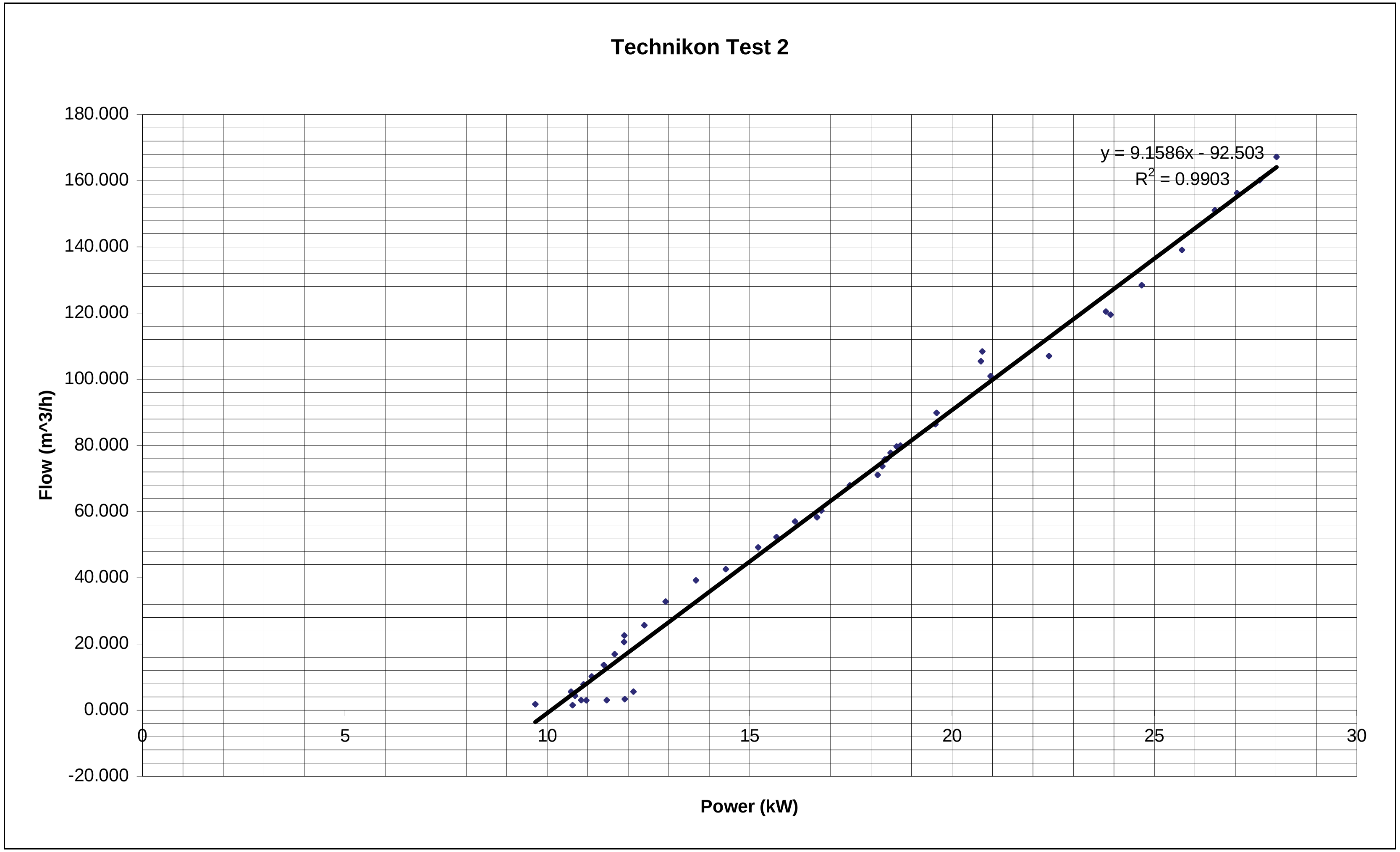


Figure 6.3 Test results for laboratory test 3

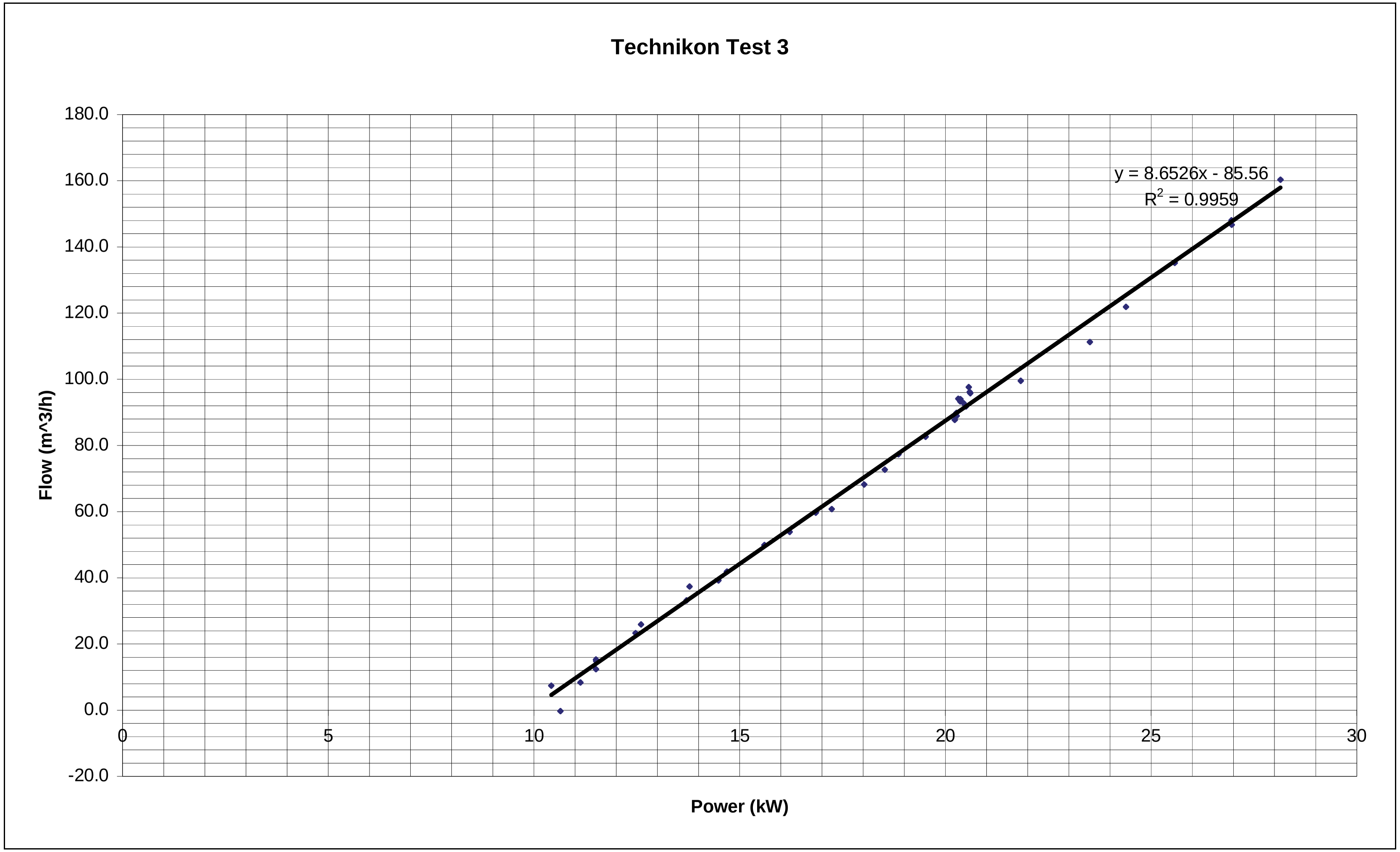
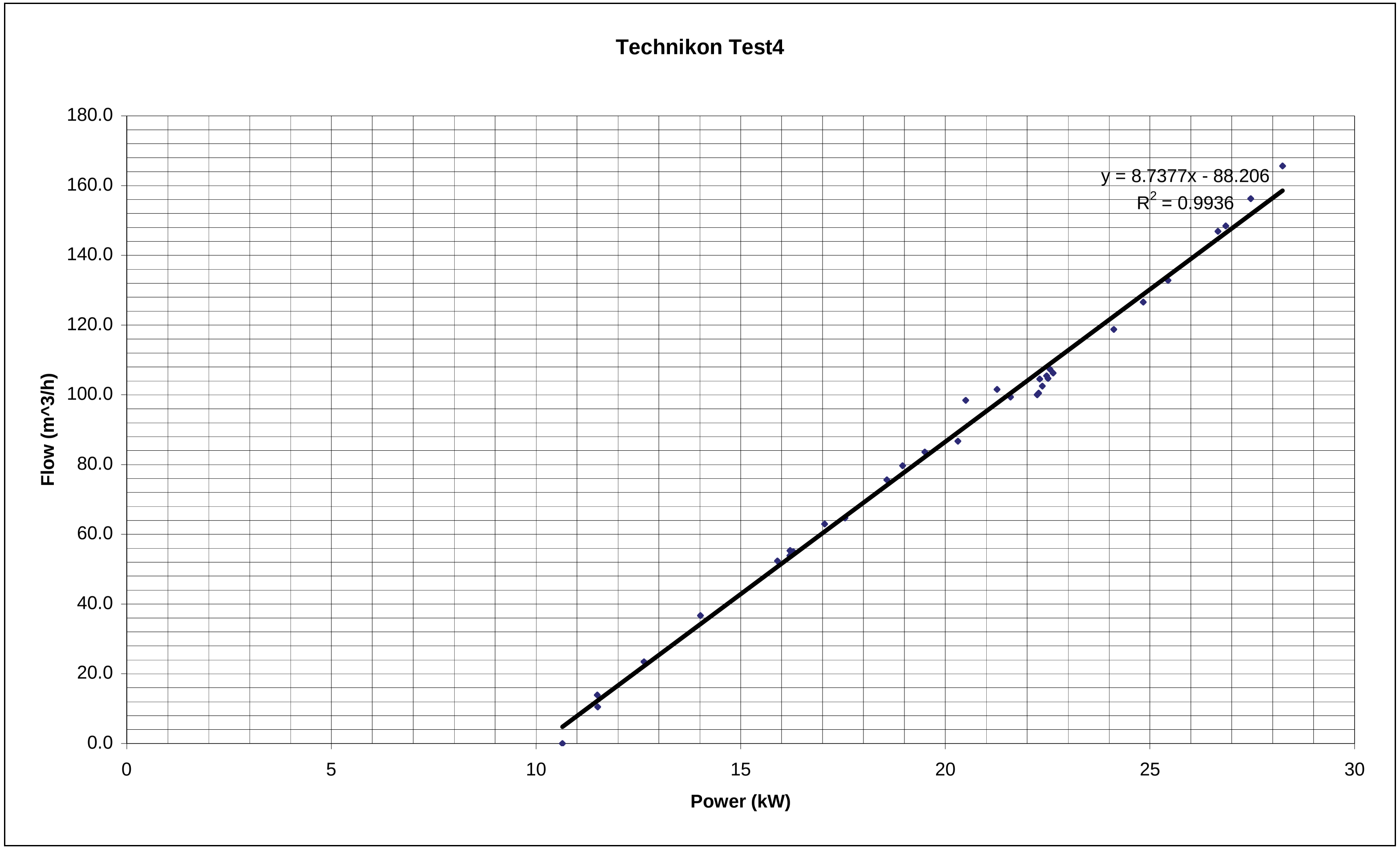


Figure 6.4 Test results for laboratory test 4



Figures 6.5 to 6.7 illustrate the influence of higher order polynomial trend line formulas applied on the regression coefficient for pump test 4. It shows that there is an improvement with more complex functions, although not very significant. This, however, does not actually make a difference to the accuracy of the electronic water meter, as will become clear when the meter is described in paragraph 8 of this report.

Figure 6.5 Second degree polynomial trendline for flow-rate/power relationship

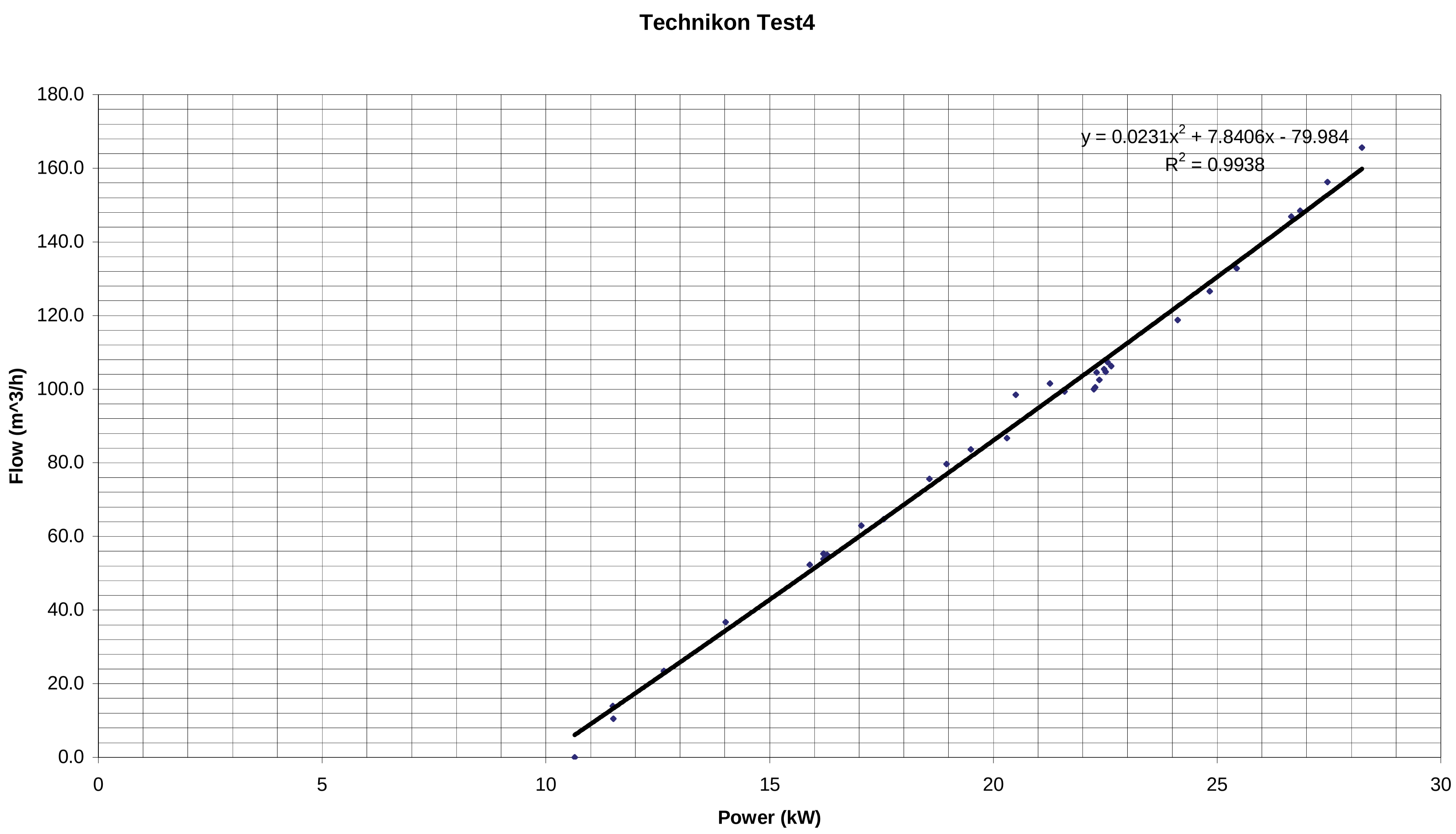


Figure 6.6 Third degree polynomial trendline for flow-rate/power relationship

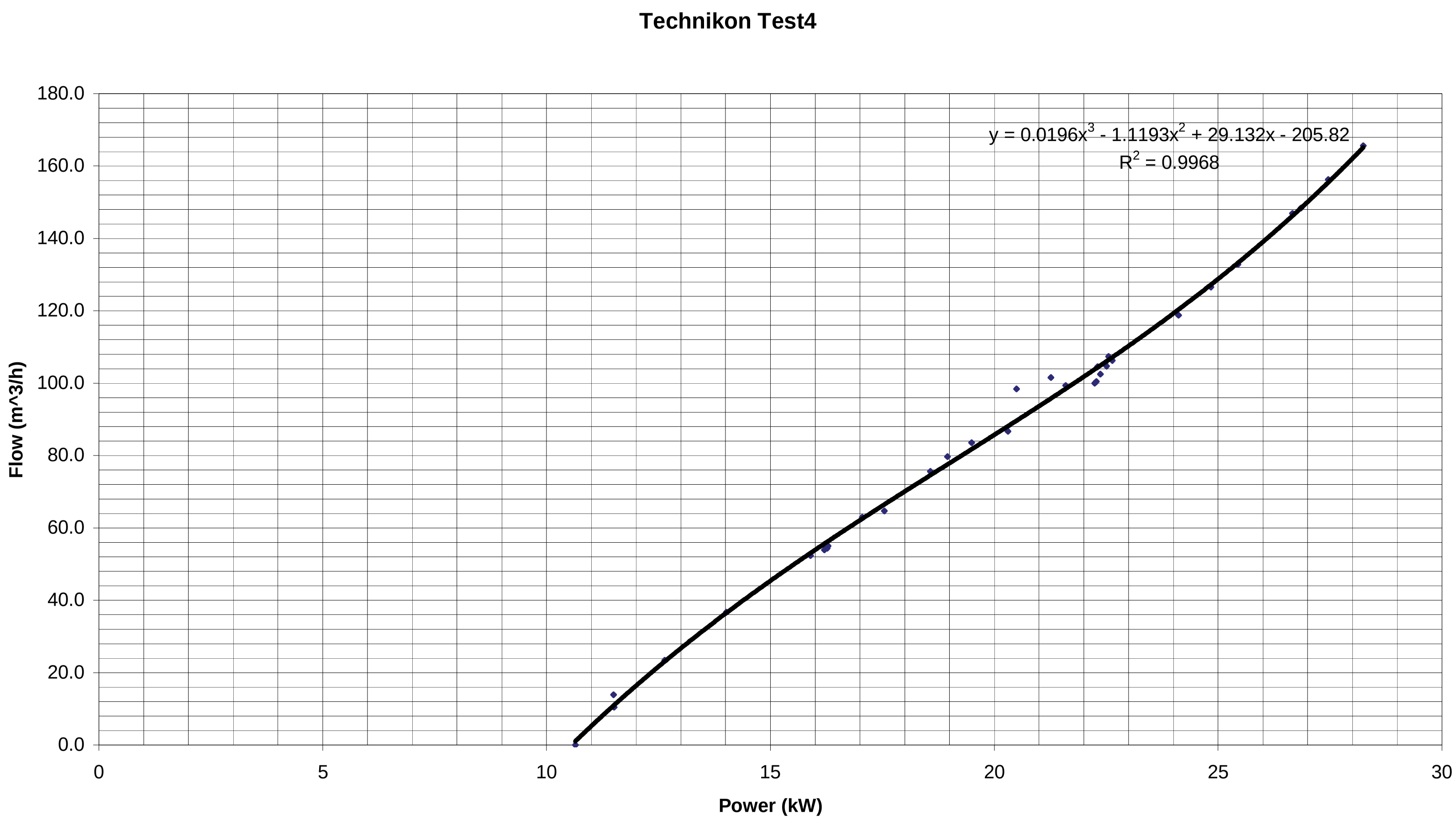
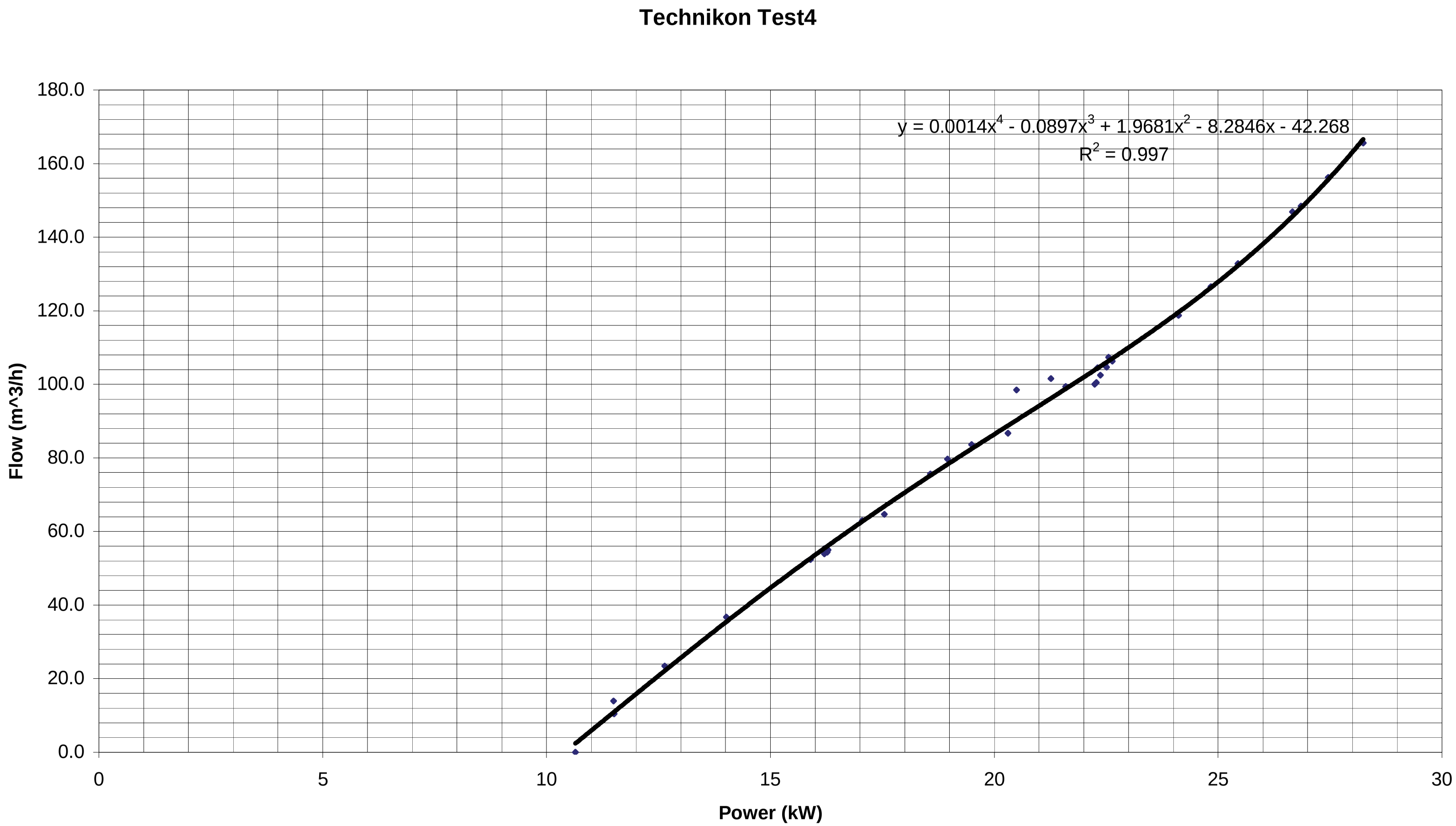


Figure 6.7 Fourth degree polynomial trendline for flow-rate/power relationship



Figures 6.8 and 6.9 shows the interesting correlation of another two parameters when compared to the flow-rate of the pump. The first is a mechanical parameter, namely the speed of the pump, which decreases due to slip as the flow increases (Figure 6.8). The second is power factor, which improves as more work is done, i.e. at higher flow-rates (Figure 6.9).

Figure 6.8 Relationship between motor speed and flow-rate

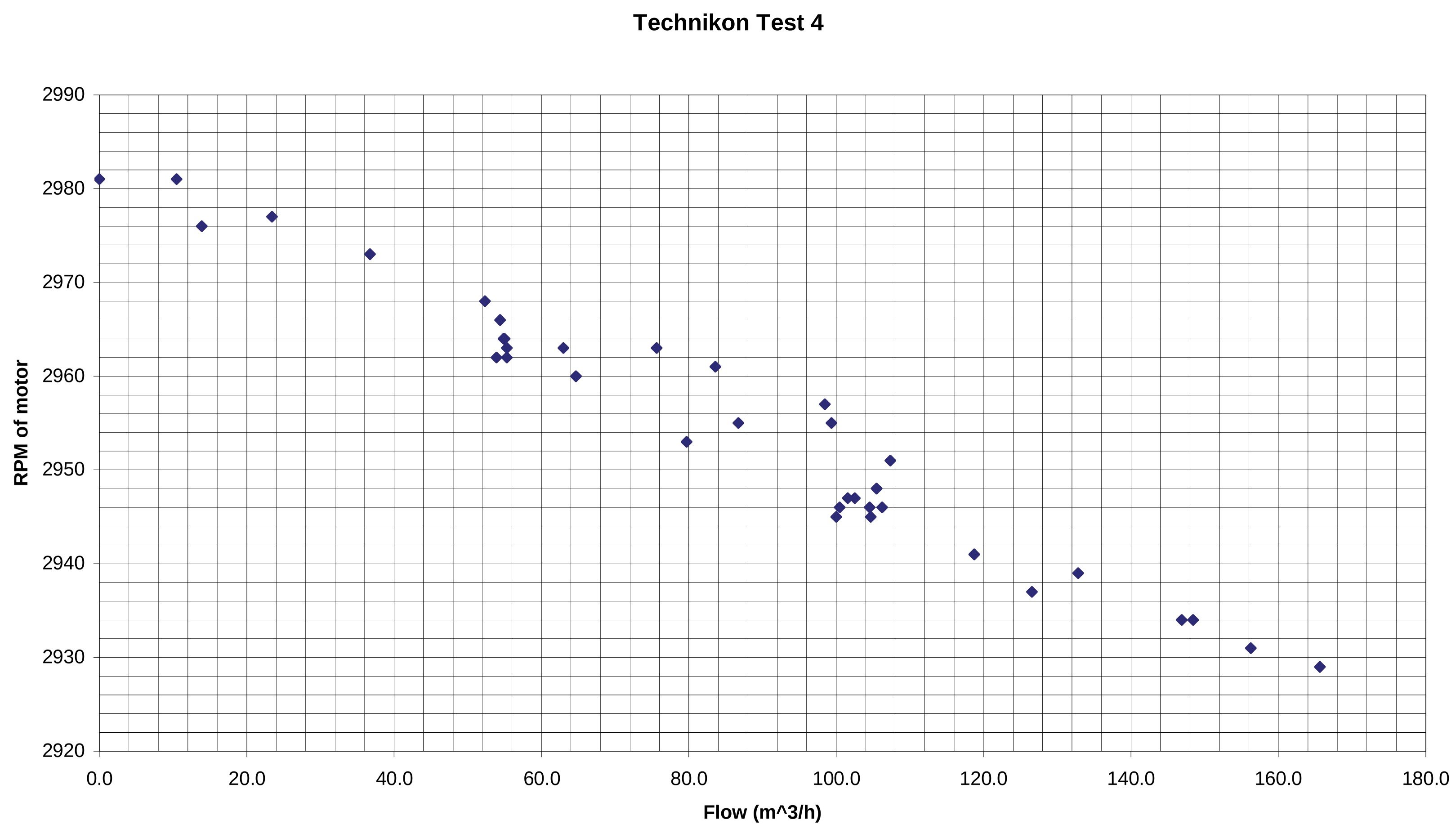


Figure 6.9 Relationship between power factor and flow-rate

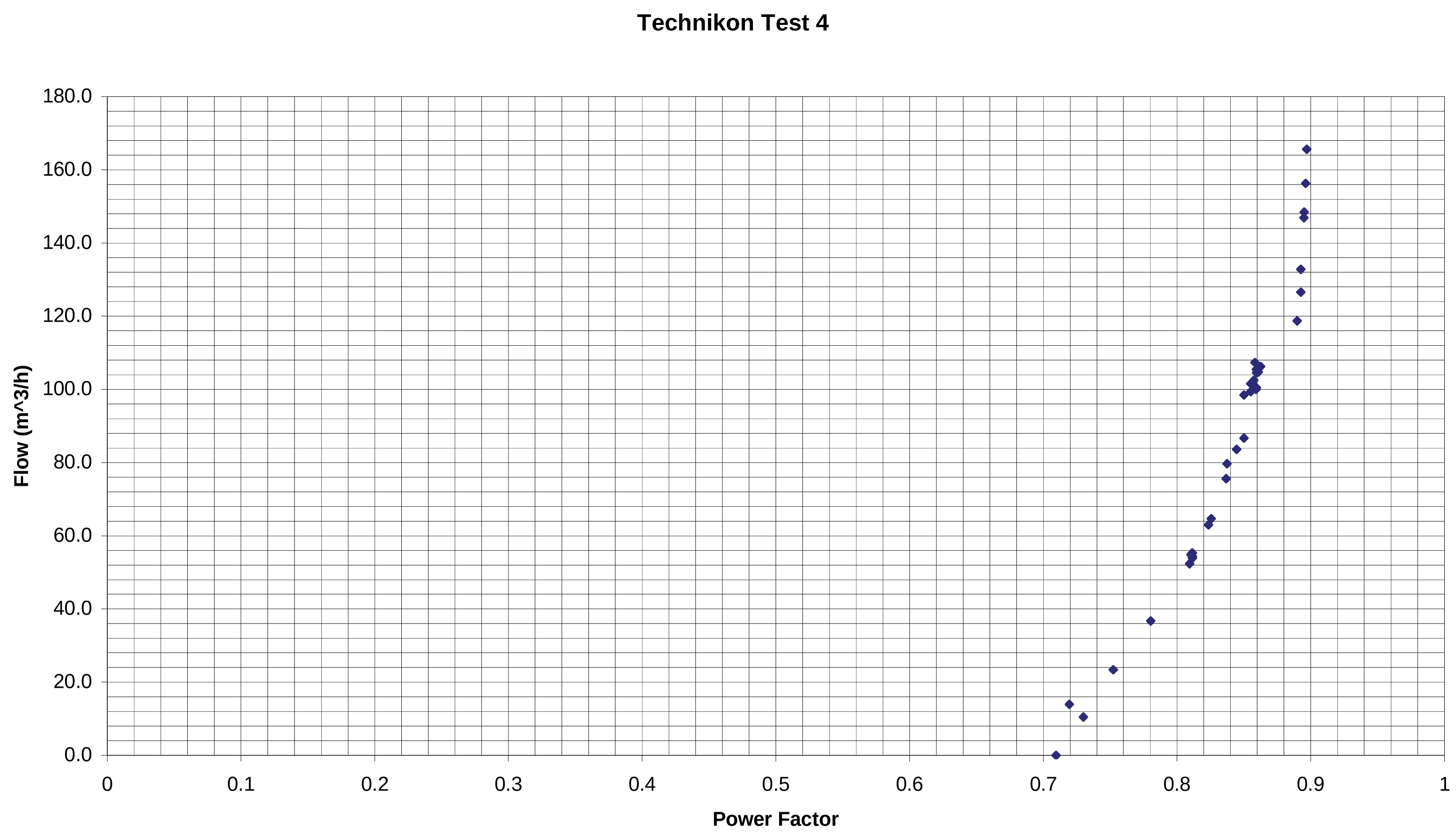
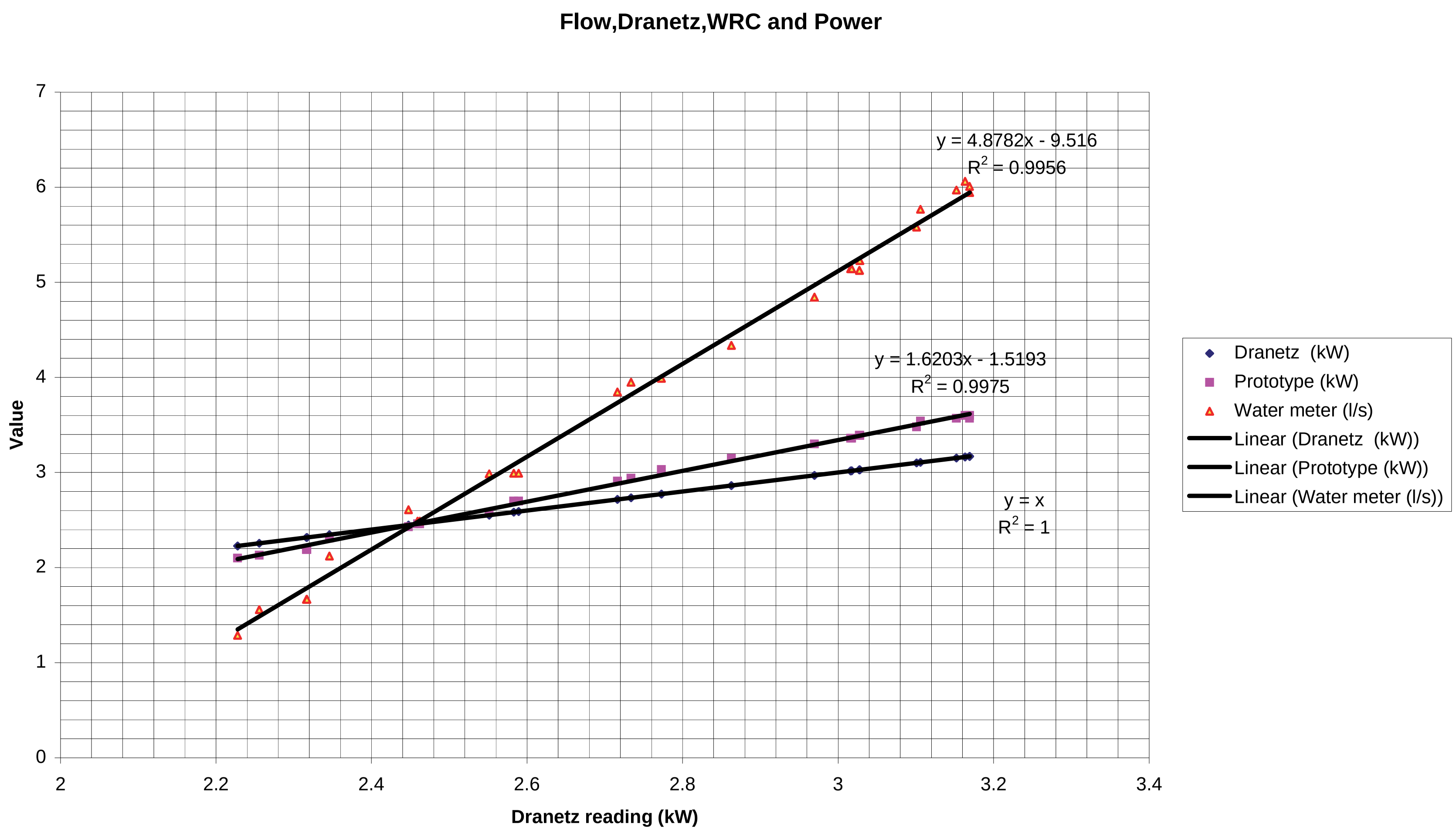


Figure 6.10 shows the results from the field test done to check the laboratory determined procedures. It contains three graphs, i.e.

- Mechanical meter flow-rate vs Dranetz power reading
- Dranetz power reading vs Dranetz power reading (to compare proto-type meter to)
- Dranetz power reading vs Proto-type power reading

The value of this graph is that it shows the effect of the uncalibrated factory setting of the CTr's in the proto-type water meter. With the necessary calibration factor this line can be positioned on to that of the Dranetz curve. It also shows that even if the CTr's are not calibrated, it will still measure accurately as long as the relationship between flow-rate and power used is programmed according to the factory settings.

Figure 6.10 Test results of test 5 (field test)



6.3 Proto-type meter tests

The measurements done at each of the five monitoring stations are discussed separately in the following paragraphs.

6.3.1 Jacobsdal test site

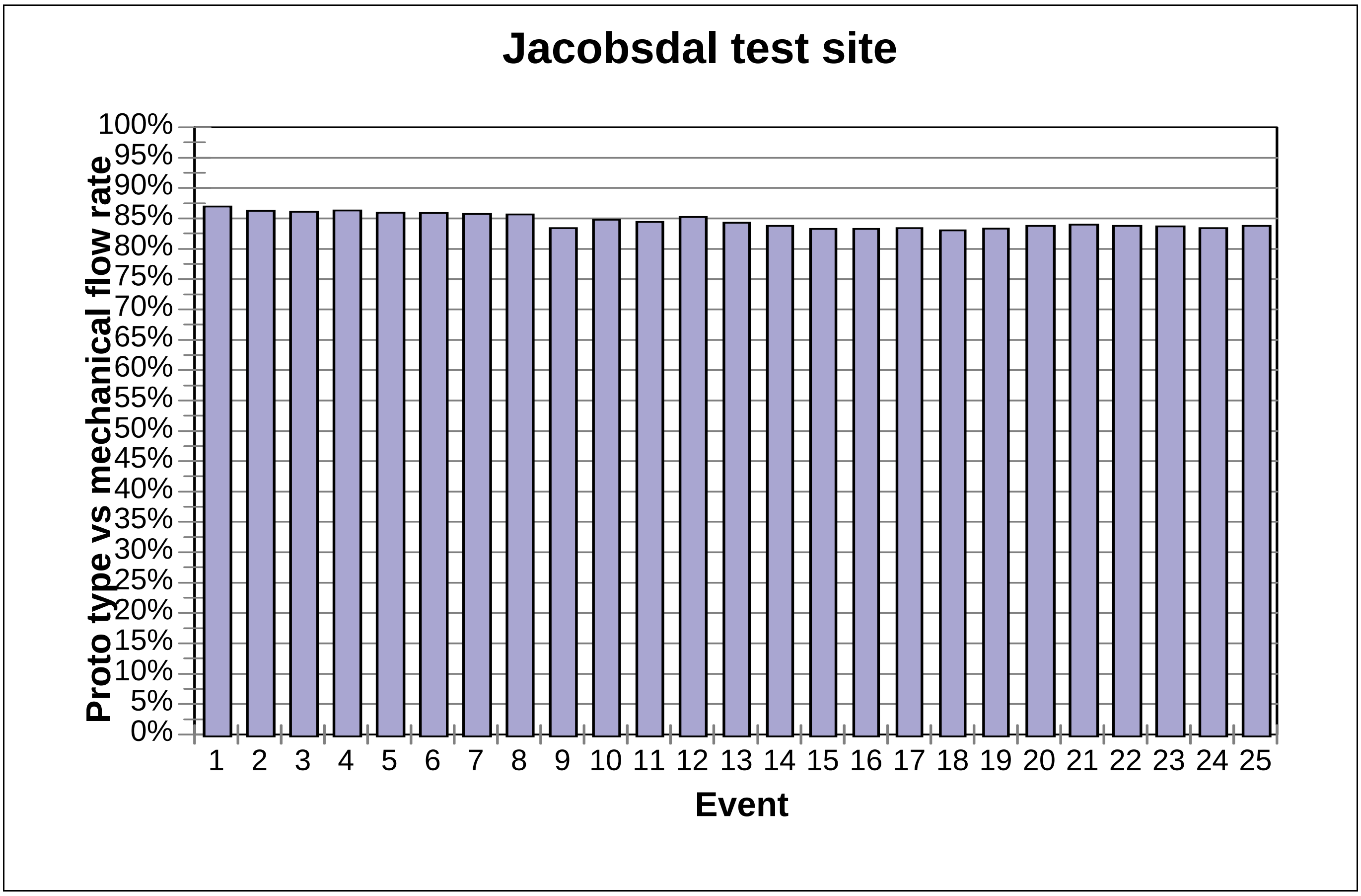
The calibration information for this site was prepared using the Dranetz system. The pilot meter was then built, and later taken back to the site for installation. After installation it showed that there was a difference in the readings between the proto-type meter and the mechanical meter. This difference was a constant (electronic meter showed approximately 84 % of the mechanical flow meter). It was decided not to change the CTr calibration setting, and that it is sufficient to observe the correlation between the two meters. As long as this remains constant, it will mean that the meter functions well. The reasons for using the mechanical meter readings instead of the ultrasonic meter readings to program the proto-type meter are given in paragraph 7.3.1.

Figure 6.11 shows the results of the measurements since installation. These measurements were done on an approximately weekly basis by the Oranje Riet WUA over a six month period. (The WUA also installed the meter). It shows a good correlation between flow-rate and power used. Over the whole period the value varied between 83.0% and 86.9%, a difference therefore of 3.9% between the two meters. On a scale of 100 % this difference could possible increase to 4.6%.

The total volume of water pumped during the monitoring period was 527 000 m^3 .

The gradual slight decline in the correlation may be due to the "running in" of the mechanical water meter, which was brand new when it was installed just before the monitoring started.

Figure 6.11 Monitoring results at Jacobsdal test site



6.3.2 Modder River test site

The calibration information for this site, as well as the installation, was done in the same way as for the Jacobsdal test site. However, in this case the meter was malfunctioning in a number of ways right from the start. Readings obtained from both this meter and the mechanical meter (which was also a new meter installed) was suspect.

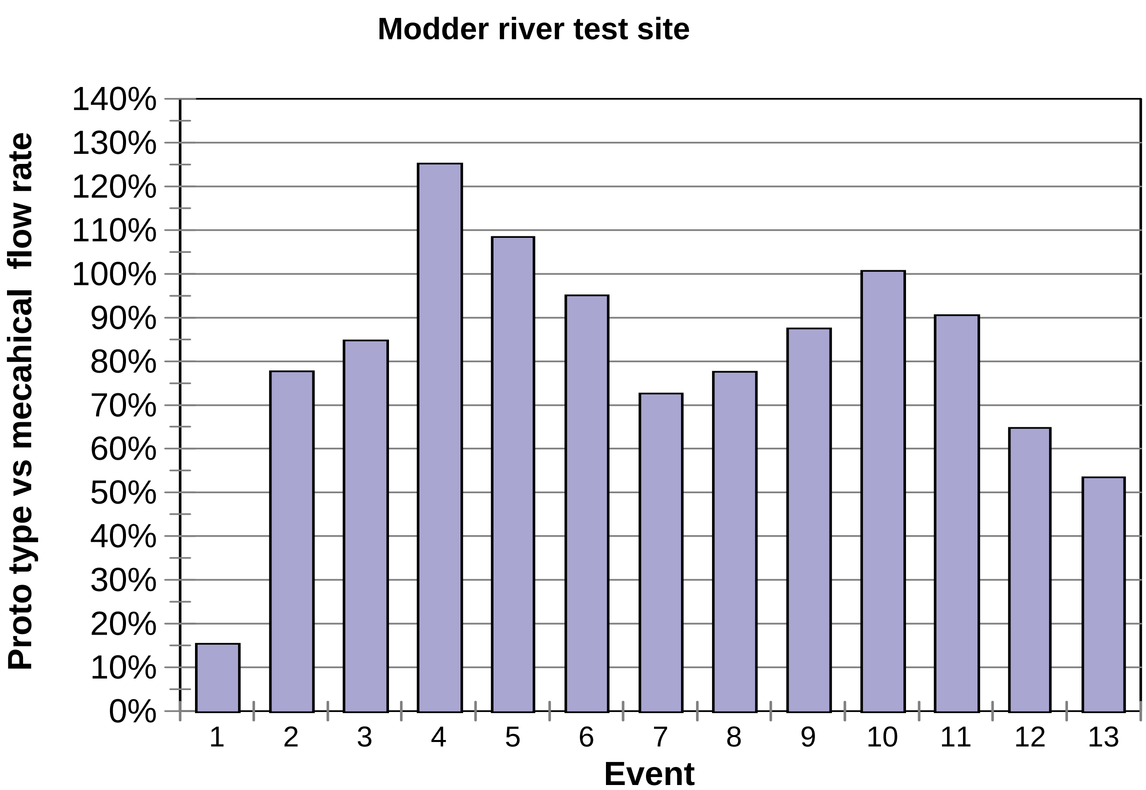
Due to rust inside the old delivery steel pipe readings from the ultrasonic meter were very inconsistent, and could therefore not be used for this site.

Approximately three weeks after installation the WUA reported that the meter became very hot, and it was removed and sent back for checking at the CT. It was clear that it overheated excessively, and damage was done to the CTr's. The meter was repaired and reinstalled, but readings were erratic once more. During May 2003, the WUA removed it again and it was severely damaged again due to overheating.

Nothing wrong could be found with the meter itself, and it was decided to simulate the situation using a dummy load specially built for this purpose. This likewise showed nothing that could cause the problems experienced in the field. It is possible that there is something related to the switchgear or cable connections at this site that is not fully understood by the project team.

It is clear from Figure 6.12 that the correlation the project team was looking for was not meaningful for this test site.

Figure 6.12 Monitoring results at Modder Rivier test site



6.3.3 Koelenhof test site (near Stellenbosch)

For this site the proto-type meter was used for the calibration process, although the

Dranetz was also used to take readings. The water meter in this case is a magnetic meter, with apparent high accuracy.

Three similar pumps are installed at the station, but only one pump is used. All three pumps were tested using the ultrasonic meter. These tests indicated that the way the magnetic meter is installed in the discharge manifold of the pumps (close to the inlet of the third pump) causes inaccuracies. These inaccuracies were not so significant that the readings obtained from the meter could not be used.

The monitoring results appear in Figure 6.13.

After an initial successful calibration exercise, the meter started giving erratic readings. This was observed for a while (till after event 8). The meter was then removed for inspection. Special attention was paid to aspects which could possibly cause problems, and which were discovered in the meter from the De Wet site (paragraph 6.3.4).

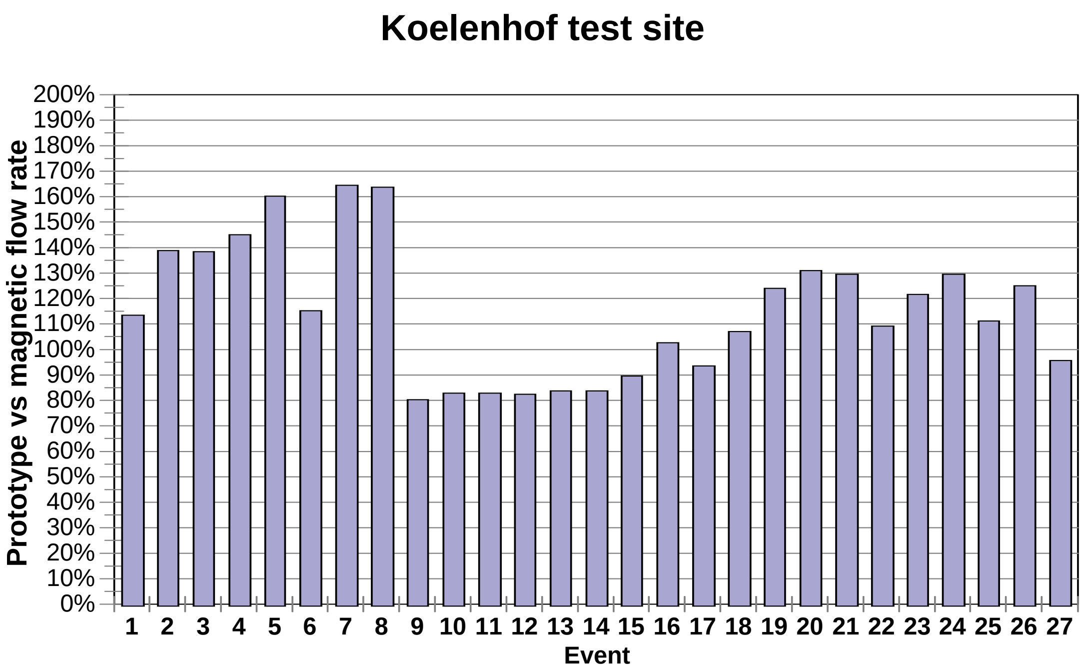
The meter was reinstalled, not replacing any of the components in the meter, but this time on another pump in the pump station. This was necessary because of maintenance work that was carried out on the original pump. The calibration was redone for this pump using the prototype meter. After calibration it was found that there was a difference in the flow-rate between the two meters. The proto-type meter was registering only approximately 80 % of that of the magnetic meter. Due to practical difficulties to redo the calibration test, it was decided to keep the calibration as it was, and observe the correlation between the two meters.

The correlation remained satisfactory for approximately two weeks, during which time approximately 71 000 m^3 of water was pumped. Then the readings became erratic once more.

The reason for this phenomenon is not clear. It is probably related to the hardware in the proto-type meter, and further tests in this regard using a dummy load is desirable.

The monitoring results of this pump appear in Figure 6.13.

Figure 6.13 Monitoring results at Koelenhof test site



6.3.4 De Wet test site (near De Doorns)

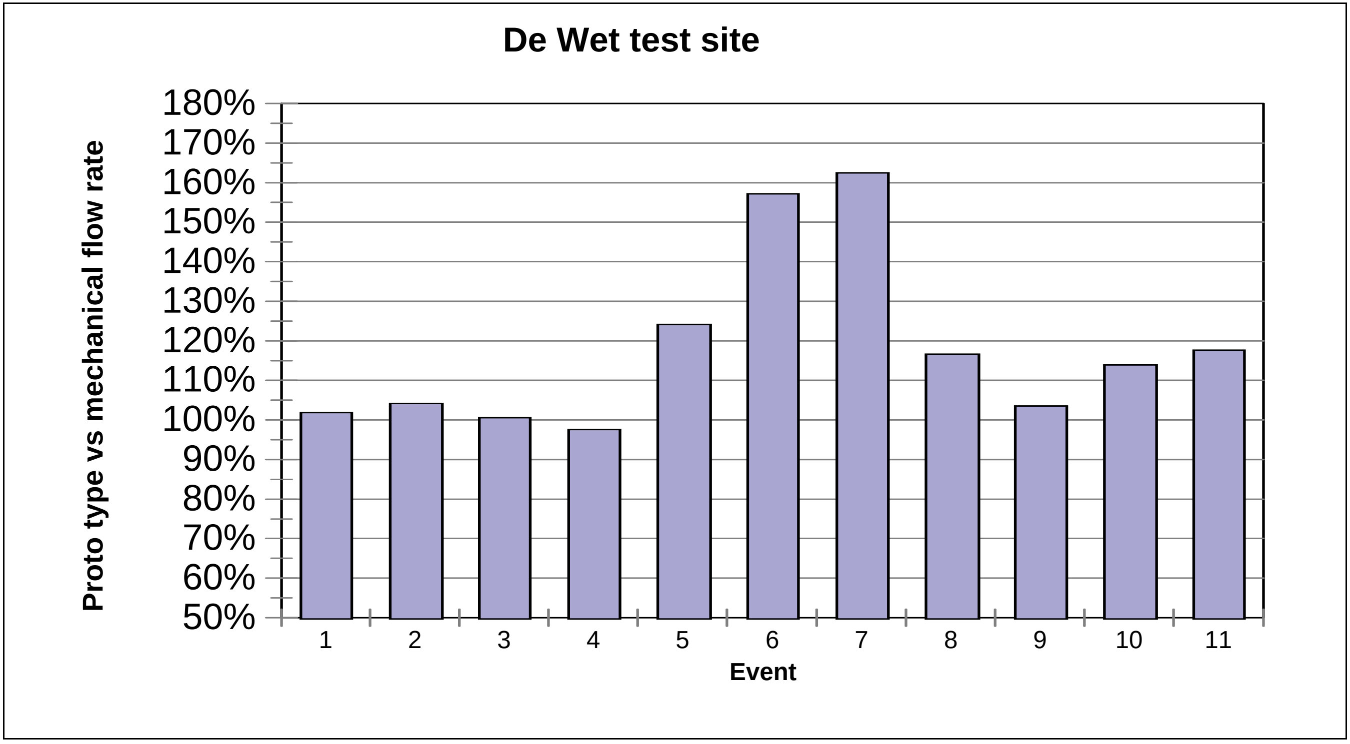
Calibration was done at this site with the proto-type meter and a newly installed mechanical flow meter. Dranetz and ultrasonic meter readings were also taken.

For the first two months of the monitoring period a good correlation between the readings of the proto-type meter and the mechanical meter was experienced (between 98 % and 104%). Figure 3.14 shows the results of the monitoring at this site. Over the next three months the readings were erratic. During this time it was noticed that there were sudden changes in the readings if the meter is handled roughly, e.g. when one hits it with the hand.

The meter was removed, and on closer inspection it was revealed that poor connections of a set of resisters fitted in the CTr's at the CT might have been the cause of the poor results. This was repaired, but unfortunately the De Wet pump station had been switched off by then for the winter season.

The observations at this site supported the correlation between flow-rate and power used, and also provided useful information for the improvement of the hardware of the meter.

Figure 6.14 Monitoring results at De Wet test site



6.3.5 Franschhoek test site

It was decided to install the repaired De Wet meter at a site in Franschhoek. This site was very accessible and available for experimentation under various operating conditions. Calibration was done with the prototype meter and a relatively little used mechanical meter (purchased for the pilot project).

Although this is a small pump (only 4.0 kW), it illustrated the correlation between a number of relevant aspects very well. Bigger electric machines are at least as stable as these small ones, and therefore it is safe to apply these findings on the larger application as well. While the pump was in operation, readings were taken at two or three hour intervals. It would therefore be possible to pick up short periods of instability, if they were to occur.

Figure 6.15 shows the results of the correlation between the two meters for 112 events (readings). The graph shows a very good correlation between the readings. The total difference in accumulated flow registered during this period of two months was 2.1 %.

Figure 6.15 Monitoring results at Franschhoek test site

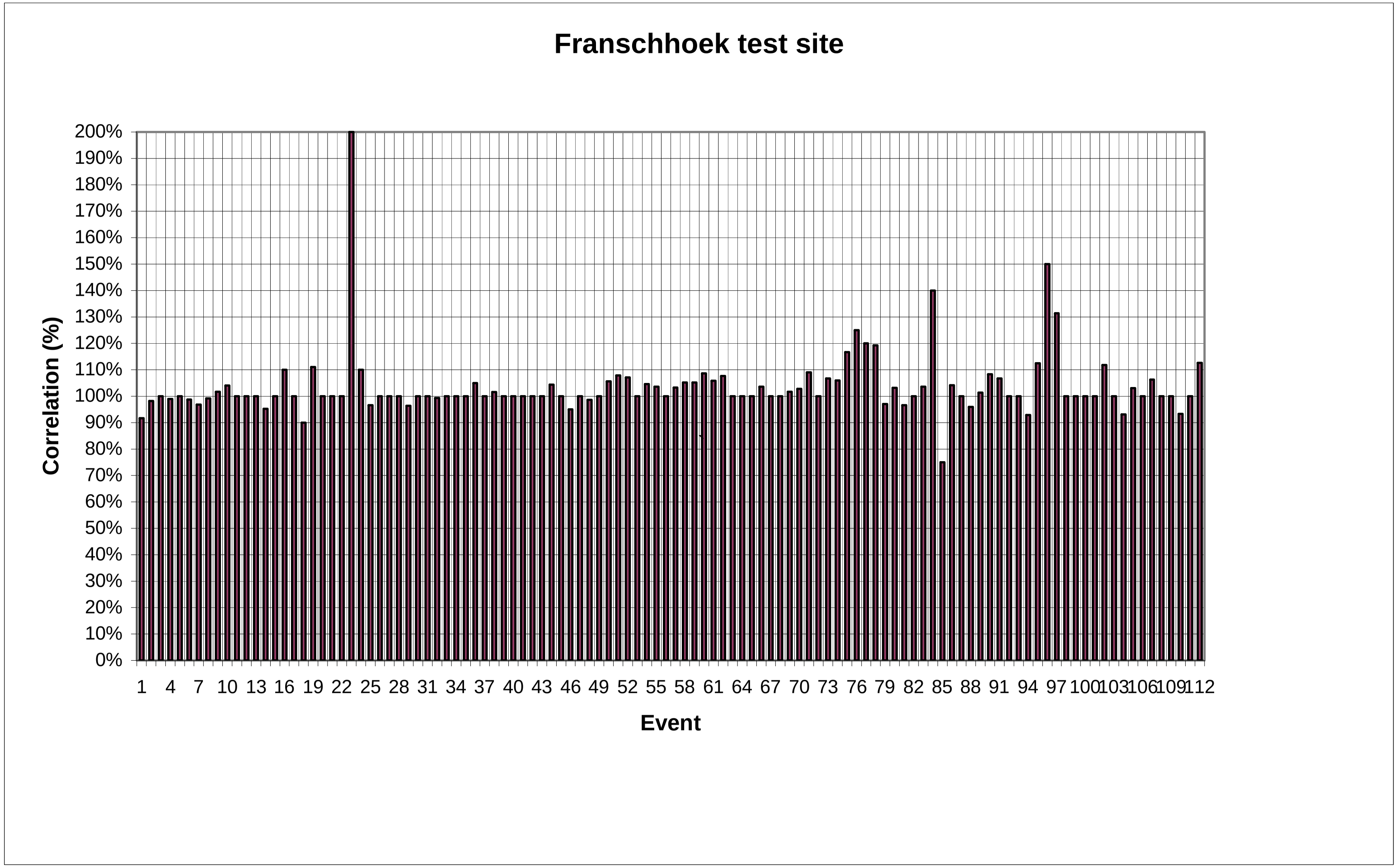


Figure 6.16 contains five graphs, which illustrates a number of other interesting relationships. These graphs are:

- Correlation between the volume of water pumped by the two meters
- Accumulative flow per kWhr (as a percentage of 1 m^3/kWhr) consumed, as registered by the mechanical flow meter.
- Accumulative flow per kWhr (as a percentage of 1 m^3/kWhr) consumed, as registered by the prototype meter.
- Flow-rate of the proto-type meter as a percentage of the maximum flow-rate of the pump. The first seven points on this graph must be ignored (zero readings).
- Power used by the pump as a percentage of the maximum rating of the electric motor. The first seven points on this graph must be ignored (zero readings).

The two graphs of the accumulated flow (proto-type and mechanical meter) are very similar (almost on top of each other) as could be expected, due to the very good correlation between the two meters. What is, however, informative is the big variation in water volume pumped per kWhr at different stages of the pump operation.

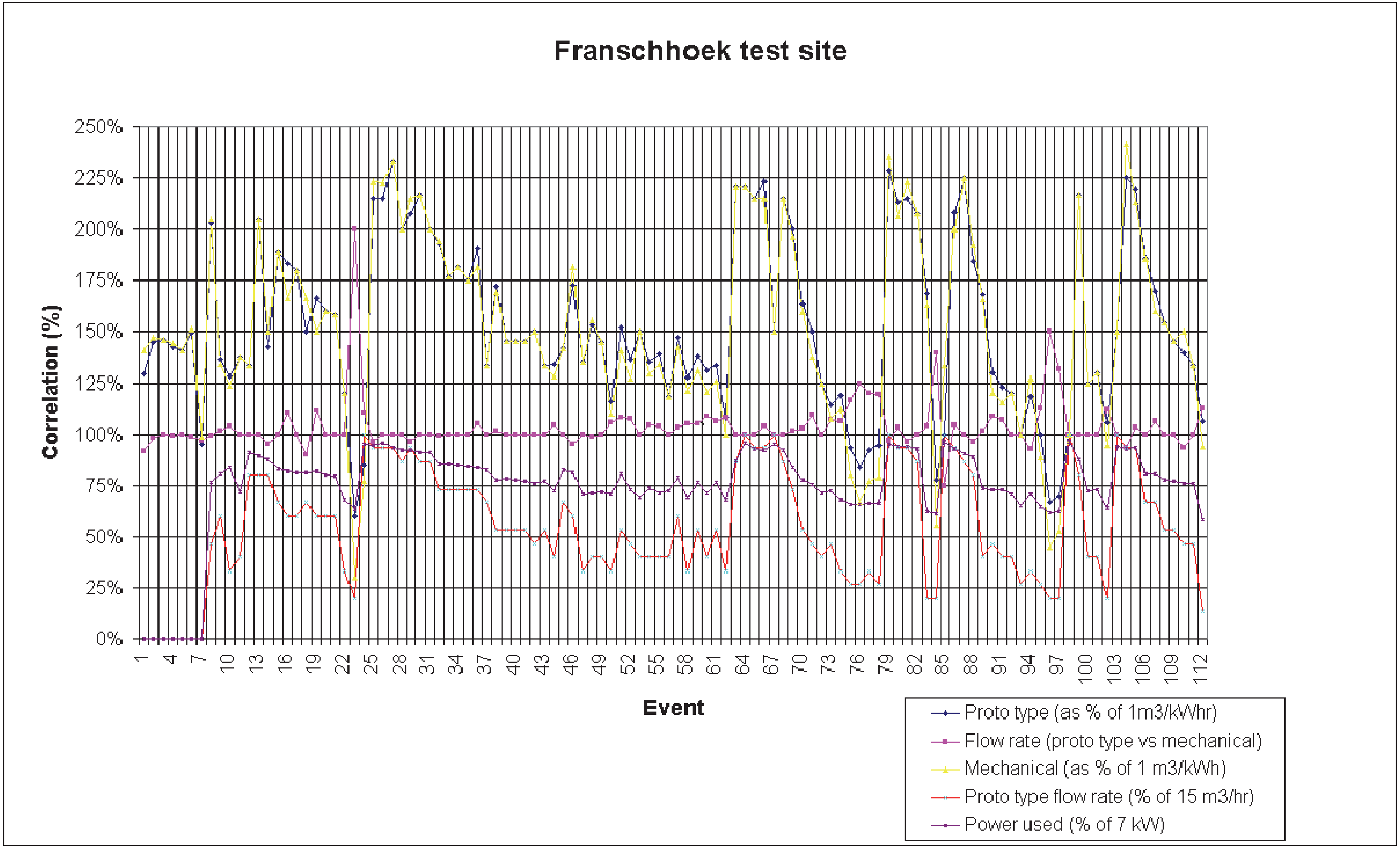
It is necessary to explain the pump management, which was operated in a special way for the purpose of the test. Between events 1 and 13 normal irrigation was practised, and flow variations were due to different block sizes on the farm. Immediately before event 14 the pump was disconnected from the irrigation network, the filter was cleaned and water was pumped back into the river, which is the water source. The filter gradually became dirty and the flow-rate of the pump consequently decreased. After event 23 the filter was cleaned and the cycle was repeated between events 24 and 44. Between events 45 and 62 normal irrigation was applied, and from 63 till the end of the test, water was once more recycled back into the river. The filter was cleaned after events 78, 88, 97 and 102.

Apart from the good correlation found between the two meters, other important information gathered from the test, as can be seen on the graphs, are the following:

- Major errors can occur by using kWhr's as a "tool" to determine the volume of water pumped. In this test variations were between 0.6 m^3/kWhr and 2.33 m^3/kWhr, while the average over the whole period was 1.49 m^3/kWhr. Variations of between -40 % and + 157 % were experienced. The implication of this is that, if the kWhr / m^3 relationship is determined for favorable conditions (maximum flow-rate), only 25% of this volume were used in unfavorable conditions (when the filter was dirty). This can have a major effect if the user is billed according to kWhr's. Calibration according to kW's takes care of this potential problem.

- The two graphs of flow-rate and power used also illustrates this point. As the flow-rate drops, the gap between the two graphs becomes bigger, indicating that there is not a linear relationship between the two.
- The biggest variation between the two water meters was experienced under low flow conditions (when the filter was dirty). This is probably due to the fact that mechanical flow-meters have a minimum beyond which their readings become inaccurate.

Figure 6.16 Results of monitoring at Franschhoek test site – various parameters



7 DISCUSSION OF FINDINGS

In the following paragraphs the findings of the different phases of the project are discussed under four headings. For the research situation the emphasis was different than what it would be for non-research situations. For convenience the latter is referred to as normal use installation. For each of the four headings the main differences between requirements for the research and normal use installations are highlighted.

7.1 Suitability of sites

7.1.1 Suitability of sites for research

In this project a substantial amount of energy was spent on identifying suitable sites for monitoring work. The reason for this was finding sites where:

- An existing reliable water meter was correctly installed. If not installed, installation of a meter had to be done
- The system components were installed in such a way that it allows for the correct positioning of the ultrasonic water meter
- It is reasonably accessible to the project team
- The operation of the pump could be changed in order to get enough readings for calibration to be done
- The particular pump will fit in with the rest of the pumps needed for this project to sufficiently cover the intended range of pumps.

The willingness of the client / farmer to cooperate could be added to the list, but actually no resistance was experienced in this regard. Instead, a rather positive attitude was experienced in finding a solution to the problems (practicality, cost, maintenance) facing them with possible mandatory water metering in future.

7.1.2 Suitability of sites for normal use

The only important aspect from the mentioned list in the previous paragraph is that the existing system component layout must allow for setting up the ultrasonic meter correctly. This is dealt with in more detail in paragraph 7.3, Calibration of Meters.

7.2 Installation of meters

7.2.1 Research installation

The experience was that a visit to the particular installation before the meter is brought to the site for installation has definite advantages. Aspects of importance in this regard are:

- Layout of pump house
- Size of motor (maximum demand)
- Accessibility to switchgear of motor
- The need for special equipment, e.g. a ladder, a drill, etc

Installation comprised of the tasks mentioned in paragraph 4.3.3

7.2.2 Normal use installation

A pre-installation visit to the site will not be necessary for the majority of installations, as most of the items required are standard items that are part of a commercial electrician's "tool kit". However, in order to have the right meter prepared beforehand for installation, the maximum power rating of the motor should be known beforehand.

Installation of the meter is described in paragraph 8.6. It can take approximately one hour for an electrician and his assistant. The cost of consumables, mainly electric wire, amounts to less than R 50 on an average.

7.3 Calibration of meters and verification of readings

7.3.1 Research calibration

The calibration procedure of the meter, and the tasks preceding it, is given in paragraph 4.3.3. During the pre-proto-type meter phase the calibration procedure was the same, except that the pilot meter was not installed and programmed. This was a very necessary stage of the project during which time much accurate data was gathered, more than could be used.

During this stage of the project much value was attached to the high degree of accuracy of the power readings, as well as accurate flow measurement. For this very reason the Dranetz Power Platform was used, as it is extremely accurate (better than 99.8 %, with a price tag of approximately R 100 000), as is the ultrasonic water-meter with an accuracy of more than 98 % (at R 25 000).

The Dranetz is the property of the CT, and the ultrasonic meter the property of the WRC, bought for WRC project K5/1265/4. Me I van der Stoep, the project leader, took all the ultrasonic meter readings.

The originally planned procedure is given in paragraph 4.3.3, and illustrates the manner in which the project team intended to carry out all the pilot meter installations. This was also the procedure followed for the first four installations.

The normal program followed was:

- Day 1: Carry out full field test
- Day 2: Download the power data from the Dranetz and the ultrasonic water-meter data from the laptop computer. Prepare all of this, together with readings manually taken, in a worksheet, and determine the power flow-rate relationship. Prepare the table for the programming of the proto-type meter.
- Day 3: Return to the site, again with all the instruments and the proto-type meter. Do the installation, program the proto-type meter and verify the readings, again using the Dranetz and ultrasonic water-meter

(Note: These three days often had long intervals in between due to the coordinating of the different members of the team who had to be present).

Two observations changed the team's perception as to the procedure to be followed. These were:

- The realisation that little value was added by using the Dranetz readings.

  The effort to gather this data was quite considerable, and at the end of the procedure it is actually only used to calculate the calibration correction factor to be applied for the CTr's. If the user is not interested in accurate electrical power readings, the CTr's with their factory settings can be used; the calibration can then be done with the proto-type meter. There will be no difference in the accuracy, whether or not the Dranetz is used.

However, it is still preferable for the CTr's to be calibrated, but this can probably be done more effectively on a dummy load with a known value.

- The fact that there were fairly large differences between the flow-rates of the ultrasonic water-meter and the mechanical water-meters.

  The reasons for these differences are dealt with in the WRC project K5/1265/4. Fact is that the team realised that it would be better to do the monitoring by using the readings obtained from the mechanical meters. Although these readings may be inaccurate, if the calibration of the proto-type meter is done using these (inaccurate) readings, the readings obtained from the proto-type meter will be the same as for the mechanical meter. It would be of little value to use the readings from the ultrasonic water-meter if it does not remain on the system to register the accumulated flow.

  Even though the error may not have a linear relationship (error vs flow-rate), the calibration is done for a number of points between a flow-rate of zero, and the maximum discharge rate of the pump. It is therefore assumed that the readings should correspond over the full scale of the flow-rate.

7.3.2 Normal use calibration

In the previous paragraph it is explained why the electronic meter that is being installed to measure flow at a particular site itself can be used for the calibration procedure. For research purposes it was decided to make use of the mechanical water-meter for the calibration of the proto-type meter. For normal use installations, however, a portable water-meter will have to be used. Most likely this will be an ultrasonic meter.

This procedure will allow for calibration of the electronic meter and verification of readings to be done simultaneously when the meter is installed. With worksheets prepared in advance, the readings can be entered on a laptop, which generates the lookup table. Calibration and programming of the meter can therefore be done in less than two hours.

7.4 Meter performance

7.4.1 Research meter performance

From the readings of all the tests done (laboratory and field tests) it is evident that there is a good correlation between power used by the pump and the flow-rate of the pump. What is more important is that this correlation is measurable and also that repetitive measurements give similar results.

This formed the basis for the programming of the electronic meter. Preliminary findings enabled the project team to design the first proto-type meter. After further tests this design was reviewed and improved, and the present format of the meter was then developed.

The monitoring done with the meter proved that the design meets the intended basic requirements. There were, however, cases where the meters failed, either right from the beginning, or in other cases at later stages. The reason for these failures was investigated, and in only one case the reason for the failure remains totally unknown.

For situations where the meters functioned well, the correlation between flow-rate and power remained within a narrow tolerance band. The slightly bigger variations sporadically experienced is probably due to a disturbance in the mechanical flow meter.

7.4.2 Normal use meter performance

The experience gained during the project showed that the correlation between power used by the pump (kW) and flow-rate can be utilised to determine the volume of water used. It also showed that an instrument could be installed to capture this information with great accuracy.

The failures experienced with some of the instruments will have to be eliminated in order to make a meter available with acceptable accuracy and reliability for water management and billing purposes. Valuable findings and improvements in this regard were made during the monitoring phase. However, it is foreseen that every meter will have to undergo a test in the manufactory facility for a minimum period before being installed. This is not too uncommon in the electronic field for this kind of "running in" to be performed on manufactured goods.

8 THE PROTO-TYPE METER

8.1 Introduction

The objective of the meter, which is basically an energy meter, is to measure and store the total quantity of water pumped by an electrically driven pump. The reading of the accumulative water quantity, in cubic meters, can be subtracted from a previous reading, to determine the total usage of water over a predetermined period. While the pump is in operation, the meter also shows the current water flow-rate in cubic meters per hour. This flow-rate and accumulative water usage is derived from the electric energy used by the pump. An internal mathematical equation and calibrated internal look-up tables convert the electric power used by the pump into a flow-rate, and also the accumulative water quantity. The current electric power in kilowatt (kW), and also the accumulative energy used in units of kilowatt-hour (kWh), are also available for continuous monitoring.

The meter is installed in the electric feeding line of the motor, and is powered directly from the mains. While the mains are off, a rechargeable backup battery enables the storage and reading of the accumulative water usage and electric energy without having to start the pump. This data is stored in non-volatile memory, and will not be lost even if the backup battery should fail.

Due to the varied circumstances under which an electric pump operates, each meter is calibrated individually for a specific installation. The calibration constants are stored in the meter in non-volatile memory. Over time the pump characteristics may vary, and recalibration may be necessary to remain within acceptable accuracy tolerances. The frequency of this recalibration will depend on the particular operating circumstances of the pump, and the quality of maintenance.

8.2 Description

The meter is housed in a 240 x 160 x 120 mm AB Plastic housing with a IP65 waterproof rating. Two waterproof cable glands allow for the entry and exit of the electric feeder cable to the pump. A sealed window on the front panel of the meter allows visible access to the 2-line by 16 character LCD Display Module that is part of the electronic circuitry. A waterproof push-button, mounted next to the display window, can be used to change the display mode between the accumulative water quantity and flow display, and the accumulative electric energy and power display. When the meter senses that the power is off, it will switch off the display and other internal electronic circuitry, and go into a low power consuming standby mode. The push-button can be used to wake the meter out of the standby mode to display the accumulative totals for reading, without having to start the pump. If no power is available, the meter will go back to the standby mode in approximately 30 seconds. When the power is switched on for a new pumping cycle, the meter will wake up from the standby mode and continue the normal measuring process.

The meter will be prepared before installation for a maximum power rating of a specific electric motor. This is done by varying the number of primary windings on the measuring current transformers (CTr's).

8.3 Specifications of the meter

The proto-type meter that was prepared for this research project conformed to the specifications listed below. In paragraph 8.14 proposals are made for slight changes to these specifications. These are based on the experience gained through the monitoring process.

8.3.1 Mains supply to the meter and pump:

Single Live line and Neutral (230 volt)
Three Phase without Neutral (380 volt)
Three Phase with Neutral (380 and 230 volt)

8.3.1	Pump/motor power ratings: (Set by the winding ratio of the CTr's)	Maximum 150 kW Minimum 4.5 kW
8.3.2	Maximum accumulative water usage:	9 999 999 m^3
8.3.4	Maximum flow-rate:	9 999 m^3/h
8.3.5	Maximum accumulative energy:	999 999 kWh
8.3.6	Maximum electric power rating:	999.99 kW
8.3.7	Internal electronic accuracy after calibration	Better than 1%
8.3.8	Standby battery life without recharging:	6 months

8.4 Installation of the meter

Although it is not illegal for an unqualified person to do an installation of this nature, it is preferable that a qualified electrician installs the meter. In this way a certificate of the correctness of installation, as well as a guarantee for the work done, can be presented.

The tools / instrumentation needed to do the installation are standard equipment used by electricians.

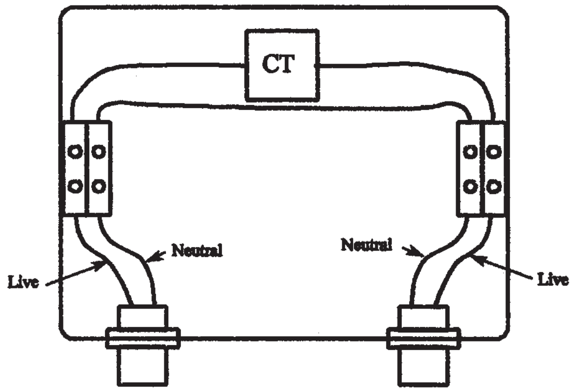
According to the particular maximum rating of the pump, a meter with appropriate winding ratio of the CTr's will be selected. Installation of the meter includes the connection of the CTr's to the electric cabling, and then mounting the meter housing to the pump house wall, or inside the box which houses the switchgear of the electric motor, or any other safe and dry place.

For smaller motors, without a star-delta starter, the meter can be electrically connected between the mains switch and the pump motor. For motors using a star-delta or other electric starter configuration, the meter may be connected on the live side of the mains, in front of the starter circuits. Entry and exit of the feeder cable to the box must be done through cable glands through the bottom of the box. The entry and exit points can be swapped for the convenience of the cable runs of the installation. The entry and exit cables should be tied to the back plate of the distribution board with saddles, to relieve the strain on the cables and cable glands on the box.

Although CTr's exist as part of the switchgear in most pumping installations, the project team took a decision that the meter should have its own CTr's. This has the advantage that normal maintenance to the switchgear can be carried out without interference with the meter.

Electric cable connections to the meter can be any one of the following three possible supply combinations:

Fiqure 8.1 - Sinqle live line and neutral



Fiqure 8.2 Three phase supplv without neutral

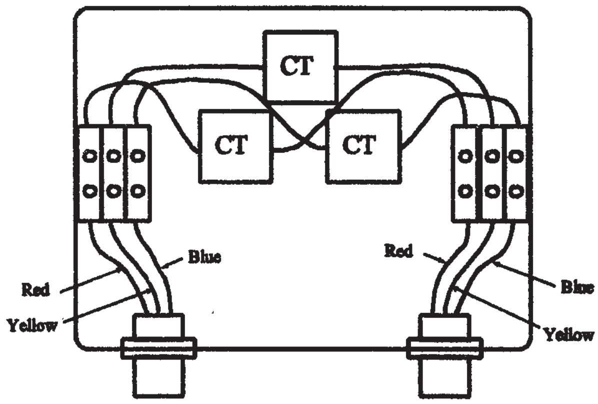
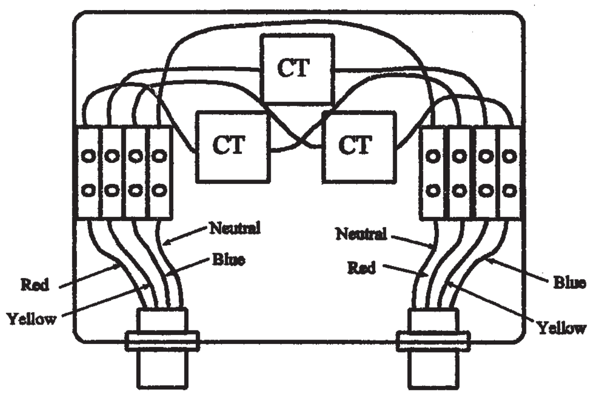


Figure 8.3 - Three phase with neutral



8.5 Calibration of the meter

8.5.1 General

After a meter has been installed, calibration needs to be done to convert the electrical power reading to a flow-rate. Although the calibration procedure may be the same, the results are unique for each pump installation. This is due to uniqueness in the performance for different pump / motor combinations.

The calibration needs to be carried out by a person who understands the procedure, and in possession of the appropriate equipment. This equipment will probably include a portable ultrasonic water meter, a lap-top computer and a stopwatch. A 1000 liter calibrated plastic tank (or larger) may be useful in situations where it is more convenient to determine the flow volumetrically than with the ultrasonic meter.

8.5.2 Calibration mode

To enter into the calibration mode, the push button of the meter must be pressed and kept down for approximately four seconds. The display will change to show "Calibration Mode" on the top line, and will request the user to enter a secret four digit Personal Identification Number, or PIN, on the second line of the display: "Enter PIN 0000". A cursor will appear and start to scan the four digits, including the space before and the space after the four digits. When the button is pressed while the cursor is on the leading space, the system will exit the Calibration Mode and return to the normal Monitoring Mode. When the button is pressed while the cursor is under one of the four PIN digits, that digit will increment by one. Repeated presses will increment the digit to 9, and roll over to 0. The button can also be kept down. Then it will increment the digit by one every half second. After the button is released for one second, the cursor will start to scan the digits and the two spaces again. After the correct number has been entered into the display, the button must be pressed while the cursor is on the space after the digits. This will test the number, and if correct, the system will enter into the calibration mode. If the number is not correct, or the button is not pressed for 30 seconds, the system will return to the normal Monitoring Mode. While the system is in the Calibration Mode, the normal measuring process will continue in the background to calculate and store the accumulative values.

8.5.3 Calibration menu

The calibration menu consists of five subdivisions, some with no entries required and others with as many as 30 figures to enter. Since there is only one button with which to enter the data, a special sequence needs to be followed to enter the data.

8.5.3.1 The connection and phase balance testing menu

After the correct PIN is entered, as described above, the display will show the raw data of the meter in a special Test Mode on the second line. It consists of a 'T', followed by three signed hexadecimal values, one for each phase, Red, Yellow and Blue. While the motor is running, these values should have the same sign, to show that the current transformers are connected correctly. The three values should be approximately the same, to show a balance between the three phases. If the button is pressed at any time during this Test Mode, the system will move to the next menu.

8.5.3.2 The winding ratio selection menu

The same electronic circuit, CTr's and software are used to cover the entire range of motors from 5,5 kW to 150 kW (monitored in this research project). The range for a specific motor is selected by the number of primary windings on the current transformers. It can vary from 1 to 15. This will influence the internal measurement of the meter, and must be compensated for by the setting of the Winding Ratio. This menu is indicated on the second display line as: "Win Ratio: 0001". The winding ratio can be changed in a similar fashion as for entering the PIN code. The cursor will, however, jump only to the least significant digit from the leading space. If the button is pressed while the cursor is on the leading space, the meter will return to the normal Monitoring Mode. A new Winding Ratio setting will not be stored if the user exits the Calibration Mode at this point.

The Winding Ratio setting will increment to 15, and roll over to 1 if the button is pressed while the cursor is on the least significant digit. To store a new setting and move to the next menu, the button must be pressed while the cursor is on the space following the number.

8.5.3.3 The calibration divider setting

The calibration divider setting is used to calibrate the power measurement of the meter against a good quality power meter. The factory setting for this number is based on the theoretical calculated value, but due to component tolerance, it may have to be adjusted. The calibration should be done on the largest power reading possible for the installation. The adjustment is directly linear to the difference between the power reading of a good quality external power meter, and the power reading of this meter. If the external reading is say 10% more than the reading of the meter, the calibration divider must be adjusted to 10% less than the current setting. This adjustment can bring the meter to a reading that has an error of less than 1%. The accuracy of the power reading of the meter, however, is not essential for the accuracy of the water flow-rate, provided the calibration lookup table is set between the power reading of this meter, and the flow-rate as measured by a good quality flow meter.

The calibration divider setting menu is indicated on the second display line as: "Cal Div: 0114". To exit to the normal Monitoring mode, the button can again be pressed while the cursor is on the leading space. The adjustment of the calibration divider is done in the same way as the PIN entry. To store a new setting and move to the next menu, the button must be pressed while the cursor is on the space after the number.

8.5.3.4 The low limit power setting

The low limit power setting is a limitation to the value of the raw data for each phase, where it will cut off any power contributions from a phase, and the meter will identify the phase as a "Zero Phase". This limit was set to prevent ambient and circuit noise to contribute small amounts of power, and therefore small amounts of water usage while the meter is on, but the pump is off. This setting was set in the factory to approximately 5% of the full power rating for each phase.

The low limit power setting is a decimal value, and can be adjusted and stored the same way as the previous calibration settings.

8.5.3.5 The lookup table menu

To ensure maximum accuracy in the power to water flow conversion, and to use the same lookup table structure for all the motor power ranges, all readings for the lookup table must be normalised to the 100 kW power range. Internally, a power reading will be multiplied by the winding ratio, converted to a flow reading in the lookup table, which is then again divided by the winding ratio.

To set the values of the lookup table for a specific installation, various readings of the meter power versus the water flow must be made over the entire range of the water flow, i.e. from fully open to fully closed.

Each reading, power and flow must then be multiplied by the winding ratio into a new table. A graph must then be drawn of the power in kW on the x-axis, and the flow in cubic meters on the y-axis. A "best fit" curve must be drawn through the points on the graph, and extended to cover the kW range up to 115,2kW. From this graph, readings for the flow must then be taken at specific kW values to enter into the lookup table in the meter. The specific kW values start at 25,6 kW, and increment in fifteen steps of 6,4 kW up to 115,2 kW. The values were chosen to make the interpolation between points possible and to limit mathematical calculations in the micro-controller.

Due to the nature of the graph, where the pump motor uses approximately one third of the full power when the water flow is zero, the lower kW values will result in negative flow numbers. The lookup table structure does not cater for negative values, and that part of the lookup table will probably never be used. To prevent any possible cases of a low power reading, such as when the power is switched off shortly after the start of a measuring period, the flow values for the small "off the scale" kW readings must be filled in as incrementing non-zero values, such as 1, 2, 3, etc. This will prevent any division by zero errors that may occur. If it does occur, the internal Watch Dog Timer reset will pull the micro-controller out of the zero division loop error and restart the device. It will, however, be better to completely prevent this.

The lookup table values are entered in fifteen steps for each of the selected kW values. Each step is shown on the second line as, e.g.: "Pw 12.80kW 1234". The kW step value is shown as the 12.80, and the corresponding flow as the 1234 in the example. The flow value can be adjusted in the same way as all the other calibration settings. To store the current setting and go to the next step, the button must be pressed while the cursor is on the space after the number. After the last step of 115,2 kW, the table will roll back to the first step of 25,6 kW. This final roll over is important to ensure that the last entry is stored.

To exit the calibration mode, the button must be pressed while the cursor is on the leading space.

8.5.3.6 Summary of calibration procedure

The calibration procedure as explained in the above paragraphs, is summarised in the following table. The table also includes an example.

Table 8.1 Summary of calibration procedure

Notes:

- The kW is read from the electronic meter, and flow is read from the ultrasonic water meter, or volumetrically determined by means of the water tank.
- After each valve setting, wait for the flow to stabilise. Normally one minute is enough.
- Care must be taken not to allow pump operation for too long at a certain condition when cavitation in the pump can be heard (high flows); rather move to a different operating condition with a lower flow-rate.
- If the pump is connected to a pipe network, an attempt must be made to get a discharge point close to the pump, preferably more or less at the same height as the pump.

8.6 Operating instructions

After installation, and the standby battery being connected to the circuit, the meter will sense that the mains are down, and go into the low power consuming standby mode. It will continuously monitor the presence of the mains supply and the pressing of the push-button.

When the mains supply is switched on, the meter will wake up and immediately start to measuring. The accumulative water usage will be displayed on the top line as a seven digit number, as: "Water: 0000000 m³. The second line will show the flow-rate of the pump in cubic meter per hour, as: "Flow: 0000m³/h. The display is updated every four seconds.

Should one or more phases of a three-phase system consume less than a preset minimum for the selected maximum rating of the pump (5% per phase), a warning message will be displayed on the bottom line for the last second of the four second display update period: "Zero Phases: RYB".

When the push-button is pressed, the display will toggle to show the electric data of the pump motor. The top line will show the accumulative total electric energy units used in kilowatt-hour, as: "Energy: 0000000kWh". The bottom line will show the current power usage in kilowatt, as: "Rate: 000.00kW". The display will be refreshed every four seconds. Should one or more phases be lost, a similar warning message will be displayed as for the Water Data mode.

Should the mains supply be lost or switched off, the display will go blank after a few seconds, and the meter will go into the low power consuming standby mode.

To take an accumulative water quantity reading while the mains power is off; the push-button will wake up the meter and display the usage total. The second line will read "Mains Power Down". The accumulative energy reading can be selected by pressing the button again. To conserve standby battery power, the meter will automatically switch off after approximately 30 seconds.

Access to the calibration menus is done through a special button sequence and the entry of a secret PIN number, as described in paragraph 8.5. Should a user accidentally enter into the PIN entry mode, the meter will reset back to one of the two standard display modes, 30 seconds after the last press of the button.

In circumstances where the meter is installed on the live side of a star-delta starter for large motors, the mains supply to the meter may stay on continuously. This is in no way harmful to the meter. Random noise in the measuring circuits is unlikely to exceed the 5% per phase limit of the maximum pump motor rating. It will therefore not register as a small flow that can add up considerably over a few weeks, while the pump is not in operation. The "Zero Phases" warning message will show, however, as can be expected.

8.7 Concluding remarks

Exhaustive tests have been done on the correct operation of the calibration mode. It may still happen that the system can freeze or something unforeseen can happen. In such a case, the mains power must be switched off and the standby battery disconnected for approximately 60 seconds. When the power is reconnected, the device will restart from a reset point, and the error will have disappeared.

8.8 Financial aspects

The financial implications involved in the electronic water metering procedure can be broken down to three levels. These are namely the cost of the meter itself, the cost of installation and calibration, and the cost of maintenance. These costs are described in the following paragraphs.

8.8.1 Cost of the meter

Considerable research was done on the procedure whereby the meter should function. There is a strong relationship between the sophistication of the meter and the cost thereof. The project objective, however, demands an accurate, simple to install, tamper-proof and affordable meter. The basis therefore was to keep it simple, without loosing accuracy and durability. The outcome of all this was an inexpensive meter with a very basic processor, a relatively easy procedure to install, calibrates and program. The information captured by the meter also goes beyond what one gets from the standard meters used in the field today.

The cost of the meter can be broken down into components and labour. Components amount to R 1 100 per meter, and labour to R 1 400 per meter, therefore the total cost of a meter amounts to R 2 500. One can, however, expect that there can be considerable reduction in the cost of the meter if produced in mass. Depending on the selling structure, the selling price of the meter can be between 30 % and 60 % above the cost price. For the purpose of this report it is anticipated that the cost price of the meter will be R 2000 and that the selling price of the meter will be R 3000.

8.8.2 Cost of installation

For the purpose of costing it is accepted that a qualified electrician does the installation. Approximately one hour is needed, and the total cost (assistant, consumables and traveling) can amount to R 300.

8.8.3 Cost of calibration and commissioning

The person doing the calibration should preferably have appropriate technical knowledge about pumps and hydraulics. With some experience in the calibration procedure it should be possible to do the calibration and programming of the meter in two hours. Total cost can amount to R 400.

8.8.4 Cost of maintenance

The meter should last for a period of 20 years, with very little maintenance required. For the purpose of this research project it is accepted that the meter will have to be replaced after 15 years and that the annual maintenance will be 1% of the cost of the meter. It is further anticipated that the meter is recalibrated every four years (based on interviews with pump manufacturers).

The cost to read the meter will be similar to that of conventional meters. However, making use of new technology may offer advantages for the electronic meter in this regard. This is briefly discussed in paragraph 8.14.

8.8.5 Total meter cost

The estimated total cost of the meter is summarised in Table 8.2. The maintenance cost is discounted at 12% for 15 years.

Table 8.2 Estimated total cost of electronic water meter

Item	Approximate cost (R)
Cost of the meter	3000
Cost of installation	300
Cost of calibration and commissioning	400
Cost of maintenance (discounted)	749
Total cost	4449

8.9 Tampering issues

Most mechanical and electrical instruments (in all fields) available currently can be tampered with, and the amount of energy that goes into these efforts will depend on the "benefit" which is gained from the result. If the meter is used for billing purposes, there will be a financial benefit, but if it is used for management and / or scheduling, accuracy of the meter it will be of great importance to the user.

It can be considered that, as part of the constitution of the WUA's, the farmers are primarily held responsible for the meters.

Potential tampering with the meter can basically be done in two ways:

- Tampering with the electronic components in the box. This can be protected similarly to the Escom meters, which makes it an offence if tampered with. The software of the instrument is protected with a password only made available to the relevant responsible person.

  It can therefore be accepted that the electronic side of the instrument cannot be tampered with.

- Tampering with the connections between the meter and the electric circuit of the electric motor switchgear. The opportunity for tampering here is that the meter can be disconnected, or that additional wires are installed parallel to the wires to which the CTr's are connected. Both of these practices will be obvious to anyone with only a basic knowledge of electricity. However, inspections will be necessary to make sure that this kind of tampering does not occur.

  A way to deal with this in a more preventative way, is to seal all the terminals with hot wax, and then to imprint it with a unique emblem of the responsible person (the way letters / parcels are sealed in the Post Office). Any tampering with these terminals will be clearly visible.

8.10 Safety and quality issues

The components sourced for the prototype meters are of a good quality, and will meet the standards (safety and quality) required by industry.

The only mechanical component is the button whereby programming is done, and which is also used to toggle between volumetric and electrical power displays. It is a durable waterproof button with an IP65 rating. For the frequency it is used for this application, it will last the expected life of the water meter.

The box that contains the electronic components is of a good quality for external use, and also has an IP65 rating.

The general expected life of electrical components are defined in 24 hour, 42 days and 20 year periods. Ninety five percent of the changes in component value change occur within the first 24 hours. Insofar as the accuracy of measurement is influenced by the ageing of components the analogue components are in such balance that changes will cancel each other out.

If components should fail, 99% of these failures will occur during the first 42 days. Thereafter it should last for at least 20 years, if used under the normal circumstances for which it is designed.

The accuracy of the readings done by the CTr's should not change over a period of 20 years if used within the design specifications of these components.

In the light of the above, it may be desirable to subject all instruments to a running-in period of 42 days prior to calibration. This will eliminate the risk of recalibration due to changes that can occur during this early stage of operation.
With regards to the safety of the installation, it is recommended that a qualified person do it. This will give the necessary accreditation to the installation, and the work can be guaranteed.

8.11 Legal issues

During the inaugural meeting possible implications, which relevant legislation may have on the legal aspects of the meter, were raised. It was suggested that the project team address this aspect parallel to the technical aspects.

This issue was discussed with several individuals with appropriate background, and the project team came to the conclusion that additional information on the proposed procedure and equipment should preferably be on the table in order to make substantial progress in this regard.

At some stage of the project a parallel was drawn between what happened in the 1970s and 80s when electronic speed measuring (radar) was introduced on the South African roads. Many cases went to court, and in most instances judgement was in favour of the driver, the reason being that sufficient doubt could be generated in court about the accuracy of the meter.

However, there is a significant difference in the two situations: the radar meter was specifically used as a method to issue penalties, which is a criminal procedure, while the electronic water meter is a method for determining the volume of a consumable to be paid for. A further reason why it took so long before the readings of the radar meter were accepted by the courts was that the authorities did not want to cooperate in getting the instruments evaluated or tested.

In the case of the electronic water meter (if agreed that it is an acceptable procedure to measure and bill water use), it could be considered that the user signs an agreement that he will accept the readings of the meter. The alternative for him/her will be to make use of an alternative acceptable method.

If the user uses the water meter for his own management and scheduling purposes, this is obviously not an issue.

Mr Nando Baard, a steering committee member, submitted the possible problems in this regard to a senior legal advisor in DWAF, who was intensively involved with the development of the new Water Act. The legal advisor's opinion is that if the meter is tested and approved by and independent organisation, e.g. the SABS, a problem in the acceptability of the readings is not foreseen.

It is suggested that the legal issue be included amongst those issues to be addressed in the way forward for this project.

8.12 Comparative position

Against the background of the difficulties experienced with water metering in general, and as discussed in paragraph 2 of this report, a comparison can be made between the electronic water meter and other conventional methods. This comparison appears in Table 8.3, and is based on the findings of this research project. The remarks as it appears in the table reflect how the electronic meter compares with the other meters mentioned.

Table 8.3 Comparative positions between the electronic water meter and other conventional methods

Method used to measure flow	Aspect to compare							
	Accuracy	**Cost of meter**	**Cost of installation**	**Ease of installation**	**Maintenance**	**Subject to tampering**	**Energy loss due to additional friction**	**Remoteness of sites**	**Acceptability**
Measuring of pump operating time	Much more accurate	n.a.	n.a	n.a	n.a	n.a	Same	More sensitive	More acceptable
Measuring of electricity used (kWh)	Much more accurate	Higher cost	Same	Same	Same	Same	Same	Same	Probably less acceptable
Measuring with mechanical rotor type water meter	Better or same	Lower cost	Lower cost	Much easier	Lower cost	Less subject	Less	Same	Probably less acceptable
Measuring with an electromagnetic water meter	Less accurate	Much lower cost	Lower cost	Much easier	Higher cost	More subject	Less	Same	Probably less acceptable
Measuring with ultrasonic water meter	Less accurate	Much lower cost	n.a	n.a	Same	n.a	Same	Same	Probably less acceptable

Mention is made in paragraph 3.4 of pressure differential measurement. Potential exists for this method, but due to insufficient data, it was excluded from the methods compared.

8.13 Issues related to feasibility and acceptance

In paragraph 10 recommendations are made on further actions needed to implement this method of water measurement in practice. Preliminary results show that the procedure can be accepted as a practical method to measure the volume of water used at an acceptable level of accuracy.

It must, however, be understood that accuracy will only be maintained if routine calibrations are done.

This "condition" may appear to be a negative aspect, but the amount of information about the pump performance gained in the calibration procedure is very valuable to the user and serves as a necessary preventative maintenance operation, otherwise probably neglected by management.

8.14 Possible improvements

The research project was successful in establishing a good procedure to capture data and to develop an instrument to convert power readings into flow measurements. There are uncertainties that have to be checked and verified, but these are expected to be explicable.

Relatively small changes to proto-type meter (mainly programming) are proposed as following:

- Allow for one decimal digit for flow-rate readings (0.1 m^3/hr)
- Consider activating a serial port (already provided for in the meter) for downloads or reprogramming.
- Replace present display with a display with a light. Most pump houses are fairly dark, making it difficult to read the meter without a flashlight.
- Increase the inactive interval (when in the programming mode before it goes back to

monitoring mode) from 30 seconds to 60 seconds. Sometimes the system returns to the monitoring mode while programming.

- Change the look-up table so that more points can be entered over the active area of the pump curve. At present there can be quite a few points below a flow-rate of zero, and above the maximum flow-rate of the pump.

Apart from these issues, other useful aspects to investigate for implementation are the following:

- Transfer of real-time data via cell phone. Preliminary cost estimates indicate that it is possible to receive data at a capital cost of R 3 000 plus the cost of an SMS per transfer.
- Capturing information about the performance of the electricity supply to the site
- Performance of power factor improvement equipment to be installed
- Capturing of low and high flow conditions
- Sending of warning signals for signs that may be detrimental to the pump and electric motor. To the knowledge of the project team the correct analysis of the electrical data captured simultaneously in the process of measuring the volume of water pumped is of great value to the user, and does not exist in the present pump management procedures of farmers.

9. CONCLUSIONS

The test to measure whether the project was successfully completed is to check the results / findings against the project objectives. The objective of this project was namely to develop a certain procedure, or method. In order for this procedure to be practical and acceptable to the industry (users of water), four criteria to be met were specified. These criteria were kept in mind in developing the procedure. There was, however, no guarantee that all the criteria would be met, which would then impact on the acceptability of the procedure, and not as such on the project objective.

The first check is therefore whether the procedure was developed successfully, and then to test practicality and acceptability thereof against the four criteria. This is done in the following paragraphs.

9.1 Success of the procedure / method developed

The basis of the procedure is the theory that there is a sound correlation between power used and the work done (water pumped) by a pump. This theory is briefly explained in Chapter 3 of this report.

The important next step in the procedure was to develop a method to measure this mentioned correlation. The project team is confident that a practical and effective method was developed to determine the correlation. This method is well documented in this report.

The final step in the procedure was to develop, build, install and monitor a proto-type meter, based on the above-mentioned principles. The project also met this part of the objective, and the meters that were developed and monitored, enabled the team to make useful recommendations with regard to further development thereof. The meter, its installation and management are well documented in this report.

9.2 Practicality and acceptability of the procedure

The four criteria that were specified are dealt with separately in the following paragraphs.

9.2.1 The accuracy of the meter must be acceptable

There are strong indications, based on the monitoring experience, that the accuracy of the method and meter will be acceptable. Indications are there that the meter is more accurate than the ordinary mechanical flow meters that are used to measure agricultural water. The reason for this may be the effect of the quality of the water (dirt) on the mechanical meters.

Certain problems developed during the monitoring stage, some of which are still unsolved (Chapter 7)[D1]. These are, however, not regarded as reason for general concern about the accuracy of the meter.

[D1] See Appendix D

9.2.2 The meter must be tamper-proof

Tampering with electrical and electronic equipment can never be ruled out. The project team believes, and make certain proposals in this regard, that the meter is reasonably tamper-proof. The incorporation of cell phone technology will make it very difficult to tamper with the equipment.

9.2.3 The installation of the meter in an existing system must be simple

There is almost no comparison between the installation of this meter, and the correct installation of conventional meters in an existing system. The effort and cost are substantially less for the electronic meter for most installations.

9.2.4 The cost of the meter must be lower than that of conventional water meters

The project team managed to develop a cost effective meter, consisting of good quality and reliable components. The same meter is used for all applications, and the cost of the meter therefore does not increase according to the flow rate of the pump. For larger meters e.g. 100 mm and bigger, the cost of the installed electronic water meter is less than that of conventional meters.

9.3 Closing remarks

The project team is of the opinion that the project objectives, as well as the criteria for accuracy and acceptability have been met. The method that was developed may well be accepted in the future as a practical alternative to measure water consumption at electrically driven pumping installations.

The recalibration of the meter every few years may appear to be negative attachment to the meter. It must, however, be seen against the background that there are almost no other maintenance necessary to the meter, and more important, the very valuable information which becomes available about pump efficiencies during calibration. This will be of great importance to the owner in the programming of maintenance of the pump.

10. THE WAY FORWARD

The way forward will to a great extent be determined by the opinion of the steering committee of this project, as well as the WRC. The project team is of the opinion that, in considering the future of electronic water meters, the following aspects should be among those to be addressed:

- Further testing of the meter as a first step in a limited installation phase.

  This may be the most effective if done as part of WRC Project K5/1265/40. It is suggested that at least 20 meters be installed to run parallel to other meters. The existing four test sites can be included. The range of pumps to be included should cover preferably the whole spectrum found in the agricultural field, including borehole pumps. DWAF and the Department of Agriculture should be involved, even if it implies only receiving test results on a regular basis. WUAs should be included in the monitoring of the meters, to acquaint themselves with the procedures, as well as coming up with proposals for changes, or improvement of the system. Their input on preventing possible tampering with the meter will be of special value.

- Establish the reasons for failure of two of the meters[D2]

  The project team must try to establish the reason for the damage to the Modder River meter, and the reason for the faulty readings at the Koelenhof pump station. It will probably mean that a thorough investigation be done on site to establish if possible faulty switchgear / installation caused the faulty readings.

- Relevant legal issues

  With the first instruments in operation, and considerable test data available, the relevant legal issues can now be addressed effectively. A possible procedure for this is to address it in conjunction with the legal units of DWAF and the Department of Agriculture.

- Application of cell phone technology

[D2] See Appendix D

This subject has been touched on in this project only superficially. It is a very rapid developing technology and will undoubtedly be applied in the irrigation industry increasingly. It is suggested that some of the proposed testing stations be equipped with cell phone communication technology.

- Business opportunity offered

There can be an attractive business opportunity attached to the meters, should the procedure be accepted by the industry, and a decision on how this needs to be dealt with should be taken. This is for purposes of opportunities in South Africa and abroad.

- Transfer of technology

It is probably too early to suggest a program for technology transfer, but the installation of the meters and getting DWAF, the Department of Agriculture and WUA's involved, is already a beginning of this process.

11. CAPACITY BUILDING

During the more than three years that the project lasted, capacity building occurred, and mainly centered on personnel and students of the CT. These were the following:

- One junior lecturer, Stephan Terblanche, was involved during the initial stage of the project, while two senior lecturers, Les Borril and Daan de Beer was involved for the whole period. Several other lecturers of the mechanical and electrical departments were also involved with group discussions.

- Seven diploma students and one post-diploma student (Marc Wust) at the CT, as well as one post-graduate student at the University of Stellenbosch assisted with the project on a sporadic basis. Their assistance included installations, the calibration process, the building of the testing facilities in the CT laboratory, and analysis of data.

- Equipment were installed at the CT, and made available for training of students. These included the testing pump facility, electric measuring equipment and an electric dummy load. The Elsenburg Agricultural College has indicated that they are interested in the testing facility for purposes of making a video of a pump test, which are to be used for student training.

- To some degree capacity building also occurred during regular contact with farmers and personnel of WUAs during the monitoring process (Danie de Wet, Oranje-Riet WUA, Frikkie Joubert Worcester-Oos WUA, and Rudolph van Dijck, Kogmanskloof Irrigation Board). They had a keen interest in the work of the project team, and are eager to know about the outcome of the project. A farm labourer in Franschhoek was trained to take frequent meter readings over a period of three months. During this time he developed a good understanding of the importance of accuracy.

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APPENDIX A

LABOROTORY TEST RESULTS

PUMP TEST 1 **2001/04/06**
MARC WUST **FRANCOIS DU PLESSIS**

Time	CHA Vrms	CHB Vrms	CHC Vrms	CHA Irms(	CHB Irms(	CHC Irms(A	CHABC W's	CHABC V	CHABC V	CHABC P	CHA Hz	CHABC Vunb(V)									
09:56:30 AM	384.32	385.14	381.8	0.137	0.082	0.08	0.002	0.077	0.078	0.0338	49.997	0.50844	**EVT**	**TIME**	**FLOW(S)**	**RESSURE (**	**kWh**	**kVAr**	**Acc Flow**	**owrate (m^3**	**Cycles**
10:22:00 AM	383.26	383.77	380.8	21.094	23.534	22.13	14.173	14.735	-4.033	-0.9618	50.049	0.47396	19	10:22	0.00	0.613	5.28	1.96		0.00	
10:22:45 AM	382.67	383.3	380.4	21.094	23.434	22.121	14.151	14.698	-3.972	-0.9628	49.958	0.44846	20	10:22,45	0.00	0.610	5.43	2.01		0.00	
10:21:36 AM	383.77	384.24	381.12	21.135	23.697	22.201	14.248	14.812	-4.051	-0.9618	50.071	0.50184	18	10:21	0.55	0.612	5.20	1.93		0.55	
10:00:29 AM	380.69	380.6	377.77	21.193	23.694	21.923	13.995	14.635	-4.275	-0.9563	49.952	0.50607	2	10:00	1.40	0.610	0.41	0.34		1.40	
10:01:43 AM	381.37	381.45	378.64	21.269	23.746	22.08	14.08	14.731	-4.332	-0.9557	50.01	0.48427	3	10:01	2.57	0.612	0.64	0.42		2.57	
10:29:23 AM	383.37	383.89	381.03	21.44	23.761	22.411	14.348	14.941	-4.167	-0.9602	50.004	0.45268	22	10:29	110.50	0.612	6.78	2.52		3.258	1
10:02:47 AM	380.66	380.72	378.03	21.368	23.727	22.172	14.053	14.739	-4.445	-0.9534	50.013	0.46744	4	10:02	4.20	0.610	0.86	0.50		4.20	
10:20:26 AM	383.07	383.75	380.72	21.487	23.93	22.642	14.398	15.02	-4.273	-0.9586	49.994	0.46925	17	10:20	4.95	0.610	4.96	1.84		4.95	
10:03:53 AM	380.19	380.53	377.84	21.513	23.806	22.488	14.137	14.843	-4.529	-0.9523	49.942	0.44071	5	10:03	6.21	0.611	1.09	0.58		6.21	
10:31:12 AM	383.7	384.03	381.22	21.845	24.181	22.725	14.557	15.207	-4.401	-0.9572	49.988	0.46021	23	10:31	51.50	0.610	7.18	2.67		6.990	1
10:05:09 AM	380.07	380.39	377.49	21.644	24.147	22.683	14.227	14.974	-4.666	-0.9502	49.952	0.4836	6	10:05	8.30	0.612	1.36	0.67		8.30	
10:32:33 AM	382.43	382.82	380.05	22.008	24.323	22.958	14.55	15.272	-4.637	-0.9528	50.004	0.45013	24	10:32	37.10	0.611	7.45	2.77		9.704	1
10:06:09 AM	379.65	379.92	377.12	21.862	24.256	22.849	14.276	15.068	-4.819	-0.9474	49.955	0.46785	7	10:06	10.30	0.610	1.57	0.75		10.30	
10:19:10 AM	382.85	383.44	380.33	22.063	24.613	23.231	14.676	15.403	-4.678	-0.9528	49.979	0.49053	16	10:19	11.37	0.611	4.70	1.74		11.37	
10:35:41 AM	383.26	383.7	380.68	22.142	24.613	23.198	14.71	15.447	-4.715	-0.9521	50.013	0.48605	25	10:35	31.50	0.612	8.14	3.02		11.429	1
10:07:32 AM	380.66	380.84	378.08	22.136	24.54	23.074	14.463	15.27	-4.899	-0.947	49.985	0.46659	8	10:07	12.45	0.613	1.88	0.85		12.45	
10:36:37 AM	383.11	383.63	380.54	22.261	24.773	23.381	14.773	15.544	-4.829	-0.9504	50.01	0.49205	26	10:36	27.90	0.610	8.35	3.10		12.903	1
10:08:44 AM	379.79	380.11	377.47	22.334	24.585	23.307	14.478	15.351	-5.106	-0.943	50.007	0.43648	9	10:08	14.59	0.611	2.15	0.95		14.59	
10:37:28 AM	382.6	383.11	380.16	22.43	24.83	23.559	14.801	15.609	-4.954	-0.9482	50.004	0.46651	27	10:37	24.20	0.609	8.55	3.16		14.876	1
10:38:39 AM	382.38	382.89	379.76	22.468	25.048	23.656	14.842	15.673	-5.036	-0.9469	49.988	0.50292	28	10:38	23.00	0.610	8.81	3.25		15.652	1
10:09:45 AM	378.61	379.02	376.11	22.424	24.897	23.565	14.502	15.436	-5.288	-0.9395	49.948	0.47908	10	10:09	17.35	0.608	2.39	1.02		17.35	
10:39:40 AM	382.29	382.75	379.79	22.843	25.28	23.967	14.98	15.873	-5.246	-0.9437	50.013	0.4766	29	10:39	19.70	0.610	9.04	3.33		18.274	1
10:10:46 AM	378.42	378.71	375.92	22.768	25.162	23.858	14.619	15.605	-5.459	-0.9368	49.945	0.46859	11	10:10	20.02	0.610	2.61	1.10		20.02	
10:41:11 AM	381.72	382.04	379.11	23.061	25.549	24.097	15.039	15.971	-5.372	-0.9417	49.961	0.48635	30	10:41	35.80	0.610	9.39	3.45		20.112	2
10:18:03 AM	382.48	383.01	379.98	23.16	25.685	24.355	15.182	16.106	-5.378	-0.9425	49.964	0.48449	15	10:18	21.09	0.609	4.45	1.65		21.09	
10:42:32 AM	382.88	383.3	380.28	23.44	25.948	24.562	15.315	16.285	-5.532	-0.9404	50.004	0.48827	31	10:42	32.10	0.610	9.71	3.55		22.430	2
10:12:05 AM	378.16	378.34	375.57	23.274	25.667	24.313	14.831	15.909	-5.759	-0.9321	49.939	0.47218	12	10:12	23.70	0.608	2.92	1.19		23.70	
10:49:31 AM	380.45	381.03	377.8	23.454	26.081	24.801	15.174	16.244	-5.798	-0.9341	49.994	0.51559	32	10:49	28.90	0.610	11.44	4.10		24.913	2
10:13:51 AM	377.34	377.56	374.68	23.905	26.353	25.032	15.085	16.295	-6.162	-0.9257	49.933	0.48887	13	10:13	28.31	0.605	3.38	1.33		28.31	
10:52:05 AM	379.81	380.53	377.52	24.211	26.597	25.615	15.467	16.685	-6.255	-0.927	49.985	0.46562	34	10:52	36.30	0.606	12.06	4.29	87	29.752	3
12:53:46 PM	382.93	383.3	380.47	21.793	24.102	22.598	14.436	15.108	-4.457	-0.9554	49.994	0.46058	85	12:54	11.20	0.604	3.50	1.44	205	32.143	1
10:53:36 AM	379.46	380.08	377.02	24.543	27.029	25.928	15.61	16.886	-6.436	-0.9244	49.97	0.48342	35	10:53	33.20	0.604	12.45	4.40		32.530	3
10:15:00 AM	378.45	378.71	375.76	24.688	27.202	25.913	15.569	16.884	-6.535	-0.922	49.933	0.49635	14	10:15	33.40	0.604	3.68	1.42		33.40	
10:54:40 AM	380.07	380.6	377.77	24.93	27.229	26.2	15.779	17.099	-6.588	-0.9227	50	0.45268	36	10:54	32.20	0.604	12.75	4.49		33.540	3
10:56:13 AM	379.41	380.01	377.02	25.113	27.504	26.481	15.853	17.226	-6.739	-0.9203	49.979	0.47207	37	10:56	30.60	0.605	13.15	4.61	89	35.294	3
10:57:32 AM	379.41	379.85	376.65	25.34	27.954	26.747	15.964	17.382	-6.88	-0.9183	50	0.52568	38	10:57	29.20	0.605	13.51	4.71	90	36.986	3
10:58:39 AM	379.2	379.64	376.39	25.649	28.307	27.055	16.097	17.573	-7.05	-0.9159	49.985	0.53243	39	10:58	27.60	0.605	13.81	4.80	91	39.130	3
10:59:40 AM	379.06	379.49	376.56	26.173	28.564	27.487	16.268	17.825	-7.283	-0.9126	50.031	0.47852	40	10:59	26.50	0.603	14.10	4.88	91	40.755	3
10:50:38 AM	380.05	380.84	377.52	23.795	26.416	25.31	15.34	16.493	-6.057	-0.9301	50.004	0.51248	33	10:50	25.80	0.610	11.69	4.18		41.860	3
12:54:41 PM	382.5	382.94	380.12	24.936	27.241	25.972	15.947	17.18	-6.395	-0.9281	50.007	0.45713	86	12:55	17.20	0.604	3.77	1.52	206	41.860	2
11:00:49 AM	378.66	379.05	376.09	26.452	28.884	27.762	16.383	17.991	-7.437	-0.9105	50.013	0.48627	41	11:00	25.20	0.604	14.42	4.97	92	42.857	3
11:01:47 AM	378.8	379.21	376.42	26.833	29.102	28.09	16.53	18.189	-7.589	-0.9087	50.028	0.45443	42	11:01	24.40	0.602	14.71	5.05	93	44.262	3
01:12:22 PM	377.6	377.89	374.73	23.99	26.564	25.141	15.143	16.381	-6.247	-0.9243	49.958	0.53335	99	13:12	8.00	0.590	10.22	2.92		45.000	1
11:14:07 AM	376.96	377.53	374.59	29.15	31.407	30.56	17.478	19.433	-8.495	-0.8993	49.958	0.47185	50	11:14	31.70	0.589	18.55	6.01	104	45.426	4
11:03:22 AM	378.73	379.02	376.18	27.121	29.458	28.339	16.648	18.351	-7.724	-0.9071	50.043	0.47556	43	11:03	31.50	0.602	15.70	5.16	94	45.714	4
11:04:39 AM	378.63	379	376.18	27.427	29.715	28.664	16.8	18.547	-7.862	-0.9056	50.013	0.46551	44	11:04	30.50	0.601	15.56	5.27	95	47.213	4
01:11:13 PM	375.38	375.93	372.81	27.572	30.011	28.942	16.619	18.407	-7.912	-0.9028	49.964	0.50762	98	13:11	14.90	0.540	9.91	2.84		48.322	2
11:05:52 AM	378.33	378.74	375.88	27.84	30.084	29.102	16.947	18.746	-8.015	-0.9039	50.022	0.46792	45	11:05	29.40	0.600	15.93	5.36	96	48.980	4
11:07:04 AM	378.02	378.43	375.53	28.085	30.398	29.362	17.044	18.882	-8.127	-0.9026	50.028	0.47878	46	11:07	28.30	0.597	16.29	5.46	97	50.883	4

11:08:28 AM	377.6	378.05	375.15	28.352	30.609	29.661	17.132	19.015	-8.25	-0.9009	50.034	0.47341	47	11:08	27.80	0.596	16.73	5.57	98	51.799	4
11:10:09 AM	377.1	377.58	374.64	28.574	30.872	29.927	17.224	19.121	-8.302	-0.9008	49.964	0.48271	48	11:10	26.80	0.593	17.26	5.70	100	53.731	4
11:11:33 AM	376.63	376.94	373.98	28.929	31.292	30.193	17.314	19.244	-8.402	-0.8995	50.007	0.49535	49	11:11	25.60	0.592	17.71	5.51	101	56.250	4
11:15:21 AM	377.17	377.86	374.68	29.33	31.748	30.865	17.616	20.261	-10.009	-0.8694	49.988	0.49917	51	11:15	24.90	0.589	18.96	6.11	105	57.831	4
11:16:28 AM	376.87	377.53	374.59	29.694	31.908	31.146	17.712	19.729	-8.69	-0.8977	50	0.46303	52	11:16	24.00	0.588	19.32	6.20	106	60.000	4
11:17:33 AM	377.05	377.65	374.61	30.259	32.561	31.725	17.986	20.798	-10.444	-0.8647	50.049	0.48583	53	11:17	23.11	0.585	19.68	6.29	107	62.311	4
01:07:02 PM	378.52	378.83	376.13	30.596	32.779	31.672	18.201	20.294	-8.976	-0.8969	50.022	0.4482	94	13:07	11.40	0.566	8.35	2.49	223	63.158	2
12:56:00 PM	382.6	382.75	380.02	26.56	28.884	27.475	16.702	18.187	-7.198	-0.9183	50.016	0.46596	87	12:56	11.30	0.583	4.08	1.60	207	63.717	2
11:24:10 AM	376.37	376.9	374.03	30.64	32.803	31.983	18.058	20.939	-10.599	-0.8624	50.034	0.46277	54	11:24	28.20	0.583	21.95	6.82	114	63.830	5
11:30:39 AM	378.21	378.64	375.74	31.085	33.301	32.358	18.419	21.32	-10.738	-0.8639	50.043	0.47259	55	11:30	27.20	0.580	24.21	7.35	121	66.176	5
11:31:39 AM	377.69	378.08	375.2	31.437	33.655	32.66	18.522	21.505	-10.927	-0.8612	50.034	0.47422	56	11:31	26.60	0.575	24.56	7.43	122	67.669	5
11:32:42 AM	377.74	378.17	375.43	31.886	33.939	33.053	18.723	21.772	-11.112	-0.8599	49.994	0.44457	57	11:32	25.80	0.573	24.95	7.51	123	69.767	5
11:33:47 AM	377.05	377.39	374.71	32.258	34.31	33.414	18.828	21.959	-11.301	-0.8573	49.997	0.44809	58	11:33	25.30	0.569	25.34	7.60	125	71.146	5
11:37:24 AM	376.68	376.97	374.19	32.52	34.658	33.719	18.933	22.117	-11.431	-0.856	49.955	0.4671	59	11:37	24.40	0.565	26.67	7.90	129	73.770	5
11:38:27 AM	377.29	377.58	374.78	33.047	35.214	34.26	19.223	22.508	-11.709	-0.854	50.031	0.47248	60	11:38	24.40	0.563	27.06	7.99	130	73.770	5
12:58:05 PM	381.96	382.16	379.23	33.038	35.513	34.177	19.721	22.849	-11.536	-0.8632	50.049	0.49769	88	12:58	18.90	0.562	4.48	1.70	208	76.190	4
11:39:28 AM	377.38	377.42	374.92	33.632	35.612	34.568	19.425	22.791	-11.92	-0.8523	50.031	0.43752	61	11:39	23.10	0.558	27.44	8.06	131	77.922	5
11:40:35 AM	376.63	376.75	374.21	34.089	36.053	35.074	19.593	23.045	-12.132	-0.8501	49.973	0.43811	62	11:40	22.20	0.549	27.87	8.16	133	81.081	5
01:00:09 PM	376.51	376.52	373.96	34.648	36.791	35.582	19.853	23.418	-12.423	-0.8477	50.007	0.45205	89	13:00	17.30	0.545	5.27	1.87	211	83.237	4
01:09:10 PM	377.24	377.49	375.01	34.473	36.452	35.458	19.872	23.357	-12.275	-0.8507	49.952	0.41869	96	13:09	8.65	0.493	9.16	2.67	226	83.237	2
01:08:19 PM	377.74	378.01	375.22	34.525	36.748	35.674	19.991	23.495	-12.343	-0.8508	49.976	0.47107	95	13:08	8.50	0.511	8.82	2.60	225	84.706	2
11:41:31 AM	376.75	377.01	374.5	34.898	36.766	35.911	19.978	23.576	-12.519	-0.8473	49.985	0.42329	63	11:41	21.00	0.541	28.23	8.24	134	85.714	5
11:46:30 AM	376.75	377.06	374.12	35.276	37.497	36.538	20.229	23.927	-12.776	-0.8455	50.013	0.49309	64	11:46	40.90	0.534	30.27	8.67	142	88.020	10
01:10:04 PM	374.51	374.84	371.99	36.242	38.44	37.461	20.472	24.395	-13.264	-0.8392	50.013	0.47685	97	13:10	8.00	0.441	9.52	2.75	227	90.000	2
11:47:40 AM	376.25	376.52	373.98	36.303	38.147	37.322	20.568	24.435	-13.194	-0.8417	50.004	0.42699	65	11:47	38.40	0.518	30.74	8.77	144	93.750	10
11:48:54 AM	376.25	376.35	374.05	37.2	38.902	38.058	20.938	24.955	-13.58	-0.8389	50.049	0.39952	66	11:48	36.20	0.597	31.27	8.88	146	99.448	10
11:51:33 AM	376.18	376.31	373.93	37.858	39.648	38.759	21.264	25.4	-13.89	-0.8372	50.013	0.41001	68	11:51	35.10	0.478	32.42	9.11	150	102.564	10
11:50:31 AM	376.06	376.16	373.84	37.901	39.609	38.768	21.259	25.398	-13.899	-0.8369	50.013	0.40316	67	11:50	34.80	0.493	31.96	9.02	148	103.448	10
11:52:40 AM	375.95	376.09	373.56	38.833	40.694	39.785	21.702	26.041	-14.393	-0.8333	50.049	0.43463	69	11:52	32.60	0.477	32.90	9.21	152	110.429	10
01:01:57 PM	375.78	376	373.21	38.326	40.54	39.442	21.565	25.804	-14.173	-0.8356	50.025	0.47693	90	13:01	16.30	0.483	6.06	2.03	213	110.429	5
11:53:43 AM	375.43	375.67	373.28	39.656	41.355	40.563	22.05	26.507	-14.711	-0.8318	49.967	0.40275	70	11:53	31.50	0.462	33.39	9.31	154	114.286	10
11:54:45 AM	375.38	375.5	373.18	40.625	42.322	41.457	22.469	27.106	-15.161	-0.8289	50.025	0.40301	71	11:54	30.20	0.450	33.85	9.40	156	119.205	10
11:55:49 AM	374.65	374.86	372.34	41.33	43.156	42.27	22.797	27.562	-15.49	-0.827	49.948	0.43207	72	11:55	28.60	0.425	34.37	9.50	158	125.874	10
11:57:08 AM	373.71	373.87	371.5	42.322	44.008	43.219	23.132	28.091	-15.941	-0.8234	49.982	0.41116	73	11:57	27.60	0.408	35.00	9.62	161	130.435	10
11:59:41 AM	374.32	374.32	371.99	43.085	44.787	43.876	23.513	28.607	-16.297	-0.8218	50.049	0.41713	74	11:59	27.00	0.388	36.27	9.86	167	133.333	10
12:00:49 PM	373.47	373.47	371.12	43.501	45.177	44.246	23.619	28.798	-16.477	-0.8201	50.016	0.42102	75	12:00	26.05	0.372	36.81	9.96	169	138.196	10
01:02:50 PM	374.96	375.05	372.25	42.625	44.824	43.666	23.519	28.507	-16.11	-0.825	50.028	0.49283	91	13:02	13.00	0.391	6.47	2.11	215	138.462	5
12:01:40 PM	374.13	374.37	371.83	43.888	45.669	44.867	23.936	29.179	-16.69	-0.8202	50.031	0.43348	76	12:01	25.60	0.359	37.25	0.05	172	140.625	10
12:02:50 PM	373.64	373.64	371.24	44.49	46.246	45.287	24.126	29.474	-16.931	-0.8185	50.028	0.42892	77	12:02	24.90	0.343	37.86	0.16	174	144.578	10
12:04:05 PM	373.99	374.23	371.43	44.837	46.805	45.926	24.417	29.84	-17.152	-0.8182	50.031	0.47697	78	12:04	24.40	0.330	38.50	0.28	177	147.541	10
12:05:11 PM	373.28	373.66	371.01	44.729	46.527	45.763	24.284	29.678	-17.06	-0.8182	49.967	0.44052	79	12:05	24.40	0.325	39.07	0.38	180	147.541	10
01:03:47 PM	374.13	374.09	371.45	45.008	47.104	45.849	24.535	29.926	-17.136	-0.8198	50	0.4727	92	13:03	11.80	0.325	6.96	2.21	218	152.542	5
12:06:57 PM	373.14	373.38	370.91	45.375	47.047	46.275	24.527	30.028	-17.324	-0.8168	49.976	0.42065	80	12:06	23.10	0.308	40.01	0.55	185	155.844	10
12:08:09 PM	373.35	373.73	371.26	46.056	47.666	46.973	24.884	30.485	-17.61	-0.8163	49.976	0.40872	81	12:08	23.00	0.285	40.64	0.67	187	156.522	10
01:04:52 PM	373.94	373.99	371.36	46.615	48.627	47.485	25.295	30.952	-17.838	-0.8171	50.031	0.46862	93	13:04	11.20	0.272	7.52	2.31	221	160.714	5
12:09:49 PM	373.61	373.68	371.17	46.926	48.715	47.771	25.319	31.07	-18.009	-0.8148	50.004	0.44334	82	12:09	22.30	0.251	41.54	0.83	192	161.435	10
12:11:05 PM	373.59	373.57	371.03	47.683	49.497	48.461	25.679	31.546	-18.319	-0.814	50.004	0.45598	83	12:11	21.10	0.200	42.23	0.96	195	170.616	10
09:59:10 AM	381.91	381.81	378.85	21.216	23.863	21.982	14.111	14.737	-4.247	-0.9575	49.988	0.52742	1	09:59		0.610	0.11	0.22	81		

PUMP TEST 2 **2001/06/22**
MARC WUST **FRANCOIS DU PLESSIS**

EVT	X	CHA Vrms	CHB Vrms	CHC Vrms	CHABC V	CHA Irms(	CHB Irms(	CHC Irms(	CHABC Ir	CHABC W	CHABC V	CHABC V	CHABC P	CHA HZ	EVT	TIME	FLOW		PRESSURE	EVT	TIME	FLOW	PRESSURES		KWH	KVAR	RPM
																	mA	m^3/h					DEL	SUCTION			
2	2001/06/22 14:41	382.89	384.46	383.76	384.11	21.046	22.26	26.284	69.591	10.406	14.91	10.679	0.6979	49.943	1	14:41:10	3.98	-0.313	0.605	1	14:41:15	0	61	5.5			2979
3	2001/06/22 14:43	384.41	386.27	385.33	385.8	21.265	22.707	26.777	70.749	10.625	15.219	10.896	0.6981	50.001	2	14:43:34	4.098	1.531	0.607	2	14:43:50	2.84	61	5.5			2980
1	2001/06/22 14:38	383.79	385.53	384.29	384.9	28.317	29.06	32.654	90.029	9.707	19.272	16.648	0.5037	50.053	0	14:38:00	4.115	1.797	0.607	0	14:36:45	5.6	0	0			-
5	2001/06/22 14:46	385.14	386.88	386.21	386.54	21.793	23.063	27.323	72.182	10.966	15.555	11.033	0.7048	49.995	4	14:46:45	4.191	2.984	0.607	4	14:46:45	7.682	61	5.5			2978
4	2001/06/22 14:45	384.91	386.81	386.09	386.44	21.546	22.919	27.222	71.689	10.839	15.437	10.992	0.702	50.007	3	14:45:20	4.194	3.031	0.606	3	14:45:15	5.283	61	5.5			2982
6	2001/06/22 14:48	381.64	383.41	382.81	383.11	22.087	23.414	27.785	73.286	11.47	15.653	10.652	0.7327	50.016	5	14:48:46	4.194	3.031	0.606	5	14:48:45	14.25	61	5			2977
8	2001/06/22 14:50	382.07	383.69	382.84	383.28	22.626	24.085	28.187	74.901	11.916	16.019	10.706	0.7438	50.065	6	14:50:10	4.213	3.328	0.607	6	15:50:00	18.96	61	49			2979
10	2001/06/22 14:55	382.87	384.24	383.38	383.8	21.344	22.631	26.453	70.421	10.687	15.09	10.654	0.7081	50.028	8	14:55:10	4.281	4.391	0.607	8	14:55:15	4.5	61	5.5	10.76	0.033	2979
9	2001/06/22 14:52	382.07	383.34	382.55	382.95	23.055	24.409	28.373	75.832	12.13	16.225	10.778	0.7474	50.019	7	14:52:15	4.357	5.578	0.606	7	14:52:15	21.33	61	4.8			2975
11	2001/06/22 14:56	382.82	384.31	383.53	383.92	21.29	22.536	26.493	70.321	10.588	15.067	10.719	0.7026	49.946	9	14:56:30	4.357	5.578	0.605	9	14:56:30	6	61	5.5	17.1	0.53	2976
13	2001/06/22 15:00	383.08	384.65	384.14	384.4	21.672	22.831	27.127	71.634	10.899	15.357	10.818	0.7096	49.943	10	15:00:00	4.5	7.813	0.605	10	15:00:00	7.6	61	5.2	33.37	1.04	2976
14	2001/06/22 15:01	382.23	383.79	383.1	383.45	21.84	23.111	27.225	72.182	11.099	15.448	10.746	0.7184	49.928	11	15:01:10	4.653	10.203	0.604	11	15:01:15	10.5	61	5	38.88	1.22	2975
15	2001/06/22 15:02	382.42	384.12	383.46	383.8	22.166	23.482	27.721	73.368	11.398	15.717	10.821	0.7252	49.937	12	15:02:30	4.875	13.672	0.604	12	15:02:30	14	61	5	44.38	1.39	2973
16	2001/06/22 15:03	382.11	383.96	383.36	383.66	22.413	23.776	28.177	74.363	11.665	15.91	10.82	0.733	49.949	13	15:03:48	5.085	16.953	0.604	13	15:03:45	17.5	61	4.75	50.16	1.57	2973
52	2001/06/22 15:40	384.12	385.91	385.45	385.68	22.879	24.159	28.629	75.667	11.899	16.259	11.078	0.7318	49.964	39	15:40:15	5.32	20.625	0.602	39	15:40:15	22	61	4.5	225.82	7.9	2969
18	2001/06/22 15:04	382.61	384.29	383.74	384.02	22.778	24.085	28.491	75.357	11.904	16.145	10.904	0.7374	49.961	14	15:04:51	5.445	22.578	0.604	14	15:05:00	20	61	4.5	36.21	1.75	2973
19	2001/06/22 15:06	382.49	384.15	383.57	383.87	23.297	24.712	29.125	77.136	12.4	16.519	10.914	0.7506	50.035	15	15:06:15	5.643	25.672	0.605	15	15:06:15	25	61	4.25	62.52	1.96	2975
20	2001/06/22 15:07	382.21	383.79	383.12	383.47	23.99	25.445	29.79	79.226	12.925	16.958	10.976	0.7622	50.001	16	15:07:34	6.1	32.813	6.01	16	15:07:30	30	61	4	69.64	2.19	2972
22	2001/06/22 15:08	381.64	383.41	382.79	383.11	24.888	26.423	31.001	82.31	13.675	17.597	11.075	0.7771	49.973	17	15:08:55	6.512	39.250	0.601	17	15:09:00	39	61	4	76.2	2.39	2967
24	2001/06/22 15:11	381.71	383.39	382.89	383.14	25.906	27.397	32.151	85.458	14.41	18.27	11.232	0.7886	49.967	18	15:11:25	6.727	42.609	0.599	18	15:11:30	44	61	3.5	88.46	2.79	2967
25	2001/06/22 15:12	381.47	383.15	382.55	382.85	26.976	28.581	33.37	88.925	15.212	19.012	11.406	0.8	49.964	19	15:12:30	7.15	49.219	0.0597	19	15:12:30	49	60.5	3.5	93.63	2.96	2966
26	2001/06/22 15:13	380.79	382.62	381.91	382.28	27.461	29.231	34.044	90.731	15.662	19.358	11.377	0.809	49.964	20	15:13:35	7.35	52.344	0.593	20	15:13:30	51	60.5	3.5	98.78	3.13	2966
27	2001/06/22 15:14	381.83	383.62	382.86	383.26	28.09	29.876	34.716	92.684	16.122	19.84	11.564	0.8125	50.053	21	15:14:45	7.65	57.031	0.592	21	15:14:45	53	60.25	3.5	104.2	3.33	2966
29	2001/06/22 15:15	381.1	382.79	382.25	382.52	28.864	30.571	35.644	95.075	16.666	20.3	11.593	0.8208	50.022	22	15:15:50	7.73	58.281	0.587	22	15:15:45	60	60	3.25	109.88	3.5	2966
51	2001/06/22 15:38	381.36	383.17	382.72	382.95	29.016	30.683	35.843	95.54	16.77	20.411	11.632	0.8217	50.001	38	15:38:37	7.86	60.313	0.583	38	15:38:30	61	60	3	217.89	7.63	2959
30	2001/06/22 15:16	381.1	382.77	382.29	382.52	30.043	31.713	36.949	98.706	17.475	21.088	11.804	0.8286	50.016	23	15:16:00	8.35	67.969	0.579	23	15:17:00	67	60	3	115	3.68	2963
31	2001/06/22 15:18	379.82	381.43	381.08	381.26	31.028	32.679	38.07	101.772	18.162	21.674	11.828	0.8379	50.013	24	15:18:16	8.55	71.094	0.571	24	15:18:15	73	59	3	121.43	3.92	2962
59	2001/06/22 15:47	381.24	382.84	382.36	382.61	31.263	32.973	38.259	102.493	18.28	21.901	12.061	0.8346	49.958	44	15:47:35	8.72	73.750	0.501	44	15:47:30	75	52	-4	261.34	9.14	2953
57	2001/06/22 15:46	381.24	382.93	382.34	382.64	31.297	33.111	38.37	102.775	18.34	21.956	12.073	0.8352	49.952	43	15:46:30	8.85	75.781	0.522	43	15:46:30	76	55	-2	254.89	8.91	2953
60	2001/06/22 15:48	382.07	383.53	383.15	383.33	31.446	33.064	38.437	102.949	18.383	22.029	12.137	0.8345	49.98	45	15:48:55	8.85	75.781	0.531	45	15:49:00	74	54	-1	267.24	9.55	2954
55	2001/06/22 15:45	381.9	383.58	382.98	383.28	31.513	33.3	38.586	103.396	18.484	22.136	12.178	0.835	49.98	42	15:45:30	8.976	77.750	0.548	42	15:45:30	78	56	1	250.32	8.75	2954
54	2001/06/22 15:43	380.76	382.67	382.08	382.38	31.611	33.529	38.913	104.053	18.632	22.227	12.119	0.8383	49.973	41	15:43:45	9.1	79.688	0.562	41	15:43:45	80	58	2.75	243.08	8.49	2951
33	2001/06/22 15:19	379.3	380.81	380.37	380.59	31.917	33.577	38.943	104.436	18.723	22.22	11.965	0.8425	49.958	25	15:19:45	9.12	80.000	0.562	25	15:19:45	80	58	2.75	128.17	4.14	2956
53	2001/06/22 15:41	380.1	381.81	381.37	381.59	33.071	34.91	40.502	108.487	19.59	23.132	12.301	0.8468	49.961	40	15:41:50	9.53	86.406	0.546	40	15:42:00	88	56	2.5	233.39	8.15	2948
35	2001/06/22 15:21	380.15	381.98	381.46	381.73	33.026	34.94	40.587	108.551	19.619	23.166	12.321	0.8468	49.995	26	15:21:45	9.75	89.844	0.549	26	15:21:45	88	56	2.5	139.41	4.53	2953
50	2001/06/22 15:37	380.01	381.84	381.37	381.59	34.956	36.9	42.8	114.655	20.953	24.477	12.653	0.856	50.01	37	15:37:15	10.46	100.938	0.52	37	15:37:15	108	53	2	211.44	7.41	2945
61	2001/06/22 15:50	379.15	380.6	380.35	380.47	34.819	36.509	42.355	113.688	20.715	24.208	12.528	0.8556	49.998	46	15:50:21	10.75	105.469	0.464	46	15:50:15	104	49	-45	273.66	9.58	2944
38	2001/06/22 15:24	378.89	380.53	380.18	380.35	37.249	39.129	45.351	121.726	22.395	25.959	13.129	0.8627	49.967	28	15:24:50	10.85	107.031	0.479	28	15:25:00	109	50	1.5	152.71	5.02	2946
36	2001/06/22 15:23	378.56	380.24	379.82	380.05	34.779	36.644	42.496	113.916	20.748	24.236	12.528	0.856	49.952	27	15:23:30	10.94	108.438	0.523	27	15:23:30	104	54	2	146.61	4.8	2948
49	2001/06/22 15:35	378.54	380.41	379.89	380.16	39.424	41.546	47.959	128.935	23.918	26.904	12.318	0.8889	50.028	36	15:35:50	11.65	119.531	0.435	36	15:36:00	120	46	0.5	206.4	7.22	2936
40	2001/06/22 15:26	377.92	379.46	378.95	379.21	39.449	41.399	47.713	128.561	23.8	26.789	12.296	0.8884	49.97	29	15:26:10	11.71	120.469	0.439	29	15:26:00	120	46	0.25	158.52	5.26	2939
41	2001/06/22 15:27	377.85	379.29	378.71	379	40.866	42.812	49.167	132.849	24.685	27.737	12.65	0.8899	49.989	30	15:27:15	12.22	128.438	0.405	30	15:27:30	132	42	0	164.57	5.49	2935
43	2001/06/22 15:28	377.47	379.05	378.57	378.81	42.373	44.413	51.11	137.895	25.68	28.8	13.037	0.8916	49.943	31	15:28:30	12.902	139.094	0.356	31	15:28:30	141	37	-1	169.81	5.71	2933
44	2001/06/22 15:29	377.59	379.27	378.73	379	43.532	45.674	52.558	141.763	26.492	29.662	13.344	0.8931	49.998	32	15:29:45	13.67	151.094	0.317	32	15:29:45	146	33	-1.25	175.3	5.94	2929
46	2001/06/22 15:30	376.53	378.2	377.64	377.93	44.517	46.666	53.617	144.793	27.041	30.239	13.533	0.8942	49.943	33	15:31:00	14	156.250	0.277	33	15:31:00	156	29	-2	181.29	6.18	2926
47	2001/06/22 15:32	376.88	378.46	377.81	378.14	45.361	47.546	54.484	147.393	27.6	30.817	13.705	0.8956	50.001	34	15:32:10	14.25	160.156	0.245	34	15:32:00	161	26	-2.5	186.23	6.4	2925
48	2001/06/22 15:33	376.69	378.34	377.64	378	45.976	48.235	55.281	149.492	28.018	31.257	13.858	0.8962	50.01	35	15:33:15	14.7	167.188	0.233	35	15:33:00	166	23	-3	191.68	6.63	2923

PUMP TEST 3 **2001/07/09**

MARC WUST **FRANCOIS DU PLESSIS**

Evt	X	CHA Vrms	CHB Vrms	CHC Vrms	CHA Irms(	CHB Irms(	CHC Irms(	CHABC W	CHABC V/	CHABC V/	CHABC PI	CHA HZ	EVT	TIME	FLOW mA	FLOW m^3/h	PRES	EVT	TIME	FLOW	PRESSURES DEL	PRESSURES SUCTION	KWH	KVAR	RPM
																		-1	11:56:30		0	5,8	0	0	
1	2001/07/06 10:58	381.36	384.54	383.05	20.689	23.503	23.796	10.644	15.222	10.8834	0.6991	50.007	0	10:58:48	3.982	-0.3	0,592	0	11:58:30		61	6	3,06	0,3	2981
50	2001/07/06 12:02	382.19	385.28	383.69	20.584	23.325	23.467	10.419	15.11	10.943	0.6895	49.967	37	12:02:33	4.474	7.4	0,596	37	12:02:30	(8,0)	61	6	309.28	11,03	2973
3	2001/07/06 11:02	379.75	382.92	381.61	21.163	23.961	24.265	11.128	15.471	10.7485	0.7192	49.961	1	11:02:15	4.536	8.4	0,594	1	11:02:15	9,0	61	6	20,13	0,63	2971
4	2001/07/06 11:03	380.72	383.68	382.34	21.682	24.49	24.642	11.506	15.826	10.8677	0.7269	50.028	2	11:03:55	4.794	12.4	0,596	2	11:04:00	12,4	61	5,5	28,11	0,87	2982
41	2001/07/06 11:49	384.57	387.37	385.8	22.042	24.875	24.793	11.511	16.175	11.3635	0.7117	50.047	28	11:49:21	4.951	14.9	0,592	28	11:49:15	16,5	61	5	246,45	8,62	2978
49	2001/07/06 12:01	381.34	384.3	382.72	21.795	24.658	24.639	11.508	15.907	10.9824	0.7234	49.949	36	12:01:25	4.981	15.3	0,595	36	12:01:15	16,6	61	5,2	303.21	10,58	2970
5	2001/07/06 11:05	380.3	383.37	382.1	22.854	25.773	25.929	12.468	16.647	11.0315	0.7489	49.992	3	11:05:10	5.491	23.3	0,594	3	11:05:15	23,6	61	4,9	33,18	1,02	2977
40	2001/07/06 11:48	384.45	387.3	385.61	23.292	26.351	26.098	12.602	17.087	11.5396	0.7374	50.028	27	11:48:10	5.658	25.9	0,589	27	11:48:15	27,5	61	4	240,68	8,44	2975
6	2001/07/06 11:06	380.01	383.01	381.68	24.374	27.518	27.445	13.71	17.71	11.2111	0.774	50.01	4	11:06:25	6.124	33.2	0,591	4	11:06:30	34,3	61	4,5	39,89	1,25	2975
38	2001/07/06 11:47	383.67	386.52	384.85	24.726	27.915	27.523	13.782	18.059	11.6693	0.7631	50.013	26	11:47:10	6.392	37.4	0,580	26	11:47:15	38	60,5	3	235,76	8,27	2972
7	2001/07/06 11:14	381.38	384.44	382.63	25.411	28.859	28.335	14.485	18.519	11.5422	0.782	50.019	5	11:14:28	6.510	39.2	0,589	5	11:13:30	40,0	61	4,1	81,57	2,63	2970
37	2001/07/06 11:46	383.27	386.21	384.5	25.824	29.168	28.671	14.691	18.832	11.7823	0.78	50.043	25	11:46:35	6.681	41.9	0,573	25	11:46:30	44	60	2	232,48	8,16	2969
8	2001/07/06 11:16	383.32	386.66	384.83	26.872	30.577	30.068	15.601	19.727	12.0723	0.7908	49.985	6	11:16:01	7.195	49.9	0,584	6	11:16:00	50	61	4,0	87,01	2,81	2961
35	2001/07/06 11:45	383.27	385.94	384.38	27.928	31.286	30.596	16.214	20.222	12.0837	0.8018	50.043	24	11:45:45	7.447	53.9	0,557	24	11:45:45	54	58	1	228,95	8.03	2966
9	2001/07/06 11:17	384.31	387.56	386.01	28.627	32.297	31.898	16.852	20.98	12.4963	0.8032	49.988	7	11:17:15	7.820	59.7	0,577	7	11:17:15	60.00	60	3,5	92,69	3,02	2965
33	2001/07/06 11:44	382.07	385.06	383.38	29.162	32.817	32.088	17.238	21.128	12.2159	0.8158	50.019	23	11:44:57	7.891	60.8	0,542	23	11:45:00	63	56,5	0	224,89	7,90	2960
32	2001/07/06 11:43	382.04	385.09	383.5	30.207	33.911	33.198	18.027	21.871	12.385	0.8242	50.065	22	11:43:40	8.365	68.2	0,524	22	11:43:45	69	55	-1	219,50	7,70	2961
10	2001/07/06 11:22	381.05	384.49	382.98	30.776	34.73	34.224	18.528	22.368	12.5322	0.8282	49.958	8	11:22:25	8.652	72.7	0,558	8	11:22:30	75	59	3,4	117,41	3,91	2958
30	2001/07/06 11:42	381.93	384.89	383.53	31.413	35.081	34.423	18.86	22.688	12.6119	0.8312	50.056	21	11:42:40	8.950	77.3	0,505	21	11:42:30	74	53	-2	214,39	7,52	2959
28	2001/07/06 11:41	380.72	383.44	382.2	32.436	36.028	35.325	19.519	23.271	12.6689	0.8387	50.034	20	11:41:35	9.289	82.6	0,485	20	11:41:30	84	51,5	-3	208,76	7,32	2957
27	2001/07/06 11:39	380.32	383.23	381.72	33.354	37.239	36.319	20.229	23.971	12.8599	0.8439	50.031	19	11:39:30	9.613	87.7	0,462	19	11:39:30	85	49,5	-4	198,86	6,96	2955
25	2001/07/06 11:38	380.27	383.15	381.56	33.418	37.336	36.34	20.274	24.006	12.8555	0.8445	50.034	18	11:38:20	9.693	89.0	0,470	18	11:38:15	90	50	-3	192,25	6.74	2954
24	2001/07/06 11:36	380.23	383.25	381.87	33.385	37.254	36.503	20.268	24.013	12.8765	0.844	50.013	17	11:36:48	9.750	89.8	0,480	17	11:36:45	90	51	-2	185,50	6,46	2954
15	2001/07/06 11:29	380.34	383.61	381.94	33.557	37.767	36.841	20.5	24.27	12.9895	0.8446	50.043	12	11:29:10	9.875	91.8	0,514	12	11:29:15	92	54,5	2,0	149,72	5,12	2954
16	2001/07/06 11:30	380.15	383.42	381.91	33.504	37.593	36.844	20.44	24.208	12.972	0.8442	50.01	13	11:30:55	9.940	92.8	0,509	13	11:31:00	95	54,5	1,5	157,73	5,43	2954
20	2001/07/06 11:33	380.15	383.2	381.61	33.493	37.471	36.521	20.36	24.094	12.887	0.8448	50.037	15	11:33:52	9.970	93.3	0,499	15	11:34:00	95	53	0	172,95	5,98	2955
18	2001/07/06 11:32	380.56	383.7	382.22	33.44	37.468	36.681	20.363	24.154	12.9921	0.843	50.01	14	11:32:35	10.017	94.0	0,506	14	11:32:30	93	54	1,0	165,74	5,72	2954
22	2001/07/06 11:35	379.82	382.89	381.39	33.426	37.373	36.524	20.315	24.036	12.8476	0.8451	50.028	16	11:35:14	10.023	94.1	0,489	16	11:35:15	90	52	-1	178,56	6,20	2955
11	2001/07/06 11:24	380.6	383.82	382.13	33.792	37.935	36.986	20.605	24.412	13.0885	0.844	49.998	9	11:24:17	10.130	95.8	0,520	9	11:24:15	100	55	0,9	126.51	4,25	2957
12	2001/07/06 11:26	380.72	383.92	382.08	33.767	37.978	36.886	20.591	24.418	13.1227	0.8433	50.004	10	11:26:05	10.156	96.2	0,521	10	11:26:00	96	55	2,7	134,51	4,55	2954
13	2001/07/06 11:27	380.44	383.44	381.82	33.817	37.85	36.844	20.567	24.351	13.0333	0.8446	50.016	11	11:27:21	10.250	97.7	0,517	11	11:27:15	93	55	2,5	140,65	4,79	2955
48	2001/07/06 11:59	377.77	380.77	379.33	35.702	39.729	38.692	21.832	25.533	13.2383	0.855	50.059	35	11:59:45	10.370	99.5	0,493	35	11:59:45	101	52	2,2	295,28	10.39	2949
42	2001/07/06 11:51	380.7	383.46	382.1	38.217	42.314	41.214	23.512	26.859	12.9834	0.8754	50.05	29	11:51:41	11.120	111.3	0,448	29	11:51:45	113	48	1,5	257,50	9,04	2947
43	2001/07/06 11:52	376.42	379.27	377.7	39.651	43.977	42.579	24.391	27.679	13.0833	0.8812	50.013	30	11:52:45	11.801	121.9	0,417	30	11:52:30	122	45	1	262,24	9,23	2938
44	2001/07/06 11:53	375.08	378.05	376.56	41.458	45.926	44.561	25.575	28.88	13.4144	0.8855	50.01	31	11:53:37	12.650	135.2	0,37	31	11:53:30	134	40	0	266,71	9,41	2933
46	2001/07/06 11:56	375.34	378.34	376.91	43.557	48.114	46.72	26.961	30.334	13.9041	0.8887	50.04	33	11:56:28	13.390	146.7	0,299	33	11:55:30	146	32	-2	279,93	9,97	2972
45	2001/07/06 11:54	375.17	377.98	376.56	43.671	48.13	46.667	26.954	30.33	13.9059	0.8887	50.028	32	11:54:49	13.475	148.0	0,303	32	11:54:45	150	33	-1	271,93	9,63	2932
47	2001/07/06 11:57	375.17	378.15	376.75	45.426	50.067	48.607	28.145	31.593	14.3536	0.8907	50.068	34	11:57:40	14.260	160.3	0,245	34	11:57:50	161	26	-2	285,75	10,22	2929

PUMP TEST 4 **2001/08/20**

MARC WUST **FRANCOIS DU PLESSIS**

	X	CHA Vrms	CHB Vrms	CHC Vrms	CHD Vrms	CHABC Vr	CHA Irms(	CHB Irms(	CHC Irms(	CHD Irms(
1	2001/08/20 15:19	378.13	383.11	382.57	0.103637	382.83	20.013	22.58	24.942	0.00172
2	2001/08/20 15:21	378.93	383.75	383.26	0.102533	383.52	21.088	23.719	25.988	0.001755
44	2001/08/20 16:00	381.64	385.52	385.11	0.088343	385.31	21.69	23.883	25.764	0.001664
3	2001/08/20 15:22	379.57	384.28	383.93	0.101186	384.09	22.512	25.276	27.495	0.001733
4	2001/08/20 15:24	378.82	383.42	382.74	0.099097	383.07	24.2	27.329	29.075	0.001734
6	2001/08/20 15:25	377.57	381.94	381.17	0.101561	381.57	26.701	30.128	31.489	0.001699
41	2001/08/20 15:57	378.44	382.53	381.98	0.091391	382.26	27.295	30.48	31.849	0.001627
37	2001/08/20 15:56	378.77	383.27	382.38	0.091056	382.83	27.171	30.693	31.969	0.001661
39	2001/08/20 15:56	378.82	383.3	382.4	0.090261	382.85	27.163	30.662	31.948	0.001644
42	2001/08/20 15:58	379.31	383.2	382.71	0.085498	382.95	27.501	30.559	31.883	0.001631
35	2001/08/20 15:54	378.35	382.77	381.67	0.092219	382.23	27.138	30.711	31.739	0.001606
36	2001/08/20 15:55	378.51	382.94	381.88	0.086956	382.42	27.122	30.662	31.754	0.001618
8	2001/08/20 15:25	376.98	381.2	380.64	0.101489	380.92	28.326	31.728	33.135	0.001618
34	2001/08/20 15:53	378.35	382.84	381.76	0.089072	382.3	28.914	32.663	33.664	0.001606
10	2001/08/20 15:26	377.05	381.22	380.69	0.100207	380.95	30.445	34.02	35.306	0.00167
33	2001/08/20 15:52	377.78	382.41	381.33	0.094741	381.87	30.843	34.819	35.77	0.001583
11	2001/08/20 15:27	376.13	380.53	379.84	0.098907	380.18	31.66	35.557	36.702	0.001614
32	2001/08/20 15:51	376.13	380.77	380	0.094301	380.4	32.735	36.793	37.867	0.001632
12	2001/08/20 15:28	376.13	380.51	379.72	0.100996	380.11	33.125	37.136	38.138	0.001671
14	2001/08/20 15:29	376.2	380.77	379.74	0.107171	380.25	34.631	38.948	39.74	0.001685
30	2001/08/20 15:48	375.31	379.86	379.05	0.099215	379.44	35.632	39.85	40.736	0.001628
29	2001/08/20 15:47	374.74	379.31	378.5	0.091306	378.92	35.67	39.984	40.853	0.001624
31	2001/08/20 15:50	375.28	379.67	378.67	0.092304	379.16	34.296	38.39	39.113	0.001604
27	2001/08/20 15:45	375.71	379.96	378.84	0.094945	379.4	35.975	40.208	40.672	0.001618
28	2001/08/20 15:46	374.72	379.24	378.34	0.098677	378.78	35.747	40.044	40.826	0.001625
25	2001/08/20 15:42	374.34	378.55	377.84	0.093776	378.18	36.264	40.299	41.062	0.001647
26	2001/08/20 15:44	375.85	380.05	379.22	0.098828	379.64	36.168	40.211	40.896	0.001671
24	2001/08/20 15:41	374.55	378.79	378.31	0.093651	378.56	36.377	40.348	41.376	0.001667
15	2001/08/20 15:32	376.2	380.77	379.72	0.097041	380.23	36.074	40.466	41.185	0.001668
17	2001/08/20 15:33	374.48	379.07	377.96	0.095182	378.52	38.479	43.053	43.618	0.001657
23	2001/08/20 15:39	373.87	378.17	377.41	0.097862	377.8	39.763	44.067	44.777	0.00165
18	2001/08/20 15:34	373.66	378.05	377.12	0.09526	377.59	40.623	45.16	45.727	0.001682
19	2001/08/20 15:35	372.46	377.21	376.15	0.102008	376.68	42.396	47.273	47.828	0.0017
22	2001/08/20 15:38	373.54	378.1	377.24	0.098519	377.68	42.74	47.41	48.043	0.001681
20	2001/08/20 15:36	372.31	376.9	376.01	0.105962	376.47	43.754	48.546	49.116	0.001678
21	2001/08/20 15:37	372.57	377.02	376.27	0.100207	376.66	45.035	49.745	50.383	0.001686

	CHABC Irn	CHD W(Vo	CHABC W	CHD VA(V	CHABC VA	CHD VAR(	CHABC VA	CHD PF(V	CHABC PF	CHA HZ(V	CHABC Vunb(Volts)
1	67.54	1.57E-07	10.644	1.78E-07	15.001	8.49E-08	10.5713	0.8793	0.7095	49.989	0.82029
2	70.792	1.61E-07	11.508	1.8E-07	15.764	8.12E-08	10.7758	0.8923	0.7299	50.019	0.79916
44	71.341	1.28E-07	11.497	1.47E-07	15.981	7.29E-08	11.0999	0.8684	0.7194	49.995	0.6383
3	75.284	1.56E-07	12.638	1.75E-07	16.8	7.93E-08	11.0668	0.8917	0.7523	50.016	0.7892
4	80.609	1.5E-07	14.017	1.72E-07	17.958	8.42E-08	11.2272	0.8716	0.7804	50.007	0.74238
6	88.317	1.49E-07	15.898	1.73E-07	19.639	8.73E-08	11.531	0.8627	0.8094	49.98	0.69868
41	89.619	1.25E-07	16.203	1.49E-07	19.968	8.1E-08	11.6676	0.8384	0.8114	49.983	0.66578
37	89.832	1.28E-07	16.27	1.51E-07	20.051	8.01E-08	11.7168	0.8484	0.8114	50.065	0.70874
39	89.77	1.28E-07	16.238	1.48E-07	20.031	7.56E-08	11.7295	0.8602	0.8105	50.019	0.70789
42	89.938	1.2E-07	16.288	1.39E-07	20.087	7.16E-08	11.7541	0.8583	0.8108	50.01	0.63484
35	89.584	1.28E-07	16.205	1.48E-07	19.974	7.4E-08	11.6752	0.8662	0.8113	49.986	0.6775
36	89.54	1.22E-07	16.208	1.41E-07	19.974	7.04E-08	11.6718	0.8658	0.8114	50.013	0.68451
8	93.19	1.38E-07	17.051	1.64E-07	20.7	8.87E-08	11.7372	0.8413	0.8236	49.955	0.69172
34	95.246	1.25E-07	17.548	1.43E-07	21.255	7.05E-08	11.9926	0.8702	0.8256	50.01	0.69257
10	99.773	1.42E-07	18.572	1.67E-07	22.191	8.83E-08	12.1462	0.8492	0.8368	50.007	0.68661
33	101.43	1.26E-07	18.956	1.5E-07	22.637	8.17E-08	12.371	0.8387	0.8374	50.016	0.71805
11	103.92	1.43E-07	19.497	1.6E-07	23.084	7.15E-08	12.3583	0.8939	0.8446	49.983	0.7136
32	107.393	1.31E-07	20.307	1.54E-07	23.889	8.04E-08	12.5849	0.8525	0.85	50.038	0.75099
12	108.394	1.5E-07	20.5	1.69E-07	24.112	7.69E-08	12.6943	0.8901	0.8501	50.001	0.70188
14	113.32	1.61E-07	21.593	1.81E-07	25.253	8.16E-08	13.0949	0.8922	0.855	50.022	0.71224
30	116.217	1.39E-07	22.245	1.61E-07	25.889	8.27E-08	13.2442	0.8588	0.8591	50.025	0.73047
29	116.51	1.27E-07	22.278	1.48E-07	25.92	7.64E-08	13.2501	0.8569	0.8594	49.986	0.73838
31	111.796	1.27E-07	21.264	1.48E-07	24.863	7.66E-08	12.8853	0.8558	0.8552	50.007	0.68381
27	116.855	1.32E-07	22.372	1.54E-07	26.085	7.87E-08	13.4156	0.8588	0.8575	50.004	0.65116
28	116.616	1.38E-07	22.305	1.6E-07	25.951	8.14E-08	13.2629	0.8616	0.8595	49.989	0.7178
25	117.626	1.34E-07	22.51	1.54E-07	26.149	7.72E-08	13.3062	0.8661	0.8608	49.995	0.68305
26	117.281	1.41E-07	22.474	1.65E-07	26.154	8.52E-08	13.3783	0.8563	0.8593	50.028	0.66428
24	118.105	1.33E-07	22.636	1.56E-07	26.247	8.1E-08	13.2841	0.855	0.8624	50.028	0.70864
15	117.724	1.43E-07	22.557	1.62E-07	26.281	7.67E-08	13.4852	0.8806	0.8583	49.998	0.70854
17	125.148	1.39E-07	24.117	1.58E-07	27.102	7.39E-08	12.3634	0.8833	0.8898	49.973	0.71049
23	128.604	1.38E-07	24.837	1.62E-07	27.83	8.32E-08	12.5535	0.8569	0.8925	49.973	0.69337
18	131.51	1.4E-07	25.441	1.6E-07	28.504	7.88E-08	12.853	0.8708	0.8925	49.986	0.69457
19	137.499	1.53E-07	26.659	1.73E-07	29.788	8.15E-08	13.2883	0.8824	0.8949	49.98	0.74904
22	138.19	1.46E-07	26.854	1.66E-07	29.999	7.87E-08	13.3681	0.8798	0.8951	49.989	0.73152
20	141.415	1.54E-07	27.464	1.78E-07	30.643	8.93E-08	13.5887	0.8646	0.8962	49.967	0.73492
21	145.163	1.52E-07	28.24	1.69E-07	31.476	7.4E-08	13.9027	0.8989	0.8971	49.961	0.72406

	EVT	TIME	FLOW mA	FLOW m^3/h	PRESSURE *.01 m	EVT	TIME	FLOW m^3/h	PRESSURES DEL	PRESSURES SUCTION	KW	KVAR	RPM
						-1							
1	0	15:18:00	4	0.0	0,592	0	15:19:00	0	61	6	17.71	19.8	2981
2	1	15:22:00	4.67	10.5		1	15:22:00	11.1	61	6	16.27	20	2981
44	35	16:00:37	4.89	13.9		35	15:00:30	15	61	5	16.18	20.45	2976
3	2	15:22:54	5.5	23.4		2	15:23:00	22.9	61	4.5	14.32	20.25	2977
4	3	15:24:04	6.35	36.7		3	15:24:00	38	61	4	11.86	20.45	2973
6	4	15:25:03	7.35	52.3		4	15:25:00	52.5	60	3.5	8.62	21.25	2968
41	33	15:57:47	7.45	53.9		33	15:57:50	55-56	60.5	2.5	7.96	20.95	2962
37	31	15:56:09	7.48	54.4		31	15:56:00	56	59	1.5	7.87	21.05	2966
39	32	15:56:57	7.51	54.8		32	15:57:00	55-56	60	2	7.87	21.1	2964
42	34	15:58:47	7.52	55.0		34	15:58:50	56-57	60.5	3.1	7.87	21.15	2964
35	29	15:54:03	7.54	55.3		29	15:54:00	55	57	0	7.93	21.05	2962
36	30	15:55:24	7.54	55.3		30	15:55:20	55	58	1	7.93	21.05	2963
8	5	15:25:58	8.03	63.0		5	15:26:00	62.5	60	3	5.98	21.7	2963
34	28	15:53:08	8.14	64.7		28	15:53:10	65	56	-0.3	5.59	21.5	2960
10	6	15:26:52	8.84	75.6		6	15:27:00	72.5	59.5	3	3.82	21.75	2963
33	27	15:52:10	9.1	79.7		27	15:52:00	80	54	-1	3.1	22	2953
11	7	15:27:40	9.35	83.6		7	15:27:40	85	57	3	2.08	22	2961
32	26	15:51:10	9.55	86.7		26	15:51:10	90-94	51	-2	0.85	22.3	2955
12	8	15:28:19	10.3	98.4		8	15:28:20	94	55	2.5	0.55	22.5	2957
14	9	15:29:53	10.36	99.4		9	15:30:00	99-108	53	2	98.66	22.94	2955
30	24	15:48:19	10.4	100.0		24	15:48:20	103	44.5	-4	97.4	22.94	2945
29	23	15:47:28	10.43	100.5		23	15:47:20	104	45.5	-3	97.37	22.89	2946
31	25	15:50:04	10.5	101.6		25	15:50:00	100-108	48	-3	99.05	22.49	2947
27	21	15:45:21	10.56	102.5		21	15:45:15	105	48	-1	97.22	22.99	2947
28	22	15:46:24	10.69	104.5		22	15:46:15	104	46.5	-2.4	97.31	22.89	2946
25	19	15:42:45	10.7	104.7		19	15:42:50	106	50	1	96.92	23.04	2945
26	20	15:44:05	10.75	105.5		20	15:44:00	106	48.5	0	96.98	23.14	2948
24	18	15:41:10	10.8	106.3		18	15:41:10	105	50	1.5	96.8	23.09	2946
15	10	15:32:43	10.87	107.3		10	15:32:45	106.5	50	1.5	97.07	23.39	2951
17	11	15:33:48	11.6	118.8		11	15:33:50	120	45	1	94.28	23.99	2941
23	17	15:39:41	12.1	126.6		17	15:39:45	127	42	0	92.84	24.34	2937
18	12	15:34:49	12.5	132.8		12	15:34:50	134	40	0	91.82	24.84	2939
19	13	15:35:50	13.4	146.9		13	15:35:50	148	34	-1	89.75	25.24	2934
22	16	15:38:44	13.5	148.4		16	15:38:45	148	23	-1	89.45	25.39	2934
20	14	15:36:53	14	156.3		14	15:36:50	158	30	-2	88.31	25.74	2931
21	15	15:37:53	14.6	165.6		15	15:37:50	170	25	-2.5	86.99	26.19	2929

PUMP TEST 5 **2001/10/31**
MARC WUST **FRANCOIS DU PLESSIS**

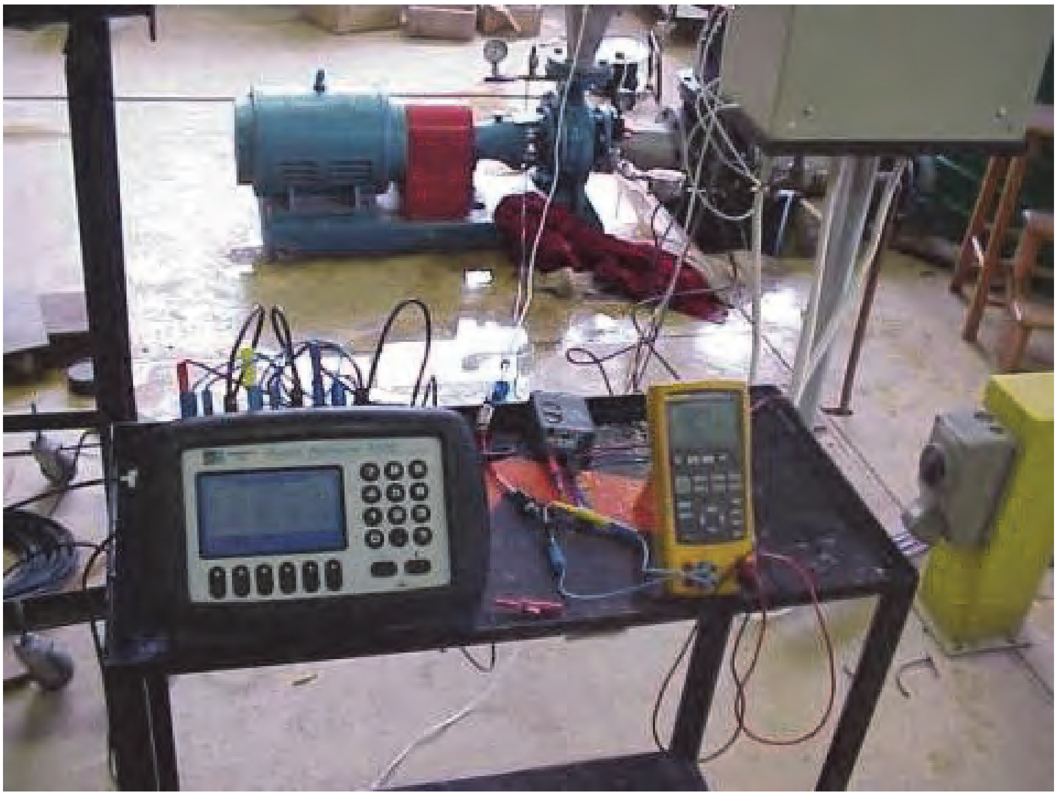
X	CHA Vrms	CHB Vrms	CHC Vrms	CHD Vrms	CHABC Vr	CHA Irms(	CHB Irms(	CHC Irms(	CHD Irms(	CHABC Irr	CHD W(Vo	CHABC W	CHD VA(V	CHABC VA	CHD VAR(	CHABC VA	CHD PF(V	CHABC PF	CHA HZ(V	CHABC Vu	Vloei gemeet(M^3/h,L		WRC mete
2001/10/31 11:45	381.4	379.94	379.53	0.47	379.74	3.6878	3.8337	3.6447	0.001631	11.167	-7.6E-07	2.2277	7.67E-07	2.4197	-1.1E-07	-0.9448	-0.9888	-0.9205	49.98	0.29176	4.64	1.29	2.10
2001/10/31 11:47	381.73	380.65	379.76	0.5202	380.2	3.7143	3.8933	3.7235	0.001642	11.331	-8.4E-07	2.2557	8.54E-07	2.4582	-1.3E-07	-0.9771	-0.9885	-0.9176	50.024	0.26721	5.61	1.56	2.13
2001/10/31 12:07	384.05	384.5	383.62	0.5694	384.05	3.7954	3.8937	3.896	0.001592	11.585	-9E-07	2.3163	9.07E-07	2.5346	-1.4E-07	-1.0294	-0.9882	-0.9138	50.04	0.11405	6	1.67	2.19
2001/10/31 12:07	384.24	384.64	383.74	0.5688	384.19	3.7943	3.9069	3.8908	0.001642	11.591	-9.2E-07	2.3169	9.34E-07	2.5327	-1.5E-07	-1.0232	-0.9872	-0.9147	50.04	0.12102	6	1.67	2.19
2001/10/31 11:48	379.92	379.15	377.84	0.7374	378.49	3.9457	4.1813	3.9733	0.001572	12.1	-1.1E-06	2.3459	1.16E-06	2.59	-2.2E-07	-1.0974	-0.9825	-0.9058	49.98	0.29714	7.64	2.12	2.31
2001/10/31 11:51	379.85	378.89	377.79	0.9598	378.33	4.2072	4.4035	4.1811	0.001533	12.791	-1.4E-06	2.4476	1.47E-06	2.7308	-2.6E-07	-1.2107	-0.9843	-0.8962	49.992	0.27749	9.39	2.61	2.43
2001/10/31 12:04	382.48	381.73	381.07	0.9108	381.4	4.2039	4.3402	4.154	0.001587	12.698	-1.4E-06	2.4592	1.45E-06	2.7411	-2.5E-07	-1.2106	-0.9854	-0.8971	50.02	0.19125	8.96	2.49	2.46
2001/10/31 12:04	382.36	381.47	380.86	0.9087	381.17	4.2079	4.3413	4.1522	0.001602	12.701	-1.4E-06	2.4621	1.46E-06	2.7432	-2.4E-07	-1.2094	-0.9865	-0.8975	50.016	0.2109	8.96	2.49	2.46
2001/10/31 12:01	383.82	383.77	382.45	1.1166	383.11	4.3363	4.5149	4.3638	0.001524	13.215	-1.7E-06	2.5513	1.7E-06	2.8494	-2.9E-07	-1.2689	-0.9852	-0.8953	49.952	0.23239	10.75	2.99	2.58
2001/10/31 11:52	380.74	380.27	379.01	1.1138	379.64	4.4851	4.6981	4.4819	0.00162	13.665	-1.8E-06	2.5828	1.8E-06	3.0331	-2.7E-07	-1.5903	-0.9885	-0.8514	50.065	0.26537	10.77	2.99	2.70
2001/10/31 11:52	381.14	380.62	379.41	1.1132	380.02	4.4977	4.6944	4.4865	0.001595	13.678	-1.8E-06	2.5892	1.78E-06	3.0418	-3E-07	-1.5964	-0.986	-0.8512	50.065	0.25912	10.77	2.99	2.70
2001/10/31 12:03	380.53	379.31	378.52	1.4742	378.91	4.8241	4.9942	4.7171	0.00156	14.535	-2.3E-06	2.7163	2.3E-06	3.2128	-4E-07	-1.7155	-0.9844	-0.8455	50.008	0.28313	13.85	3.85	2.91
2001/10/31 11:53	379.03	378.7	377.21	1.5172	377.95	4.8395	5.0523	4.8499	0.001583	14.742	-2.4E-06	2.7337	2.4E-06	3.2398	-4E-07	-1.7387	-0.9862	-0.8438	50.028	0.29369	14.22	3.95	2.94
2001/10/31 12:06	380.16	380.72	379.29	1.5355	380.02	4.8929	5.0394	4.9448	0.001521	14.878	-2.3E-06	2.7728	2.33E-06	3.292	-3.9E-07	-1.7745	-0.9858	-0.8422	49.976	0.20197	14.36	3.99	3.03
2001/10/31 11:54	379.81	379.24	377.35	1.6814	378.3	5.083	5.362	5.1016	0.00155	15.547	-2.6E-06	2.8628	2.61E-06	3.4111	-4.3E-07	-1.8546	-0.986	-0.8392	49.98	0.38189	15.61	4.34	3.15
2001/10/31 11:55	381.21	380.6	378.94	1.8951	379.78	5.3165	5.5687	5.2924	0.001585	16.177	-3E-06	2.9695	3E-06	3.5593	-5.2E-07	-1.9623	-0.985	-0.8342	50	0.34697	17.44	4.84	3.30
2001/10/31 12:02	380.32	378.93	378.61	2.0185	378.77	5.5113	5.6702	5.3574	0.001601	16.539	-3.2E-06	3.0162	3.23E-06	3.6291	-5.4E-07	-2.0181	-0.9861	-0.8311	50.012	0.2687	18.51	5.14	3.36
2001/10/31 12:02	380.32	378.65	378.59	2.0201	378.63	5.5367	5.6813	5.3465	0.001622	16.565	-3.2E-06	3.0175	3.28E-06	3.635	-5.6E-07	-2.0267	-0.9854	-0.8301	50.016	0.29884	18.51	5.14	3.36
2001/10/31 11:56	381.03	380.72	378.82	2.0169	379.76	5.4352	5.7063	5.4425	0.001581	16.584	-3.1E-06	3.0274	3.19E-06	3.6427	-5.4E-07	-2.0259	-0.9854	-0.8311	50.036	0.35895	18.45	5.13	3.39
2001/10/31 11:56	381.03	380.72	378.82	2.0169	379.76	5.4352	5.7063	5.4425	0.001581	16.584	-3.1E-06	3.0274	3.19E-06	3.6427	-5.4E-07	-2.0259	-0.9854	-0.8311	50.036	0.35895	18.45	5.13	3.39
2001/10/31 12:08	379.52	380.06	378.73	2.0497	379.38	5.5016	5.6496	5.4994	0.001614	16.651	-3.3E-06	3.028	3.31E-06	3.6531	-5.2E-07	-2.0437	-0.9877	-0.8289	50.004	0.18773	18.82	5.23	3.39
2001/10/31 11:57	381.21	381.47	379.62	2.1924	380.56	5.5884	5.828	5.6133	0.001593	17.029	-3.4E-06	3.1009	3.49E-06	3.744	-6.1E-07	-2.098	-0.9844	-0.8281	50.032	0.3052	20.09	5.58	3.48
2001/10/31 12:05	379.24	377.71	378.05	2.2801	377.88	5.8036	5.8744	5.5434	0.001611	17.221	-3.6E-06	3.1059	3.67E-06	3.7679	-6.2E-07	-2.1331	-0.9855	-0.8242	50.028	0.24092	20.76	5.77	3.54
2001/10/31 11:58	381.12	381.12	379.34	2.3483	380.23	5.7153	5.9483	5.7033	0.001565	17.367	-3.6E-06	3.1521	3.68E-06	3.8159	-5.9E-07	-2.1502	-0.9868	-0.826	50	0.31052	21.49	5.97	3.57
2001/10/31 12:09	378.09	377.48	376.71	2.3982	377.09	5.8764	6.02	5.7574	0.00157	17.654	-3.7E-06	3.1634	3.77E-06	3.849	-6.3E-07	-2.1925	-0.9857	-0.8218	50.032	0.19008	21.82	6.06	3.60
2001/10/31 12:00	380.23	380.25	378.24	2.3792	379.24	5.7519	6.0112	5.7585	0.001536	17.522	-3.6E-06	3.169	3.65E-06	3.8389	-6.6E-07	-2.1667	-0.9835	-0.8254	49.928	0.35147	21.63	6.01	3.57
2001/10/31 11:59	380.49	380.34	378.42	2.3543	379.38	5.7591	6.0263	5.744	0.00156	17.529	-3.6E-06	3.1692	3.67E-06	3.8405	-5.9E-07	-2.1693	-0.9868	-0.8252	49.98	0.35122	21.4	5.94	3.60

APPENDIX B

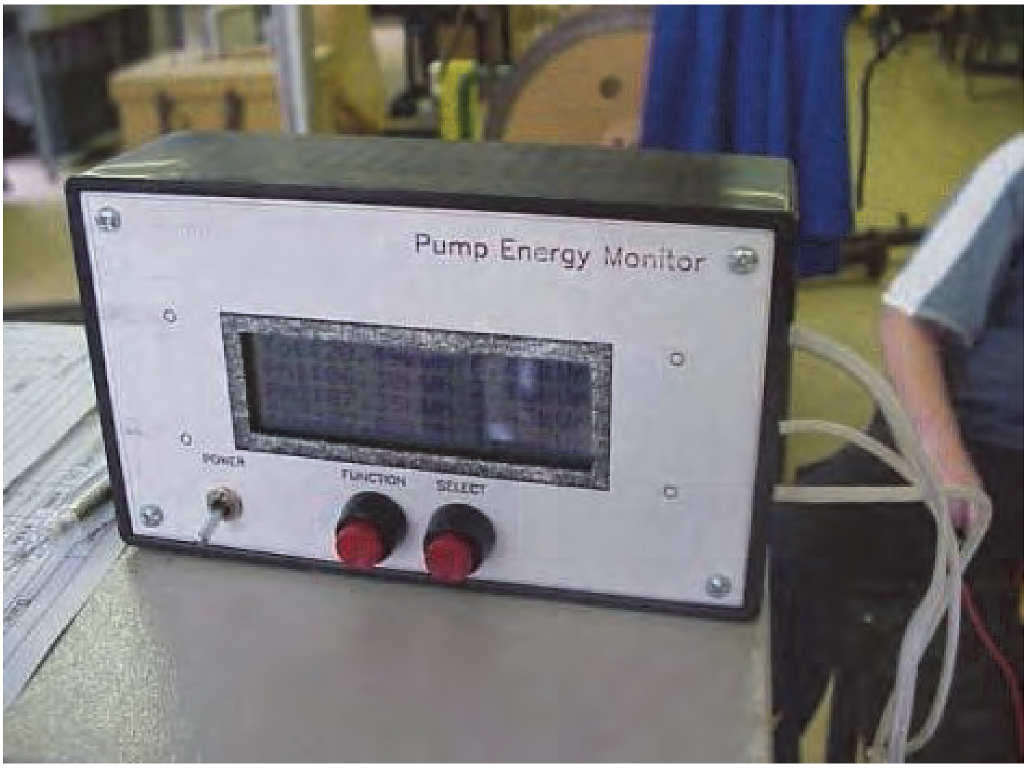
PHOTOGRAPHS

Picture 1: Laboratory installation

Picture 2: Water-meters used in laboratory: Mechanical for high flow-rates and magnetic for low flow-rates.

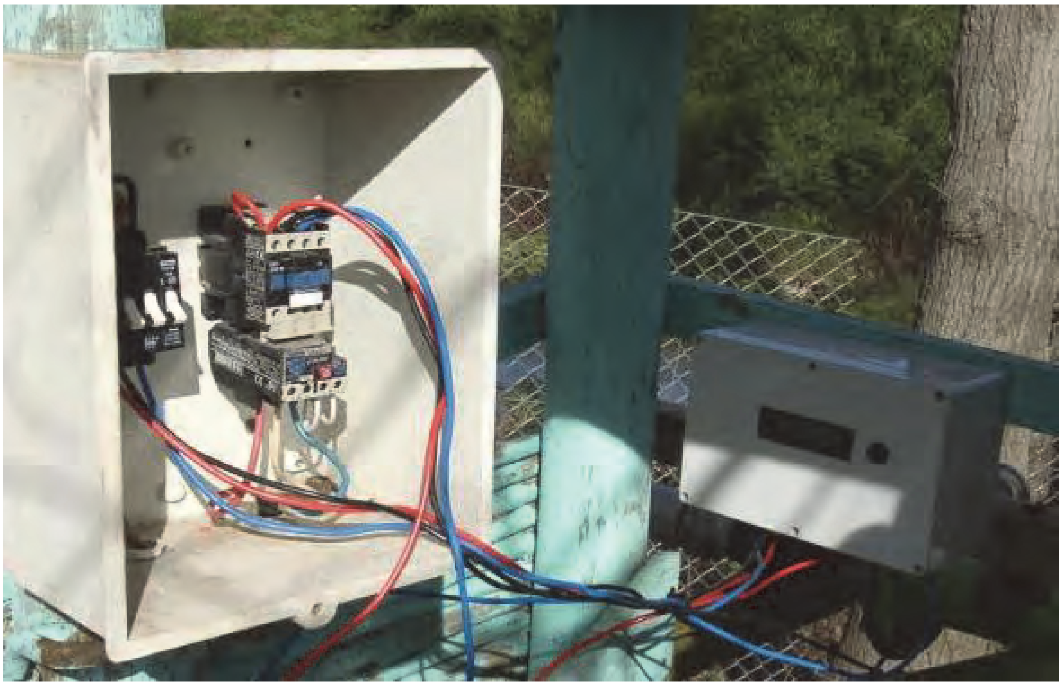


Picture 3: Power platform for measuring electrical supply in laboratory



Picture 4: First proto-type meter used in laboratory

Picture 5: Proto-type meter developed for field tests



Picture 6: Typical field installation (< 50 kW): CTr's inside meter

Picture 7: Prototype meter for larger installations (> 50 kW): CTr's outside meter

APPENDIX C

TYPICAL OUTPUT OF DRANETZ POWER PLATFORM

DRAN-VIEW - [TEST3B DNV:2]

File Edit View Tools Settings Window Help

#17 11:24:18.000 Meter mode snapshot

	X	CHA Vrms (Volts)	CHB Vrms (Volts)	CHC Vrms (Volts)	CHA Irms (Amps)	CHB Irms (k)	CHC Irms (k)	CHABC W (Volts)	CHABC VA (Volts)	CHABC VAR (Volts)	CHABC PF (Volts)	CHA HZ (Volts)
0	07/06/2001 10:58:40.000	381.36	384.54	383.05	20.689	23.503	23.796	10.644	15.222	10.8834	0.6991	50.007
1	07/06/2001 11:01:07.000	380.04	383.06	381.77	21.280	24.062	24.292	11.186	15.538	10.7836	0.7200	49.985
2	07/06/2001 11:02:18.000	379.75	382.92	381.61	21.163	23.961	24.265	11.128	15.471	10.7486	0.7192	49.961
3	07/06/2001 11:03:55.000	380.72	383.68	382.34	21.682	24.490	24.642	11.506	15.826	10.8677	0.7269	50.028
4	07/06/2001 11:05:13.000	380.30	383.37	382.10	22.854	25.773	25.929	12.468	16.647	11.0315	0.7489	49.992
5	07/06/2001 11:06:25.000	380.01	383.01	381.68	24.374	27.518	27.445	13.710	17.710	11.2111	0.7740	50.010
6	07/06/2001 11:14:24.000	381.38	384.44	382.63	25.411	28.859	28.335	14.485	18.519	11.5422	0.7820	50.019
7	07/06/2001 11:16:01.000	383.32	386.66	384.83	26.872	30.577	30.068	15.601	19.727	12.0723	0.7908	49.985
8	07/06/2001 11:17:15.000	384.31	387.56	386.01	28.627	32.297	31.898	16.852	20.980	12.4963	0.8032	49.988
9	07/06/2001 11:22:23.000	381.05	384.49	382.98	30.776	34.730	34.224	18.528	22.368	12.5322	0.8282	49.958
10	07/06/2001 11:24:18.000	380.60	383.82	382.13	33.792	37.935	36.986	20.605	24.412	13.0885	0.8440	49.998
11	07/06/2001 11:26:04.000	380.72	383.92	382.08	33.767	37.978	36.886	20.591	24.418	13.1227	0.8433	50.004
12	07/06/2001 11:27:22.000	380.44	383.44	381.82	33.817	37.850	36.844	20.567	24.351	13.0333	0.8446	50.016
13	07/06/2001 11:27:22.000	380.44	383.44	381.82	33.817	37.850	36.844	20.567	24.351	13.0333	0.8446	50.016
14	07/06/2001 11:29:10.000	380.34	383.61	381.94	33.567	37.767	36.841	20.500	24.270	12.9896	0.8446	50.043
15	07/06/2001 11:30:55.000	380.15	383.42	381.91	33.504	37.593	36.844	20.440	24.208	12.9720	0.8442	50.010
16	07/06/2001 11:30:55.000	380.15	383.42	381.91	33.504	37.593	36.844	20.440	24.208	12.9720	0.8442	50.010
17	07/06/2001 11:32:35.000	380.56	383.70	382.22	33.440	37.468	36.681	20.363	24.154	12.9921	0.8430	50.010
18	07/06/2001 11:32:36.000	380.56	383.70	382.22	33.440	37.468	36.681	20.363	24.154	12.9921	0.8430	50.010
19	07/06/2001 11:33:52.000	380.15	383.20	381.81	33.493	37.471	36.521	20.360	24.094	12.8870	0.8448	50.037
20	07/06/2001 11:33:53.000	380.04	383.06	381.49	33.504	37.501	36.571	20.377	24.114	12.8940	0.8450	50.034
21	07/06/2001 11:35:15.000	379.82	382.89	381.39	33.426	37.373	36.524	20.315	24.036	12.8476	0.8451	50.028
22	07/06/2001 11:35:15.000	379.82	382.89	381.39	33.426	37.373	36.524	20.315	24.036	12.8476	0.8451	50.028
23	07/06/2001 11:36:43.000	380.23	383.25	381.87	33.385	37.254	36.503	20.268	24.013	12.8765	0.8440	50.013
24	07/06/2001 11:38:19.000	380.27	383.15	381.56	33.418	37.336	36.340	20.274	24.006	12.8556	0.8446	50.034
25	07/06/2001 11:38:20.000	380.27	383.15	381.56	33.418	37.336	36.340	20.274	24.006	12.8556	0.8446	50.034
26	07/06/2001 11:39:30.000	380.32	383.23	381.72	33.354	37.239	36.319	20.229	23.971	12.8599	0.8439	50.031
27	07/06/2001 11:41:35.000	380.72	383.44	382.20	32.436	36.028	35.325	19.519	23.271	12.6689	0.8387	50.034
28	07/06/2001 11:41:35.000	380.75	383.42	382.17	32.447	36.041	35.310	19.526	23.273	12.6636	0.8390	50.034
29	07/06/2001 11:42:39.000	381.93	384.89	383.53	31.413	35.081	34.423	18.860	22.688	12.6119	0.8312	50.066
30	07/06/2001 11:42:39.000	381.93	384.89	383.53	31.413	35.081	34.423	18.860	22.688	12.6119	0.8312	50.066
31	07/06/2001 11:43:49.000	382.04	385.09	383.50	30.207	33.911	33.198	18.027	21.871	12.3850	0.8242	50.065
32	07/06/2001 11:44:58.000	382.07	385.06	383.38	29.162	32.817	32.088	17.238	21.128	12.2159	0.8158	50.019
33	07/06/2001 11:44:58.000	382.07	385.06	383.38	29.162	32.817	32.088	17.238	21.128	12.2159	0.8158	50.019
34	07/06/2001 11:45:48.000	383.27	385.94	384.38	27.928	31.286	30.596	16.214	20.222	12.0837	0.8018	50.043
35	07/06/2001 11:45:48.000	383.27	385.94	384.38	27.928	31.286	30.596	16.214	20.222	12.0837	0.8018	50.043
36	07/06/2001 11:46:36.000	383.27	386.21	384.58	25.824	29.168	28.671	14.691	18.832	11.7823	0.7800	50.043
37	07/06/2001 11:47:12.000	383.67	386.52	384.85	24.726	27.915	27.523	13.782	18.059	11.6693	0.7631	50.013

For Help, press F1

Start | Exp... | Cor... | Mic... | Tes... | Fin... | Inb... | D... | Wingate | 1:08 PM

Date 07/22/2003 12:45:34 Page 1
Issued by
File TEST4.X

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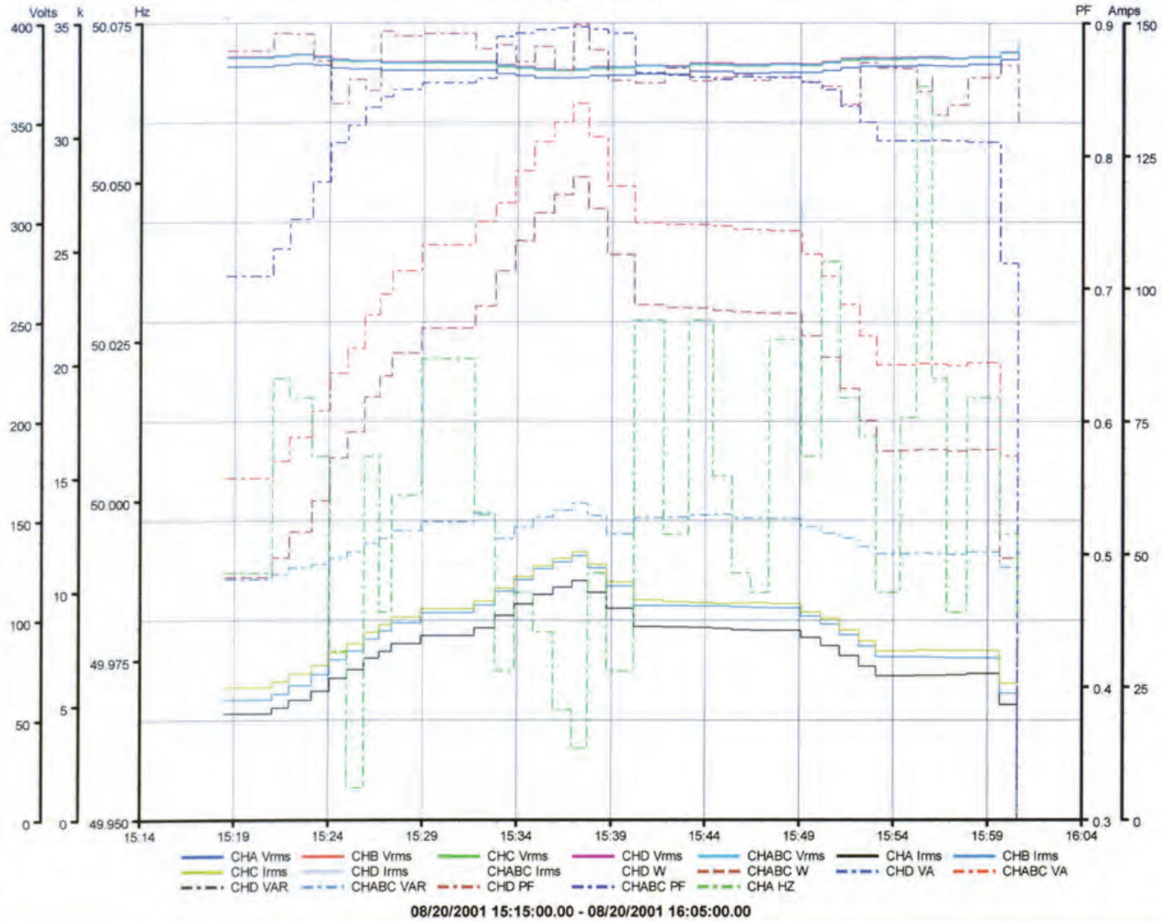
Timeplot chart



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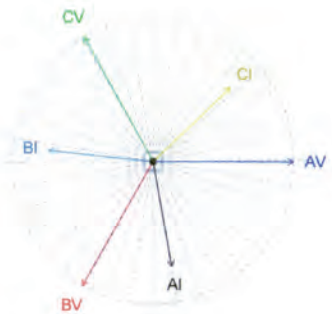
CHABC Vrms	390.31	16:01:34
CHA Irms	45.04	15:37:54
CHB Irms	49.74	15:37:54
CHC Irms	50.38	15:37:54
CHD Irms	0.00	15:21:59
CHABC Irms	145.16	15:37:54
CHD W	0.00	15:29:53
CHABC W	28.24	15:37:54
CHD VA	0.00	15:25:03
CHABC VA	31.48	15:37:54
CHD VAR	0.00	15:25:03
CHABC VAR	13.90	15:37:54
CHD PF	0.90	15:37:54
CHABC PF	0.90	15:37:54
CHA HZ	50.07	15:56:09

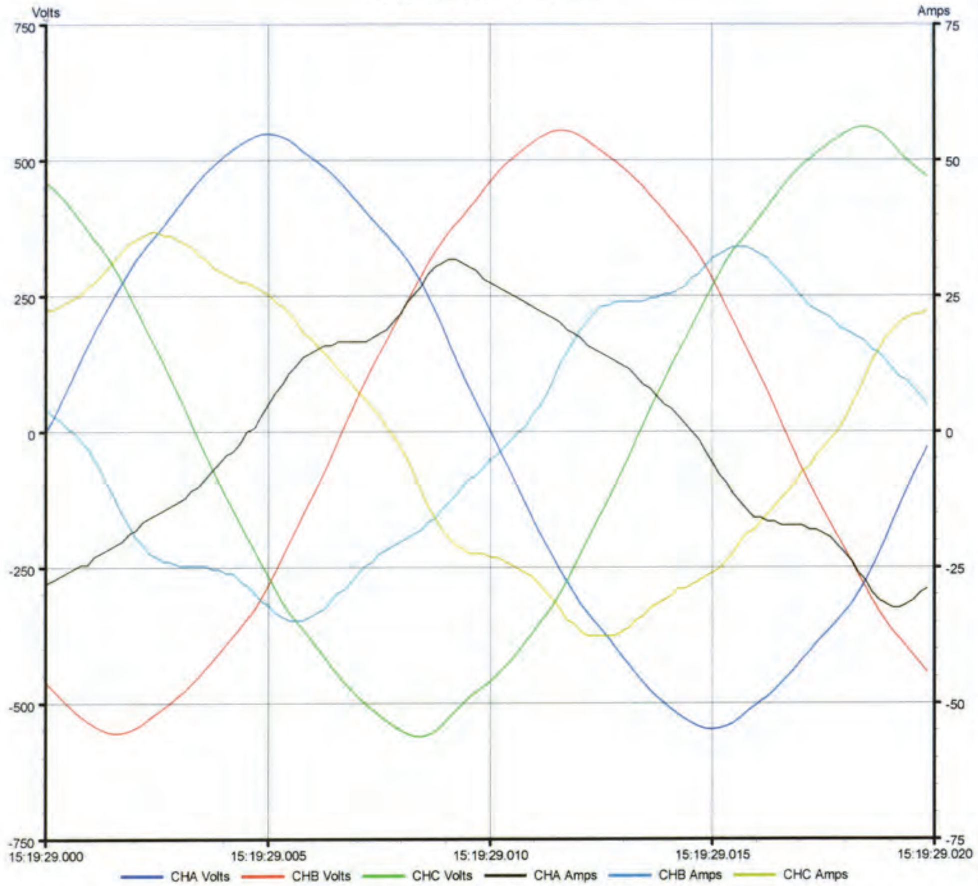
Version 4.0

DRANETZ BMI	Header ...	Date 07/22/2003 12:46:34 Page 1 Issued by File TEST4.X



10 deg/division
AV=359°, BV=240°, CV=119°,
AI=280°, BI=174°, CI=43°

Event waveform/detail



Meter mode snapshot at 08/20/2001 15:19:29.000

Version 4.0

APPENDIX D

ADDITIONAL WORK DONE AFTER FINAL PROJECT MEETING

1. INTRODUCTION

The positive results of the 40 months project were somewhat clouded by the problems encountered by two of the five proto-type meters. The reasons for the failing of the meters appeared to be of a technical nature, and not because of the concept that was researched.

The final project meeting was held in August 2003. The draft final report included a number of recommendations about proposed follow-up work. Amongst these recommendations were limited further researches to establish the reasons why the proto-type meters failed at the Modder River and Stellenbosch sites.

The steering committee supported this recommendation at the mentioned meeting, and Item 4.6 of the minutes of this meeting suggests that the project leader should approach the WRC with a proposal.

A proposal was made to, and approved by the WRC. It was considered worthwhile to make an additional relatively small investment to establish the reasons for the failures experienced, and to include the findings in the final project report. This would add value to the existing project and will allow for sooner implementation of the project outcomes.

The approved proposal to the WRC provided for the following deliverables:

- Identification of possible defects in the proto-type meters.
- Investigation of the quality of electricity supply to the site (relevant electrical parameters which may have an affect).
- Identification of possible defects with mechanical meters that could cause the "false" readings.
- Drawing of conclusions from findings.
- Put forward proposals to eliminate the problems that were experienced.

2. ADDITIONAL RESEARCH WORK CARRIED OUT

2.1 Methodology

At each of the two test sites (or proto-type meters) a further series of tests were carried out with the Dranetz Power Platform. This comprised of continuous observations while simultaneously taking readings from the proto-type meters. The objective of this exercise was to establish the quality of electricity supply to both sites, and whether any events could be detected which may have led to the failures which were experienced.

An additional 11 meters were also installed during this time at pump stations in the Rietrivier area. Based on the calibrations and further monitoring of these meters a number of important observations were done which contributed to the findings of the additional research work.

The additional work was carried out over a period of 6 months, starting in October 2003.

2.2 Findings

2.2.1 Quality of electricity supply

Variations in the supply voltage to the pumping installation can cause serious damage to electrical components if these variations exceed the maximum allowable tolerances. For both sites the supply voltage were logged for a 10-hour period. Although the supply voltage varied, this variation could not have contributed to the damage to the meters. The measured voltage and current harmonics never exceeded +/-5%.

At the Modder River site another pump on the farm that also receives electricity from the same transformer was started in order to establish whether significant variations in the supply voltage could be simulated in the system. It was also found under these conditions that the variations did not exceed the allowable tolerances.

For both installations the meters remained installed at the sites to make further monitoring possible. Both meters continued to function well. The correlation between the magnetic meter and the electronic meter at the Stellenbosch site remained consistent, whereas at the Modder River site the mechanical meter gave unreliable readings and therefore there were no reference meter available for the comparison of data.

The occurrence of the loss of one of the electrical phases (which could result in high currents in the remaining phases) was discussed with the farmer at the Modder River site. He confirmed the occasional occurrence of these events, one of which did take place approximately at the same time as when the meter was damaged. The reason for this event was that a tree fell on the overhead electrical supply line.

Simulations were then performed in the laboratories at the Cape Technikon. The simulations used a three phase delta-star connected transformer and a three-phase delta connected motor without load. The result showed that there was a 16% increase in current in two of the phases. It is important to note that a much greater increase is expected for a motor with a load. This increase in current could cause the shunt resistors to overheat, resulting in the damage seen in the CTr (blackened resistor and rusting of the core at the location of the shunt resistor).

Further evidence of damage to the meters became known when the 11 meters were installed in the Riet River area. Very soon after the first meter was installed, important electronic components inside were destroyed by lightning. It was relatively easy to determine the cause of the damage in the laboratory of the Cape Technicon.

2.2.2 Conclusions

Based on the findings of the additional work done the project team could (with reasonable certainty) draw the conclusion that faulty readings obtained from the electronic meters were the result of damaged components in the meter. This damage was caused by unforeseen events in the electrical supply system, and not the result of poor quality electricity supply by Escom. Intentional damage by removing one of the phases is unlikely since this can also result in severe damage to the electrical motor.

2.2.3 Recommendations

The project team considered different mechanisms that can be used to protect the meter against damage of this nature and came up with possible solutions in this regard. It firstly needs to be equipped with lightning protection, and secondly installed in such a way that it switches the pump off as soon as it senses a power surge or a lost phase. This will not only protect the meter, but also the electric motor that drives the pump. The additional cost involved with these two alterations is approximately R 400 per meter.

In order to reduce temperature build-up in the instrument, the CTr's were removed from the plastic housing. The size of the CTr shunt resistors were also increased and these improvements had the desired effect. The additional cost with regard to these changes is negligible.

During this period further thoughts were given to the reliability of the hardware of the meter in order to ensure that it is acceptable as an alternative for reliable water metering. This led to a limited survey being performed on accredited affordable instrumentation with acceptable accuracy already being used in this field. The survey showed that such instrumentation does indeed exist and are used to monitor the quality of power supply in different applications.

It was concluded that making use of this technology is a viable option, and further discussions are presently taking place to determine the needs for such a development. Basically the concept will be to add a relative simple piece of electronic equipment (electric circuitry with a programmable processor to accommodate the look-up table) to an existing meter. The existing meter provides for downloading of the information to computer through direct communication or via modem. Some of these meters are highly accurate (measuring errors of less than +/- 1 %), and for the purpose applied, gathers a large quantity of useful information. This includes information that can be used by the farmer, or service provider, for improved electric bill management. With the look-up table added to the instrument, comprehensive information will be available on the continuous abstraction rate of the pump, obviously also including peak flow-rates, which are important for bulk water supply management. The commercially available instrument also contains build-in protection features, as well as features to limit tampering with the meter. Together with the programmable circuitry further protection of the supply system can be built in to switch the pump off under certain conditions, e.g. conditions of no and high flows, dangerous voltage surges, etc.,

Finality has not yet been reached about the cost of the electronic water meter when making use of commercially available metering equipment, but indications are that it will be more expensive. However, if the cost of further development to have the original instrument approved by an accredited organization is taken into account, over time this difference in cost will become less significant.