Developing an Effective Irrigation Water-Use Meter

MAF Policy Technical Paper 00/11

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Disclaimer

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Foreword

This is one of a series of 10 technical bulletins, which report the detail of projects commissioned by MAF Policy on sustainable irrigation.

This work arises as part of MAF's contribution towards Government's "Sustainable Land Management Strategy."

The projects in this series broadly divide into two groups, technical irrigation design factors and management factors. A key issue identified by farmers at the onset of this work was that to ensure irrigation could operate in sustainable ways physically and for the environment, it also had to be profitable irrigation.

The emphasis on water use efficiency and cost effectiveness of plant and management, which has arisen from this, has been developed throughout the research. It is clear that win/win situations are possible. Improvements for both environmental and farm profitability objectives can be achieved.

More efficient ways of monitoring and managing water use on farms are described in the series.

There is a large amount of base data and technical information in these papers which is likely to be helpful background for designers, consultants and local and regional authorities.

Much of this information is also being incorporated into a simpler National Irrigation Handbook. This is being designed as a ready reference for farmers and commercial firms, and will be available in 2001.

An overall summary of the technical reports in this series and copies of the reports themselves can be obtained from: Information Bureau, Ministry of Agriculture & Forestry,
PO Box 2526, Wellington.

A B Walker
Director
Policy Information & Regions

The other technical bulletins in this series are:-

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Summary

This project was initiated to develop a prototype irrigation water use meter that could be easily installed and used with reliable results on all types of pressurised irrigation systems. The development of this meter was required to significantly increase the applicability and value to agriculture of indicators of sustainable irrigation and the adoption of best management practices currently being developed through MAF Operational Research Project contracts.

Six of the sixteen economic and environmental indicators of sustainable irrigation recommended in MAF Policy Technical Paper 00/03 have water use as one of their components. To calculate these indicators, each day the total volume of water used on a farm for irrigation and the rate at which it is taken must be measured.

It became apparent during testing of the Best Management Guidelines (MAF Policy Technical Paper 00/03), that installation of readily available flow meters at reasonable cost was rarely possible. A recent study by Canterbury Regional Council in the Christchurch-West Melton district (McEwan et al., 1998) confirmed this finding.

There was an urgent need for a flow meter that was robust, easy to install, farmer friendly with simple user controls, and low cost. A flow meter that uses a pressure measurement (which is relatively easy to make) to calculate the flow rate (which is much more difficult to measure), was proposed. Lincoln Environmental was contracted by MAF Policy to develop a prototype meter.

The meter was constructed with a good quality, watertight case to ensure robustness. Installation is very easy, as it can be connected into a system anywhere a pressure tapping is available. The user interface is simple, and should be able to be operated by farmers given limited written instructions. Battery life has been calculated to last for a typical irrigation season. The meter has been designed so that the retail price, including the pressure sensor, is expected to be less than $1000.

The meter is currently undergoing field testing on a frost protection irrigation system, and other than some minor software problems, has performed to specification. These small problems will be rectified and at the beginning of the irrigation season (October 1998), the meter will be installed on an irrigator for further testing.

As we are confident that the prototype meter will fill the need identified, another two meters will be constructed for use on the 1998/99 MAF Policy project to further test the Best Management Guidelines and to calculate the Indicators of Sustainable Irrigation.

1 Introduction

1.1 BACKGROUND

Within its responsibility of providing policy advice to Government, MAF Policy has identified the need to:

"Promote sustainable farm and orchard management planning including collaborative development of best management practice guidelines, and to provide environmental indicators or reporting systems for monitoring soil quality, water quality, air quality, biodiversity and energy use."

Within the objective of facilitating resource management there is a need to promote sustainable irrigation, and an Operational Research Programme has been formulated to meet this need. A program was designed with the aim of developing procedures that lead to sustainable irrigation and to have those procedures adopted and used by the New Zealand farming industry.

A study to develop a set of indicators that farmers could use to monitor the sustainability of their irrigation management practices was funded by MAF Policy (MAF Policy Technical Paper 00/03). This study was followed by the development of best management guidelines for sustainable irrigated agriculture. (MAF Policy Technical Paper 00/05).

Following on from this, two projects, the first to test the measurement and use of the Indicators and the second to test the use of the Guidelines, were implemented. The first project was completed by Agriculture NZ (MAF Policy Technical Paper 00/04), and Lincoln Environmental completed the second (MAF Policy Technical Paper 00/06).

1.2 RELEVANCE OF FLOW TO INDICATORS AND GUIDELINES

To enable the indicators to be calculated and the Best Management Guidelines to be used efficiently, both depths of water applied and soil moisture status must be determined throughout the season. This is a fundamental requirement of the process. Without being able to realistically determine both of these components, the process is of limited use.

Six of the sixteen economic and environmental indicators of sustainable irrigation recommended in MAF Policy Technical Paper 00/03 have water use as one of their components. Examples are production/m^3 of water used, energy used per m^3 of water pumped, and daily percentage of water flowing onto the farm that is stored in the root zone.

To calculate these indicators, each day the total volume of water used on a farm for irrigation and the rate at which it is taken must be measured. This enables total seasonal volumes and depths of water applied to be calculated. Without flow measurements, the key indicators of sustainable irrigation cannot be determined.

Traditionally, application depths have been estimated using data supplied from irrigator or sprinkler manufacturers, but this practice is compromised by:

- Pressure fluctuations in the water supply line;
- Poor data relating to travel/rotation speed of broad-acre irrigation systems and their running time;
- Poor data on the "as-installed" hydraulic characteristics of the irrigation system.

The best way to accurately calculate water use is to measure it with a flow meter.

1.3 FLOW MEASUREMENT

Totalising flow meters are used for measurement of irrigation water use in limited numbers in some areas of New Zealand, mainly in horticultural areas where irrigation systems tend to be relatively small. They are generally installed at the water supply or pump headworks. Their primary purpose is to provide information on water use to regional councils for resource management.

Typically, these flow meters require lengths of straight pipe equivalent to 8-10 diameters upstream and 4-6 diameters downstream of the meter for accurate readings. On a system using 200 mm diameter pipe, this means that approximately three metres of straight pipe is required. Shorter lengths of straight pipe expose the meters to turbulence, which makes them inaccurate.

When inspecting the irrigation systems of farms for the testing the Best Management Guidelines (MAF Policy Technical Paper 00/06), it was found that none of the irrigation systems on the farms visited were designed in a way that allowed installation of readily available flow meters at reasonable cost. The extent of this problem was not known before the project started. A recent study by Canterbury Regional Council in the Christchurch-West Melton district (McEwan et al., 1998) found that only 15% of installations were suitable for monitoring using a portable ultrasonic flow meter, particularly at system headworks (the pipework at the beginning of the system). A much smaller percentage of those sites were suitable for permanent flow meter installations.

Generally, only newer installations of irrigation system headworks have the required length of straight pipe. In most of the older systems, the mainline has an elbow immediately downstream of the gate valve, and often the mainline will branch out immediately at a tee underground below the elbow. To convert the headworks to allow a flow meter to be correctly installed, particularly on the larger systems, could be quite an extensive and costly exercise.

Although the general thinking by water managers such as regional councils is that the flow should be measured at the pump or the system headworks, this approach is more suited to resource management than to irrigation management. For irrigation management, flow should be measured at each irrigator or block, so that the amount of water applied to a specific area can be determined, regardless of the number of irrigation units or pumps on the system. In fact, the only time that measuring flow at the pump can be recommended for irrigation management is when there is only one pump and one irrigator on the system, and the flow out of the pump equals the flow out of the irrigator.

In addition to providing useful data for irrigation management, measuring flow on irrigators rather than system headworks has an additional benefit. In districts where water is not currently metered, there is little public support among the farming community to monitor water usage, because putting in flow meters is seen as the first step towards charging for water. Measuring flow at irrigators is seen as one step removed from the resource monitoring process, and is likely to be more easily accepted by farmers.

Unfortunately, installing flow meters on irrigation machinery is not as simple as it may appear. Travelling irrigators, for example, are not constructed in a way that allows easy installation of flow meters. Two problems arise. The first is that there is almost never a section of straight pipe on the machines long enough to install a meter correctly. The second is that most meters cannot be installed where they will be subjected to excessive forces (such as at the back of an irrigator). This makes installation of standard in-line meters on travelling irrigators difficult, and in many cases, impractical.

An extensive exercise to try to find practical and cost-effective solutions to the flow measurement problem was carried out. After all options were considered, it was decided that monitoring pressure rather than flow, and calibrating for flow would be the most suitable method, as it would not require any infrastructural changes. Pressure sensors are relatively inexpensive, and are easy to install, either at system headworks or on irrigators.

Although pressure can be measured using pressure sensors, additional equipment is needed to record the pressures, and calibration to calculate the flow from the pressure measurements must be carried out. The lack of a suitable commercially available product that could measure pressure and record flow rate or volume of water used led to the need for this project.

2 Objective of Project

This project was initiated to develop a prototype irrigation water use meter that could be easily installed and used with reliable results on all types of pressurised irrigation systems. The development of this meter was required to significantly increase the applicability and value to agriculture of irrigation performance measures currently being developed through MAF Operational Research Project contracts.

3 Description of Flow Meter

3.1 GENERAL FARMER NEEDS

To ensure the meter would meet farmer's needs, a number of basic requirements had to be met. These were:

- very robust;
- easy to install;
- battery-powered with a one-season battery life;
- battery change-over could occur without loss of stored data;
- waterproof;
- lightning protected;
- farmer friendly with simple user controls, and
- low cost.

In terms of output, the meter was required to provide on-demand visual display of:

- current pressure;
- current flow rate;
- accumulated volume.

3.2 BASIC CONCEPT

The fundamental concept of the proposed flow meter is to use a pressure measurement (which is relatively easy to make) to calculate the flow rate (which is much more difficult to measure). The task of developing a satisfactory relationship between flow and pressure for the particular irrigator that the meter is fitted to is central to this concept. For the majority of irrigation machines, this relationship will be easily obtained by a simple field calibration, and as many machines use standard nozzle configurations, the information will be transferable to many farms. Equipment suppliers could easily provide the information to farmers. For more unique situations, a specific field calibration for that situation will be required.

3.3 HYDRAULIC CONSIDERATIONS

In terms of hydraulic considerations, the four factors considered in the development of the flow meter were:

- The desirable level of accuracy for both total accumulated flow and the current flow rate;
- The appropriate sampling interval used to interrogate the pressure sensor;
- The appropriate time period used to update the accumulated total volume, and
- The most appropriate form of the flow – pressure relationship used to transform the pressure readings into a flow rate.

For the initial development of the flow meter the following approaches to these issues were adopted.

3.3.1 Accuracy

The intended use for the proposed device is to aid farmers in the management of their irrigation systems. For this purpose an accuracy of plus or minus 5% for both total volume and current flow rate was considered to be adequate (for a total application depth of say 50 mm this would represent an accuracy to a depth of 2.5 mm).

3.3.2 Sampling Interval

Sampling interval relates to how often the software has to activate the pressure sensor and to make a reading. Choice of a suitable sampling interval has a considerable impact on the design of the proposed flow meter and on the resulting accuracy of the system. In particular it has a significant bearing on the overall power requirements and battery life.

The most appropriate interval is governed to a large extent by the expected deviation and rate of change of irrigator operating pressures. In all systems, the biggest deviation that will be experienced will be under start-up and shutdown conditions. Irrigation systems that have a number of different irrigators running at once may also experience additional pressure variations throughout any one particular set or run due to changing hydraulic conditions within the system. These changes will not be as extreme as the start /stop condition but may well take place over a longer time period.

As part of the Testing if Best Management Guidelines project conducted over the 1997/98 summer, several months of pressure records were obtained for a centre-pivot irrigator. This irrigator was operated as part of an overall system comprising two interconnected systems (separate wells, pumps and irrigators) in which the irrigator management was quite independent for most of the season. This lead to a very wide range of operating conditions in terms of the pressure supplied to the centre-pivot system. These variations were considered to be at the upper end of those likely to be experienced by most irrigation systems under normal circumstances and therefore this data set provided a very useful test for the selected sampling interval.

We concluded that the most appropriate sampling interval based on our knowledge of the typical range of conditions likely to be encountered for different irrigator types and operating systems is one minute, i.e. the meter should take a pressure reading every minute.

3.3.3 Updating Accumulated Volume

Although the meter may take a pressure reading every minute, updating accumulated volume every minute may be unnecessary and wasteful of power.

The installation of standard in-line flow meters is likely to be adopted for small flows on systems using small pipe sizes, as it will probably be lower cost. On this basis, a decision was made to record accumulated volume to a resolution of one cubic metre. For a very small system with a flow rate of 10 m^3/h, the time taken to accumulate one cubic metre is six minutes. For systems with flow rates greater than 60 m^3/h (as most of the systems using the metre will be), the time taken to accumulate one cubic metre will be less than one minute.

Updating accumulated volume when the volume increases by one cubic metre, but not more than once every minute has been adopted.

3.3.4 Flow Pressure Relationship

There were two main ways in which this issue could be addressed. The first is by use of a mathematical relationship (i.e. an equation) which relates flow to pressure. The second is by the use of a look-up table of pressures and corresponding flows, which could be used with an appropriate interpolation technique to estimate the flow for any given pressure. To determine the most appropriate technique, the theoretical flow-pressure relationship for a number of different irrigator types (i.e. guns, rotating booms, linear move systems, centre-pivots etc. was investigated). Issues such as attainable accuracy and ease of obtaining and entering the necessary data were other factors considered.

On balance, the use of a look-up table was preferred as it could be used to implement all types of pressure-flow relationships and did not rely on fitting data to mathematical equations.

Although the number of measured pressure-flow points is often limited, graphing the relationship enables additional points to be determined for the meter's look-up table. As the meter uses linear interpolation of the look-up table data to determine flow rate for any intermediate pressure, the higher the number of pairs of points (maximum 20), the greater the accuracy.

4 Technical Development

4.1 TECHNICAL SPECIFICATION

The technical specification was based around research into available components and systems. Governing criteria based on a requirement specification were:

- To keep the total component cost as low as practicable while maintaining data reliability and consistency (<$300+GST excluding the pressure sensor);
- A system design that could be completed within a relatively short time frame;
- Maintaining a focus on potential future version including extra facilities, e.g. data logging capabilities, communication with other devices, extra sensing options;
- To use components and designs that would keep power consumption sufficiently small so that large batteries or multiple battery renewal during a season would not be required;
- A robust device taking into consideration the environment that it will be used in, and
- A simple user interface.

The requirement specification was a list of the functionality required to meet the needs of the user. This was then used to produce a design specification from which the designs of the individual sub-systems were formulated.

4.2 DESIGN OVERVIEW

Figure 1 is a block diagram of the system, which shows the micro controller and its connections to the various sub systems.

The system appearance and functionality were given a strong bias, as a practical instrument needs to be intuitive, simple to use, and featured with only what is required. A user interface comprising of a four line alphanumeric display and simple keypad were chosen. The display always shows the three main variables (current pressure, current flow rate, and accumulated volume) and any key press will bring up a simple menu (see Appendix I for display flow chart).

To reduce power consumption, the micro controller (CPU or central processing unit) and all the sub-systems, except for the real-time clock are switched off. Every minute, the real-time clock starts the CPU, which activates and reads the pressure sensor and updates the pressure. It calculates the flow by interpolating data from the table of pressure/flow characteristics that has been entered by the user and stored in secure memory. These outputs are then displayed on the LCD screen.

If a key has not been pressed, as is typically the case, the CPU immediately turns itself off. If a key has been pressed, the CPU is activated. It determines which keys are pressed and actions them accordingly (see Appendix I for display flow chart). If a key is not pressed for 30 seconds then the CPU again turns itself off.

The firmware flow chart is included as Appendix II.

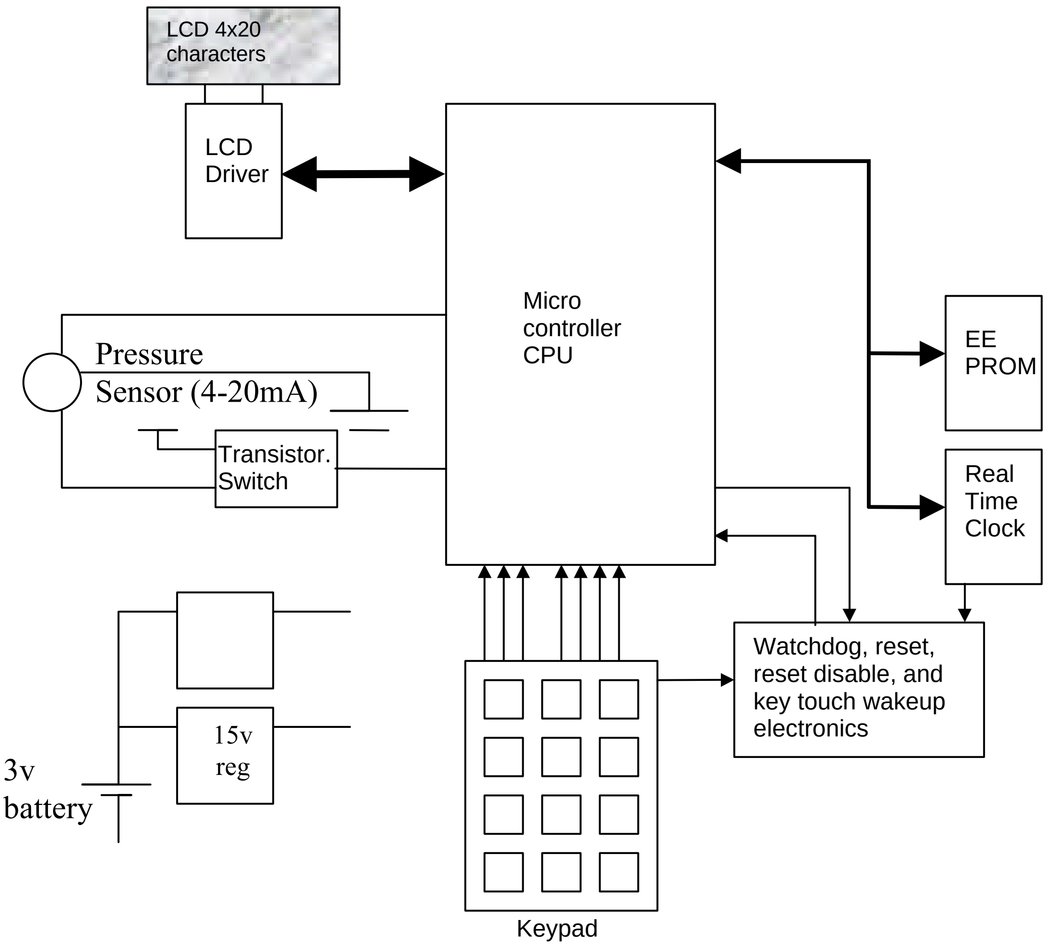


Figure 1

4.3 WORK PROGRAMME

Following formulation of the research and specification stages, individual sub-systems were designed independently. They comprise:

- The external housing (machining required for display window and keypad);
- Micro controller (CPU);
- Data storage (memory) and its interface to the CPU;
- Analogue to digital signal conversion and pressure sensor interface (lightning protection) and its interface to the CPU;
- Keypad (0-9, '.' And '↵') and its interface to the CPU;
- Display (with 4 by 20 characters) and interface to the CPU, and
- Power regulation (5 volts for components and 15 volts for the pressure sensor) and filtering.

The individual sub-systems were used to design a circuit board layout, which was then fabricated. The external housing was tested for water intrusion and the components mounted on the circuit board and tested. Running concurrently to the physical design, software was written and compiled. A development aid was used to debug the software.

The meter was then laboratory tested, prior to in-the-field testing. Further refinements required to obtain a satisfactory working prototype were completed, and other useful alterations to firmware or hardware noted for possible later versions.

4.4 CHANGES TO SPECIFICATIONS

The specification required that all data was to be stored securely. Non-volatile RAM was chosen, specifically EEPROM (Electrically Erasable Programmable Read Only Memory), which maintains data even when power is removed. This is a cheap, reliable way to store data. However, the number of times that the EEPROM can be written to, is limited. While this is not an issue for the look-up table values for flow and pressure and the pressure sensor type since these values will only usually be entered once, it is an issue for frequent updating of accumulated volume. For the prototype, the accumulated volume is secure except when power is lost (i.e. when the batteries are replaced).

4.5 COMPONENT AVAILABILITY/COST

The components chosen for the prototype were obtained from component suppliers based on convenience and speed of arrival, rather than lowest cost. With this in mind, it is expected that the future cost for components excluding the pressure sensor could decrease from the current $400 to approximately $200. Manufacturing costs could be expected to result in a factory cost of $400 for the meter. Marketing and distribution cost, plus a 4 to 20 mA pressure sensor (approximately $400) suggest a likely retail value of $1,000.

5 Field Testing

The development period for the prototype meter coincided with the winter months and therefore it was not possible to gain access to an operating irrigation system to field test the meter. Instead, advantage was taken of Lincoln Environmental's involvement with an experimental sprinkler frost protection system to provide a suitable test installation. The advantages of this particular installation were:

- Detailed design information was available for the system;
- The system was heavily instrumented and parameters such as operating pressure and operating times were already being monitored;
- The site was visited regularly as part of the original research programme;
- The system represents (on a small scale) a typical horticultural irrigation block, and
- The environment was expected to be harsh.

5.1 CALIBRATION

Accurate information on the actual design of the installation was readily available. The IRRICAD™ design program was then used to analyse the system performance in terms of flow for a wide range of pressures downstream of the control valve. This analysis provided the data for the lookup table required enabling the meter to convert pressure measurements to flow rate and to total volume used.

5.2 INSTALLATION

The pressure sensor was installed downstream from the control valve at the same location as the existing (and separately monitored) pressure sensor used as part of the control system for the frost protection experiment. The flow meter itself was mounted on a stake adjacent to the sensor. The installation mimics that which would be used if the meter were being used for monitoring the flow into a typical orchard block.

5.3 PERFORMANCE

Early results suggest that the flow meter is performing adequately in terms of converting system pressure to current flow rate and total flow volume. Some minor problems with the software in terms of its robustness to operator error and error checking and some cosmetic (but important) details of the user interface have been identified. These problems are relatively easy to overcome, and other than re-programming the microprocessor, do not require any physical change to the basic concept of the meter. This test will continue until the end of the frost protection 'season' (late October) when the software will be upgraded and the unit transferred to monitor the performance of a more conventional irrigation system.

6 Conclusions and Recommendations

The purpose of this project was to develop a prototype irrigation water use meter that could be easily installed and used with reliable results on all types of pressurised irrigation systems.

The basic requirements listed in Section 3.1 have largely been met.

The meter has been constructed with a good quality, watertight case to ensure robustness. Installation will be very easy, as it can be connected into a system anywhere a pressure tapping is available. The user interface is simple, and should be able to be operated by farmers given limited written instructions. Battery life has been calculated to last for a typical irrigation season. The meter has been designed so that the retail price, including the pressure sensor, is expected to be less than $1000.

Although the accumulated volume resets to zero when the batteries are changed, we do not see this as a significant problem because batteries will need to be replaced each year, and it seems logical to reset the accumulated volume at the same time.

The meter is currently undergoing field testing on a frost protection irrigation system, and other than some minor software problems, has performed to specification. These small problems will be rectified and at the beginning of the irrigation season (October 1998), the meter will be installed on an irrigator for further testing.

As we are confident that the prototype meter will fill the need identified in the previous year’s MAF Policy Research projects, another two meters will be constructed for use on the 1998/99 MAF Policy project to further test the Best Management Guidelines and calculate the Indicators of Sustainable Irrigation.

7 References

IRRICAD™ : Irrigation design software package developed by AEI Software, Lincoln University, Canterbury, New Zealand.

Lincoln Environmental (1997): Indicators of sustainable irrigated agriculture. Report to MAF Policy, Report No 2720/1. MAF Policy Technical Paper 00/03

Lincoln Environmental (1997): Best management guidelines for sustainable irrigated agriculture. Report to MAF Policy, Report No 2720/2. MAF Policy Technical Paper 00/05

Lincoln Environmental (1998): Testing of best management guidelines. Report to MAF Policy, Report No 2780/1. MAF Policy Technical Paper 00/06

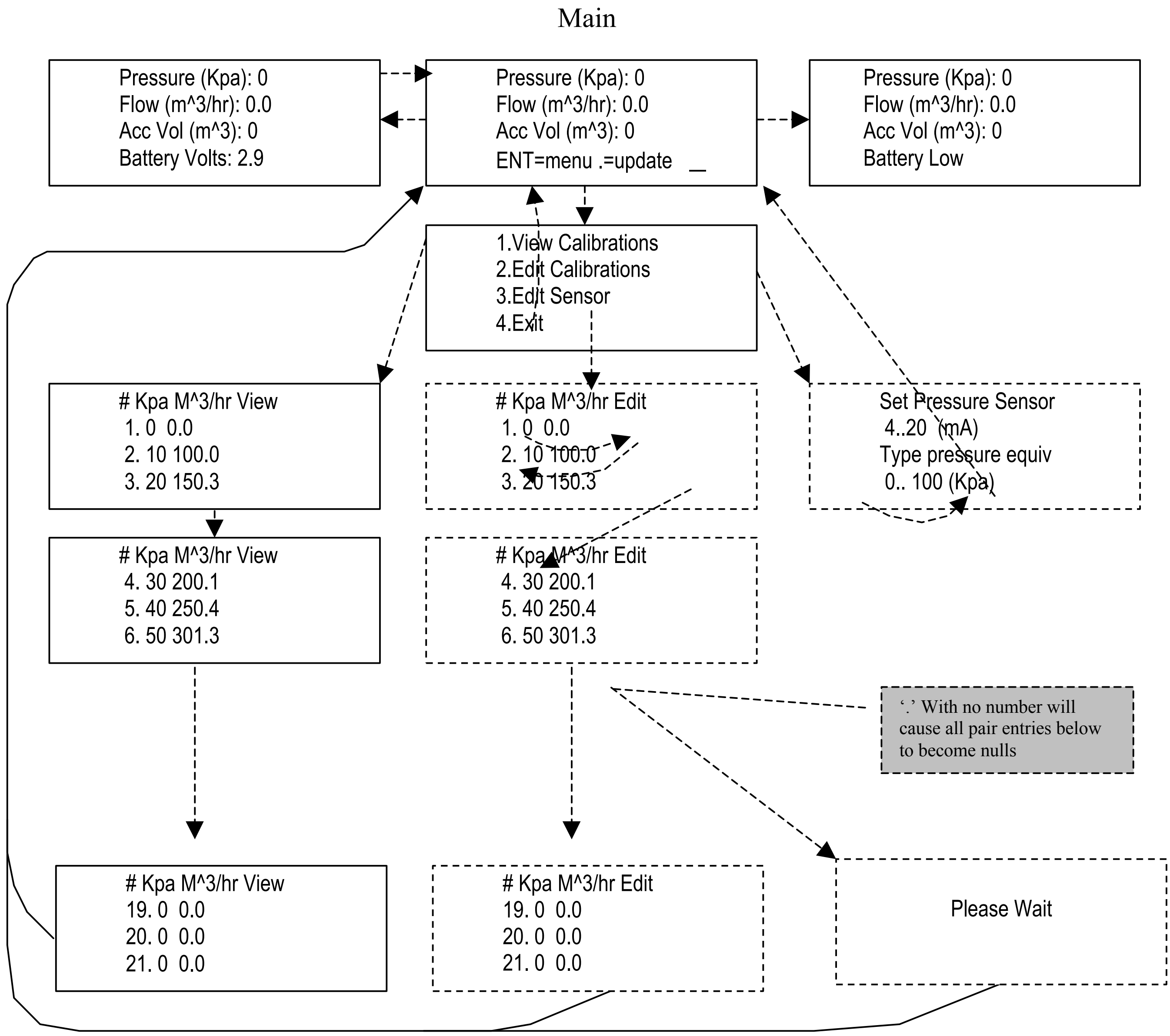
McEwan, G; Smith, G; Speidel, S (1998): Compliance monitoring of the West Melton restricted water use zone. Canterbury Regional Council unpublished report No U98/06

Wells, C; Barber, A (1998): Field testing indicators of sustainable irrigated agriculture. Agriculture New Zealand report to MAF Policy. MAF Policy Technical Paper 00/04

Appendix I:

DISPLAY FLOW CHART

Display Flow Chart
2091 Flow Meter
30 June 1998



Arrows show possible display routes - usually by hitting the '¿' key, or entering numbers where appropriate.

Appendix II:

FIRMWARE FLOW CHART

Firmware Flow Chart
2091 Flow Meter
30 June 1998