

Optimising the Performance of Battery Electromagnetic Flow Meters.
A Case Study in Meter Specification and Performance.

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Abstract

The aim of this paper is to review both the performance and the advances made over the last four years in the operation of buried battery electromagnetic water flowmeters installed within a distribution network.

The authors will review the original design criteria and installation decisions in the light of subsequent experience, highlighting the obvious and not so obvious lessons learned.

They will, then, outline some of the methods used to assess the condition of the buried meters in-situ and illustrate the very real changes in performance which have been achieved through optimisation of meter software parameters.

Further to this optimisation, the developing role of GSM equipped meters is illustrated and the case made for the economic pursuit of wholelife costing through interactive monitoring of performance.

The increasing demands for Traceability and Data Quality, driven by Water Industry Regulators, are discussed and the role of meter verification, including static electronic methods such as the ABB CalMaster, is assessed.

Finally, the need for Users to clearly define their Application Needs and to be able to both Specify and understand the range of performance being offered by Manufacturers is discussed with illustrations linked to the new International CEN, ISO and OIML water meter Standards.

1 Introduction and Background

This paper describes work undertaken within the last year both to review and to improve the performance of a number of buried, battery powered electromagnetic water flowmeters installed within the network of Severn Trent Water during late 1998. Collectively these meters constitute what is termed a Small Area Monitor (SAM). The term Small Area Monitor, (SAM), was originally coined to describe a metered area comprising between 50 and 100 unmetered residential properties. For the owner of the meters, Severn Trent Water, it's Small Area Monitor now forms a key element in assessing Customer water demand.

Full details of the selection of the ABB AquaMaster battery powered electromagnetic meter manufactured by ABB Ltd are contained in an earlier paper published in May 2001. However, it is very instructive to recount the reasons for the original choice of instrument, in order to set the scene for the recent review work and to illustrate how the intervening 5 years has brought with it various changes in the emphasis placed on different elements of the original Specification.

As the successor to two earlier battery instruments from ABB - the VBC and the AquaMag - the ABB AquaMaster was designed as a commercial water meter, rather than as a traditional EM flowmeter for general application. In order to meet Customer expectations key parameters were identified, namely: -

1. Exceptional low flowrate performance: required to either match or exceed the then current equivalent mechanical Woltmann style Specification referenced in ISO Standard 4064, Class C.
2. Tolerance to severe non-ideal installation conditions whilst maintaining compliance with the published meter accuracy limits.
3. Compliance with all of the developing requirements of the European Standards Committee on water meters, CEN, as well as the ISO and OIML Committees.
4. Installed meter performance which delivered a battery life of at least three years.
5. Robustness of design and of installation: with the sensor capable of IP68 performance when submerged or when buried. (Burying of meters had been established in the UK).
6. Simplicity of installation, with no on-site setup/programming; necessitating an intelligent sensor which stored meter calibration factors and all site settings.
7. Interchange-ability of the meter electronics: allowing interchange of individual transmitters without configuration modifications or reprogramming of any sort.
8. Security of Data: implemented by requiring the sensor to store the flow totaliser data, thus ensuring conformity with Weights & Measures guidelines and ensuring that any exchange of transmitters did not lose the registers holding the values of accumulated water volume.
9. Integrated pressure measurement capability: to be implemented as an option by the User but to be an integral part of the formal instrument's design.
10. Integrated data loggers: to be implemented as an option, but to be an integral part of the formal instrument's design.
11. Integrated telemetry: to be implementable as an option, using primarily, radio. This to include both flow, pressure and totaliser data.

Note that at the time of original installation, late 1998, (a) no mention was made of GSM capability, the text revolution was only just starting and (b) that there was only one Manufacturer, Messrs ABB Ltd in the battery electromagnetic meter market. This has recently, circa 2004, changed.

Whilst ABB claimed compliance with all of the above, there was at the time a lack of independent data, especially relating to field conditions, and a programme of work was undertaken to explore and to confirm performance under field and non-ideal hydraulic conditions. The baseline for meter performance was thus probably more thoroughly researched than for any other water meter of its time.

2 Operational Experience 1998 -2004

The original installations of buried meters were begun in November 1998, over five and a half years ago. When examined with the luxury of hindsight, overall the SAM scheme has been a real success built on solid foundations. In this section we will review how careful initial design has paid substantial benefits and we will illustrate the way in which unforeseen problems have been addressed, leading to a new generation of meter electronics.

However, in order to understand how the intervening years have changed the different elements demanded of the scheme, it is essential to recap on the original design criteria.

The text revolution was only just starting and (b) that the subject of verification of flowmeters verges on the wider topic of dry calibration [4]. We may identify several levels of verification/dry calibration as set out in Table 1. We consider these in turn.

2.1 Buried meter Design & Installation Criteria

Unlike many installations which are undertaken in the UK Water Industry, where new equipment is fitted into existing Network pipework, it was decided to standardise the mechanics of the sensor side of the task, as opposed to individually fitting meters into the many and varied locations on a bespoke basis.

To provide sufficient upstream and downstream clearances all of the meters were pre-assembled on a workbench with 1m spool pieces of pipe of identical diameter to the meter bore and installed as a pre-formed, standardised section. Two stainless steel “earth” rings for fluid bonding were used on all assemblies, despite the manufacturers published data sheets that required only one and a separate earth strap was connected from the flow tube to the transmitter; again, a practice not required by the manufacturer but deemed to be a useful “insurance”.

In the light of past unhappy experiences, great care was taken to avoid physical damage to the sensor at the installation stage by the Civil Engineering Contractors. Damage during installation is always a contentious issue when retrospectively investigating flowmeter data anomalies and it was essential to closely control this phase of the work in order to maximise the level of Confidence in the new flowmeters.

Cable runs were all ducted, and their integrity was checked before and after backfilling the excavation. All meters were bedded in sand and protected by a paving slab and marker tape. All cable lengths were left at the factory length of 10 metres.

Most importantly, the use of a pre-formed section not only provided ideal hydraulic conditions for the meter but ensured that the physical connections were made well away from the EM sensor.

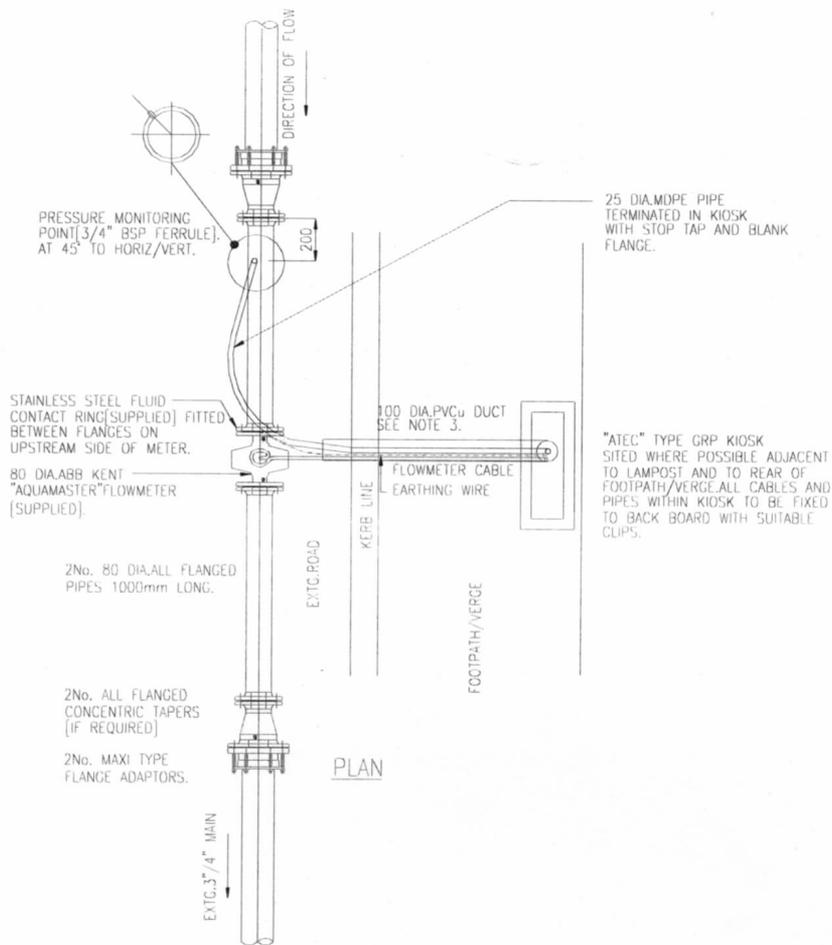


Figure 1: Detail of meter spool piece installation

A pressure tapping was installed on each installation to enable logging of diurnal variations.

2.2 Original Meter Performance Criteria

The choice of a battery powered electromagnetic meter was taken only after extensive test work, backed by operational experience of the earlier generation battery emags. Given the role that the SAM was engineered to fulfil, long-term stability of the meter calibration was deemed to be of the highest priority. This had been achieved by the manufacturer through digital signal processing and demonstrated in a series of tests undertaken in Australia where a twin meter package was tested over an extended period.

Parts of these Australian results are shown in Figures 3 and 4 with the DN 100 AquaMaster operating first on mains power then on battery. The results are plotted against velocity in the 100mm pipe bore, on a log scale. Normalising the results to velocity gives a graph and specification independent of pipe diameter.

TWIN AquaMaster DN100 TEST TRANSFER UNIT, SENSOR A
Mains Power. Rig: ABB UK & Australian National Standard Rig

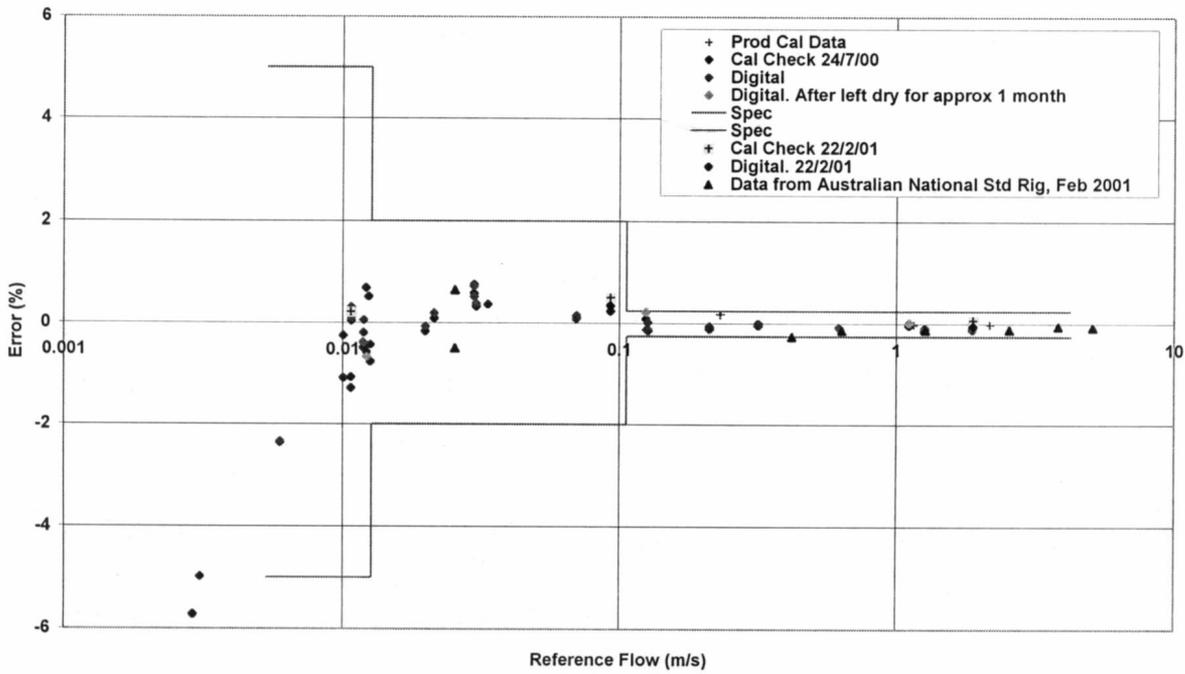


Figure 2: AquaMaster, Meter A on mains power

Twin AquaMaster DN100, Battery mode, Meter A. Rig: 16 / 160 rig.

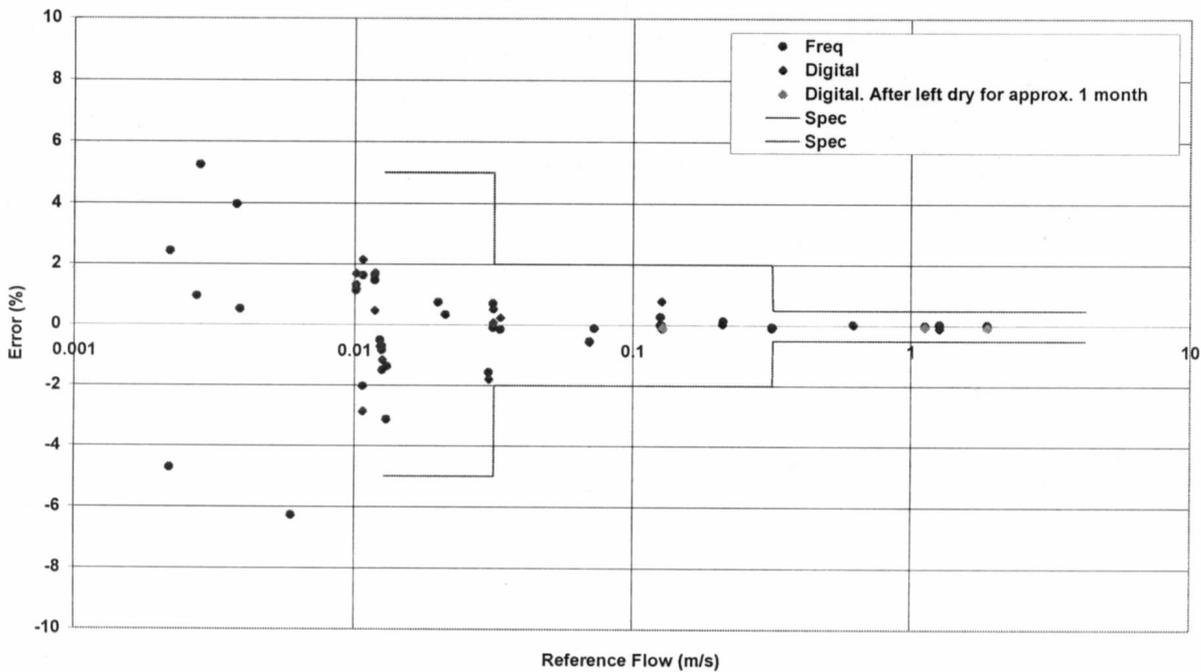


Figure 3: AquaMaster, Meter A on battery power

The Manufacturer's specification envelope for the mains powered AquaMaster considerably exceeds the current ISO 4064 Class C, reaching far lower flowrates and, at higher flowrates, a tighter $\pm 0.25\%$ accuracy specification.

This should be compared with the battery results, which match more closely the ISO 4064 Class C Specification. The specification envelope on this battery data is equivalent to ISO 4064 Class C, but with a tighter upper zone flow region where AquaMaster is specified to maintain $\pm 0.5\%$ rather than the 2% of its mechanical equivalent.

2.3 Original Data & Reporting Criteria

At the time of installation it must be remembered that the AquaMaster was viewed as an improved alternative to the traditional mechanical meter. For data logging and data recovery it was at that point no different to its mechanical counterpart i.e. its primary task was to output volume based pulses to a separate electronic datalogger.

Moreover, the focus on the data being recorded was essentially in two parts

- (a) Firstly, on daily, integrated volume data; which constituted the *raison d'être* for the Small Area Monitor
- (b) Secondly on flowrate data, derived indirectly from volume; but only for the secondary purpose of identifying any leaks with the monitor

Interest in detailed events was not considered important given that the hierarchy of priorities was to determine average water utilisation per connected household within the SAM. Given this focus, the traditional, International Hydrometric data standard, which is set at 15minutes, was deemed perfectly acceptable for application within the monitoring environment of the SAM.

2.4 Installation Experiences

Detailed attention to the original design and strict training of the civil engineering contractors proved its worth many times over, with the result that over the past five and a half years there have been no failures of the buried sensors nor of the buried connections, whether electrical or pressure.

Vandalism of the GRP enclosures used to house the majority of the meters transmitters caused a small number of difficulties which were resolved by using either a metal housing or relocating the equipment to small buried chambers fitted with vandal proof lids.

The largest problem came with failure of several transmitters due to water ingress. Given that the enclosure for the AquaMaster transmitter is rated at IP68 this was highly unexpected. The reasons proved to twofold.

The first centred around the fact that the cable connecting to the external datalogger was of a smaller diameter than the minimum size for which the standard ABB production gland had been designed. No quality check had been made on the datalogger manufacturer's cable and the gland was simply not water tight.

The second source of failure was human factor related and occurred when the batteries were exchanged, approximately between 18 months and two years. (The manufacturer's specification quoted 18 months but proved in practice to be somewhat conservative, erring on the side of safety). In order to exchange the battery the lid of the metal IP68 transmitter case, together with its rubber O ring gasket seal, had to be removed. Regrettably, failure by those personnel exchanging batteries, to remember to either put the gasket back, or to correctly re-seat the gasket, or to correctly do the screws up on the transmitter lid once the battery had been exchanged left

the transmitter casing open to water ingress. In the UK climate water such weakness is inevitably exploited by the elements and resulted in far more failures than had been anticipated.

Failures due to batteries expiring early, the largest risk predicted at the start of the project, were few and in almost all cases it was difficult to separate battery failure from errors in the battery exchange procedures as described above.

2.5. System Performance Experiences

As has been related there have to date been no failures of buried sensors. This is in contrast to other organisations that have reported considerable problems. Where the Severn Trent experience is different is in the attention to detail that was given to the design before hand, plus careful physical handling during installation. Both contractors employed by Severn Trent proved to be quality companies. The role of training cannot be over-emphasised.

Regarding the intrinsic flow performance there has been clear evidence that the choice of an electromagnetic meter has delivered the expected improvements in turn down and resolution of low flows which the independent testing had confirmed in the laboratory.

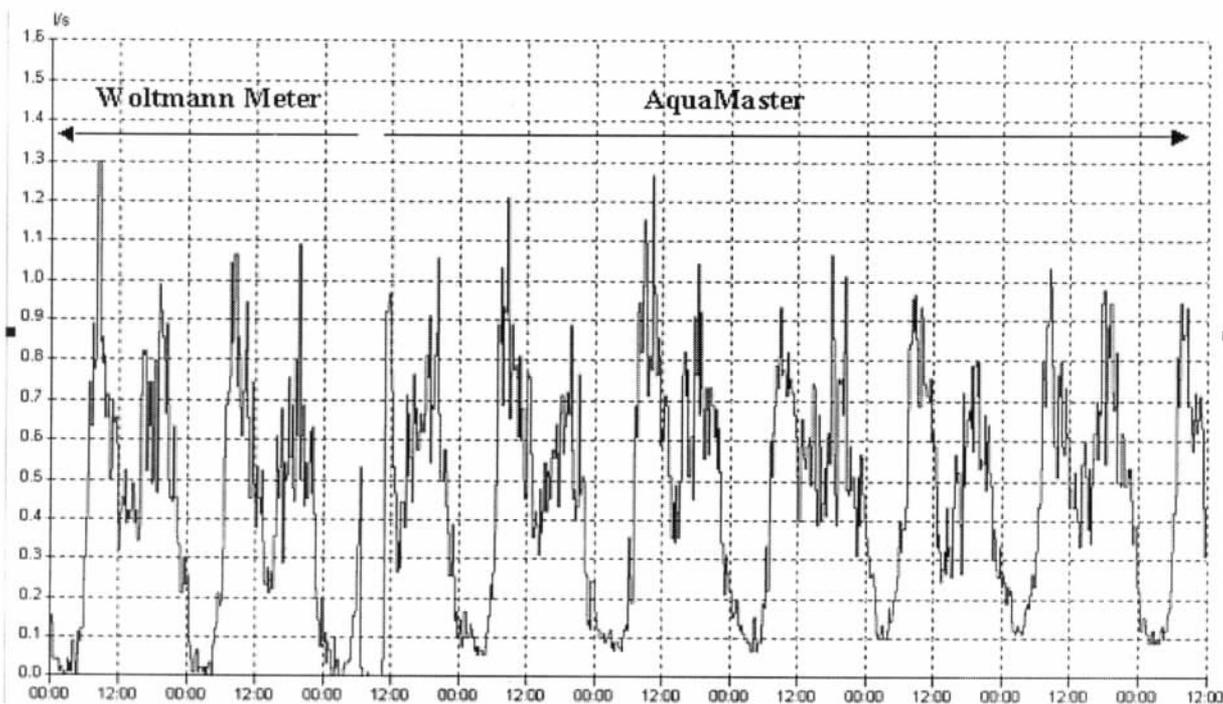


Figure 4: Example of original 1998 performance improvement (15 min data)

However, as the next section will relate, the Quality of data between sites with identically installed meters was observed to differ. In particular, flow "spikes" were sometimes observed on the data logged records but no pattern was obvious between sites. The overall performance remained very good indeed but it was clear that circumstance did exist where the quality of flow data occasionally degraded.

3. Year 5 Performance Review

Following almost 5 years of successful operation it was decided in 2003 to undertake an in depth audit of the Monitor. The remit in three parts: (1) to gather information on the *static* meter parameters (2) on the *dynamic* performance and (3) to review the month by month, year by year flows which had been recorded by the dataloggers attached to the meters. An example of the dynamic information recorded is given below.

Example of Analysis of Live Data.

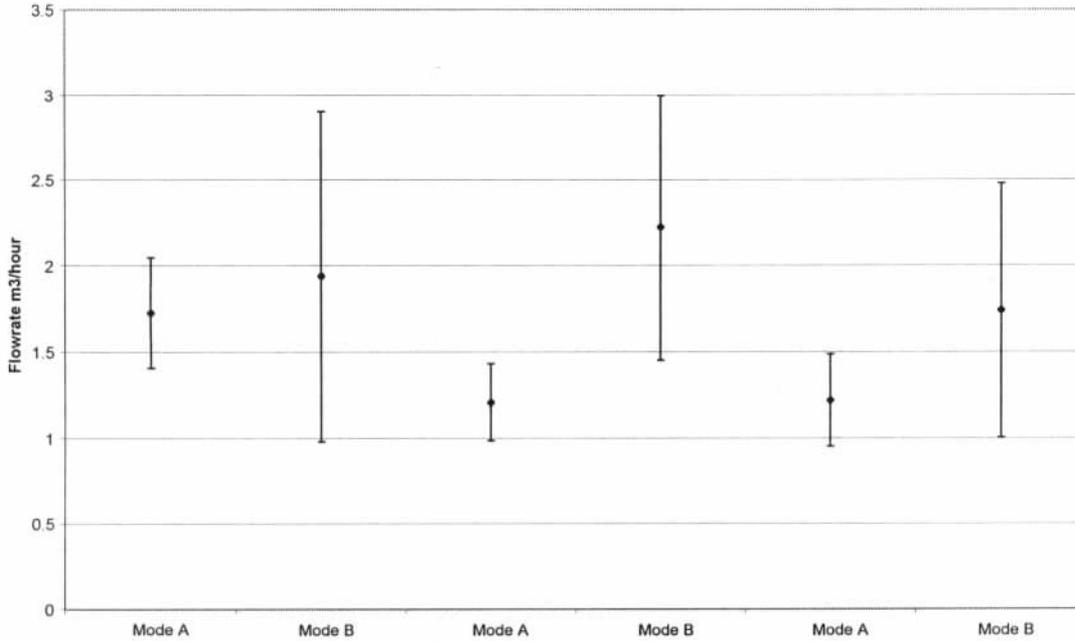


Figure 5: Graphed Statistics for differing Modes.

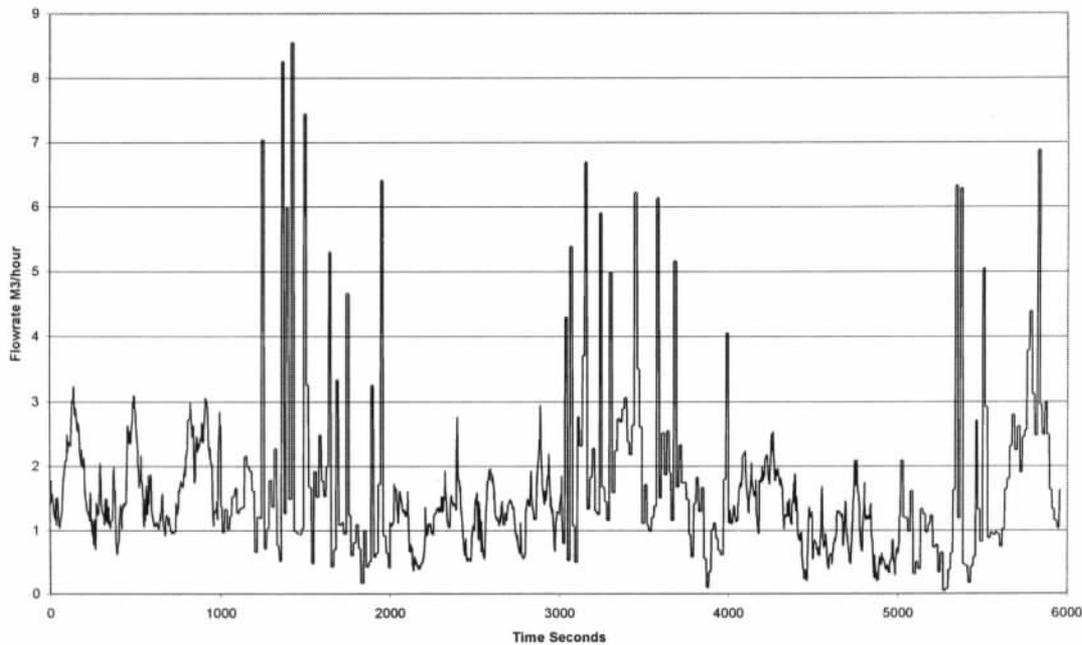


Figure 6: Raw Data taken under different Modes.

		Average	Stdev	Range	NSE
Run 1	Mode A	1.727024	0.638809	2.624631	37%
Run 2	Mode B	1.942241	1.922244	8.379931	99%
Run 3	Mode A	1.209248	0.447866	2.595381	37%
Run 4	Mode B	2.22446	1.543266	6.591877	69%
Run 5	Mode A	1.221046	0.535992	2.34271	44%
Run 6	Mode B	1.742104	1.477245	6.821676	85%

Figure 7: Detail of Statistics of raw data.

The outcome of the Review confirmed the opportunity for further improvement in the quality of the data. Currently the economic case is under examination but technically it was clear that through the deployment of new, 2nd generation electronics, plus attention to the mode in which the buried sensor could be operated, useful refinements could be achieved in the flow performance without any change to the basic sensor; which is of course buried.

4. Optimisation using 2nd Generation Electronics

The hope of the 5 year Review was to achieve an improvement in the performance of the meters beyond that which was being delivered and much beyond that which could be achieved with any alternative mechanically based meter design. Specifically low flow performance and performance over far shorter time frames were to be examined.

The approach taken was to deploy ABB's second generation AquaMaster Transmitter. This unit (i) contains over 400 fully programmable parameters, (ii) is GSM enabled thus offering stand-alone communications quite independent of the attached dataloggers which are presently in use, and (iii) has 3no. fully independent internal data loggers which can be set to log at different frequencies.

Initially two units were deployed for trials, a number which has risen to twelve now that the optimisation groundwork and experimentation has been completed.

Three areas were targeted as representing the best means of achieving the performance improvements sought.

- Attention to the values of the minimum velocity cut-offs programmed
- A reduction in the period in which data is aggregated – currently 15minutes
- A change to the mode in which the meter is operated. In effect, moving the battery performance closer to that of the mains powered units.

To date the results have been extremely encouraging and are best illustrated by looking at some of the flow data. Remembering that the Small Area Monitor's are all cul-de-sacs, it has been remarkable to observe on the data from the battery meters single toilet flushes – which are leaks but of a different order to those normally observed!

Figures 8 to 12 show the greater accuracy available with the 60 second data. The spike shown in figures 8 and 9 is flow caused by opening the hydrant next to the meter.

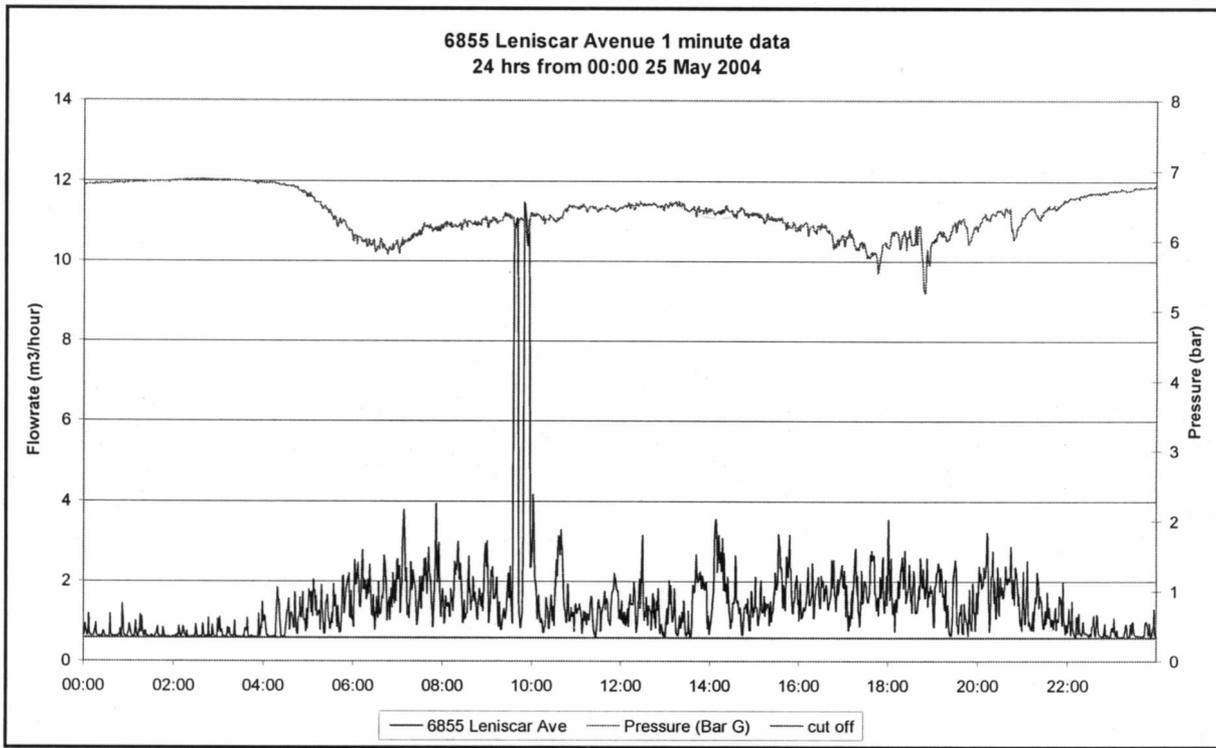


Figure 8: 1 minute data indicating double event hydrant opening

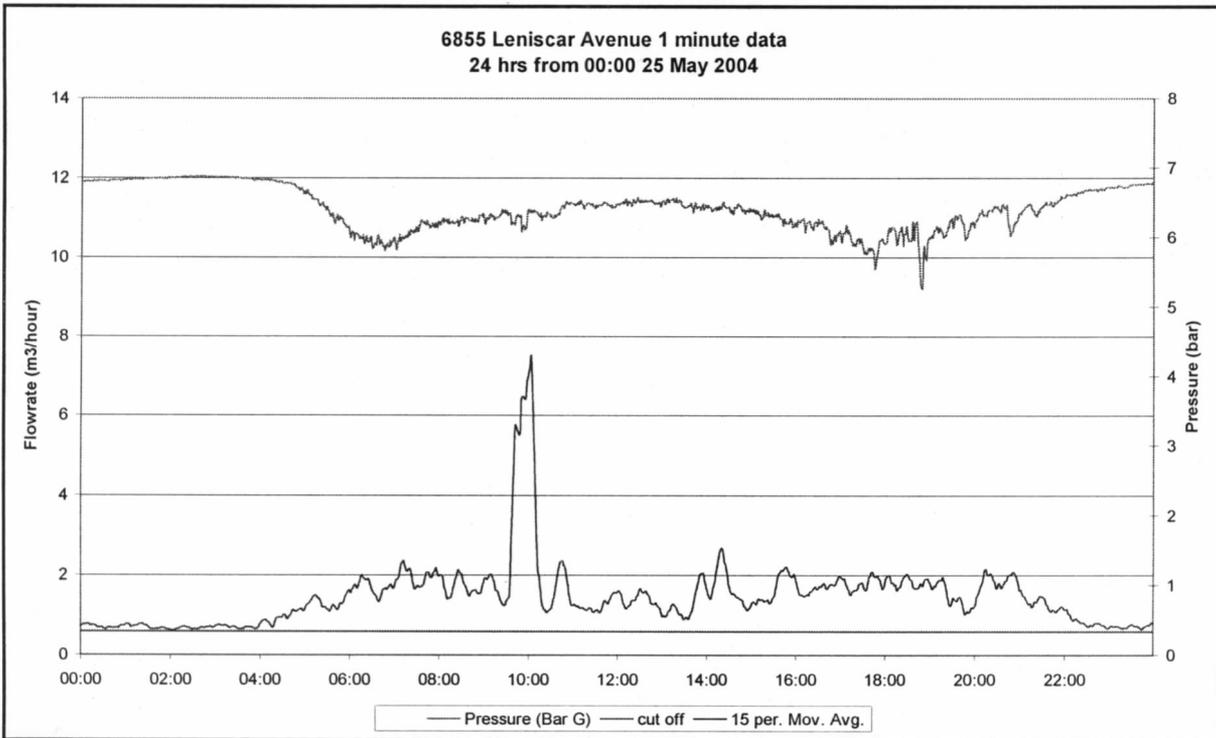


Figure 9: 15 minute data of same hydrant activity blurring true double event

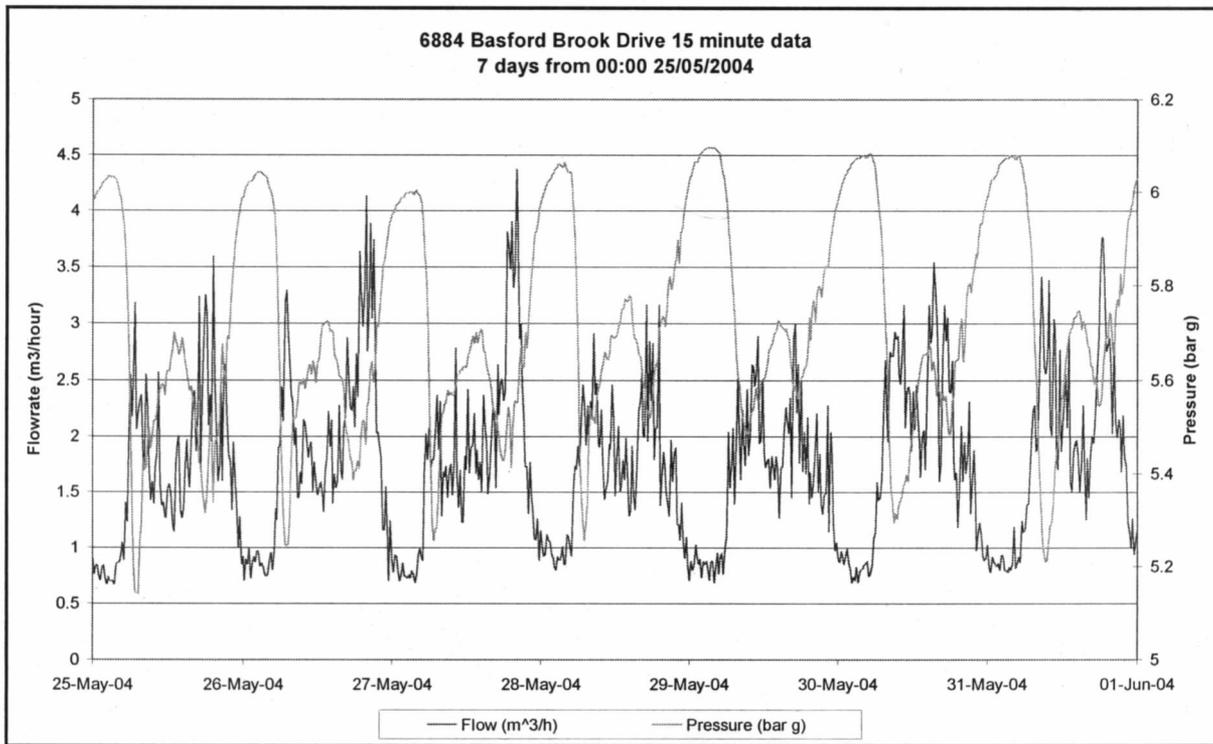


Figure 10: 7 days of 15 minute data suggesting leak

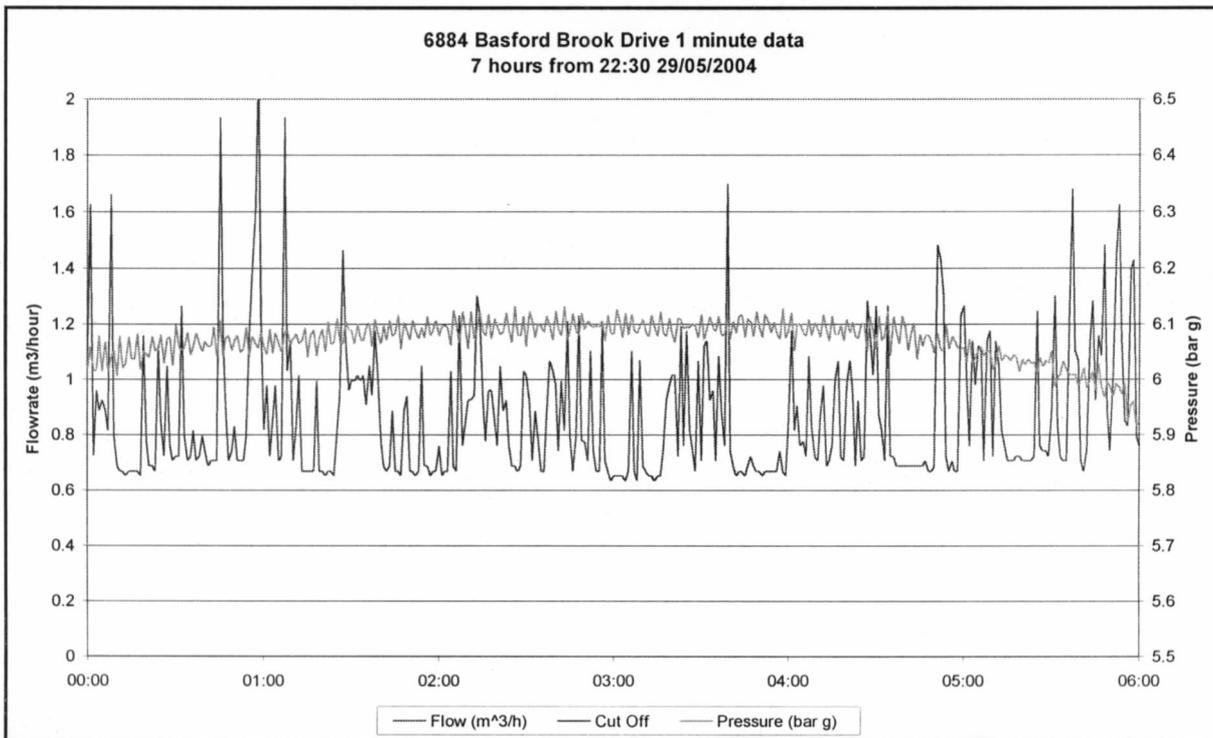


Figure 11: 6 hours of 1 minute data with raised zero confirming leak

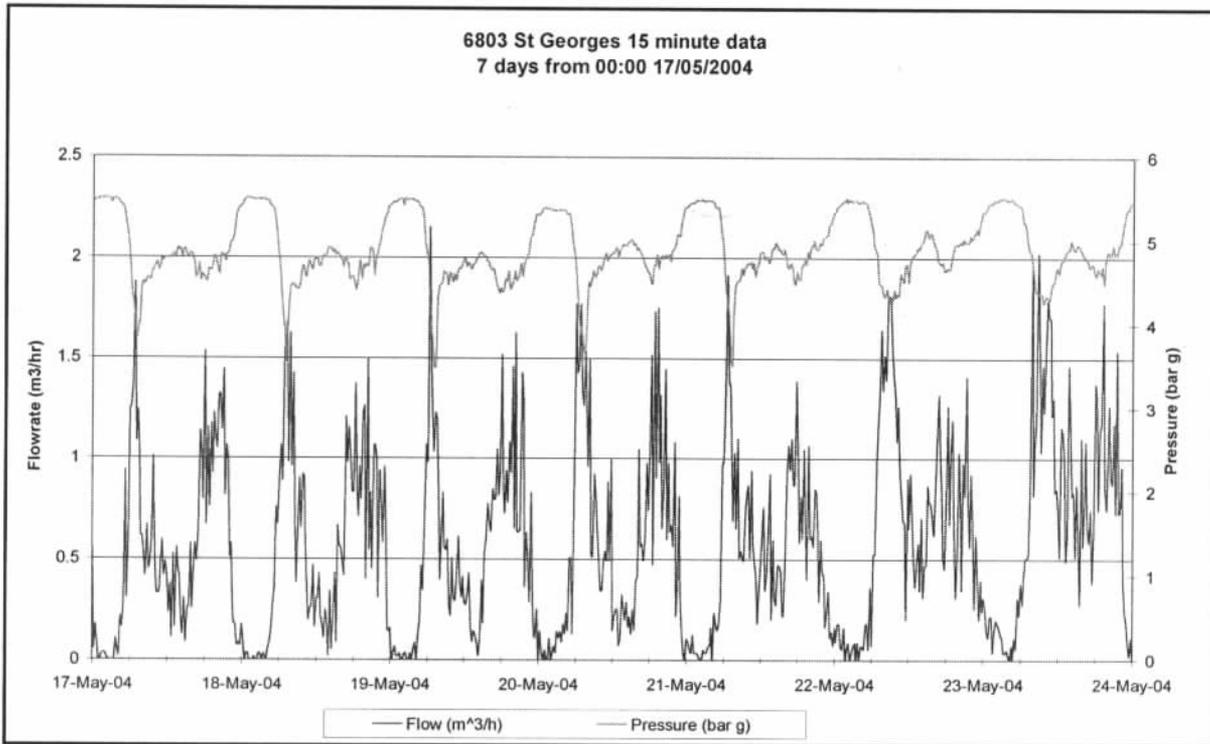


Figure 12: 7 days of 15 minute data suggesting possible leak

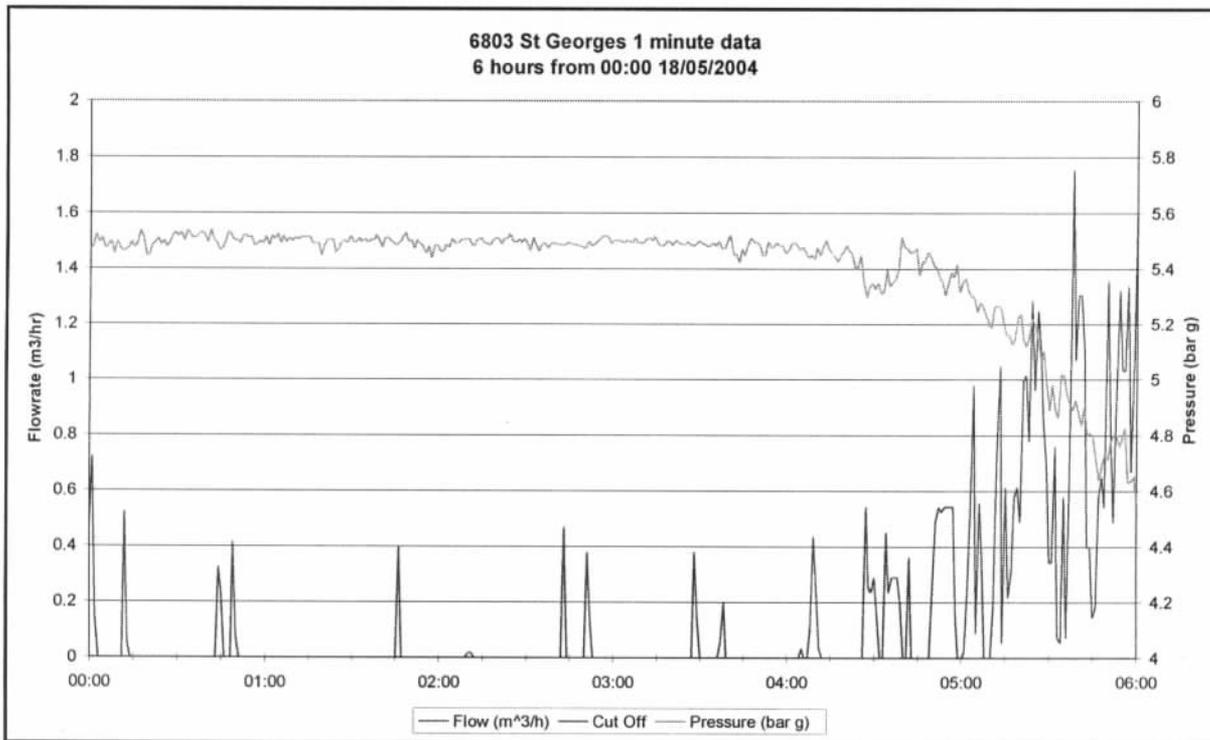


Figure 13: 6 hours of 1 minute data with zero flow periods demonstrating no leak

5. The Dividend for Meters with Integrated GSM

For meter technologists and engineers the acquisition of accurate meter data has often been wrongly viewed as an end in itself, rather than as a means to an end. In fact, the economics of collection, collation, analysis and then accurate distribution of meter information to the relevant parties within Management can often be as important as the front-end equipment.

Starting about four to five years ago the water meter data logging market in the UK underwent a quiet revolution with the introduction of GSM, text message based, data transfer. No longer was it necessary to visit each meter location every month or so to manually download flow data, using a single, one per day text message containing 96 records, one for the volume recorded in each 15 minute period, it was possible to obtain all of the manual operations electronically.

With the integration of GSM communications and the measuring instrument, as is the case with the second-generation ABB Aqua Master transmitters, operation, configuration, datalogging and maintenance all become accessible. Practically this has highly significant and far reaching implications not just for the Quality of the data, but for the manner in which the meter stock may be managed, and especially for the Management and the distribution of the flow data.

Consider some of the engineering parameters that were remotely accessed during the work described in this paper; including the optimisation exercise. For example: Battery levels, Alarm states; software and hardware status changes, including any reset conditions; electrode signal levels; datalogger resolution periods – there are three independent loggers; the phone numbers where data can be directed; low flow cut-off values; signal time constants. Indeed, ultimately the list would extend to all of the 400 plus configuration parameters.

For the “standard” User it is unlikely that much more will be demanded than that which is currently available from the independent dataloggers that are currently deployed throughout the UK to count the pulses deriving from the flow meter. However, this brings us to the importance of which measurand is Key to the particular End Use, and which technology is deployed to measure the flow.

Whilst most water companies are interested only in metered volume, for which logging of discrete pulses is adequate, flow rate is essential when the role of the data demands that flow events or time periods over which events are occurring. The classic example is for night time leakage flows where it may not be apparent which components are due to loss of water from the pipe and which attributable to short term events such as tank filling by industrial customers. Identification of flushing of water mains is another example where rate, not integrated Volume is required in order to identify events. See Figures 8 and 9.

With the advent of integrated text based GSM logging, the choice of what level of data resolution is open to the User. Thus, with a meter based upon rate, such as electromagnetic designs, it is possible to observe a whole range of events within the water distribution Network which were previously obscured by the averaging effects of slow, pulse derived, pseudo rate data.

Complete, remote GSM enabled programmability also opens up opportunities previously limited at the point of purchase, namely the ability to alter the power mode of the meter for the purposes of achieving enhanced performance.

Regarding maintenance, the ability to interrogate the meter once or twice daily and for the meter itself to be set to alarm out for a whole variety of trip conditions, is functionally and economically invaluable.

For whole-life costing the rules are effectively being re-written for battery electromagnetic meters in that integrated GSM delivers performance and condition monitoring throughout the equipment's life.

6. Data Quality & Traceability Issues

At the beginning of the paper the key role of the Small Area Monitors in assessing consumption demand was outlined. Given that the SAM data is therefore open to external examination it is essential that the Quality and Traceability of the metering system is established. Whilst at present there are no formal requirements, elsewhere in the UK the Environment Agency (EA) is developing guidelines for all buried electromagnetic meters. These will eventually be published and are likely to encompass the following ten criteria applying to the verification of buried devices.

Thus it is probable that Users shall be required to demonstrate:

- | | |
|--|-------------------------|
| 1. Provide Traceable evidence; | which is |
| 2. Accurately collected; | by |
| 3. Competent, Trained Personnel; | using |
| 4. Independently, Calibrated kit; | to create a |
| 5. Verification record Database; | which can be |
| 6. Objectively analysed; | and |
| 7. Categorised using Uncertainty techniques; | that can be |
| 8. Securely Archived; | to achieve a single |
| 9. Metering Installation Uncertainty; | which can be subject to |
| 10. Periodic Independent Review. | |

To date, the principles given above have been followed by carefully aggregating documented data which includes: (a) The layout of the meter installation & pipework; (b) all upstream and downstream disturbances; (c) details of earthing (potential equalisation); (d) details of the pipe condition; (e) formalised and documented survey methods; and (f) accurate records which are then (g) securely archived.

However, in the near future it will be possible to apply the same static verification technique to the ABB AquaMaster as has been possible for the ABB MagMaster. This technique, trademarked as CalMaster, is the subject of discussion in a separate paper. In summary, the key elements of such a system are that it is possible to

- Verify calibration of the sensor
- Verify calibration of the transmitter
- Verify continuity and integrity of the sensor – transmitter cable (if applicable)
- Have a traceable uncertainty budget and
- Operate within a Quality System – including data security

So, just as the technology of the metering is developing, so are the regulatory demands. In this interplay the role of static verification devices, such as ABB's CalMaster, will therefore be of great interest.

7. Users & Specifications: Wants versus Needs

7.1 Changed metering capabilities and user choices.

In the last 5 years since the Small Area Monitor was commissioned advances in computing, communications technologies and battery electromagnetic flowmeter instrument capabilities have opened a Pandora's box of possibilities.

Four particular areas stand out :

- 7.1.1. Integrated meter datalogging that is GSM enabled – the separate water meter and separate datalogger that may or not be GSM enabled now has a challenger.
- 7.1.2. Battery meter performance is no longer fixed – due to the ability to remotely reconfigure the mode of operation via GSM.
- 7.1.3. Power demand is now a variable in itself, being set by the meter mode which can be selected remotely by the User according to the operational demand at the time.
- 7.1.4. Static meter verification – as illustrated by the CalMaster technique – now opens up the possibility of creating true long term records of intrinsic meter accuracy and stability.

However, the explosion of opportunities brings with it the need for the meter to be treated as more than the commodity item which it is currently viewed. It has evolved to have the ability to become a free standing tool in Network management, characterisation and investigation.

Direct integration into Company systems that are main frame based, short circuiting the historic route of meter to datalogger, datalogger to PC, PC to network server, network server to Manager will no doubt follow. Indeed, with GSM direct, individual access from meter to phone is already one of the many functions available implemented.

Put somewhat prosaically, the better mousetrap has developed into a fully blown universal rodent extermination system, and one where the difficult question is where best to point the technology to gain maximum payback.

7.2 Technology choice and wholelife costing

The battery electromagnetic meter represents a higher initial capital cost option than its mechanical meter alternative. Nevertheless, battery electromagnetic meters now offer:

- a) Ability to bury sensor,
- b) direct transmitter communications,
- c) long term performance stability
- d) verification of calibration accuracy and
- e) in-built datalogging

Whereas, the alternative comprises a mechanical meter *plus*

- i. meter chambers, *plus*
- ii. replaced mechanisms *plus*
- iii. data logger interfaces *plus*
- iv. external dataloggers *plus*
- v. GSM communications costs.

Thus, when attempting to assess the true whole life costs of the electromagnetic meter versus its mechanical rival the playing field is perhaps a little flatter, especially when viewed over the typical 10 to 15 years lifetime expectation of the electromagnetic meter.

7.3 AquaMaster Performance against the CEN & ISO Specifications.

It is worthwhile comparing the AquaMaster flow performance with the new European CEN TC92 Specification for water meters. This Specification will become active in late 2004 and will be used support the change in the Law accompanying the earlier publication of the European Union's Measuring Instruments Directive (MID). For a DN100 the AquaMaster Performance is given in the table below:

	Mains Powered Mode					Turn-down	Battery Powered Mode			Turn-down
	Q1	Q2	If Q>3	Q3	Q4	R	Q1	Q2	If Q>9	R
DN 100	Q1	Q2	If Q>3	Q3	Q4	R	Q1	Q2	If Q>9	R
CEN MPE	5%	2%	2%	2%	2%	1000:1	5%	2%	2%	400:1
ABB MPE	5%	2%	0.25%	0.25%	.25%	1000:1	5%	2%	0.5%	400:1
Flow m3/hr	0.16	0.40	3.00	160	200		0.40	1.00	9.00	
Velocity (m/sec)	0.006	0.014	0.110	5.70	7.10		0.014	0.035	0.320	

Thus, under the CEN Specification criteria, the flow turn-down ratio, R, is an unparalleled R1000 when mains powered and R400 when battery powered. For comparison, the highest accuracy class C for a mechanical Woltmann meter is R166.

8. Conclusions

To summarise the performance and advances seen since 1998 in battery electromagnetic meters, as typified by the Small Area monitor of Severn Trent Water, the following has been found:

- Regarding the buried sensors, the original installation design, which utilised a spool piece approach, has proven to be extremely sound.
- Advances in transmitter electronics and software have allowed simple, retrospective, upgrading of individual flowmeters and resulted in enhanced meter performance – without replacement of the buried sensor.
- The integration of GSM text based communications to the latest transmitter electronics has provided the potential to revolutionise the management of the meter stock as well as enabling better understanding & integration of Network flow data.
- Meter Performance, Quality & Traceability demands will continue to increase but the advent of Static Verification Devices, such as ABB's CalMaster, will help to meet these requirements.
- New, performance based international Standard Meter Specifications will both rationalise the existing flow performance requirements and encourage better accuracy.
- The remarkable flexibility of the new generation of electronic meters, as typified by the ABB AquaMaster, will demand significant attention to security at all levels of the flow data chain as hardware functionality is replaced by software.

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