Socrates - Improving the accuracy of measured night-flows and legitimate use in order to understand genuine leakage levels

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This is re-printed from the paper presented at the 'Driving Down Water Leakage' conference, London, 27th - 28th October 1998. Charles Harris is responsible for the Socrates' concept and Roger Ironmonger is Managing Director of Primayer Ltd, the manufacturer of Socrates.

Introduction
- that high night line might not be leakage!

Every water company has a top hit list of problem DMAs - the ones with huge nightlines which elude all efforts to track down leakage. These invariably include unmeasured trade users - the number one headache for leakage practitioners.

Help is now at hand from SOCRATES - a new, patented, troubleshooting tool for analysing DMA nightlines - specifically designed for discriminating between areas of high use and high leakage.

Recently tested on fourteen sites in eleven UK water companies, SOCRATES has shown major benefits over conventional practice in the fight against leakage. **Lower nightlines were found on all test sites with genuine reductions ranging from 8% to 48%. On at least four sites, SOCRATES detected significant extra night use and, at a further site, discovered a major control system failure. These important features had not been detected by conventional monitoring.**

SOCRATES is much more than a conventional datalogger. Its unique statistical processing capability holds the key to teasing out the elusive boundary between legitimate night use and leakage on a site-by-site basis. It has applications in DMA demand analysis, consumption monitors, PRV fault diagnosis and finally, in leakage reporting.

Night line measurements

Nightlines - water flows into District Meter Areas (DMAs) during periods of low use by consumers - are monitored extensively by the water industry to estimate leakage levels. This is carried out using dataloggers or telemetry devices attached to flow meters. Conventionally, average values (usually via accumulated pulse counts) are recorded over 15 minute intervals. This period has been chosen for convenience; it appears to give a reasonably detailed view of network operation without overloading supervisors with data. Unfortunately, new demands on network efficiency mean much more precise diagnostic tools are required.

The problem is that conventional averaging hides important details. Figure 1 shows an example on a real DMA. The minimum 15 minute average value (the dotted line) is 5.34 litres/sec over the period 0230 to 0245. The actual flow pattern can be seen varying above and below the average value; it is markedly different and, crucially, the minimum value (an indication of leakage) is considerably lower. The above example is taken from a mixed trade/domestic DMA and it illustrates problems endemic to such sites. Varying trading and production patterns will almost always defeat conventional sampling methods.

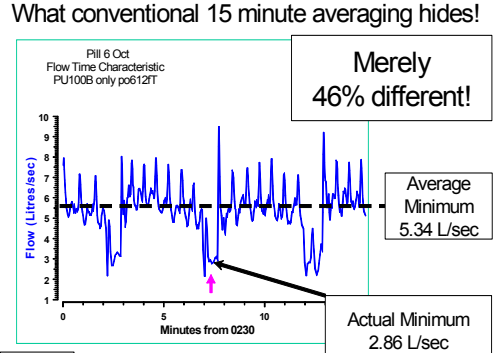
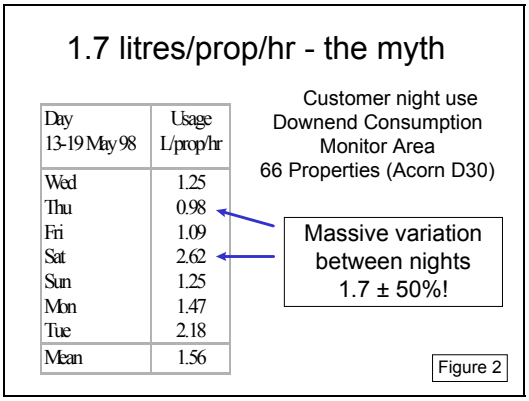


Figure 1

When accounting for leakage, practitioners also need to understand how domestic customers use water at night. Traditionally, it is assumed all domestic properties use the same average quantity of water every night regardless of social or climatic circumstances. A common global estimate is 1.7 litres per property per hour. This is perhaps the biggest single flaw in the system by which we now estimate leakage. Tests with consumption monitors show the assumption is invalid. For example, Figure 2 shows one week's data derived from such a site. The night to night variation approaches ±50%!



Day 13-19 May 98	Usage L/prop/hr
Wed	1.25
Thu	0.98
Fri	1.09
Sat	2.62
Sun	1.25
Mon	1.47
Tue	2.18
Mean	1.56

Figure 2

SOCRATES tackles these problems by exploiting the maximum resolution available from the flow measuring system. It collects thousands of data values per night which it processes into a smaller set of micro-values. This set (typically 500 values) exposes the crucial details of night lines which are masked by conventional averaging. This has enormous value in diagnosing discrepancies in trade use. It is also possible to analyse nightly distributions of micro-values to find estimates of domestic consumption which reflect prevailing site conditions.

Before looking at practical applications of SOCRATES, we first examine the technology behind the system.

High resolution measurement

On pulse generating flow meters, SOCRATES uses an advanced form of Pulse Interval Timing (PIT). On analogue meters it carries out rapid sampling.

These methods potentially enable us to probe nightlines more thoroughly than conventional pulse counting or averaging. But beware! Simple PIT measurements will give artificially low values. Before presenting results, SOCRATES processes the raw data to remove extraneous artefacts associated with the measurement system, pressure surges and hydraulic oscillations. What are these artefacts?

Measurement artefact

On pulse generating flow meters, there can be substantial variation in output pulse values unrelated to variation in the flow being measured. On some types of meter, the variation is systematic. On others it is random. SOCRATES uses proprietary filtering algorithms to remove these errors.

Transient hydraulic artefact

Sudden hydraulic disturbances (e.g. pump starts) can generate surges in networks causing flows to oscillate strongly about mean levels. The troughs of these oscillations are difficult to distinguish from genuine short term reductions in user demand. PIT measurements which do not discount such troughs will always give wrong estimates of baseline flows. The errors will be serious. To avoid errors, SOCRATES checks for sudden changes in pressure. Pressure change thresholds can be set by the user and if these are exceeded, SOCRATES assumes a transient has occurred and ignores flow data around this section of the night line.

When searching for minimum values, SOCRATES also sets restrictions on the rate at which flows are allowed to change around minimum points. This catches spikes and other short transients which are not evident in the pressure trace.

Cyclic hydraulic artefact and the micro-period

In addition to transient hydraulic artefact (i.e. a short term effect), some systems exhibit continuous low level hydraulic oscillation even after removing measurement artefact. If this ‘cyclic' hydraulic artefact is not filtered, errors will be caused by confusing trough values in natural hydraulic cycles with a periods of low user activity. SOCRATES uses autocorrelation to determine the optimum averaging time to smooth out such oscillations. This averaging time is calculated for each and every nightline; it is the minimum time over which measurements must be averaged to minimise errors. The averaging time is called the micro-period and average values calculated over such periods are called

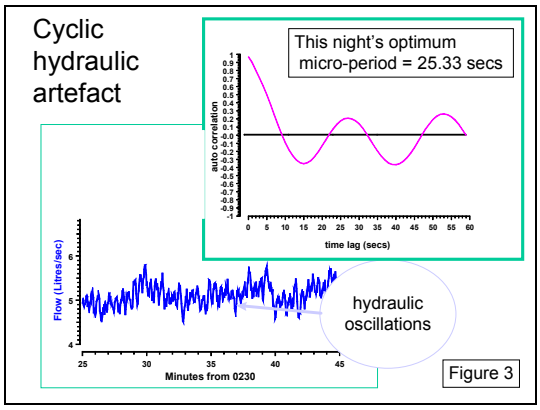


Figure 3

micro-values. Figure 3 shows an example of cyclic artefact.

Practical Applications

Diagnosing mixed trade/domestic DMAs

For each nightline, SOCRATES searches for a minimum flow value which satisfies pressure and flow transient restrictions and which is free of measurement and cyclic hydraulic artefact. Because of the measurement speed, it is able to probe deep into nightlines to reveal the lowest baseline flows. This feature is extremely useful on DMAs with trade users which use water intermittently

Figure 4 shows results from a rural DMA. SOCRATES reports a 25% lower nightline than 15 minute averaging, on the night shown. The selected minimum point at approximately 04:35 shows a stable dip in the nightline some 30 seconds long. SOCRATES rejects the minima around 04:26 as transients.

In another example, a datalogger on a city centre site had detected high ‘leakage' - the logger was reporting a minimum flow of 11.0 litres/sec. SOCRATES, however, revealed a true minimum of 6.3 litres/sec, with an additional varying flow component superimposed. This extra use explained the high nightline and saved time-consuming investigation.

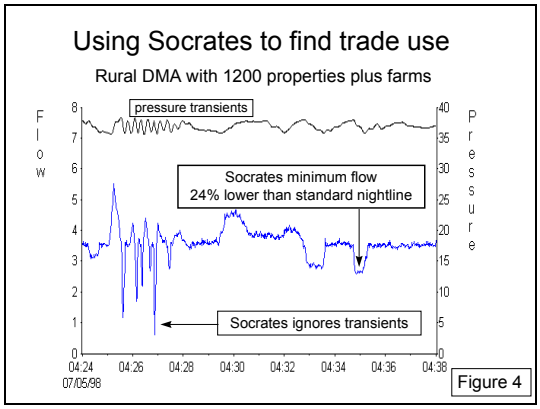


Figure 4

SOCRATES and 'fast' logging compared

We have seen that simple PIT logging is virtually guaranteed to lead to serious errors because of meter artefact, surge flows and oscillating flows. But what about standard 'fast' logging?

On many conventional logging systems, 'fast' may not be fast enough. High speed measurements are required to detect surges. No conventional logger automatically detects transients. Additionally, no conventional logger detects and compensates for measurement system error nor for micro-periodicity.

Fast logging on pulse counting systems is subject to large quantisation errors. For instance, a 3.5 litre per second flow logged every second from a pulse-head generating one pulse/litre will store the sequence of flow values as 3, 4, 3, 4, 3, etc. There will be no intermediate values. This is not precise enough.

Even if fast logging was suitable, the sheer volume of raw data would overload network supervisors. SOCRATES avoids this by processing raw measurements before presenting a limited set of key facts describing the state of the distribution system.

SOCRATES and Consumption Monitors

SOCRATES can be used to excellent effect in cul-de-sac type consumption monitors where flows into statistically chosen small groups of houses are measured to calculate per capita consumption.

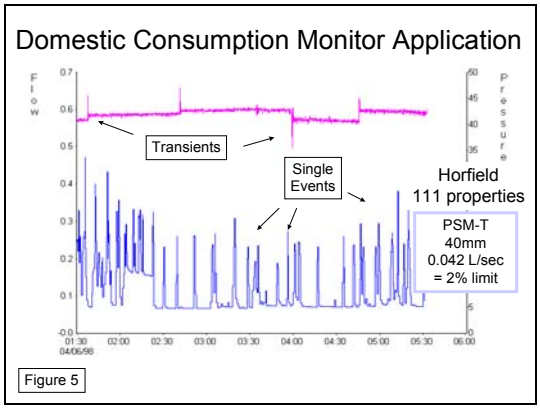


Figure 5

Consumption Monitor Application - SOCRATES compared

Horfield
111 properties
29/5/98 to 4/6/98

Day	Nightline average L/sec	Socrates Minimum L/sec	Conventional Minimum L/sec	% Difference v. SOCRATES
Fri	0.104	0.069	0.074	7.2
Sat	0.115	0.056	0.079	41.1
Sun	0.107	0.057	0.069	21.1
Mon	0.181	0.088	0.148	68.2
Tue	0.142	0.057	0.107	87.7
Wed	0.099	0.060	0.071	18.3
Thu	0.117	0.066	0.076	15.2
			MEAN	37.0%

More accurate Per Capita Consumption calculations!

Conventional leakage over-estimation here = 37% on average
Lowest leakage estimates for period are 23% different

Figure 6

Fig. 5 shows a SOCRATES nightline plot from a 111 property ACORN F50 site. Clearly evident is a 'core' flow on which intermittent 'events' such as toilet flushes, washing machine fills, etc. are superimposed. Because these sites are small, 'events' rarely coalesce. The 'core' flow will thus be very close to, if not actually at, the leakage level of the site. Figure 6 compares the reporting of the lowest nightline flows using conventional averaging and SOCRATES over one week. **Conventional averaging over-estimates the minimum flow (and hence the leakage) on this site by, on average, 37%.** This improved accuracy clearly has positive implications for Per Capita Consumption calculations used in integrated flow analyses of leakage.

Compared with conventional averaging, on sites of up to approximately 500 properties, SOCRATES routinely records minimum flows undistorted by intermittent night use. This opens the possibility of using larger consumption monitor areas. Core flow levels would still be exposed, but the larger property count would improve the statistical analysis of night use.

Breaking into the Core Flows

An average night-flow value (say over 1 hour) from a consumption monitor comprises two components: intermittent use, and 'core' flow. SOCRATES always penetrates to the core flow. Core flow itself

Statistical Analysis of CMA Core Flows

Ultimate limit of leakage flow calculated as:
Mean - 3σ = 0.042 l/sec

Date	Minimum Flow l/sec
14/8/98	0.091
15/8/98	0.055
16/8/98	0.076
17/8/98	0.074
18/8/98	0.065
19/8/98	0.074
20/8/98	0.076
21/8/98	0.093
22/8/98	0.072
23/8/98	0.070
24/8/98	0.090
25/8/98	0.064
26/8/98	0.068
27/8/98	0.080
Mean	0.0749
Sigma	0.0109

Figure 7

comprises three parts: continuous use, plumbing losses and leakage. On a consumption monitor, core flow is arguably all WASTE. An example of continuous use is a tap dripping because it hasn't been turned fully off. A plumbing loss might be a tap dripping because of a faulty washer. These two components vary randomly and are the principal reason why consumption monitor minimum micro-values vary about mean levels. A statistical estimate of the actual leakage boundary may be derived from the distribution of the minimum micro-values over a series of nights. An example is shown in Figure 7.

Estimating leakage on DMAs

The concept of core flow can be extended to DMAs. Larger DMAs (up to 2000 properties) have been simulated by adding together random sequences of real SOCRATES night-lines. These studies indicate that SOCRATES will typically penetrate the intermittent use on a 500 property DMA to within 4% of the actual core flow. On a 2000 property DMA it penetrates to within 16%.
Core flow on a DMA will comprise the same components as on a consumption monitor but with

two extra random elements: continuous trade ‘use' and the penetration error described above.

These four components vary randomly and cause minimum nightly micro-values to vary about mean levels. A statistical estimate of the actual leakage

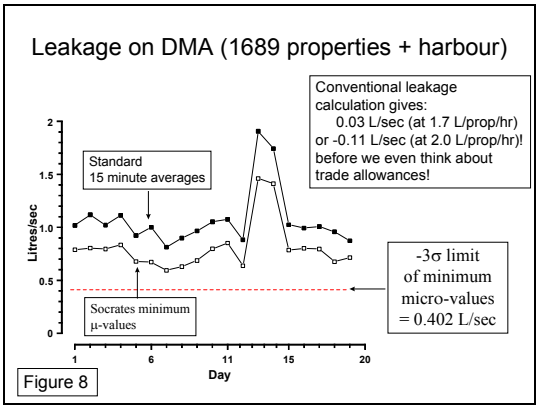


Figure 8

boundary may be derived from the distribution of these minimum values over a series of nights. Figure 8 shows a typical analysis applied to a DMA comprising 1700 properties and a harbour.

Its worth noting in this example (and it is by no means unique!), that conventional analysis yields ridiculous leakage values, even before trade allowances are subtracted. And what would the trade allowances be? How much water does a ‘typical' ship use?

In contrast to this dubious speculation, the SOCRATES method makes NO assumptions. It needs neither domestic night use or trade night use values. **The estimate is based solely on the evidence of the nightline.**

Conclusions

New demands being made on network efficiency require much more precise tools to monitor performance. Conventional monitoring, based on limited ‘average’ data-sets, masks important details of night flows so making troubleshooting difficult. In this article, we have seen practical cases where SOCRATES' high resolution data has helped the leakage manager determine what is or isn't leakage. We have also seen how simplistic measurements based solely on fast or PIT sampled ‘absolute minimum flow rates' will be dangerously misleading. We have also seen how tangible benefits are gained by using SOCRATES on consumption monitors. The errors caused by counting in intermittent night use are eliminated. The concept of ‘core flow' has been introduced and with it the potential for a completely ‘default' free analysis of leakage.

The work described in this paper has been jointly researched by Bristol Water plc.