Apparent Water Loss Control: Theory and Application

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Abstract:

Water losses are usually grouped into two types of loss; 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 somewhat more complex, and this 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. The paper will demonstrate how 4 types of Apparent Losses exist, and that each type can be further broken down into various classifications. A third reason is that certain Apparent Loss components can be both positive or negative, even going to the extent of canceling 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.

Thus, due to the complexity of the problem at hand, it is vital that every water company has a strategy for tackling Apparent Losses. This paper shall take on this very approach; a basic strategic model shall be depicted (Figure 2), and the various components that make up this model discussed in sequence. Practical applications and issues of significance shall be discussed.

Keywords:

Apparent water loss control. Meter under-registration. Billing faults. Water Theft. Strategy. Methodology. Automatic meter reading.

Introduction:

As in Real Losses, the most important first step that must be taken with regard to Apparent Losses is in their quantification, or measurement. Unless some idea is known about the volume of water that is being consumed but not being paid for, little support will be provided by the organization concerned to reduce this Apparent Loss. One must appreciate that few executives will support a capital investment if the deliverables concerned are vaguely defined. A recommended approach is to utilize the IWA water balance (see Figure 1 on page 2) as a means of computing the Apparent Loss volume for a region or locality, and generally over a 1-year timeframe (or a smaller billing cycle). Three general techniques may be utilized, either separately or collectively. These are discussed in the following hierarchy:

1. A 'top-down' water balance in which the metered consumption for all the consumers in a region is collected over a specific time frame. An Apparent Loss value is often added as a percentage, and the water supplied into the region less the metered consumption and less the Apparent Loss value is

computed as the leakage value (the Current Annual Real Loss) for that region. This approach is not accurate or robust enough to provide a defendable 'Apparent Loss' value.

2. A combined 'top-down' plus 'bottom-up' water balance. This technique involves adding a component to the calculation in step 1 above. The Real Loss value for the region is separately computed, usually via minimum night flow analysis or by some accurate estimation procedure. This is the 'bottom up' component and provides for information relating to the bottom rows of the water balance. Since the 'top down' calculation will provide the metered volume and the 'bottom up' calculation will provide the Real Loss value, subtracting these two values from the system input (column 2 in Figure 1) will provide a more accurate value for Apparent Losses for the period under review.
3. Survey sampling. This can be used to complement step 2 above, or can be done in isolation. Sampling involves identifying pilot areas (zones or DMA's that are hydraulically encapsulated and metered at the inlet) and carrying out miniature and accurate water balances where consumer meters are accurately read, leakage is accurately calculated, and the various components of Apparent Losses scrutinized to assess their impact. Various different approaches can be adopted, such as looking at the Apparent Loss value before and after a meter replacement exercise, or before and after theft investigations. Results can be extrapolated to the wider areas under the utility's jurisdiction. This sampling technique is ideal for water utilities that do not have well-developed infrastructures, and can only provide small areas of well metered and monitored consumers.

<table>
<tr><td rowspan="3">Own Sources</td><td rowspan="10">System Input

(allow for known errors)</td><td>Water Exported</td><td rowspan="5">Authorised Consumption</td><td rowspan="3">Billed Authorised Consumption</td><td rowspan="3">Revenue Water</td><td>Billed Water Exported</td></tr>
<tr><td rowspan="9">Water Supplied</td><td>Billed Metered Consumption</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="7">Water Imported</td><td rowspan="2">Unbilled Authorised Consumption</td><td rowspan="7">Non-Revenue Water</td><td>Unbilled Metered Consumption</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorised Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Mains</td></tr>
<tr><td>Leakage and Overflows at Storages</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer Metering</td></tr>
</table>

Figure 1: IWA recommended Water Balance

Whilst the remainder of this paper shall target a recommended Apparent Loss control strategy, it must be re-emphasized that support for any strategy will only follow an at least initial calculation of the amount of water that is unbilled due to Apparent Losses. Once initial support is gained, the strategy itself will provide the mechanisms that will build a better information base in order to provide better quality data, and thus also enhanced target setting.

Method:

Figure 2 on the following page describes a strategy for managing Apparent Losses that is advocated by the author. 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. And the list goes on. 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. Top executive support must be bought into at an early stage, and sustained for many years to come.

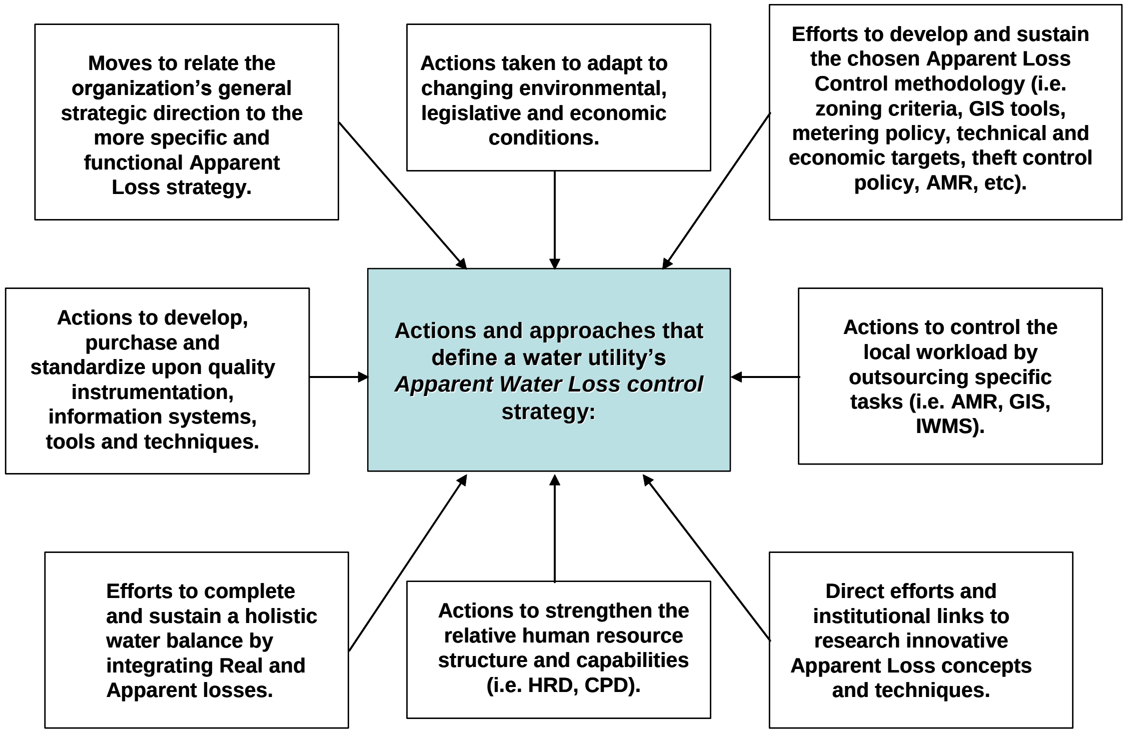

Figure 2: Apparent Water Loss Control Strategy

Discussion:

The forthcoming discussion shall delve into the various components, or dimensions, that make up the strategy defined in Figure 2 above. Where appropriate, results of trials and studies shall be included.

Dimension 1: Moves to relate the organization's general strategic direction to the more specific and functional Apparent Loss strategy.

Most water utilities have an established business plan or strategic plan. This plan will detail the mission, objectives and action plans that the organization has set out for the next 3 to 7 years. Even if the water company does not have a documented plan it will still have a general strategic direction set out in the minds of the key executives running the organization. The organization may be a 'prospector' style firm that aggressively takes on new ideas, products and services, or a 'defender' style firm that is conservative and attempts to sustain exiting services and technologies, or even a 'reactor' style firm that acts both as a prospector and as a defender, according to need. The team managing the Apparent Loss project must recognize the strategic direction of their organization, and must attempt to work in conformity with this direction whilst, at the same time, aim to win support for the various investments required. As an example, a conservative, defender style organization would be more receptive to a gradual but systematic meter change program than an all-out assault to replace tens of thousands of stopped meters within a few months. Another example for this same type of organization would be the application of systematic water theft inspections, with known and well-publicized penalties for consumers found stealing water.

Dimension 2: Actions taken to adapt to changing environmental, legislative and economic conditions.

The team managing the Apparent Loss project must not only be aware of the general strategic direction of their own organization but must be in tune with the general trends that are predominant within the locality or even the nation. For example, a known and accepted malpractice in a small island state was for government employees to tap onto water mains in summer to water public lawns, round-abouts and traffic islands.

Conversely, a deteriorating economic situation in a country may be a prelude for a more aggressive approach towards meter replacements, water billing and water theft control. A good management team will read the signs of the times and will pre-empt the actions required to build and sustain a good Apparent Loss strategy. The issue is on being proactive as opposed to reactive.

Dimension 3: Efforts to develop and sustain the chosen Apparent Loss Control methodology.

Figure 3 below depicts the IWA-recommended Apparent Loss Control methodology. The four arrows indicate the four components that make up Apparent Losses. These four components shall be described in more detail below:

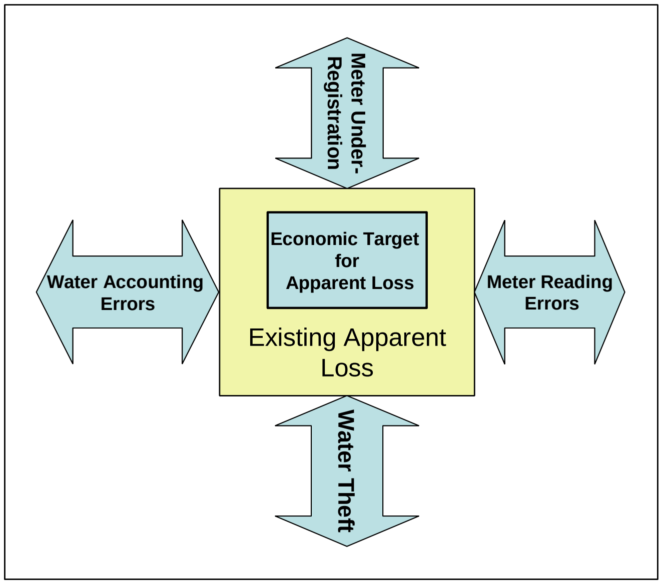

Figure 3: IWA Recommended *Apparent Water Loss Control* Methodology

The first component, meter under-registration, relates to the various errors to be found in consumer water metering due mainly to the following:

- Meter wear and tear.
- Incorrect installation practice.
- Lack of maintenance or calibration.
- Incorrect meter type and class for the application and for the consumer demand profile in question.
- Incorrect meter sizing.

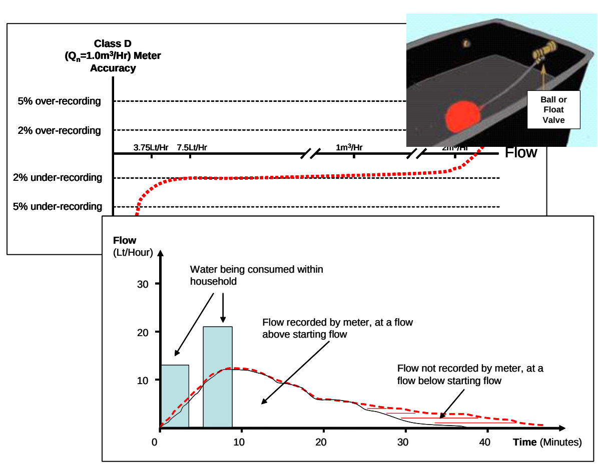

Figure 4: Tests to Size Revenue Meter According to Consumer Profile

An example of meter sizing is shown in Figure 4, where tests confirmed that a portion of very low flows induced by customer roof tanks were not being measured by the standard water meter in use (a class D, Qn=1.0m^3/Hr volumetric meter). Inadequate metering means that the meter will only read a portion of the water that passes through it, thus the consumer will only pay for a portion of the water consumed.

The second component, meter reading errors, relates to the inaccuracies of manual meter reading and the solution of this problem through automatic meter reading (AMR). In most situations meter readers will tend to 'under-read' water meter readings as this causes far less problems with the consumer, and may even be a result of agreements made with the consumer.

The third component, water theft, is most probably the easiest to conceptualize although sometimes may be very difficult to eliminate. Water theft is caused when someone voluntarily bypasses or damages the revenue water meter for a period of time. Meter bypassing may be very subtle, such as a plastic bypass that is hidden under ground or plastered into a wall. Few pipe location techniques can resolve this problem and theft inspectors often look towards zoning and zone-based water balances to indicate the general location of water theft. Portable GIS-based information systems can assist by mapping out paying consumers, thus allowing site inspectors to pinpoint possible misuse.

The fourth component, water accounting (or billing) errors are a result of adjustments or procedures that are carried out within a utility's billing system, and that result in water bills that do not truly reflect the amount of water that is consumed. A good example is a computerized procedure that estimates the amount of water consumed by 'closed' premises, since no actual readings are available. The estimated value of water consumed may be far less than the actual value, and this may even induce the consumer to retain the premises conveniently closed for future meter readings! As in the second component, automated meter reading (see Figure 5 below) goes a long way in reducing this Apparent Loss component since it eliminates estimations and illegible manual readings.

Figure 5: Automated Water Meter Reading Using RF Technology

The Apparent Loss Control methodology shown in Figure 3 also displays two boxes, an outer box and an inner box. The four arrows collectively work to try to reduce the outer box area into that of the inner box which is, in effect, a target. The outer box indicates the volume (shown as surface area) of Apparent Water Loss calculated over a fixed period through techniques such as the 'Top-Down' plus 'Bottom-Up' method described earlier. The inner box indicates an economic target for Apparent Loss reduction. This may be calculated as a generic target, say to reduce the existing Apparent Loss value by half in three years time, or may be a well-computed value that looks into detail on each of the four components. An example of this second scenario is shown in Figure 6 on the following page. This shows a tailor-made economic model that has taken a known value of meter under-registration of 6% and computed the annual savings and net present value if this 6% is to be eliminated at a specified cost. The model looks into various parameters such as the water tariff structure, the cost of the metering solution, and a scenario of possible outcomes and related savings. Scenario 3 has the highest chance of occurring, and will provide the water utility with a net present saving of Lm 4 million (Lm1 = $3) if the 6% meter under-registration is eliminated.

Enter the red values

Enter the average metered input to household in m3/120 day cycle	40
Discount rate taken at 4%	
Enter the % of water going to kitchen	9
Enter the % difference between roof tank output and roof tank input (as a % of the tank input)	6
Password for Red Cells: rooftank	
Total number of domestic consumers	140,000
Tariff Platform 1 (per cubic metre)	Lm0.17
Tariff Platform 2 (per cubic metre)	Lm1.10

Revenue relating to the elimination of rooftank under-registration (120 day cycle)	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Metered household input	40.00m3	40.00m3	40.00m3	40.00m3	40.00m3
Water into kitchen	3.60m3	3.60m3	3.60m3	3.60m3	3.60m3
Water into tank	36.40m3	36.40m3	36.40m3	36.40m3	36.40m3
Water out of tank	38.58m3	38.58m3	38.58m3	38.58m3	38.58m3
Difference between i/p and o/p of tank	2.18m3	2.18m3	2.18m3	2.18m3	2.18m3
Added annual revenue for total consumers (as per cell B9)	Lm837,477	Lm665,945	Lm580,180	Lm494,414	Lm322,883

Cost of *alternative* system: Lm5.00

	Profit (NPV) to the WSC over a 10-year period				
Scenario 1		20% at tariff 1; 80% at tariff 2	Lm6,092,606	Payback Period *(in months)*	10
Scenario 2		40% at tariff 1; 60% at tariff 2	Lm4,701,349	Payback Period *(in months)*	13
Scenario 3 (Most Probable)		50% at tariff 1; 50% at tariff 2	Lm4,005,721	Payback Period *(in months)*	14
Scenario 4		60% at tariff 1; 40% at tariff 2	Lm3,310,092	Payback Period *(in months)*	17
Scenario 5		80% at tariff 1; 20% at tariff 2	Lm1,918,836	Payback Period *(in months)*	26

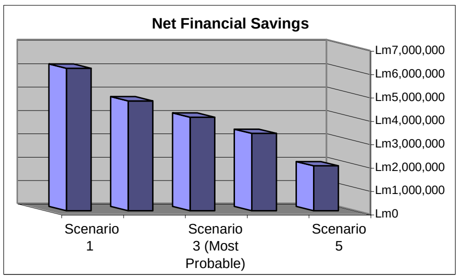

Figure 6: Economic Model Calculating the Percentage Meter Under-Registration and Financial Implications, for a System with Roof Tanks.

Dimension 4: Actions to control the local workload by outsourcing specific tasks.

No water utility can boast unlimited resources and expertise. Outsourcing and joint ventures are two of many ways in which a water utility can build a network of support services, and avoid employing permanent labour for tasks that are of a defined duration. Tasks that are commonly outsourced usually involve advanced IT or a volume of manual data capture over a limited period. An outcome of this practice is shown in Figure 7, where a seasoned IT company was recruited by a water utility to build an Apparent Loss Control tool. The project consisted of two stages. In the first stage all water consumers in the region were ‘geocoded’, that is their exact point of residence was digitized as a point on a digital map (shown as blue points for buildings with meters and red points for buildings without meters). These points were linked to the billing system so that each point related to billing, metering and water consumption data for a specific consumer. The second stage consisted of a software program that analyzed (for a defined period) the water supplied into each zone, the leakage value within each zone, the metered consumer use in each zone, and thus, by default, the Apparent Loss value for each zone.

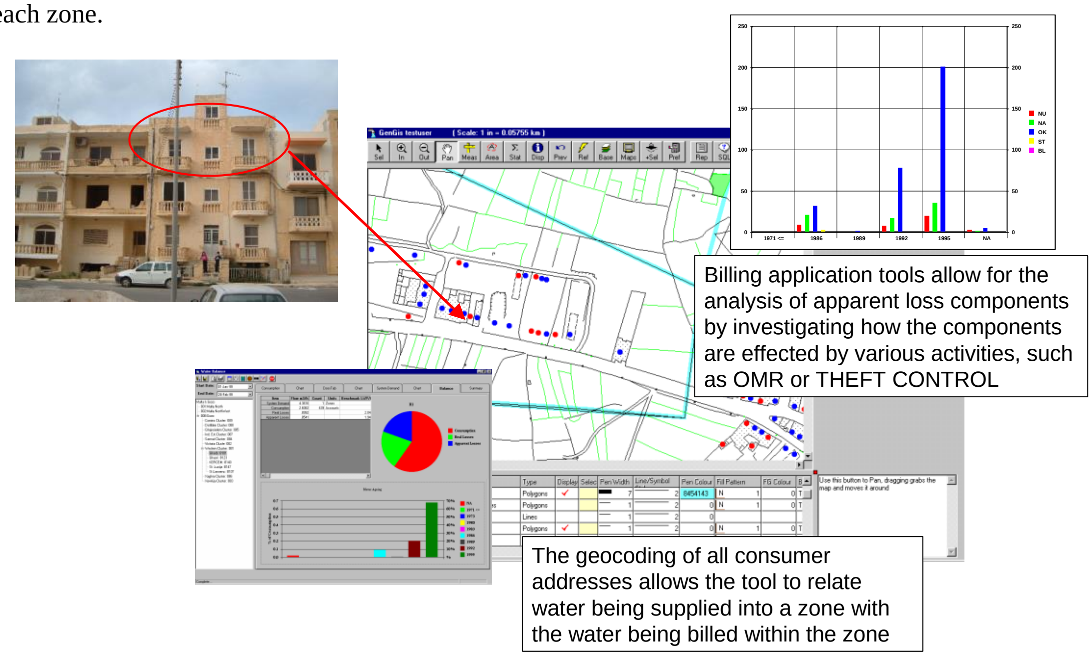

Figure 7: GIS-Based Apparent Water Loss Control Tool

Dimension 5: Direct efforts and institutional links to research innovative Apparent Loss concepts and techniques.

An excellent example of how institutional links can benefit an organization seeking to resolve its Apparent Losses is in the assistance provided by the International Water Association (IWA). Two different levels of assistance can be found. At one level the IWA disseminates knowledge and recommended best practice on a range of water-related areas, obviously including Apparent Losses. An example of this is in the application of performance indicators as a means of measuring and comparing progress in operations. The existing IWA-advocated performance indicators for Apparent Losses are as follows (Alegre et al. 2000):

- Apparent Loss in ***m^3/Service Connection/Year*** for a service connection density of greater that 20 connections per km of mains.

- Apparent loss in ***m^3/Km Mains/Year*** for a service connection density of less than 20 connections per km of mains.

- Apparent water loss in **% of System Input Volume** for transmission Systems, and **% of Water Supplied** for distribution systems.

At a second, more direct level the IWA's Water Loss Task Force hosts no less than 8 specialized teams, one of these focusing on learning in the field of Apparent Loss Control. Water practitioners following the work and publications of the IWA can gain substantial knowledge on problems such as the one under discussion, as well as on a range of possible solutions.

Not only should a water utility link to associations such as the IWA, it should also build a certain amount of research and development (R&D) capacity in house. One of the main areas that provides high returns is that of water metering. Since each and every utility has a number of unique parameters such as consumer demand profiles, water quality parameters, seasonal patterns and meter installation and maintenance practices, these need to be studied separately and collectively. Identifying the ideal metering policy is not a matter of chance, nor is it the case of following the generous advice of a water meter manufacturer!

Dimension 6: Actions to strengthen the relative human resource structure and capabilities.

An organization is a combination of resources, usually placed into 3 categories: human resources, that is, the organization's employees; physical resources such as information, equipment, instrumentation, plant and building; and organizational resources such as internal policies and procedures, and the more subtle organizational culture. Whilst these three resource categories interact and inter-relate, it is worth placing a particular focus on the human resource as it provides for the foundation of the other two categories. Human resources are the company employees, ranging from the top executives, through various management hierarchies and down to site operators, contractors and support staff. Often one is not aware of the concept of the 'weakest link', however in Apparent Losses this concept could not be more prevalent. Although it is the management who dream up strategically important projects, it is the site operators that will often make or break the project. This is especially true in the early stages of the birth of a project. One particular example of relevance relates to an incentive to replace all revenue meters in a locality with a new and more accurate meter model. The project was abandoned after it was found that a large proportion of the new meters failed after just days of operation. Some time later it was discovered that disgruntled employees had been purposely allowing dirt to enter in the new meter installation process, inevitably causing fouling of the meter mechanism. In order to avoid HR issues and to build a sustainable Apparent Loss strategy, the following factors have to be seriously taken care of:

- Training of all employees involved in the various levels of the project. Training is a continuous, cyclic process.
- Ownership: Make employees believe in the project and feel that they form part of it.
- Motivation, both intrinsic (acknowledgement and praise) and extrinsic (physical rewards for exceptional achievements). Training is also a good motivator, especially if it is tied down to progression up the job hierarchy.
- Recognition and respect. These important characteristics are all too often overlooked.

Dimension 7: Efforts to complete and sustain a holistic water balance by integrating Real and Apparent Losses.

Page 1 has already seen a discussion on the concept of the 'top down' and 'bottom up' water balance, however the importance of this concept justifies some repetition. Either as a regional water balance or simply on a test zone basis, complete water balancing provides for vital information on the volume and composition of the Apparent Loss component. Figure 8 depicts, as an example, a GIS-based tool that carries out this complete water balancing. The blue dots relate to revenue water meters, mapped out accurately onto a base map. The black lines indicate the boundaries of hydraulically encapsulated zones. Around 30 zones are evident. For each zone, one master meter records and data logs the water entering the zone, with a standard data logging interval of 15 minutes. This system input value (similar to the system input in the water balance shown in column 2 of Figure 1) for a zone is depicted as the complete surface area of the pie chart shown below. A time base of 4 months was taken so the surface area of the pie chart represents the volume of 4 months of water supplied into one specific zone. The red section of the pie chart indicates the summated volume of water metered for all the consumers in the zone, also for the 4 month period. This is calculated by the GIS tool burrowing into the billing database, for all the consumers (blue dots) within the particular zone. The green segment of the pie chart relates to the Real Loss value (leakage) for the 4-month period, calculated by looking at the diurnal effect of the master meter logging of water inflowing into the zone (called minimum night flow analysis). The blue segment of the pie chart is the remainder, that is, the Apparent Loss value for that zone during the 4-month period. The GIS tool also provides information on why the Apparent Loss value is high (or low), by providing bar charts showing the age of water meters, number of stopped meters, billing estimations, failed meter readings, etc. Studying the Apparent Loss for a zone with time, or comparing the Apparent Loss between different zones, will provide important information. This technique can also be applied for water utilities that do not have complete metering and monitoring, by identifying and zoning a pilot area and studying this area in detail as a test case.

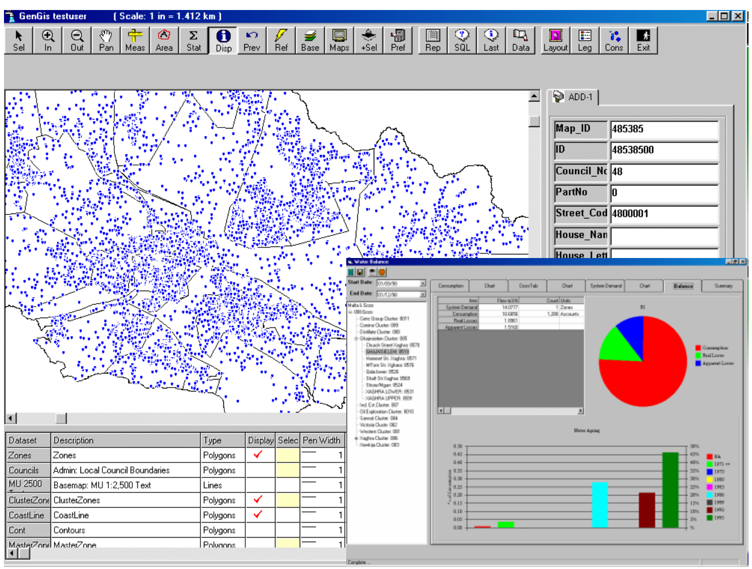

Figure 8: Integrated 'Top-Down' and 'Bottom-Up' Water Balance

Dimension 8: Actions to develop, purchase and standardize upon quality instrumentation, information systems, tools and techniques.

This final dimension provides an important contribution towards the sustaining of the Apparent Loss strategy, once launched. As has been shown, the strategy is essentially an activity in capacity building; that is building on the HR, physical and organizational resources of an organization. All investments that are made must be an intelligent trade-off between quality and cost. Excessive dependency on external assistance is to be avoided, whilst overstaffing and uncontrolled expenditure are also dangerous mistakes. Whilst standardization on trialed and tested systems and equipment is sometimes frowned upon by transparency-seeking executives, this approach is often the best way forward. So to is networking and twinning with like organizations and institutions that have mutually similar goals and ambitions.

Conclusion:

The paper has taken a holistic view of Apparent Loss Control by looking at the strategy that a water utility will need to build and sustain. It is evident that Apparent Losses relate to the efficiency of a water utility to meter and ultimately bill each and every water consumer. One may argue that water companies that do not routinely meter their consumers need not place too much focus on Apparent Losses. As water becomes more and more of a scarce resource, this scenario is set to disappear forever. Efficient metering, meter reading, billing and theft control are soon to become core competencies for the serious water utility. The International Water Association has taken the Apparent Loss topic so much to heart that the forthcoming Water Loss Task Force conference of 2007 has been renamed “Water Loss 2007” instead of the pre-planned “Leakage 2007”.

The descriptive and somewhat generic approach adopted in the paper to describe the 8 strategic dimensions has limited the amount of detail that could be provided. Many of the topics mentioned are complete subjects of discussion in themselves. Take, for example, water metering. A water company may go through years of research, trials and tests before identifying the ideal meter make, type, class and size. Similarly for meter reading, various manual and automated processes could be analyzed before the ideal meter reading system is procured. For a water utility that is still in an early stage of development, at least in relation to Apparent Losses, a pilot-project approach is often advocated. Important learning on the 4 components of Apparent Losses (see Figure 3) can be gained, even on one or two pilot zones. The strategy advocated in this paper can be built in parallel with knowledge being gained on the 4 components. Another point to emphasize is the uniqueness of the problem for each different water company. The best approach towards Apparent Loss control is to treat it as a project, one that must be managed in a holistic and integrative manner.

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