G C SIMPSON

DEVELOPMENT AND TESTING OF DATALOGGING EQUIPMENT FOR THE MONITORING OF WATER CONSUMPTION PATTERNS

Report to the
WATER RESEARCH COMMISSION
by the
DIVISION OF BUILDING TECHNOLOGY, CSIR

WRC Report No 255/1/90

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FINAL PROJECT REPORT

to the

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Division of Building Technology
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December 1989

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Mr G C Simpson	Division of Building Technology
Mr P H S Cronje	Pretoria City Council
Mr A Smook	Pretoria City Council
Mr T Westman	Pretoria City Council
Dr G C Green	Water Research Commission
Mr F P Marais	Water Research Commission

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AIMS OF THE PROJECT

* To develop, in collaboration with local industry, a low-cost, event-driven datalogger capable of recording the times at which events occur and the values of a parameter associated with the events.

* To evaluate the performance of the datalogger as a suitable device for monitoring water consumption patterns and to test the concepts on which the design of the datalogger is based.

* To develop applications in which the datalogger may be usefully deployed to gain information on the performance and the operation of water distribution systems.

* To look into the local development of suitable sensors for measuring water pressure in pipes.

This report is a condensed version of the original final report to the Water Research Commission. The main theme and findings of the research are covered, but most of the theory and detail, as well as the appendices, have been omitted.

Copies of the full report entitled "Research into the development and testing of data-logging equipment for the monitoring of water consumption patterns" may be obtained from the Division of Building Technology, CSIR by completing the order form at the back of this document.

ABBREVIATIONS

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ASCII	American standard code for information interchange
C	The "C" programming language
CACDS	Centre for Advanced Computing and Decision Support
DBT	Division of Building Technology
DMA	Direct memory access (to PC computer memory)
EPROM	Erasable, programmable read only memory
HPIB	Hewlett Packard interface bus
IC	Integrated circuit
IEEE-488	A standard for a parallel interface bus
PC	Personal computer
PCB	Printed circuit board
PCED	Pretoria City Engineer's Department (Water Branch)
PIB	Parallel interface bus
RAM	Random access memory
ROM	Read-only memory
RS-232	A standard for a serial interface bus
WISA	Water Institute of Southern Africa
WRC	Water Research Commission

INTRODUCTION

In an earlier research project, researchers at the Division of Building Technology (DBT) attempted to quantify the components of water usage in buildings, but the efforts were restricted by the lack of affordable monitoring equipment[1]. Part of the problem related to the methods being used to measure flow rates and part to the methods of collecting and recording the data required for a meaningful analysis.

It was recognised that the flow pattern at a distribution reservoir was typically continuous, slow-changing and of relatively long duration, compared to the flow at a terminal fitting of a branched water supply, where it was intermittent, rapidly changing and of relatively short duration.

In order to quantify the components of water usage accurately, it is necessary to monitor flow as close as possible to the terminal fittings, such as taps, ball-valves, and shower heads. Overseas researchers [2,3,4] achieved this by installing a turbine meter on the main supply pipe, to measure flow rates, and flow switches on each terminal branch pipe, to detect which fittings and fixture-usage combinations contributed to the measured flow. These studies were limited to specific buildings because of the high capital and installation costs involved.

It was realised that it would be difficult and expensive to replicate the overseas studies in South Africa, and alternative methods were sought which would enable large volumes of water consumption data to be captured accurately for analysis.

The reason for developing the datalogger was the need to measure flow rates and pressures at domestic water connections, in order to determine the consumption patterns and flow characteristics of the supply system. The motivation to monitor water consumption patterns derives from a desire to determine the accuracy of the design methods, codes and guidelines used to design water reticulation and branch distribution systems[5].

The major problems in undertaking monitoring at domestic meter points are:

a) the lack of electrical power "on tap"

b) the inability to run cables over access routes

c) the exposed nature of the location

d) the intermittent flow

e) the high price of suitable monitoring equipment

The Spectrum home computer, with its expansion slot, spawned a wide variety of relatively low-cost peripheral electronic devices. One of these was an environmental data recorder that recorded data at fixed intervals of time into a two kilobyte (2kb) random access memory (RAM)[6]. The data recorder used less than 2mA current at 6 volts and required 11 lines of basic programming to transfer data to the computer. The construction cost at the time was about R150.

It was apparent that, with a slight change in the design and the incorporation of an accurate timer, the device could be made to function as an event recorder, in which case it could be triggered by a modified water meter to record time instead of an external analogue parameter.

As a result, a different approach to the monitoring of water consumption was adopted and a suitable theory developed for monitoring intermittent flow. To test the theory would require the development of a simple, low-cost datalogger to capture and record data as prescribed by the theory[7,8].

In April 1988 sponsorship from the Water Research Commission (WRC) enabled DBT to continue researching the proposed method of monitoring water consumption patterns.

At the conclusion of the project, the method was being applied by the Pretoria City Engineer's Department (PCED), using a datalogger developed locally as a result of the project. A software development company has produced software for the analysis and display of the data on a personal computer (PC) and an imported datalogger, based on the same general specifications, is currently being launched on the South African market.

The DBT has been responsible for the execution of the research project, the consolidation of the documentation on dataloggers and ancillary equipment and the reporting of the research findings emanating from the use of the datalogging system.

The research was carried out in Pretoria with the co-operation of the PCED, without whose support the project would not have succeeded.

MEASUREMENT OF INTERMITTENT FLOW

The concept of "timing" the flow through a water meter rather than "counting" it overcomes the problem of measuring intermittent flow, which is typical of the flow pattern at domestic water connection points.

Water volume is measured in unit amounts by the water meter and the cumulative volume is recorded by the meter's register. By fitting a mechanism to the water meter, which triggers an "event" every time the meter registers a unit volume, the time taken for any unit (or units) of volume to pass through the meter can be measured by a timing device.

Assuming that the flow is not zero and its rate of change is reasonably small and steady, a good approximation of the average flow rate over the period between two triggered events can be found by dividing the volume metered during the period by the difference in the times at which the triggers occurred.

Since the volume of water between triggers (events) remains constant, time is the only variable that needs to be recorded. Either the times of events, or the time differences between events need to be recorded. Both methods have advantages and disadvantages:

* Times can be recorded directly without calculation in the datalogger, but the numbers are large (6 digits) and use a lot of memory space.

* Time differences calculated in the datalogger result in smaller numbers, usually 2 to 3 digits which require less memory space.

* Times can be reconstructed from time differences, but if there are errors in the data, then the errors will be carried through the entire data file when the times are calculated.

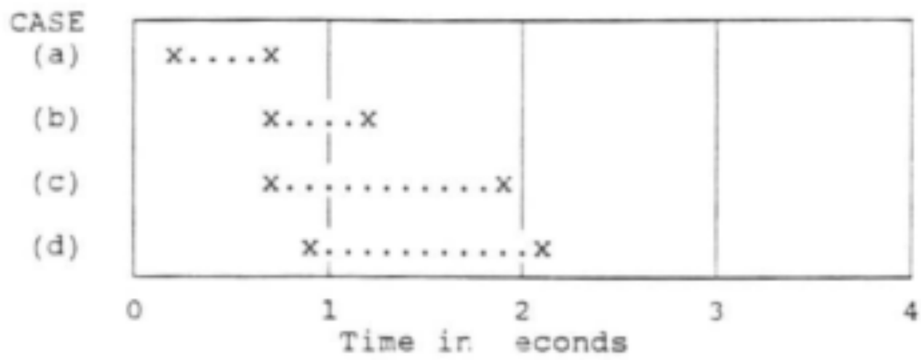
It is therefore safer to record the times and not the time differences, but at the expense of memory. Schemes for conserving memory could be applied, but information may be lost through processing and the length of the measurement and recording cycle may be increased.

The accuracy of the calculated flow rate depends on the accuracy and the resolution of the measurement of both time and volume. Because volume is measured by the water meter, it is not considered in the datalogger design. However, it must be included when determining the accuracy of the whole system.

<u>Effect of time resolution on calculated flow rate</u>

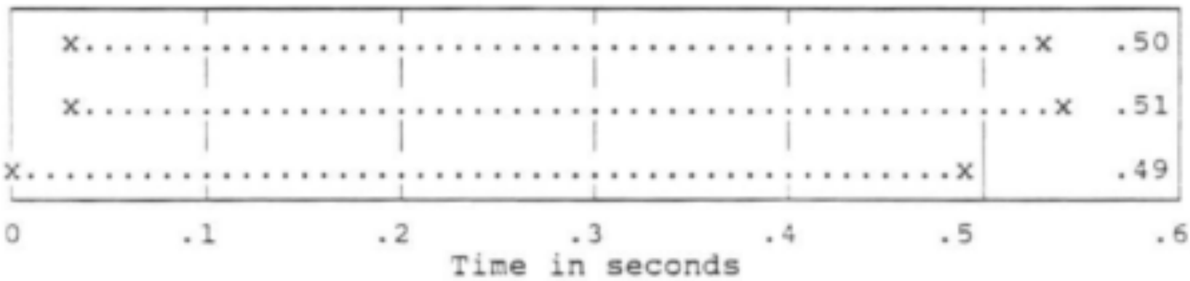
Time resolution refers to the minimum unit of time that can be measured and recorded by the datalogger. Since the cycle time of a microprocessor-based datalogger is measured in mega-hertz, it is possible for the logger to resolve time intervals at least down to 0.001 of a second. However, the time base may not provide this resolution. In most data loggers the minimum time resolution is 1 second. That is, 1 is followed by 2, 2 is followed by 3 and so on. It is not possible to have 1.2 or 3.65 seconds, because the time base does not allow it.

As far as the datalogger is concerned, time "stands still" at 1 second until it suddenly changes to 2 seconds. The implication is that the potential error in the calculated flow rate increases as a function of the flow rate and can be very significant, as illustrated in Figure 1.



CASE	TIME DIFFERENCES Actual	Measured	FLOW RATES - LITRES/MINUTE Actual	Calculated
(a)	0.50	0 - 0 = 0	120	infinite
(b)	0.50	1 - 0 = 1	120	60
(c)	1.20	1 - 0 = 1	50	60
(d)	1.20	2 - 0 = 2	50	30

Figure 1 : Effect of 1-second resolution



TIME DIFFERENCES Actual	Measured	FLOW RATES - LITRES/MINUTE Actual	Calculated	ERROR %
.500	.5	120.0	120.0	0
.510	.5	117.6	120.0	2
.510	.6	117.6	100.0	-15
.490	.4	122.4	150.0	22.5
.490	.5	122.4	120.0	-2

Figure 2 : Effect of 0.1-second resolution

Figure 2 shows that high flow rates can still lead to large errors. However as the flow rate reduces, so does the potential for error. At domestic meters the flow rate is generally under 50 l/min, corresponding to a trigger interval of 1.2 seconds. The range of potential error is between +8.3% and -7.6%.

By similar analysis it can be shown that an improvement in the time resolution to 0.01 seconds would result in the error limits reducing to about ±0.39%

Triggers and events

A trigger in event mode is a signal from a water meter indicating that it measured a unit volume. This trigger is produced when a magnetic reed switch located in the water meter is activated by a magnet connected to a gear in the register.

Only the trigger points are known with certainty in terms of time. The datalogger cannot determine the position of the magnet as it rotates and hence cannot tell if the water is flowing through the meter. However, the shorter the time interval, the more certain we are that there is activity between triggers, but the less accurate the calculated flow becomes, unless the time resolution is small.

Accuracy of time base

Since 8 to 10 days of unattended monitoring are probably adequate for determining water consumption patterns and if the allowable drift is about 10 minutes, the time base may cumulatively lose or gain 1 minute per day.

The accuracy of the time base in the design of the datalogger cannot be overemphasised and it should be matched at least to the wrap-around time, to reduce time drift as much as possible. The wrap-around time depends on the size of the largest number the datalogger can use to store time data, unless time differences are stored instead.

Recording of pressure

Pressure can have a significant effect on water consumption patterns[7,8,9,10]. This should be obvious from the basic equations for pipe flow, which give flow rate as a function of both the available pressure gradient and the physical characteristics of the pipe.

If flow rate and pressure are recorded at the meter point, the data can be used to establish the characteristics of the pipework.

In practice, pressure transducers need to be changed to suit the maximum pressure likely to occur at the monitoring point. Consider a transducer with a 3000 kPa range and an accuracy of 0.1% of span. The error range is ±3 kPa. If the pressure in the pipe is 500 kPa and the application calls for a maximum error of 1 kPa, then the use of the 3000 kPa transducer is not appropriate.

In this case, the use of 8 bits is also not sufficient to record the pressure, since the full scale range may be say 800 kPa and the recorded resolution will be 3 kPa. For most applications, 8-bit resolution is probably good enough, but if the accuracy of the transducer and the application warrants it then 10-bit resolution would be preferred. Only special pressure-measurement applications would require 12-bit resolution or greater.

HARDWARE DEVELOPMENT

The dataloggers used in the project were designed and supplied by Deltrix CC, who worked initially through the company Metal Spinnings (Pty) Ltd.

The development of the Deltrix datalogger was not without its problems. The main one was the view of Deltrix that they would "get it right first time". This proved to be wishful thinking and development took considerably longer than originally anticipated.

Since the project started there have been advances in the electronics industry and the hardware options with respect to microprocessors and electronic components are now much wider than they were. It can be expected that these will eventually be implemented in more flexible types of dataloggers, where the emphasis is on providing data in semi-standard formats for use by different applications software.

As the various features of the datalogger were evaluated during the course of the project, the specifications evolved and were compiled into a general specification for future reference.

Apart from the datalogger, other components of the system include the enclosure, pressure sensor, water meter and battery. The aim to look into the local development of pressure transducers was abandoned when it was found that suitable pressure sensors were already available on the market at prices that did not make local development feasible.

Time resolution and memory size

In the Deltrix datalogger, the time at which the datalogger was initialised is used as the origin for all future time measurements. Water passing through the water meter triggers the datalogger. The time of the event is measured from the origin, in tenths of a second, and stored in memory as an offset time in binary format.

The logger has a time resolution of 0.1 seconds and a memory capacity of 32 kb. The choice of the time resolution affects the potential error of the calculated flow rates. It also affects the wrap-around time of the datalogger and the amount of data that can be stored in a given memory size.

The use of 24 bits gives a wrap-around time of 19 days and 10 hours and the memory size is typically 32 kb. The number of records that can be stored in memory with other control information is 10,635 which corresponds to about 10 days of water consumption at the average domestic meter point.

Accuracy of time base

The Deltrix logger's time base is determined by a crystal oscillator connected to the microprocessor. A variable capacitor can be provided to allow the "clock" to be corrected for loss or gain, but the adjustment is not easy and has been used with limited success.

Pressure calibration

An essential feature of a datalogger that drives a pressure sensor and records the output, is a means by which the user can calibrate the sensor. Calibration ensures that the recorded output accurately represents the parameter being measured by the sensor and determines the conversion factors needed in analysis to convert the output to engineering units.

Datalogger enclosure

An enclosure should be supplied with the datalogger and must afford reasonable protection against physical damage. The design of the enclosure and the arrangement of the datalogger and ancillary components, such as battery and connectors, must enable the datalogger to be operated effectively. The Deltrix datalogger is constructed on a single 16 x 11 cm printed circuit board (PCB), which can be housed in a box 4 cm deep. The display, external connectors and switches are mounted separately from the PCB.

The enclosure is of major importance and its functions should be carefully determined. To provide a single enclosure for all applications is not economical, and it is probably better to adopt a layered approach, where basic protection is standard and additional requirements such as waterproofing and security from theft are provided as options at extra cost.

It is suggested that the datalogger enclosure should provide basic "soft" protection to the electronic equipment and battery, while additional "rugged" protection is provided against theft, vandalism and extreme weather conditions. Tube enclosures may offer the best complete protection at a low cost and could, for example, be made from PVC pipe and fittings.

Power supply

The datalogger should be provided with a rechargeable or low-cost power supply which is tamper-proof and fits into the enclosure. It should be able to power the datalogger for at least two weeks. Solar cells may be useful for recharging internal batteries over extended monitoring periods.

Operation of the datalogger

At the time when the project was first proposed, the industry was using dataloggers with EPROM memories. Low-power RAM memories were begining to appear, but had not gained much acceptance because of their limited memory size, cost and other constraints.

It was thought that many users would continue to want a removable memory chip, or memory pack. The Deltrix datalogger system provided a removable battery-backed RAM and a RAM reader, which could be used to initialise a RAM prior to its insertion in the datalogger.

The RAM contains the following information in a header block at the beginning of memory:

a) Items set via the PC or by datalogger control buttons

20-character string for site identification (CITY)
20-character string for site identification (SUBURB)
20-character string for site identification (ERF No.)
Start date and time (time origin)
Water meter register start and end readings
Number of units per trigger

b) Items determined by the microprocessor through interrogation of hardware settings and status during start-up procedure

Event pre-scale setting (switch set before power on)
Pressure pre-scale setting (switch set before power on)
Error code

None of the items put into RAM by the user are actually needed during the logging operation. The time and date displayed by the logger are derived from the offset time and the start time and date, which must be known if the data is to be related to real time, but which need not be recorded in memory (a piece of paper would do). However, having the information in the header block is useful for identifying the data without using a secondary non-electronic system, such as a note book.

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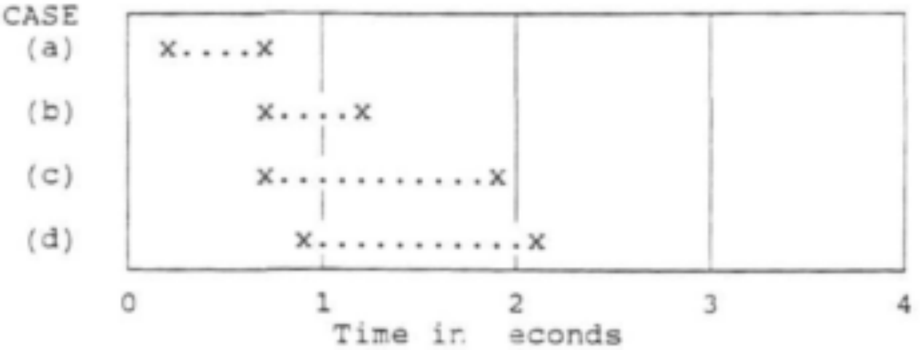

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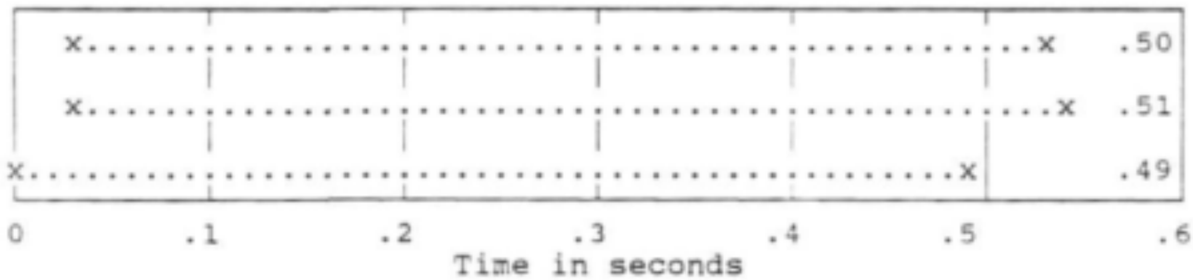
Figure 1 : Effect of 1-second resolution



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.510	.6	117.6	100.0	-15
.490	.4	122.4	150.0	22.5
.490	.5	122.4	120.0	-2

Figure 2 : Effect of 0.1-second resolution

Figure 2 shows that high flow rates can still lead to large errors. However as the flow rate reduces, so does the potential for error. At domestic meters the flow rate is generally under 50 l/min, corresponding to a trigger interval of 1.2 seconds. The range of potential error is between +8.3% and -7.6%.

By similar analysis it can be shown that an improvement in the time resolution to 0.01 seconds would result in the error limits reducing to about ±0.39%

Triggers and events

A trigger in event mode is a signal from a water meter indicating that it measured a unit volume. This trigger is produced when a magnetic reed switch located in the water meter is activated by a magnet connected to a gear in the register.

Only the trigger points are known with certainty in terms of time. The datalogger cannot determine the position of the magnet as it rotates and hence cannot tell if the water is flowing through the meter. However, the shorter the time interval, the more certain we are that there is activity between triggers, but the less accurate the calculated flow becomes, unless the time resolution is small.

Accuracy of time base

Since 8 to 10 days of unattended monitoring are probably adequate for determining water consumption patterns and if the allowable drift is about 10 minutes, the time base may cumulatively lose or gain 1 minute per day.

The accuracy of the time base in the design of the datalogger cannot be overemphasised and it should be matched at least to the wrap-around time, to reduce time drift as much as possible. The wrap-around time depends on the size of the largest number the datalogger can use to store time data, unless time differences are stored instead.

Recording of pressure

Pressure can have a significant effect on water consumption patterns[7,8,9,10]. This should be obvious from the basic equations for pipe flow, which give flow rate as a function of both the available pressure gradient and the physical characteristics of the pipe.

If flow rate and pressure are recorded at the meter point, the data can be used to establish the characteristics of the pipework.

In practice, pressure transducers need to be changed to suit the maximum pressure likely to occur at the monitoring point. Consider a transducer with a 3000 kPa range and an accuracy of 0.1% of span. The error range is ±3 kPa. If the pressure in the pipe is 500 kPa and the application calls for a maximum error of 1 kPa, then the use of the 3000 kPa transducer is not appropriate.

In this case, the use of 8 bits is also not sufficient to record the pressure, since the full scale range may be say 800 kPa and the recorded resolution will be 3 kPa. For most applications, 8-bit resolution is probably good enough, but if the accuracy of the transducer and the application warrants it then 10-bit resolution would be preferred. Only special pressure-measurement applications would require 12-bit resolution or greater.

HARDWARE DEVELOPMENT

The dataloggers used in the project were designed and supplied by Deltrix CC, who worked initially through the company Metal Spinnings (Pty) Ltd.

The development of the Deltrix datalogger was not without its problems. The main one was the view of Deltrix that they would "get it right first time". This proved to be wishful thinking and development took considerably longer than originally anticipated.

Since the project started there have been advances in the electronics industry and the hardware options with respect to microprocessors and electronic components are now much wider than they were. It can be expected that these will eventually be implemented in more flexible types of dataloggers, where the emphasis is on providing data in semi-standard formats for use by different applications software.

As the various features of the datalogger were evaluated during the course of the project, the specifications evolved and were compiled into a general specification for future reference.

Apart from the datalogger, other components of the system include the enclosure, pressure sensor, water meter and battery. The aim to look into the local development of pressure transducers was abandoned when it was found that suitable pressure sensors were already available on the market at prices that did not make local development feasible.

Time resolution and memory size

In the Deltrix datalogger, the time at which the datalogger was initialised is used as the origin for all future time measurements. Water passing through the water meter triggers the datalogger. The time of the event is measured from the origin, in tenths of a second, and stored in memory as an offset time in binary format.

The logger has a time resolution of 0.1 seconds and a memory capacity of 32 kb. The choice of the time resolution affects the potential error of the calculated flow rates. It also affects the wrap-around time of the datalogger and the amount of data that can be stored in a given memory size.

The use of 24 bits gives a wrap-around time of 19 days and 10 hours and the memory size is typically 32 kb. The number of records that can be stored in memory with other control information is 10,635 which corresponds to about 10 days of water consumption at the average domestic meter point.

Accuracy of time base

The Deltrix logger's time base is determined by a crystal oscillator connected to the microprocessor. A variable capacitor can be provided to allow the "clock" to be corrected for loss or gain, but the adjustment is not easy and has been used with limited success.

Pressure calibration

An essential feature of a datalogger that drives a pressure sensor and records the output, is a means by which the user can calibrate the sensor. Calibration ensures that the recorded output accurately represents the parameter being measured by the sensor and determines the conversion factors needed in analysis to convert the output to engineering units.

Datalogger enclosure

An enclosure should be supplied with the datalogger and must afford reasonable protection against physical damage. The design of the enclosure and the arrangement of the datalogger and ancillary components, such as battery and connectors, must enable the datalogger to be operated effectively. The Deltrix datalogger is constructed on a single 16 x 11 cm printed circuit board (PCB), which can be housed in a box 4 cm deep. The display, external connectors and switches are mounted separately from the PCB.

The enclosure is of major importance and its functions should be carefully determined. To provide a single enclosure for all applications is not economical, and it is probably better to adopt a layered approach, where basic protection is standard and additional requirements such as waterproofing and security from theft are provided as options at extra cost.

It is suggested that the datalogger enclosure should provide basic "soft" protection to the electronic equipment and battery, while additional "rugged" protection is provided against theft, vandalism and extreme weather conditions. Tube enclosures may offer the best complete protection at a low cost and could, for example, be made from PVC pipe and fittings.

Power supply

The datalogger should be provided with a rechargeable or low-cost power supply which is tamper-proof and fits into the enclosure. It should be able to power the datalogger for at least two weeks. Solar cells may be useful for recharging internal batteries over extended monitoring periods.

Operation of the datalogger

At the time when the project was first proposed, the industry was using dataloggers with EPROM memories. Low-power RAM memories were begining to appear, but had not gained much acceptance because of their limited memory size, cost and other constraints.

It was thought that many users would continue to want a removable memory chip, or memory pack. The Deltrix datalogger system provided a removable battery-backed RAM and a RAM reader, which could be used to initialise a RAM prior to its insertion in the datalogger.

The RAM contains the following information in a header block at the beginning of memory:

a) Items set via the PC or by datalogger control buttons

20-character string for site identification (CITY)
20-character string for site identification (SUBURB)
20-character string for site identification (ERF No.)
Start date and time (time origin)
Water meter register start and end readings
Number of units per trigger

b) Items determined by the microprocessor through interrogation of hardware settings and status during start-up procedure

Event pre-scale setting (switch set before power on)
Pressure pre-scale setting (switch set before power on)
Error code

None of the items put into RAM by the user are actually needed during the logging operation. The time and date displayed by the logger are derived from the offset time and the start time and date, which must be known if the data is to be related to real time, but which need not be recorded in memory (a piece of paper would do). However, having the information in the header block is useful for identifying the data without using a secondary non-electronic system, such as a note book.

The Deltrix datalogger has a control panel on which are mounted the liquid crystal display, a rotary switch for selecting display functions, a toggle switch for selecting English or Afrikaans prompts, three push-buttons for changing information and settings and a 9-pin male D-connector for RS232 communications. The eight display functions available are described below:

Function 0 displays the amount of memory remaining as a percentage of total available memory. Pressing two adjacent buttons resets the value to 99.99%. This operation sets the address pointer (or end of file marker, EOF) to the beginning of memory. It does not erase previously recorded data, but the next event will cause data to be written in memory from the beginning, thus overwriting the old data.

A character, displayed in brackets, indicates the event pre-scale setting as the number of triggers per event. The character can be one of 0 1 2 3 4 5 6 7 8 9 : ; < = > ? and these sixteen characters represent the integer numbers from 0 to 15.

A third piece of information is the number of litres that causes a trigger. Pushing one of the buttons increments the value in the sequence 1, 10, 100, 1000. This feature was based by Deltrix on the switch positions available on the Castle water meter, but Kent water meters can provide triggers at half the smallest value of the register. A four-decimal-point meter register provides a trigger every 0.5 litres.

Function 1 displays the date and time. Characters in the display can be edited by pushing the left or right button. The next character to the left is selected by pushing the centre button. It was found that this is a very cumbersome way of changing the date and time. Changes in the time field can be made internally by changing the time origin. The display merely reflects the sum of the time origin and the current value of the offset time.

Functions 2 to 4 display the city, suburb and Erf No. respectively.

Functions 5 and 6 display the start and final readings from the water meter.

The information in functions 2 to 6 is entered by the user, either from the PC during initialisation, or by pushing the buttons to change data, character by character. The latter is a very time consuming and frustrating exercise.

Function 7 displays the pressure in kPa to a resolution of 10 kPa and the pressure prescale setting is shown in brackets as a number from 0 to 9. The setting of the prescale to 0 means that only events are recorded by the datalogger. A setting of 5 would mean that a pressure recording is made every fifth event.

Data transfer

Two-way communication is possible between the PC and the datalogger on a batch basis. For setting the header block information, Deltrix has provided a PC software program that accepts input and then writes this information to the datalogger memory. The same program can be used to dump the datalogger memory to RAM in the computer, where the data are then decoded and stored in an ASCII file on disk.

Data transfer can also be achieved by transporting the memory chip from the datalogger to a RAM reader linked to the computer.

Error codes

An error code is contained in the output file from the data logger. There is little the operator can do about errors, but it is useful to know what problems occurred during the monitoring period.

DATALOGGER SYSTEM EVALUATION

The effectiveness of data transfer to a PC computer was evaluated and found to be acceptable in terms of speed and accuracy. Data transfer from the PC to the datalogger for initialisation purposes is cumbersome, but this is a minor software related problem which can be corrected. It was found that the use of a battery-powered portable PC greatly improved the usability of the datalogger, avoided the need to transport memory chips and reduced the risk of incorrect settings and data loss.

The data files are stored on disk in ASCII format and the files are considerably larger than the 32kb of data that they represent. Data-transfer timing errors can cause the data to be corrupted and it is necessary to check the integrity of all sections of the data files. One advantage of the method used by Deltrix to record the data is that data corruption in one part of the file does not necessarily affect the rest of the data, since each item is independent and can be evaluated on its own.

A change to a more efficient method of recording or storing data may lose this advantage and would require a higher standard of hardware performance.

Datalogger performance

There were two phases in the performance evaluation of the datalogger system. The first was spent in discovering and correcting the faults. During this period of approximately one year the data from the logger was of little value. The second phase of collecting data started in April 1989, after the performance of the system had been improved to a point where the data was consistently valid and could be used to analyse water consumption patterns over periods of one to two weeks.

The first phase concentrated on the electronic behaviour of the datalogger and the detection of errors in the hardware, ROM programs and PC software. There were a few hardware problems which were corrected by Deltrix fairly quickly. The software errors took longer to correct and at times every correction seemed to generate twice as many new errors.

Unfortunately, attempts to correct problems with the pressure monitoring function of the datalogger met with partial success. The designer has so far been unable to solve the transducer calibration problems to the satisfaction of the research team.

Eventually, the hardware performance and the content and format of the data files were good enough to enable the datalogger to be used for practical water consumption monitoring. The dataloggers were tested under typical operating conditions at a selected domestic metering point, where their performance was closely monitored. A number of operational problems were eliminated and procedures for initialisation, termination and data transfer were evaluated and adjusted.

Following the trial evaluation of dataloggers, the monitoring of water consumption patterns at several points in the suburbs of Pretoria was undertaken, to test the datalogging concept in the field and acquire data on consumption patterns and flow-pressure relationships.

The data from the datalogger was modified, by user-written PC software, to conform with DBT's concepts and requirements. An example of the file format adopted by DBT is given below in Figure 3.

The datalogger performed well in the field under a wide range of conditions. Only the pressure monitoring performance was disappointing. Analysis of the data revealed a problem with the interpretation of the data when calculating flow rates, which revolves around the uncertainty of the flow between events. Apart from this, the use of event times to measure flow rate and water consumption patterns appears to work well and has some definite advantages over other methods.

0 0 1 1 2 2 1 5 0 5 0 5	Comments on format
TITLE1$ PRETORIA ERF 1675	Site identification
TITLE2$ GARSFONTEIN	Site identification
TITLE3$ 1.0 litres/trigger	Used instead of UNITRIG
REGISTER1 80.2721	Water meter start reading
REGISTER2 85.7221	Water meter end reading
TIMEZERO$ 22:42:45	Start time (as set)
DATEZERO$ 31/12/89	Start date (as set)
ERROR 8	A battery low error
UNITRIG 0	Means 10^0 = 1 l/trigger
TRIGEVNT 1	Every trigger is an event
EVANAL 1	One pressure per event
ACCEV 5387	Total events recorded
601650	Start time (time origin)
4341,350	
4530,350	Note that actual data
16357,350	starts from column 11
16545,350	in the header block.
...	Titles are given to help
...	identify the data and
590671,350	distinguish it from time
590759,360	and pressure data.

Figure 3 : Format of data file

Only the Deltrix datalogger was evaluated, since no other dataloggers were submitted for testing. This was partly because the other dataloggers were unable to meet the data format, single analogue channel and time resolution requirements within the cost limitations. Another reason could be the comment made at a Water Institute of Southern Africa workshop, which was "Why must DBT and PCED be different from everyone else?"

Triggering and recording events

The quality of the switch in the water meter is important, and the duration of any switch bounce must be as small as possible to enable the trigger points to be clearly identified. Since the time resolution is 0.1 seconds, two events with the same time represent a flow rate of more than 600 litres/min.

The triggering of the datalogger should be tested at initialisation. In one case, a week's data was not recorded because one of the wires to the PCB had broken inside the housing. This is a common problem in any equipment, but the Deltrix logger is most susceptible since there are several wire connectors in the housing that can accidentally be snagged or damaged by over-flexing.

Time base

In terms of the 3-second per day drift limit, the accuracy and stability of the time base was found to vary from logger to logger. The Deltrix loggers were found to gain 8.5 seconds per day, or 1 minute per week. This was acceptable for a monitoring period of one to two weeks.

Time synchronisation

Before taking the datalogger to the monitoring site, a guess was made for the time that the logger would be switched on and this would be written into memory using the PC software. In the field, the operator would wait until four seconds before the start time set in memory, and then switch on the datalogger. If necessary, a correction was then made to the time using the push buttons on the control panel.

The ability to transmit the real time from the clock in the PC to the datalogger would be very useful, and would enable several dataloggers to be synchronised.

Display and header block data

The provision of a display has proved to be extremely useful. Black box approaches do not enable the operator to check that the system is functioning correctly. A display allows the operator to check that the control data has been set and that the whole system is functioning correctly.

Data transfer and filing

Not enough attention has been paid to the storage of data in the PC environment. DBT has written software to remove the blanks from the short files and this reduces the file size by about 30%.

The PCED and DBT have used an archiving program called PKARC to reduce the file sizes further. Although the files have to be de-archived before they can be used, the program generally "crunches" a file to about 30% of its original size. The use of the de-blanking program, followed by the archive program, can reduce the file size by about 75%. At this point the files are a little larger than the original binary file from the datalogger.

Water meter performance

Meters of both the inferential and the positive displacement type were used in this project. It was found that the water meter was a major source of error in the system. In particular, the addition of the trigger mechanism to an inferential meter, decreased the accuracy of the meter.

The additional gearing adds drag to the meter, causing it to go slower. With time, distortions may occur in the plastics parts and friction can vary depending on the position of the gears. This causes the meter to "stick" at points until the force of the flow is sufficient to overcome the friction.

The effects are more pronounced at low flow rates. One of the inferential meters only started to measure consistently above 8.5 litres/minute. In general, size 3 and 5 meters should start to record from 0.1 litres/minute and should be recording accurately to within ±2% at 0.42 litres/minute. Apart from leaks, the minimum flow rate expected at a terminal fitting is about 3 litres/minute.

The positive displacement meters do not have additional gearing. The only addition is the provision of a circular magnet on the main register gear. A reed switch is located in the brass housing close to the magnet. As the register gear turns, the reed switch is activated twice per revolution by the rotating poles of the magnet. This arrangement is very neat and is likely to be more reliable than the system used in the inferential meters.

At low flow rates, the positive displacement meters performed better than the inferential meters. They also have the advantage of a non-return valve that prevents backflow. The datalogger is not able to detect which way the meter is turning and regards any trigger as representing water consumption in the forward direction.

Note that average flow rates, calculated from the interval between two events, are not real if they are less than the start-up flow rate of the meter.

Computers

It was found that data transfer between the Deltrix datalogger and the computer was more reliable with AT-type machines with 80286 processors, than with XT versions with 8088 processors. The portable computer used by DBT to initialise the datalogger and collect data in the field was an XT version.

An advantage of using a portable PC in the field is that the data can be copied from the datalogger and evaluated at the monitoring site. On the basis of the results the monitoring can be continued if necessary.

Software

One of the main factors limiting the effectiveness of the datalogger was the PC software for contolling the datalogger. Good quality datalogger communications software must be supplied by the manufacturer of the datalogger.

The extent to which a datalogger designer can satisfy the applications requirements of the user is limited. A program may be required to just display the recorded data and do a few calculations, or more complex data-processing may be called for. The user must not b- restricted in his options to process and analyse the data b. the assumptions or opinions of the datalogger designer. This comment does not apply only to the Deltrix system, but also to other systems where the user is obliged to use expensive software with limited capabilities, because access to the raw data is difficult, if not impossible.

Pressure sensors

The intention at the beginning of the project was to encourage research laboratories at universities, the CSIR or in industry, to develop low-cost piezoresistive or strain gauge sensors for measuring water pressure. The initial optimism was short-lived when it became clear that local industry was not interested in developing products for which there was no proven market.

It was concluded that locally developed pressure sensors would be more expensive than the imported alternatives, without necessarily being a better product.

The first two dataloggers were supplied with Pioden Controls BP16 sensors with a range of 0 - 500 psi, or 0 - 3500 kPa and a strain gauge bridge resistance of 1000 ohms. A high-resistance bridge uses less current than the more common 500 ohm bridges and therefore saves battery power.

No problems were experienced with the transducers but experience in the field indicated that the pressure monitoring system is not reliable.

Several overseas manufacturers offer a range of piezoresistive pressure sensors for hydraulic applications. Some of these were obtained from IC Sensors in California at prices between R400 and R500.

These pressure sensors are much smaller in size than strain gauge types and can be mounted very close to, or on, the PCB thus minimising electrical interference with the transducer output signal. The implementation of these will require changes to the ROM since the calibration constants are different. The input/output resistance of the IC Sensor's models is 4400 ohms and the sensors require a supply current of 1.5 mA, which may also influence the hardware design of the datalogger.

EVALUATION OF CONCEPTS

Once the datalogger system was functioning reliably, it was possible to begin collecting data and evaluating the time-of-event method for determining water consumption patterns. The data analysis falls into two areas, the first being the analysis of the data for errors, and the second the analysis of the data for the information it contains.

Error detection and correction

The number of events in a data file can be as many as 10635 and it is not feasible to check this manually. It was found that errors were occurring in the data files, due either to false triggering, errors in the ROM or PC software, or glitches during data transfer via the RS232 ports.

Programs have been written to check data files for errors, reformat the files, calculate times and flows and prepare frequency histograms and tables of the data. The applications software detects and marks "bad" data, which can then be examined by the operator and discarded or included, depending on the seriousness of the error.

An estimation of the number of errors can be made if the start and end meter readings were accurately recorded. This is not as easy as it sounds, since the accuracy of the meter reading depends on how well the register was assembled and where the digits and pointers are when the meter is read. For example, the next higher digit may already have changed while the lower digit still appears as a 9.

Problem data files were found to be related to loose memory chips on the first two dataloggers. In later versions, the memory chips were firmly held by the normal IC sockets.

Data analysis for flow rates

The use of the time difference and the unit volume to calculate the average flow during the event is only valid if there is continuity of flow between the two events.

It was clear that the flow was zero between many pairs of events, and that the calculated flow rate could not be applied at the middle of the interval (or to the whole interval) in all cases. Until a better procedure can be devised, it was decided that the calculated flow rate would be applied to the time of the second event used in the calculation.

In most cases this appeared to be satisfactory, except for the first flow in any group, or "macro-event". The first event in a macro-event will usually be assigned a flow rate that is very small, because of the typically long period since the last macro-event. The begining of a macro-event can therefore usually be identified by a low flow rate, followed by a number of higher but similar flow rates.

The low flow rate is seen as a marker and not a true representation of the actual flow rate at the time. While it is easy to see the macro-events in a graph or print-out, devising a software routine to identify macro-events is not simple. One possibility is to look at the average flow rate either side of an event and assign the higher value to the event. However, the real issue is deciding which events can be logically grouped together. If this problem can be solved, the leading and trailing events can be identified and their flow rate values adjusted accordingly by the computer.

Independent or isolated events suffer from a problem similar to the lead event in a macro-event. No means of determining their true flow rate appears to exist, other than to use higher resolution water meters to resolve the flow into macro-events.

Usually, these isolated events do not constitute a large proportion of the total consumption. Analysis of the frequency distribution for flow rate at a monitoring point can help to identify the proportion of low flows in the record. The frequency distribution, adjusted to compensate for the "imaginary" low flows, may be used to improve the accuracy of the flow rates at independent events, since these will probably follow the same distribution.

Further work is needed in this area. Monitoring a single point using two dataloggers with different meter resolutions, say 1 litre and 0.5 litres, may help with the development of analysis algorithms.

Cumulative flow

Since each event represents a fixed volume, the data is very useful for producing accurate cumulative volume graphs. These graphs can be differentiated to yield the flow hydrographs.

By adding several data files together according to the time sequence of the data it should be possible to produce a combined cumulative volume graph for any number of meter points. This may be a useful method for predicting peak flows in distribution systems.

Flow analysis

By applying the average flow rates over the intervals between events, each event can be assigned two flow rates. Because the intervals are short, it is assumed that the histogram represents a continuous flow and may also be part of a macro-event.

We cannot determine the actual flow rates at any time, but we do know that the area under the flow rate curve must equal the unit volume between events and that only one flow rate can be assigned to an event. Therefore, with macro-events, it is possible to construct an approximate flow rate curve such that these two conditions are met and the result should be sufficiently accurate for practical purposes.

Once the macro-events have been defined, reasonable assumptions can be made about the independent events. In practice it is unlikely that the independent event will be significant in terms of high flow rate, but may be very significant for detecting low flow rates.

The existance of low flows, with particular reference to leaks, can be detected in the data by analysing time periods (such as midnight to 6:00) for events occurring at regular intervals. This assumes that the water meter or trigger device is sensitive enough to detect low flow rates in which we are interested.

SOFTWARE DEVELOPMENT

Simple software routines have been developed for converting and preparing data files for detailed analysis. A problem was the format to be used for presenting data in ASCII files. A standard format was eventually adopted which enabled the data to be accessed by software such as DBASE, SUPERCALC and LOTUS, as well as custom software written in various languages.

It was found that the ASCII file, created by the Deltrix data transfer software, contained a large number of blank characters. The re-formatting program was written to remove these blanks and thereby reduce the file to about 70% of its original size.

The standard 640-kb PC does not have sufficient memory to enable full datalogger files to be analysed by most of the commercial spreadsheet programs. DBASE is an exception but tends to generate very large disk files in an analysis. For this reason, custom software is necessary if the full potential of the data is to be realised.

PCED recognised this and commissioned Bottom Line Software of Pretoria to write software to process the data according to their requirements. This software will be adequate for most applications in the municipal water supply field; however, research applications will generally require specific software for each task.

DBT achieved the objective of formatting the data in such a way that it was accessable to other programs and remained as "raw" as possible. Software to locate and correct errors in the data files has been written, but is limited because detailed information on the method of transferring data from the datalogger has not been divulged by Deltrix.

APPLICATIONS FOR THE DATALOGGING SYSTEM

In this report, the potential uses of the datalogger system is limited to water-monitoring applications. In practice, the system may be used within its limitations in other applications calling for event monitoring.

The phenomena under consideration must be able to generate event data. In the case of pipe flow this is achieved by the use of water meters, or some device that rotates in the flow and can be adapted to operate a switch. The triggers from the device must accurately represent some standard unit of volume if the data are to be used to estimate flow rates.

Applications of the datalogging system lie in the collection of data for the verification of methods used by engineers to design water reticulation networks and size the pipework in buildings. Although the methods are well documented in the literature, the flow rates and pressures assumed at the design stage are seldom verified. In practice this situation can lead to under- or over-design of water supply distribution systems unless the performance of the installation can be measured and checked against the design criteria.

This could be achieved by deploying several dataloggers to measure and record flows and pressures simultaneously at several points within a reticulation system. The data will enable the accuracy of the design methods to be checked under dynamic operating conditions.

Single recorders could be used to determine the flow pattern and the flow-pressure relationships at selected points. The methodology could also be applied to pressure-loss problems in networks, changing characteristics of pipelines and leak detection.

During the project, PCED tender evaluations showed that the data logging concept and the Deltrix datalogger were more successful than other alternatives. The Meinecke datalogger has however been steadily developing in the direction of the Deltrix datalogger and is expected to become an industry standard, if it has the flexibility indicated by its agents, Liquid Meters (Pty) Ltd.

It is understood that collaboration between the software developers and the manufacturers is taking place regarding the improvement of software features and data storage format for practical applications, under the general guidance of PCED and, when required, the CSIR.

Applications other than water consumption monitoring were not pursued, because of:

a) the poor resolution and flexibility of the analogue channel of the datalogger,
b) the lack of suitable trigger mechanisms for most potential applications, and
c) the fact that the amount of time required to establish the water monitoring application had been underestimated.

Water consumption patterns

The datalogging system was designed primarily for monitoring water consumption patterns, particularly the intermittent flow patterns found in domestic water supplies.

In this application, the test meter was installed in series with the municipal water meter and the meter readings were noted for both meters at the beginning and end of the recording period. A comparison of the readings enabled the accuracy of the municipal meter to be established.

The record of both pressure and flow rate at the meter point can be used to determine the supply and demand characteristics of the supply. For example, the flow-pressure data will indicate if complaints of low flow rates and pressures are due to lack of pressure on the municipal side of the meter, or poor flow characteristics on the user's side of the meter.

Peak factor analysis

The combined water consumption pattern of a group of consumers can be monitored by deploying one or more dataloggers at appropriate bulk meter points in the reticulation. The process can be repeated for different sized groups and an analysis of the data should yield the relationship between the number of consumers and the expected peak factors.

More importantly, the cause, duration and frequency of peak flows can be measured. The result could lead to a more accurate method for the design of networks based on the cumulative frequency of flow rates, or probability of failure.

Distribution system performance

The potential exists to use the datalogger to monitor flow rates and directions in distribution networks. The practical value of doing this is probably not great, except where definite problems need to be resolved on small networks.

Pipeline characteristics

The hydraulic characteristics of a pipeline can be established by using two dataloggers to monitor the flow rate and pressure at each end of a long pipeline. The pressure resolution must be accurate enough to enable the head loss between the monitoring points to be determined and the flow rate would need to be reasonably steady to avoid excessive error due to pressure transients between the points.

If the measurements can be made and the head-loss coefficients for the pipeline calculated, then periodic monitoring should indicate any changes in the condition of the pipeline. A difference in the total recorded flow during a period, recorded at each end with an allowance for metering errors, would indicate the magnitude of any leakage occurring along the pipeline.

Design of alternative water supply systems

Since a distribution system only operates at peak load for a small part of the day, its capacity is under-utilised most of the time. In developing areas it may be more cost effective to provide storage at the point of use and save on the initial capital required to construct the distribution system.

The water consumption data obtained by the datalogger system can be used to produce accurate cumulative volume graphs, or water-demand curves. These enable end-storage tanks to be correctly sized to eliminate peak demand on the distribution system.

Future trends

The applications for the datalogger system are expected to increase as the reliability and flexibility of the hardware improves. The availability of suitable trigger mechanisms for applications will also affect the implementation of the system.

An event-mode datalogger is limited in its applications to those situations where events can be used to trigger a recording. It can be effectively used to monitor water flow in pipes, but is not geared to monitoring open-channel flow.

Since the start of the project, the demand for suitable monitoring equipment for a number of applications in open-channel flow monitoring appears to have increased. The implementation of the fixed interval and variable tracking modes in the datalogger would enable the system to be used for channel flow monitoring, storage tank status and similar applications.

The Centre for Advanced Computing and Decision Support (CACDS) of the CSIR has been looking into the theory of variable tracking, with a view to designing and implementing an efficient algorithm in the microprocessor-based datalogger. At the time of writing, they had not completed their study but it is hoped that the results will be published early in 1990.

Results

Graphical representations of results obtained by PCC using the datalogger are presented on pages 24 to 28.

CONCLUSION

The monitoring concept developed by DBT has been very effective in obtaining and analysing data on water consumption patterns. The development of the necessary hardware enabled the concept to be tested against the requirements for which it was designed and the results have confirmed the original expectations.

In this respect, the main objective of the project was achieved with the development and implementation of the Deltrix datalogger. The results from the datalogger were used to evaluate the methodology on which the monitoring concept was based. The conclusion is that the method has its advantages and disadvantages, but is better than other available methods for monitoring and analysing data for intermittent flow situations.

The means of collecting the data, that has been established, will facilitate further research in this field[11]. The development of improved software should overcome many of the problems encountered in the analysis of the data.

During the project, a need was identified for a three-mode datalogger to cover applications for:

* Event monitoring
* Fixed time interval monitoring
* Variable tracking for efficient memory use on open channel monitoring applications.

From an analysis of construction of the Deltrix datalogger, it was deduced that this need could be met by enhancing the ROM software. A three-mode datalogger, if developed, should be compatible with existing standards and formats established in this project and would improve the utility of the dataloggers available for general use.

RECOMMENDATIONS

Practical application of the datalogging system has revealed a number of areas in both hardware and software components that can be improved and developed.

One of the main areas is the development of the theory and software for estimating flow rates and identifying components of water use, or macro-events from the data.

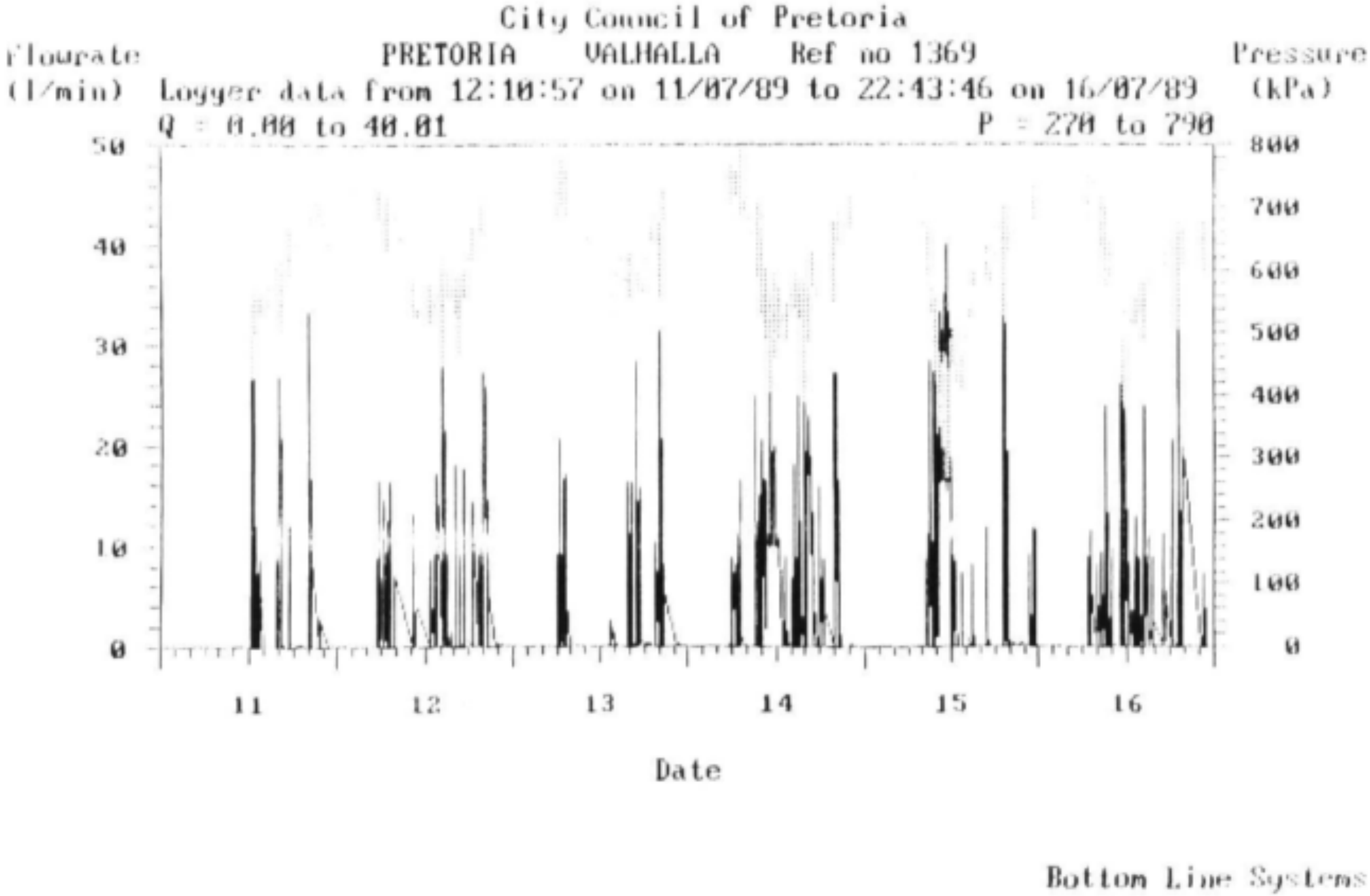
Data must be measured and recorded accurately and a common, or flexible format should be used to store the data in the computer environment. This is necessary if applications software is to be given a chance to develop.

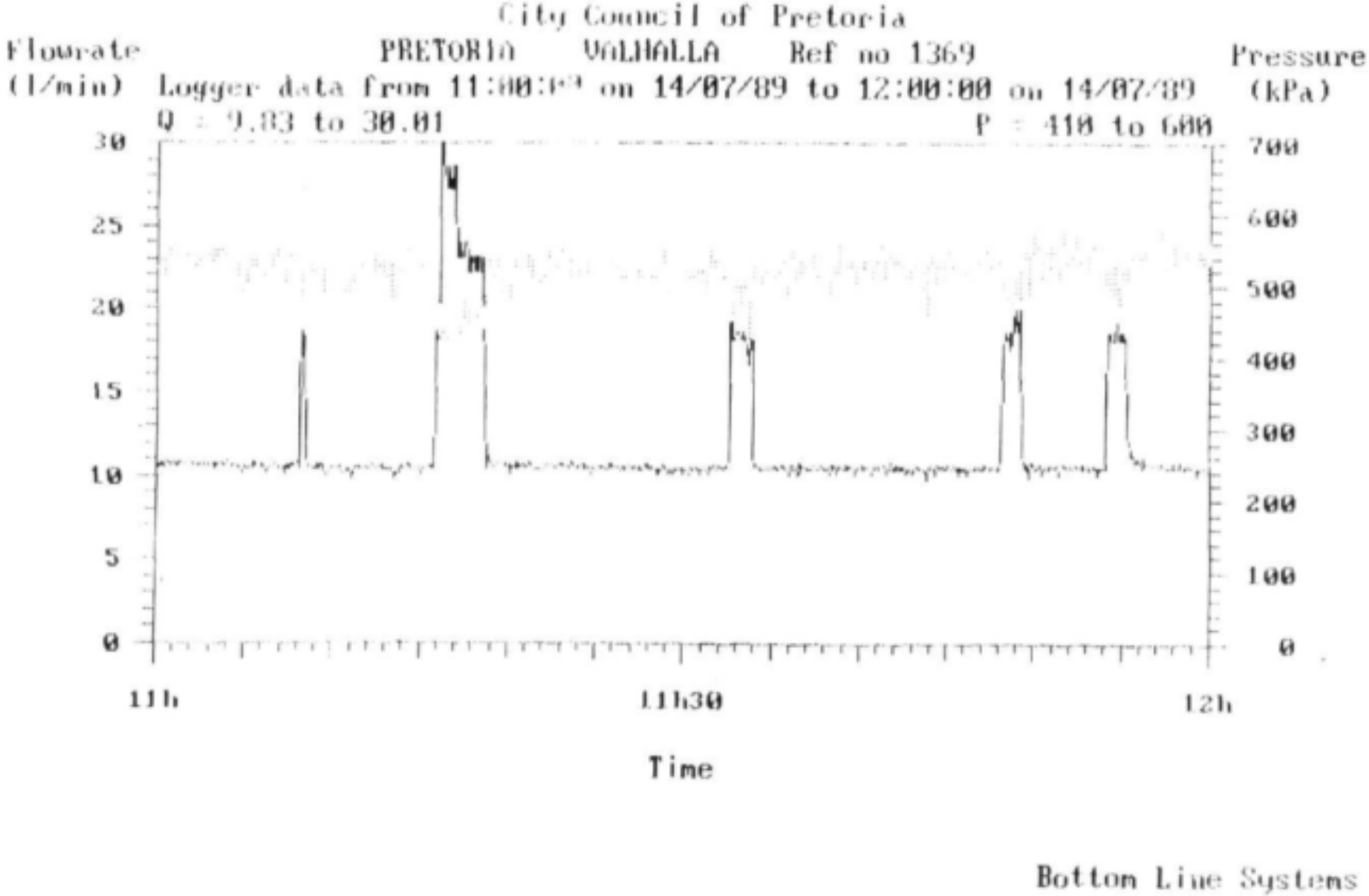
Specifications for electronic equipment should be flexible, but it is important that the equipment performs the tasks for which it was intended to the required standards.

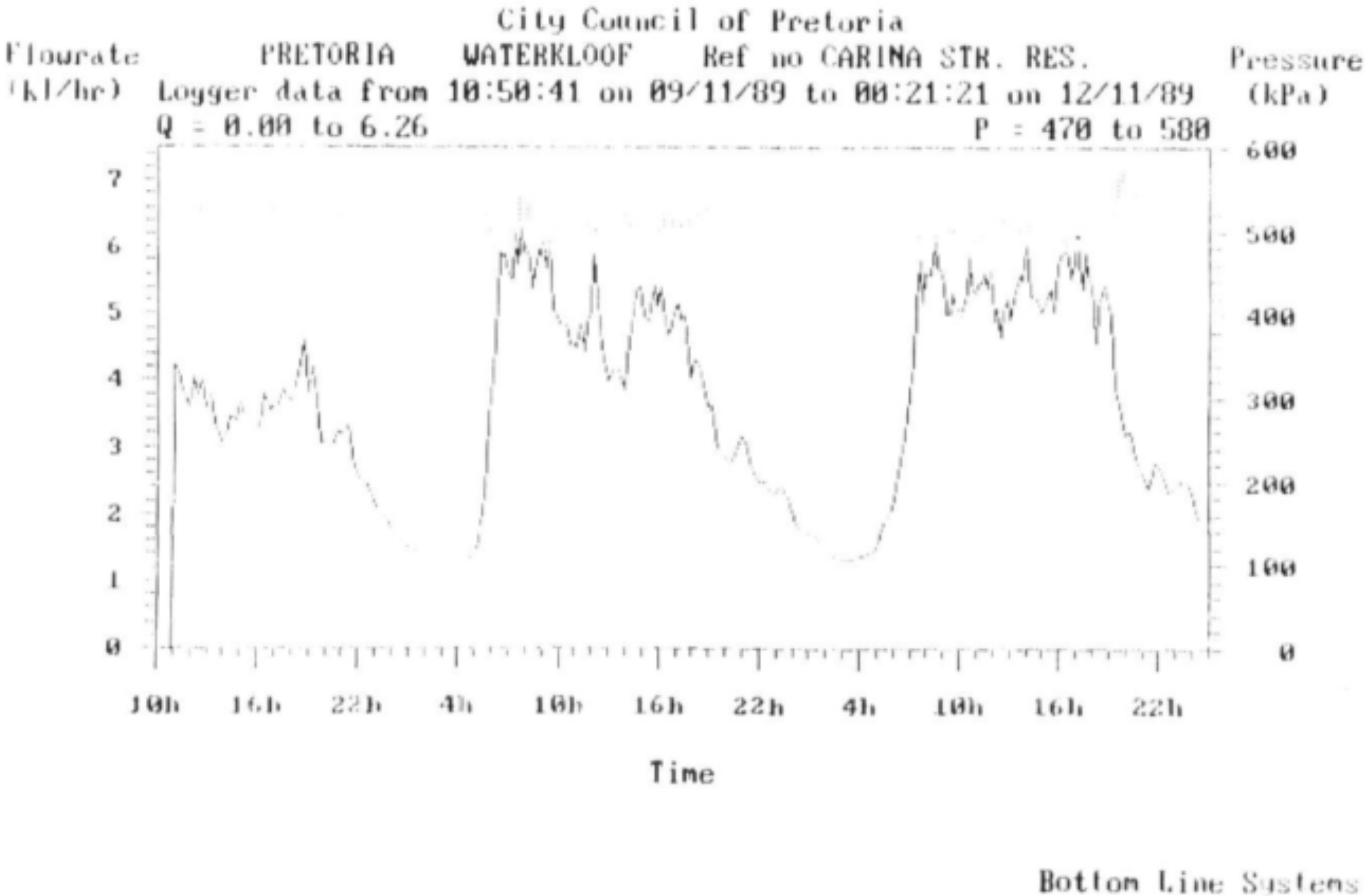
More types of trigger mechanism that relate to definable quantities are required, if the method of mass-flow determination by logging events is to progress beyond the water monitoring field. Such trigger devices exist for traffic monitoring applications, for example, but extensive monitoring equipment already exists in this field.

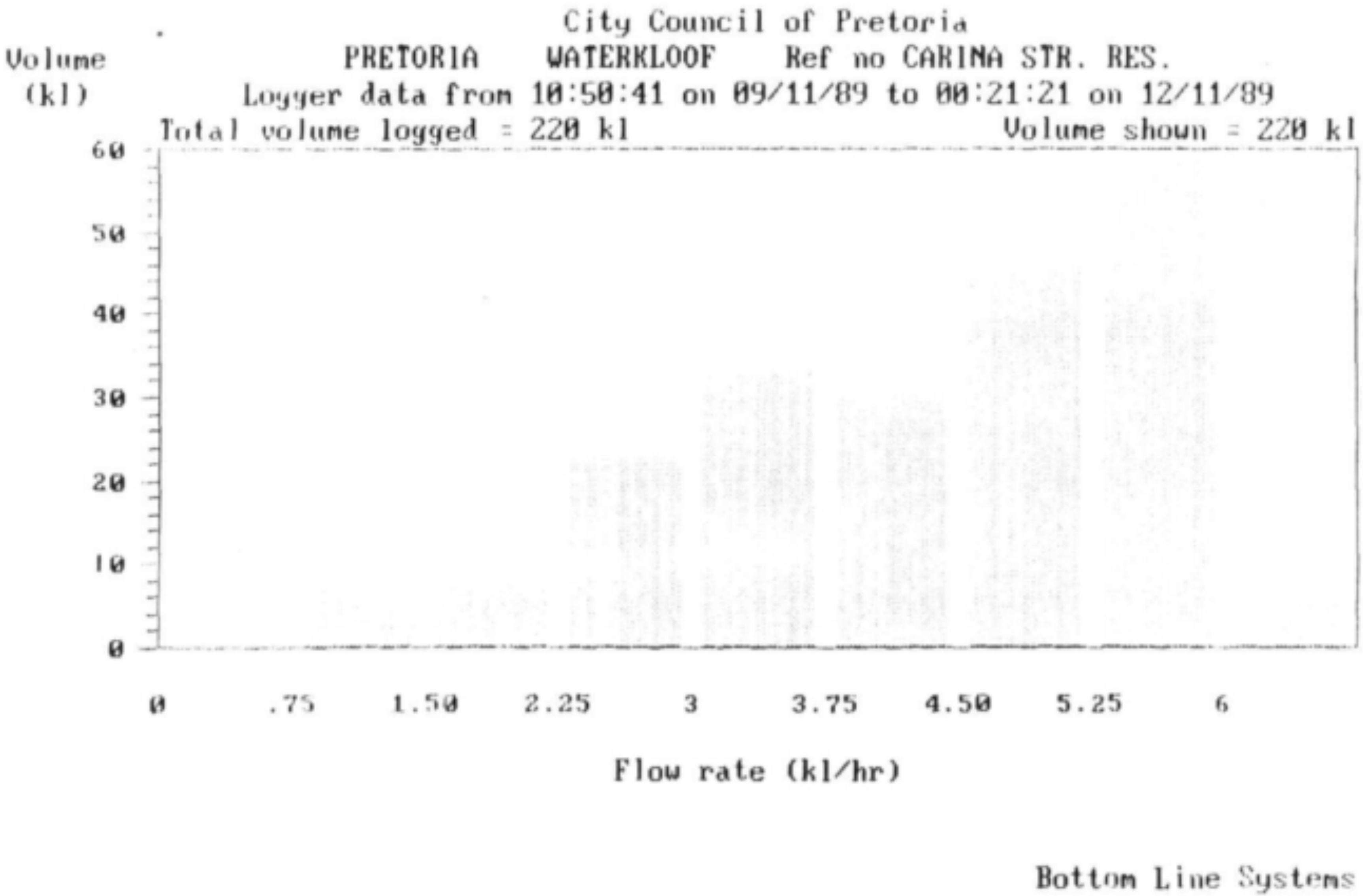
With respect to the existing datalogger, the performance of the analogue channel must be improved.

The development of a datalogger with three operating modes should be encouraged. However, the formats of the data files created in each of the modes should be consistent.


City Council of Pretoria
PRETORIA VALHALLA Ref no 1369
Flowrate (l/min)
Logger data from 12:10:57 on 11/07/89 to 22:43:46 on 16/07/89
Pressure (kPa)
Q = 0.00 to 40.01
P = 270 to 790
50
40
30
20
10
0
800
700
600
500
400
300
200
100
0
11
12
13
14
15
16
Date
Bottom Line Systems


City Council of Pretoria
PRETORIA VALHALLA Ref no 1369
Flowrate (l/min)
Logger data from 11:00:00 on 14/07/89 to 12:00:00 on 14/07/89
Pressure (kPa)
Q = 9.83 to 30.01
P = 410 to 600
30
25
20
15
10
5
0
700
600
500
400
300
200
100
0
11h
11h30
12h
Time
Bottom Line Systems


City Council of Pretoria
Flowrate (kl/hr)
PRETORIA WATERKLOOF Ref no CARINA STR. RES.
Logger data from 10:50:41 on 09/11/89 to 00:21:21 on 12/11/89
Q = 0.00 to 6.26
P = 470 to 580
Pressure (kPa)
7
6
5
4
3
2
1
0
600
500
400
300
200
100
0
10h 16h 22h 4h 10h 16h 22h 4h 10h 16h 22h
Time
Bottom Line Systems

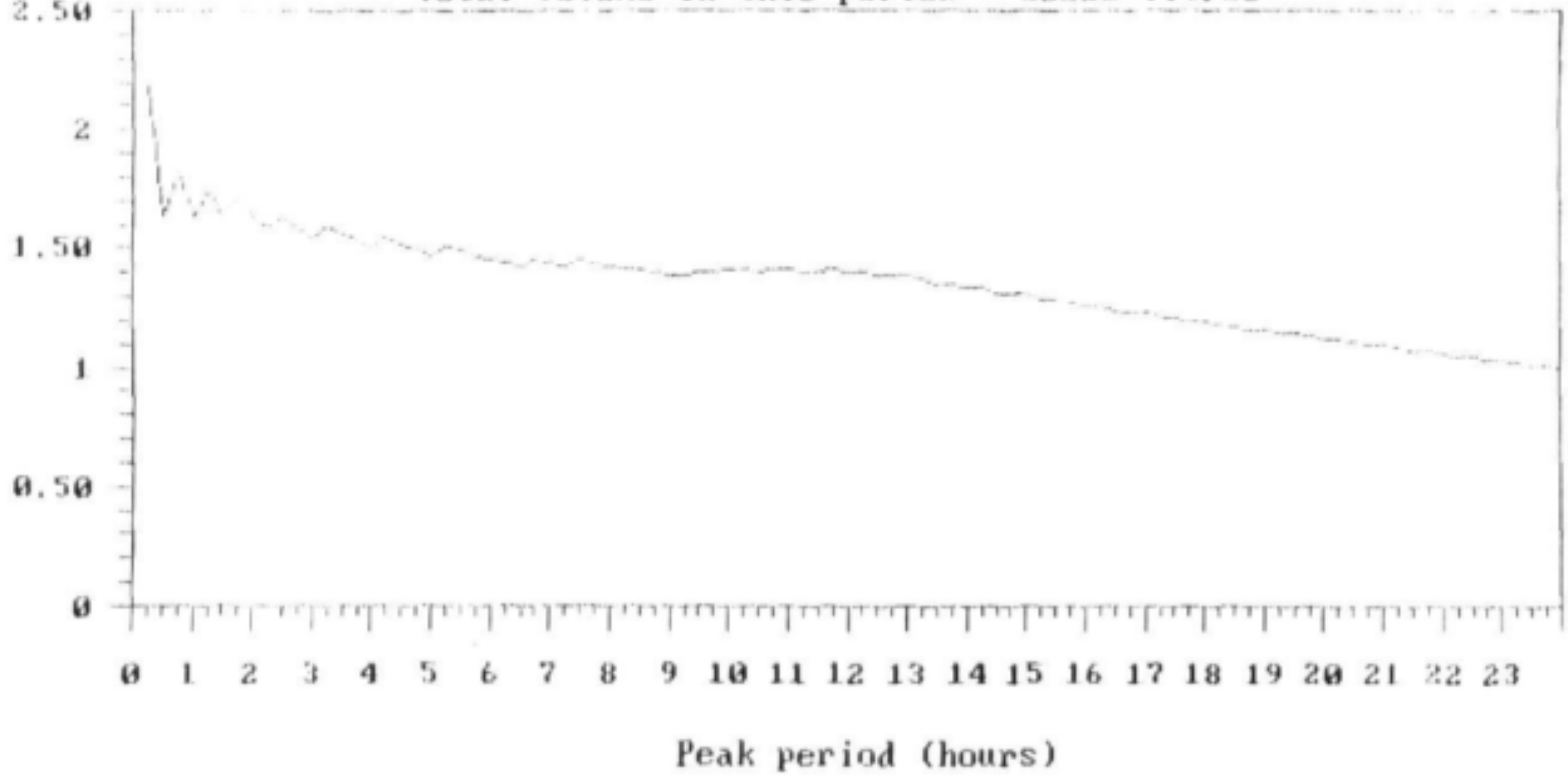

City Council of Pretoria
PRETORIA WATERKLOOF Ref no CARINA STR. RES.
Logger data from 10:50:41 on 09/11/89 to 00:21:21 on 12/11/89
Total volume logged = 220 kl
Volume shown = 220 kl
Volume (kl)
60
50
40
30
20
10
0
0
.75
1.50
2.25
3
3.75
4.50
5.25
6
Flow rate (kl/hr)
Bottom Line Systems

City Council of Pretoria

Peak factor PRETORIA WATERKLOOF Ref no CARINA STR. RES.

Peak factor for 24-hour period from 00:00:00 on 11/11/89

Total volume in this period = 88000 litres



Bottom Line Systems

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