Trials to Quantify and Reduce in-situ Meter Under-Registration

Authors: **Ing. Alex Rizzo.** alex@rizzoconsultants.com
Ing. Michael Bonello. ESDL@maltanet.net
Ing. Stephen Galea St. John Stephen.galeastjohn@wsc.com.mt

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Introduction

The paper shall look at three sequential issues: 1) the theory behind Apparent Water losses; 2) modern techniques for measuring Apparent Losses and revenue water meters; and 3) two alternative solutions for controlling consumer meter under-registration. The theory in question relates to the International Water Association's methodology of dividing Apparent Losses into four components, allowing for a systematic solution to the problem. Techniques for measuring meter readings shall look at an innovative ZigBee based automatic meter reading system. Finally, the paper shall look at two potential in-situ solutions to meter under-registration; the magnetic water inlet valve and the unmeasured flow reducer. Both solutions are viable, according to the specific situation a water utility faces.

The Theory behind Apparent Water Loss Control

The IWA groups water losses into two types; Real Losses, which are the physical losses (or leakage) and Apparent Losses, which are caused by revenue meter under-registration, water theft and billing errors. Real Losses are an expense to a water utility for a number of reasons: the leaking water costs money to produce; maintaining the water network to avoid further losses is expensive; and additional capital expenditure may be required in the form of new production plant, and as a result of the losses. Apparent Losses are not so much an expense to the water utility as they are a loss of potential revenue. Apparent Losses relate to water that is being consumed, but not being paid for. Thus for every cubic metre of water unbilled as a result of an Apparent Loss, the water utility loses the opportunity of collecting money for that cubic metre of water. Whilst the concept of Real Losses is fairly easy for one to understand, that of Apparent Losses is more complex for a number of reasons: First of all Apparent Losses are somewhat more subtle or intangible, when compared to Real Losses. Imagine comparing a leaking valve (a Real Loss) with a billed consumption for a household that is being under-estimated due to an inaccuracy in a water utility's billing system (an Apparent Loss). As a second example, compare a weeping (slight leakage) service pipe (a Real Loss) to a well hidden illegal service that is being used intermittently and intelligently (an Apparent Loss).

A second reason is in the multidimensional nature of Apparent Losses. Four types of Apparent Losses exist, as shown in Figure 1 on the following page. The first loss, water theft, can occur in a variety of ways: Water can be stolen from an illegal connection, from a bypassed water meter, from a damaged water meter, or simply from the neighbour's plumbing system! The second loss, meter under-registration, consists of a situation where the consumer meter is incapable of measuring all the flows passing through it. Flows below the accurate starting flow of the meter are a particular problem. The third and forth losses, meter reading errors and billing errors go hand in hand. Meters can be misread or alternatively wrongly computed in a utility's billing system. Also, certain Apparent Loss components can be both positive or negative, even going to the extent of cancelling out the effect of other components. As an example a water utility may be over-billing substantially due to an incorrect 'closed premises' estimation policy, whilst at the same time substantial meter under-registration in the locality exists.

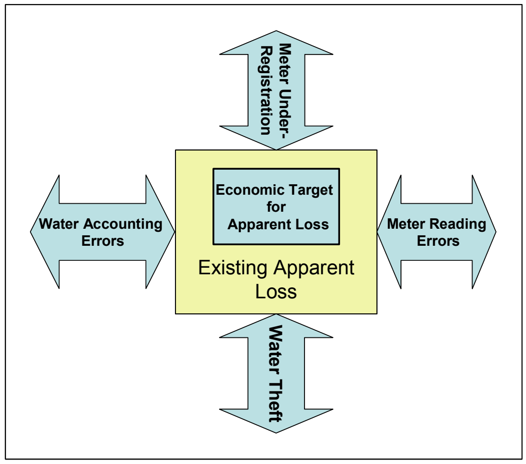

Figure 1: The IWA Apparent Water Loss Control Methodology

Thus, due to the complexity of the problem at hand, it is vital that every water company has a strategy for tackling Apparent Losses. Figure 2 below describes a strategy advocated by the authors for managing Apparent Losses in an integrative fashion. The multidimensionality of the model is result of the various levels in which Apparent Losses impact upon a water utility. Whilst to a certain extent Real Losses can be managed by a single, functionally organized section, the same cannot be said for Apparent Losses. Policy decisions on water tariff structures may impact upon the amount of water theft taking place. Purchasing policies may impact upon the quality and availability of water meters. Finance and budgeting decisions may impact upon the means being utilized to read or estimate meter readings. Oversight agencies or institutions may demand reduced interference to certain key consumers, etc, etc. For this reason an Apparent Loss control strategy must relate to the various hierarchies and decision-making levels within a water utility. It must be applied as a centralized initiative, taking the form of a project that may one day evolve into an operation when running efficiently enough. As in all projects, all changes need a champion! The main challenges lie in management; managing the human resources (employees), the physical resources (instrumentation and equipment) and the organizational resources (such as quality procedures). Hence, for effective Apparent Loss control, one must have a focused, dedicated and well led management team.

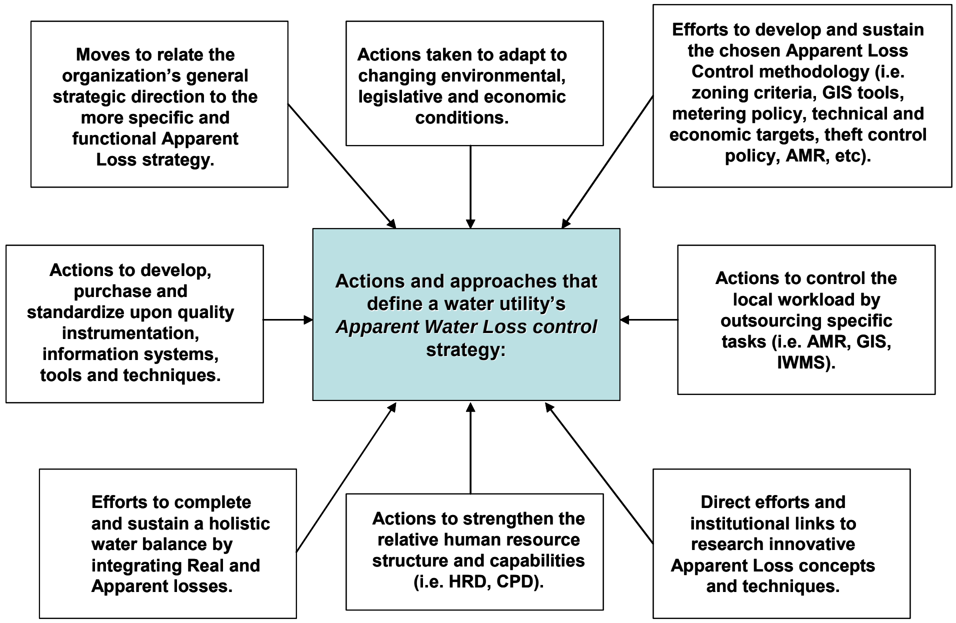

Figure 2: Strategic Control of Apparent Water Losses

Measuring Water Meter Readings and Computing Apparent Losses

The authors have been through the experience of developing and successfully commissioning two automatic meter reading (AMR) systems on the Island of Malta. The paper will look at the transition from an earlier radio frequency (RF) system to the more modern ZigBee-based typology. Various organizations and utilities world-wide are turning towards ZigBee after finding out that AMR systems such as '*power line carrier (PLC)'* or '*GSM-based AMR'* come at a huge expense and a compromised functionality. A further issue is one of flexibility: The ideal system will allow the user to be able to acquire data in a fully automated fashion, if need be, or alternatively to download data on site. Furthermore the system must allow for a transition from reading to data logging, this requiring enhanced memory and more varied data input channels.

Radio Frequency AMR

Radio frequency, or RF, automatic reading is possibly one of the most commonly used and popular AMR systems around. The popularity is a result of low cost and robustness, with hundreds of thousands of units sold yearly by companies such as Ramar, Itron and Schlumberger worldwide. RF units are usually low power, at below 8w, work at standard telemetry frequencies (usually at around 400MHz), and boast lithium batteries that provide a 5-year lifetime. The units are sealed, tamper-proof, and disposable. RF-based AMR in Malta has been around since 2003, serving its purpose to acquire data and transmit for the 100 metre range that the system allows. Of course repeaters can be used to gather and boost data to a further point, but at an expense.

The ZigBee Typology

It is this limited range of standard RF systems that brought about the concept of Zigbee. The ZigBee wireless-personal-area-networking (WPAN) technology has been designed from the ground up with one application in mind; low speed, low data rate sensors. The ZigBee Alliance specified the ZigBee foundation as per the wireless standard IEEE 802.15.4, which defines and handles the radio section (PHY and MAC) of the ZigBee technology.

What does ZigBee stand for, anyway? The name was coined from the zigzag dance which certain African honeybees use to relay information, related to location and distance of sources of nectar, to other bees. Likewise, the ZigBee specification enables data packets to propagate through nodes in a mimic of the honeybees' dance.

Low-power wireless sensors typically source their power either from a battery or parasitically. The latter employs age-old principles based on magnetic and electrical energy coupling. This may take the form of a coil of wire wound around a current carrying conductor which induces a tiny E.M.F. in this coil. The energy thus gleaned is harvested in super-capacitors for subsequent use during RF data transmission and reception. In the former case, the battery has to be used so sparingly that its lifetime should equal the listed shelf-life. This may be as high as ten years (alkaline batteries). The only way to achieve such performance is to have the ZigBee node in sleep mode for 99% of its lifetime.

A further characteristic of the ZigBee technology which enables compliant nodes to achieve such an enviable performance is the use of the 2.4GHz frequency band as stipulated in the IEEE 802.15.4 standard and which allows nodes to exchange data at a maximum of 250kbps. Such a high data rate ensures that nodes are awake for a couple of milliseconds only.

A ZigBee network may have any of the following topologies;

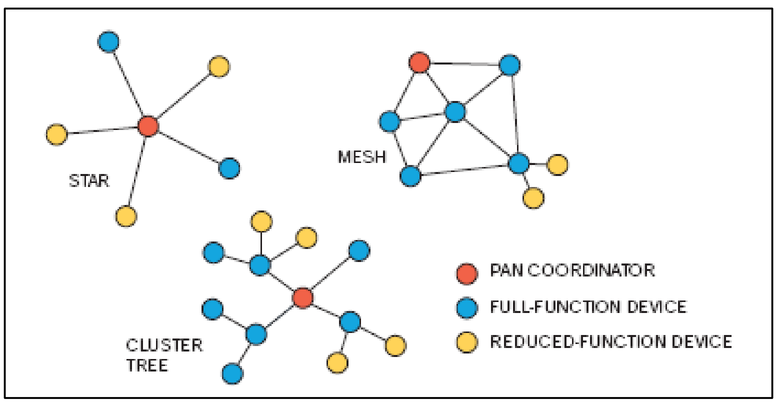

Figure 3: Various ZigBee Topologies

The Star topology involves only end devices (the sensors which are mostly in sleep mode and represented by the reduced function devices) and the coordinator, which manages the network. The tree involves another device, called a Router (shown as a full function device). A Router is typically run from an AC point and acts as a relay, a messenger, of data packets between nodes which are out of each others radio range. This is feature gives the ZigBee technology its much vaunted feature of data hopping where spatially distant nodes may communicate with each other via such hopping. The mesh topology allows full peer-to-peer communication. The technology has been deployed locally in an AMR pilot project for the Water Services Corporation. In both instances, the ability of the ZigBee network to manage the propagation of data along the most appropriate path ensured the robustness of the network. ZigBee automatic reading is essentially an ideal compromise between a conventional RF system that transmits to a 100 metre, or so, distance, and a fully automated system that relays data to a base PC. With a ZigBee system data can be relayed to a pickup point, it can be downloaded in the vicinity of the transponder, or it can alternatively be relayed all the way to the base PC. The fact that the Zigbee system builds its own network as it propagates data allows for reduced costs and enhanced flexibility. The transponders also have the reliability and ruggedness of the earlier RF based modules, and are self-powered and disposable (if need be). It is understandable that major water utilities worldwide are now turning towards Zigbee to find a solution to their AMR requirements. AMR essentially solves two Apparent Loss components; meter reading errors and billing errors. It also allows for effective water accounting exercises to be implemented. By choosing a hydraulically encapsulated zone, monitoring the summated water consumptions via AMR, and comparing these values to the water intake into the zone, one can accurately compute both Real and Apparent water losses. Through AMR, comparisons can be made every few minutes, and precise computation can be made regarding the zone's meter under-registration value.

Figure 4: A ZigBee AMR Transponder Latched onto a Water Meter

Two Alternative Solutions for Controlling Water Meter Under-Registration

The last section of the paper shall look at two unique ways of reducing meter under-registration for revenue water meters that are already installed and functioning. The authors are of the opinion that three options should be in fact available, and not two. The first option is the utilization of the ideal water meter that registers all the flows passing through it, and at 100% accuracy. This water meter does not yet exist, and metering experts have serious doubts that water meters will ever measure flows down to zero litres per hour. The second option, available for indirect plumbing systems, is to utilize a roof tank valve that has an immediate closure. The third option, for both direct and indirect plumbing systems, is to utilize a flow manipulation valve.

Before looking for a solution, one must first understand the problem. All water meters have a starting flow (Q_s) at which the meter starts to register, albeit inaccurately. In Figure 5 below, this would be at around 3.75 litres per hour. The meter also has a minimum accurate flow value Q_{min}, at which the meter starts to measure fairly accurately (up to 5% inaccuracy). At around 150% of Q_{min} the water meter moves into the accurate measurement range, called the transitional flow, or Q_t. The value for the meter depicted below is 11.5 lt/Hr, at which the meter will achieve a maximum accuracy of below 2% error. This is normally retained until Q_{max}, which is double the nominal, or mid-value flow Q_n. As a meter ages its accuracy curve deteriorates, and especially flows below the transitional flow will be measured with difficulty, if at all. The challenge of both meter under-registration solutions is thus to induce flows through the consumer's meter that are above this transitional flow. Indirect plumbing systems, that is consumers with roof tanks, cause an additional problem due to the low flows generated by the tank's ball valve.

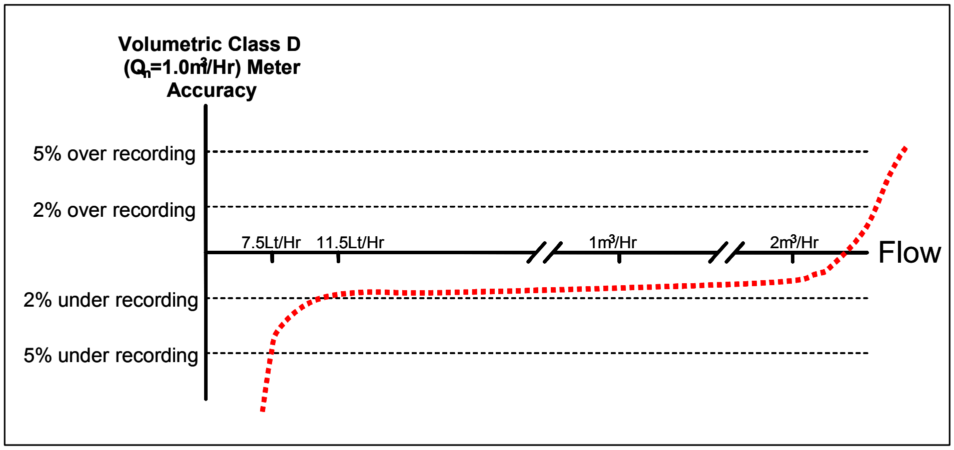

Figure 5: Accuracy profile for a Q_n = 1.0m^3/Hr Water Meter

The First Meter Under-Registration Solution: The Magnetic Water Inlet Valve.

Figure 6 depicts a magnetic water inlet valve. For consumers with an indirect plumbing system (roof tanks), this valve is the ideal engineering solution. The valve is installed within the rooftank instead of the standard ball valve. The valve features a mini float with an embedded magnet that operates a diaphragm inside the valve, not unlike that of a diaphragm-type pressure reducing valve. The rising water level lifts the valve's float, and the magnet of this float moves a stainless steel pilot plunger. This plunger, in turn, induces the diaphragm to close (or open if the water level is receding). The shut-off of the valve is almost instantaneous, allowing for either a flow in excess of 100 lt/Hr, when open, to zero litres per hour, when closed. There is simply no intermediate flow. The valve thus ensures that all flows that pass through the revenue meter are way in excess of the transitional flow. The main limitation that must be overcome with the valve is in the accessibility of consumer roof tanks. Two solutions exist; 1) legislation that enforces the use of the valve, and 2) incentives by water utilities that subsidize the valve and promote its advantages (such as its very low failure rate).

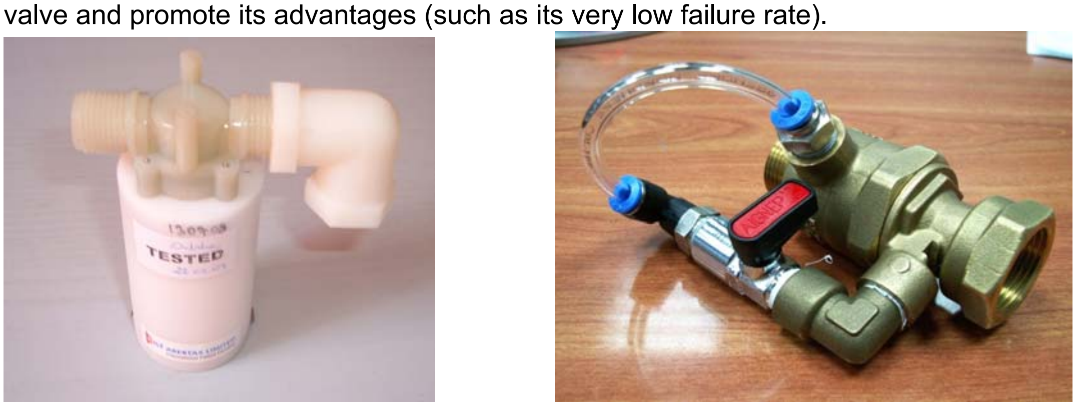

Figure 6: Two Solutions to Meter Under-Registration: The Magnetic Water Inlet Valve (Left) and the Unmeasured Flow Reducer (Right)

Possibly the most interesting aspect about the magnetic water inlet valve is in the economic dimension. The valve is inexpensive, at around €5 per valve. The cost of the valve plus that of a single jet meter roughly equals the cost of a more accurate volumetric meter. Modelling the economics of the valve for the Island of Malta (roughly a half million inhabitants), if the valve were to be installed on all consumer tanks, the local water utility would stand to gain in the region of €1.4M yearly, at no initial expense (i.e. by buying valve plus jet meter instead of volumetric meter). This would be due to the reduction in meter under-registration from a conservative value of 6% to close to 0%. The economics show the huge potential of the valve for systems with indirect plumbing. The valve is small, easy to install, and maintenance free.

The Second Meter Under-Registration Solution: The Unmeasured Flow Reducer (UFR).

For the problem of access to roof tanks, or for consumers who have direct plumbing systems, a different solution exists. The solution lies in manipulating the flow pattern of the water through the meter so that all flows that are registered are in excess to the minimum accurate flow of the meter. This solution is the unmeasured flow reducer, or UFR. At low flows the UFR causes water to pulse through the meter at flows above the minimum accurately measured flow for that meter. At higher flows the UFR opens up, allowing water to pass unobstructed. The valve works through a differential pressure concept. The valve will remain closed until the water pressure downstream of the valve is at least 0.4 bar less than the water pressure upstream of the valve. This will happen as the consumer draws water within the household. At that point in time the valve will open up, resulting in a negligible 0.1 bar head loss. Once the internal consumption stops, the differential pressure will disappear and the valve will close down again. This closing and opening of the valve occurs in bursts, or batches. Thus, in effect, the valve induces water to pass through the water meter in pulses that are above the Q_{min} of the water meter. Figure 7 on the following page shows the effect of a UFR on the accuracy of a water meter. The UFR can be installed directly upstream or downstream of the consumer meter.

In a bid to test the effectiveness of the UFR valve, the national water utility in Malta identified a small zone for pilot study purposes. The zone was chosen in accordance with the ages of the water meters in the zone, allowing for a normal distribution of meter ages with an average of five years in age.

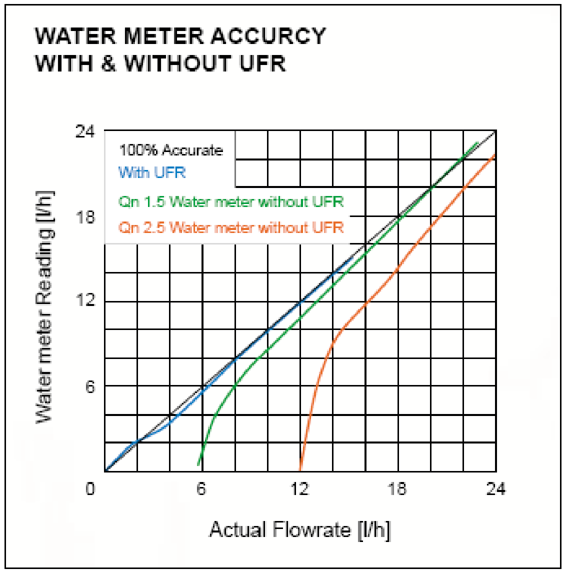

Figure 7: The Effect of the Unmeasured Flow Reducer on Water Meter Accuracy

By installing UFR devices in series with each consumer meter, the water utility could study the meter under-registration value for the zone without UFR's (i.e. by opening their bypass valve) and then with UFR's. In the pilot zone in question, application of the UFR units increased the metered volume of water by a substantial 5.5% to 6% of the water supplied to the zone (Table 1 below). If the results of applying UFR on the pilot zone are extrapolated over the complete jurisdiction of the relevant water utility, an increase in annual revenue to the tune of €1.3M would be gained.

Test	Global % Under-registration vs. Master Meter		% Overall Improvement
	UFR Bypassed	UFR Active	
1	18.1	12.1	6.0
2	26.7	21.2	5.5
3	28.0	22.2	5.8

Table 1: Effect of UFR's on Water Meter Under-Registration

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