Chapter 18

Appendices

Paper 1: Water balance – From the desktop to the field

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Summary: Have you ever wondered what you do with the water balance after the various components have been calculated? Or how you can use the numbers to work out an investment strategy and an action plan and how to prioritise your actions in order to get the best return on your investment? This paper shows how the water balance can be used to derive an action plan for reducing non-revenue water as well as the relevant returns on investment for each action. Also it gives a full working model of how the Water Balance is taken to the next stage. Furthermore it details the actions that are appropriate to be taken for each one of the above main components of the water balance in order to reduce non-revenue water and provides justification for each action proposed. It also expands on current thinking and knowledge in the planning and prioritisation of non- revenue water reduction options that are available to water utilities and recommends a basic action plan matrix.

Keywords: Water Audit, NRW reduction strategies, NRW action plan matrix

Editor(s): Stuart Hamilton and Bambos Charalambous
doi: 10.2166/9781789060850_0151

INTRODUCTION

Most water utilities use the water balance to calculate non-revenue water and to find the amount of water being lost. It is obvious that this is extremely useful and must be worked out in order to have a clear picture and to account for each constituent component of the water balance.

The planning of non-revenue reduction activities to be carried out and ultimately the compilation of an action plan are based on the findings of the water balance and in particular on the main components, namely, Authorised Billed Consumption, Unbilled Authorised Consumption, Apparent Losses and Real Losses. Depending on the amount of water which is being lost in each one of the above components which comprise the Non-Revenue Water, the action plan is targeted in order to provide the best return with the minimum of investment in the shortest time possible.

Accountability of water is extremely important in this process. This is achieved through a validated Water Audit which could be carried out internally by experience water utility personnel or by external auditor.

WATER AUDIT

A water audit is a thorough accounting of all water into and out of a utility as well as an in-depth record and field examination of the distribution system that carries the water, with the intend to determine the operational efficiency of the system and to identify sources of water loss and revenue loss. It should include but not limited the following:

- A thorough accounting of all water into and out of a distribution system.
- A Water Balance calculation including inspection of system records and data verification.
- A meter testing and calibration program.

A water audit is a critical first step in the establishment of an effective water loss management program. With the successful completion of a system water audit, the utility gains a quantified understanding of the integrity of the distribution system and begin to formulate an economically sound plan to address losses. Water loss in a public water system can be a major operational issue. Non-revenue water components can significantly affect the financial stability of the utility. Addressing the issues associated with the non-revenue components will certainly entail a significant cost for the utility. The economic trade-offs between value of lost water given it generates no revenue and the investment to reduce this loss requires careful planning and economic judgment. The utility needs to clearly understand the type of loss as well as its magnitude. Water resource, financial and operational consequences must be weighed when considering these issues and the decision taken is unique to every system.

A brief summary of the main steps to perform an initial water audit is given below for ease of reference:

(1) The amount of water put into the distribution system is determined.
(2) The authorised consumption (billed+unbilled) is obtained from records.
(3) Water losses are calculated (water losses = system input − authorised consumption).
(4) Apparent losses are estimated (theft + meter error + billing errors and adjustments).
(5) Real losses are calculated (real losses = water losses − apparent losses).

The above steps are an example of a top down audit, which starts at the “top” with existing information and records. It may also be known as a desktop audit or paper audit since no additional field work is required. Distribution systems are dynamic. The audit process and water balance has to be periodically performed to be meaningful to a utility’s water loss management program.

After performing an initial top down audit it may become evident that some of the numbers are approximate estimates and inspire little confidence in their accuracy. The next action in the audit process is to refine the quantities that may have been initially estimated and begin reducing non-revenue water losses. A bottom up approach is often implemented after top down audit has been completed which can help in identifying the real losses component more accurately thus adjusting the initial Apparent losses estimate. A bottom up approach will help with finding real losses and begins by looking at components or discrete areas in the distribution system. It also assesses and verifies the accuracy of the water loss data associated with individual components of the distribution system.

It is important to stress that although utility personnel are well experienced and are familiar with the operational characteristics of the network it may be worth while having an external or independent audit carried out. External audits are usually an excellent way of helping water utilities to analyse and improve their data. It must stressed the external audits are an independent process, ensure accurate reporting, improve data collection and accuracy by identifying statistical and reporting errors and is an excellent method of helping utilities to improve their performance.

There are many types of audits that will analyse water use, from distribution system balances to household reviews. The accuracy of results depends on the methods used to generate the data. Audits have an important part to play in the development of strategic action plans for water efficiencies and financial savings as well as short and long term management. Therefore it is vital they are undertaken in ways which ensure that the most accurate data possible is generated (Queensland Environmental Protection Agency/Wide Bay Water, Manual 2, Water Audits p43).

ASSESSING LOSSES – IWA WATER BALANCE

A significant contribution to reaching the point of water accountability was the establishment of the IWA Water Balance (Figure 18.1.1) which is a useful tool in analysing the various components of water production, storage and distribution. Through this analysis the utility will gain an understanding of the magnitude of the water loss problem and will set priorities for rectifying the situation based on the component analysis of the Revenue and Non-Revenue Water elements.

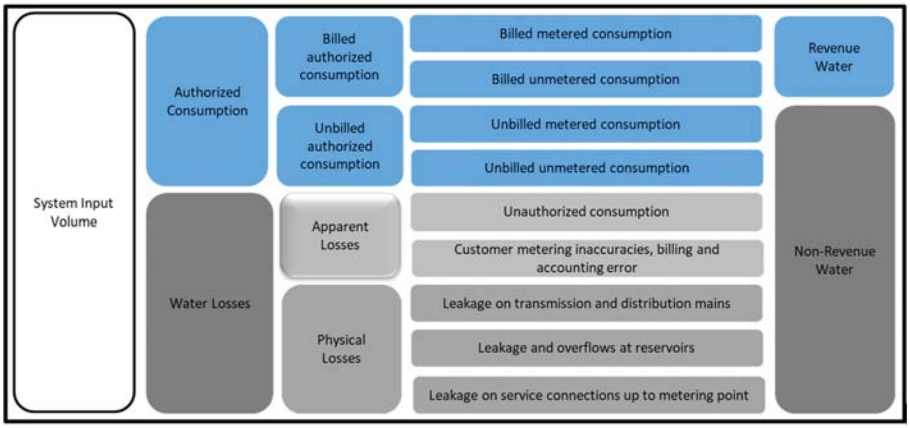


Figure 18.1.1 IWA Water Balance. (Source: IWA Water Loss Specialist Group)

The findings from the water balance and in particular its main components should:

- Assist in estimating the best return with the minimum of investment in the shortest time possible
- Form the basis for planning NRW reduction activities
- Provide sufficient information for an effective action plan

It is strange however, that for a number of reasons instead of following the above desired results a different approach is adopted which follows the steps below:

- Limited and/or unreliable data is used
- Calculate non-revenue water
- Find the amount of water lost
- Do not like the outcome
- Change assumptions made to suit
- Management 'blaming' staff for not doing their job
- Employees pointing out lack of funding, commitment and support by management
- Finally, work out figures to suit management and employees

Obviously the above approach will result in serious problems for the utility and it must be avoided at any cost. The Water Balance is a useful tool which if used correctly it will certainly point the way to the actions and measures that need to be taken to reduce NRW. Answers to the questions below will take you to the next stage from the desk top to the field environment.

- Have you ever wondered what you do with the water balance after the various components have been calculated?
- Or how you can use the numbers to work out an investment strategy and an action plan?
- Or how to prioritise your actions in order to get the best return on your investment?

Answers to the above questions and what could be done with the water balance will be demonstrated using examples from case studies.

CASE STUDY EXAMPLES

Top down approach

In this example the constituent components of the water balance are entered into the water balance using absolute volume figures and working out the corresponding percentage figures (Table 18.1.1). It is this percentage figures which are usually quoted and has to be stressed that they could be misleading as a performance indicator since they are strongly influenced by consumption as well as changes in consumption.

The Non-Revenue Water is often expressed as a percentage of the System Input Volume. However, a true financial performance indicator needs to reflect costs as well as volumes. An improved financial indicator can be used by converting the Non-Revenue Water Volume to values. An example is shown in Table 18.1.2 below where the NRW volumes in the above Water Balance were converted to values using the corresponding unit value for water. The unit value for Unbilled Authorised Consumption and Apparent Losses is usually the average sale price of water to customers. The unit value for Real Losses is usually taken as the marginal cost of water that is the unit cost of producing and distributing water into the network or bulk charge whichever is the higher.

Table 18.1.1 Top down approach using the IWA Water Balance

System Input Volume 11.985.560 100,00%	Authorised Consumption 10.276.626 85,74%	Billed Authorised Consumption 10.216.698 85,24%	Billed metered consumption (including water exported) 10.216.698(85,24%)	Revenue water 10.216.698 85,24%
			Billed unmetered consumption Zero	
		Unbilled Authorised Consumption 59.928 0,50%	Unbilled unmetered consumption Zero	Non-Revenue water 1.768.862 14.76%
			Unbilled unmetered consumption 59.928 (0,50%)	
	Water Losses 1.708.934 14,26%	Apparent Losses 299.639 2,50%	Unauthorised use 59.928 (0,50%)	
			Metering inaccuracles 239.711 (2,00%)	
		Real Losses 1.409.295 11,76%	Real losses on raw water mains and at the treatment works Zero	
			Leakage on transmission and/or distribution mains 80.458 (0,67%)	
			Leakage and overflows at storage tanks 11.986 (0,10%)	
			Leakage on service connections up to the metering point 268.913 (2,24%)	
			Detectable Losses 1.047.938 (8,74%)	

Table 18.1.2 Converting NRW Volume Components to Values

Non-Revenue Water 1,768 862 m^3	Components of Non-Revenue Water	Assessed unit value of NRW component	Assessed total value of NRW component	Assessed total value of Non-Revenue Water € 1127 436
	Unbilled Authorised Consumption 59 928 m^3	1,2 €/m^3	€ 71 914	
	Apparent Losses 299 639 m^3	1,2 €/m^3	€ 359 567	
	Real Losses 1 409 295 m^3	0,8 €/m^3	€ 1 127 436	

From Table 18.1.2 it can be seen that the Real Losses have the biggest financial loss for the utility and it is evident that this area is critical and should be examined further. This examination should provide proof that repairing the leaks and savings this amount of water which is being lost makes financial sense for the utility. In order to arrive at this result the following methodology needs to be followed.

From the top down analysis in Table 18.1.1 the amount of detectable losses are 1047938 m^3. This figure is equivalent to a Night Line reduction of 1 047 938 m^3/365 days/20 hrs = 144 m^3/hr. Assuming an average leak of the order of 1.6 m^3/hr then the number of equivalent leaks that should be located and repaired is 90. Given that the network length is 345 km it works out that there is on average 1 leak every 3.83 km. Assume a leakage detection team comprises 2 technicians with an average output of 2.5 km per day, 5 day working week and a weekly charge of €5000/week. The average number of leaks found by the team per week is $5 \times 2.5/3.83 = 3.26$, say 3 leaks found per week. The total time required to find all leaks will be 90 leaks/3 = 30 weeks. Based on the above the following financial calculations can be made

- Total Cost for locating leaks = 30 × €5000 = €150 000
- Total Cost for repairing leaks = 90 × €1500 = €135 000
- Water Saving = 1 047 938 m^3 × €0.8/m^3 = €838 350
- NET SAVING = €838 350 – €150 000 – €135 000 = €553 350

It obvious from the above calculation that the utility will have a considerable saving by moving forward with repairing the leaks first and an action plan to this effect should be work out.

In order to highlight a different approach to the above the apparent losses in Table 18.1.2 are increased with the corresponding reduction in the real losses. The revised figures are shown in Table 18.1.3 below.

In this instance the action plan needs to be different to the above for the following reasons:

- The Apparent Losses are almost equal to Real Losses in terms of revenue loss
- Need to deploy a strategy that will maximise benefits
- Tackle apparent losses with the minimum expenditure; reduce unauthorised consumption, meter reading and accounting errors at the first instance which will increase revenue.
- Simultaneously reduce leakage in order to save money in producing/buying less water.
- Invest savings in further reducing Apparent and Real Losses.

Table 18.1.3 Converting NRW Volume Components to Values (Revised). Water balance – From the desk top to the field

Non-Revenue Water	Component of Non-Revenue Water	Assessed unit value of NRW component	Assessed total value of NRW component	Assessed total value of Non-Revenue Water
1768 862 m^3 (14,76%)	Unbilled Authorised Consumption **59 928 m^3 (0.50%)**	**1,2 €/m^3**	**€ 71 914**	€1 678 917
	Apparent Losses **599 639 m^3 (5,00%)**	**1,2 €/m^3**	**€719 567**	
	Real Losses **1109 295 m^3 (9.26%)**	**0,8 €/m^3**	**€887 436**	

Bottom up audit – case study to show bottom up and top down comparisons

It this example it is explained how the bottom up audit is extremely useful in complementing the top down approach. The case study data used are of the area of ‘Sky’ in Piraeus, Greece (Kanellopoulou, S., 2011). The main characteristics of the area are as follows:

- Length of network = 56km
- Number of consumers = 16840
- Service connections = 4000

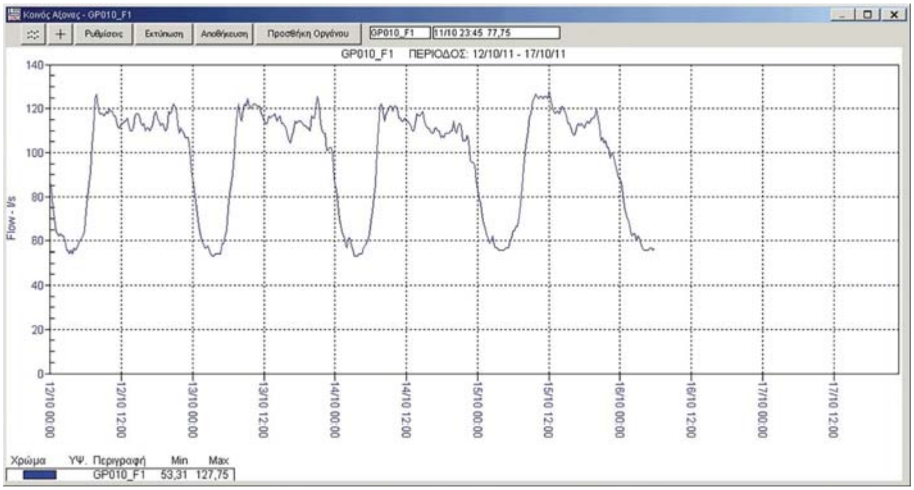
A top down approach is carried out and the result is given in the table below. It should be noted that under the Real Losses the two main constituent components are included:

- Background Leakage on mains and service connections, and
- Detectable Losses

In order to verify the assumption made for the Apparent Losses a bottom up audit will be carried out based on measured values. The Minimum Night Flow (MNF) as measured is shown in Figure 18.1.2. The Minimum Night Flow is 55 lit/sec (198 m^3/hr). Based on this measured figure a bottom up audit is carried out of the constituent components of the MNF in order to arrive at the amount of potentially detectable losses as shown in Table 18.1.4.

As it can be seen from Table 18.1.4 below the potentially Detectable Losses are 2352 m^3 per day compared to the overall figure of 2631 m^3 per day estimated for all Real Losses in the system using the Top Down approach (Table 18.1.5).

This exercise shows that the initial assumption for Apparent Losses is reasonable and the NRW reduction plan should concentrate on reducing the Real Losses particularly in locating and repairing the leaks in the distribution network. The potentially detectable losses comprise 89% of the overall Real Losses which is of the right order considering that apart from a small percentage of Background Losses and Customer Night



Χρώμα	ΥΨ.	Περιγραφή	Min	Max
▬		GP010_F1	53,31	127,75

Figure 18.1.2 Minimum Night Flow Diagram for the area of Sky, Piraeus, Greece. (Software: Intranet telemetry application, 2006, EYDAP, Athens, Greece)

Table 18.1.4 Bottom up audit for the area of Sky, Piraeus, Greece

Description	m^3/hr	Daily (m^3)
Minimum Night Flow (measured)	198	198 × 20 hr = 3960
Background Losses (calculated)	21	21 × 24 = 504
Customer Night Use	46	46 × 24 = 1104
Potentially Detectable Losses	3960-504-1104	2352

Table 18.1.5 Top down approach for the area of Sky, Piraeus, Greece

Description	m^3/year	Average Daily Volume (m^3)
Input volume	2 898 100	7940
Construction	1 881 575	5155
Non-revenue water	1 016 525	2785
Unbilled Authorised Consumption (measured)		26
Apparent Losses (assumed 2.5% of consumption)		129
Real Losses		2630

Use the remainder is attributed to losses in the distribution network which could potentially be located and repaired. Of course the Economic Level of Leakage must be taken into consideration in deciding how much of the amount of potentially detectable losses is financially worthwhile recovering.

Benchmarking of non-revenue water

It is extremely useful to have a matrix which could be used to benchmark the performance of a utility based on the NRW figures.

The authors have developed and are proposing for use an action plan matrix which is based on the percentage of System Input Volume for each constituent component of the Non-Revenue Water. The action plan matrix which is shown in Table 18.1.6 provides guidance as to the general actions that could be taken depending on the percentage figure in order to reduce the NRW in each component.

Of course the proposed matrix is only a guideline and much more investigation and development of this Matrix is required. The intention is to provide a guideline as to the general actions required which could be carried out by the utility whilst collecting and validating further data and information for more detailed analysis which will result in specific water loss management strategies.

CONCLUSIONS

It could not be stressed enough that utilities must target their actions and investments in order to get the maximum benefit. To achieve this it is important to have the necessary knowhow either internally or externally in order to be in a position to justify a proposed NRW reduction action plan which above all

Table 18.1.6 Proposed action plan matrix for NRW

Water Balance Component	% of System Input Volume	Suggested Action
Unbilled Authorised Consumption	Up to 1%	Considered within acceptable limits
	1% to 5%	Introduce new tariffs
	5% and above	Review overall billing policy
Apparent Losses	Up to 2%	Considered within acceptable limits
	2% to 5%	Reduce unauthorised consumption, meter reading and accounting errors
	5% and above	Review metering accuracy/policy
Real Losses	Up to 5%	Considered acceptable, may be uneconomic to reduce
	5% to 10%	Reduce visual leakages and overflows at storages and fix visual network leaks
	10% and above	Improve active leakage control, effective maintenance, pressure management

should be financially viable and sustainable. Needles to say in order to carry out such a plan the right level of knowledge and experience are required.

So, tackle first whatever gives you the quickest revenue return which will provide money for the longer term savings – think of the returns and not get caught up in the expensive solutions because it may be more attractive.

It is important to be understood that the Water Balance is the starting point for any NRW work. This paper aims to show that this could be done at the very early stages without having to wait until DMAs, pressure management, and so on. are set up and data collected and analysed.

The Water Balance provides sufficient information to assist in the drafting of a NRW master plan in order to move ahead with water loss reduction and in parallel to make strategic improvements to the network. In the past it was thought necessary, mostly in developing countries, to develop DMAs in order to drive a NRW reduction master plan. The authors are suggesting that this could be done in parallel and that in the initial stages the Water Balance is the vehicle for driving a NRW Master Plan.

FURTHER READING

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Paper 2: Intermittent supply leakage nexus – Dealing with the complex interrelation of intermittent supply and water losses

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Abstract: In many world regions Intermittent Water Supply (IWS) systems are prevalent. It is evident from the results presented in this paper that although intermittent water supply may seem to be a solution to a water shortage situation in overall terms the water balance is adversely affected. Supplying less quantity in an intermittent manner causes such deterioration to the network that when continuous supply is re-established additional quantities are lost through increased leakage, which in fact places an added financial burden on the utility. It is therefore evident that no matter how good a network is, intermittent supply operation has definitely a detrimental effect on its integrity and in addition the amount of water 'saved' is later 'lost' and in greater quantities through increased levels of leakage. Such operational conditions should be avoided especially in pipeline networks that have been designed for continuous supply. In addition it has been shown that the domestic demand is in effect inelastic and in fact the quantities of water saved by the customers were very small. It is the authors' opinion that better results could be achieved through a structured conservation programme rather than intermittent supply. Of course such programmes are to be introduced as part of an overall strategy for water conservation both on the supply and demand side

Keywords: Intermittent water supply, water losses, continuous supply

GENERAL

IWS systems can be defined as piped water supply service that is available to consumers for less than 24 hours per day. In Latin America and the Caribbean, it is estimated that 60% of the population is served by household connections having intermittent service (PAHO & WHO 2001). In Africa and Asia, it is estimated that more than one-third and one-half of urban water supplies respectively, operate intermittently (WHO & UNICEF 2000).

In an IWS situation, the consumers usually secure their water supply through the use of ground and/or roof tanks or smaller capacity individual containers, where water is stored during the length of time that the supply is provided in order to be used during the period that the supply cut-off. It is worth noting that IWS is enforced not only in cases where there is water shortage but also where the hydraulic capacity of distribution networks is such that cannot satisfy demand as well as in cases where the network is severely deteriorated resulting in high leakage.

In many instances there is no indication how long intermittent supply will be in place. In many countries around the world IWS is the norm rather than the exception. The hydrological conditions in each case could impact adversely on water supply for years in which case conserving as much as possible the limited water resources may not be the long term solutions but it may be necessary to add to the water balance new non-conventional water resources. In many countries water shortage problems were overcome through the desalination of brackish or saline water. Of course exploring every potential water source available may be the only solution in many instances, but leakage reduction is always one of the least expensive and quickest solutions to ensure that water will be available when needed.

It is generally considered that IWS is not an ideal form of supply and should not constitute a permanent solution however it is applied by many water utilities with great ease mainly as a measure for dealing with water shortage or drought conditions without seriously looking into alternative solutions. It is also the authors' experience that some water utilities are applying IWS as a measure to reduce extremely high leakage from their networks which of course prevents them from maintaining a continuously pressurised network with all the adverse repercussions.

Even though in a number of instances it may not be possible to avoid IWS, the advantages of IWS if any, are very few and lack substance in order to convince that the use of intermittent supply is a sustainable modus operandi for water distribution networks. Intermittent supply is usually introduced either as an emergency measure, when the water availability is limited or in some cases it is introduced as a measure to control water use and to reduce leakage. In the first case when there is limited water availability, there may be no alternative to the rationing of water and an intermittent supply cannot be avoided once the supply resource has been depleted. In the second case, however, where the intermittent supply is introduced as a water saving measure there may well be alternative interventions that can provide savings without some of the problems that tend to accompany such pressurising and depressurising of the distribution network (Mckenzie, 2016).

In many systems IWS was not an element of initial system design but rather reflects a combination of deteriorating infrastructure and demand growing beyond design limits. A possible combination of factors, such as: water scarcity, prolonged drought periods, population growth, urbanisation and increasing demand, lack of awareness and forward planning may have been the root causes of IWS for many water utilities. Inevitably IWS is the cause of serious problems in the proper operation and management of a water distribution network.

The Vicious Cycle of IWS

Normally water reticulation networks are designed to provide piped water on a continuous basis without any discontinuity in this supply apart from extremely short intervals where the supply is cut-off for routine maintenance or fixing of pipe breaks. However, in some instances changing hydrological conditions may result in water shortage and the water utilities are unable to meet existing needs. In some geographical areas this situation may take the form of a cyclic phenomenon where periods of low rainfall are repeated every few years, resulting in water rationing and the temporary application of IWS (Charalambous, 2009) applied as a measure to deal with such circumstances (Figure 18.2.1).

Implications of IWS

Although intermittent supply is usually introduced either as an emergency measure or as a measure to control water use and to reduce leakage it is however a situation worthwhile avoiding through proactive planning and timely response to critical conditions. The adverse effects of intermittent supply on water quality, customer service and integrity of the distribution network as well as the financial repercussions to the utility are highly significant. Some of these are analysed below.

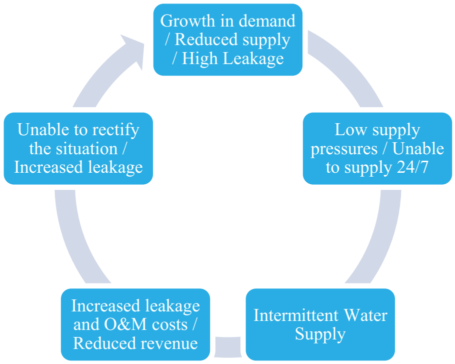

Figure 18.2.1 Vicious Cycle of IWS. (Source: Author)

Water quality deterioration/Health hazard

Intermittency entails a high risk of contamination, which creates substantial health hazards. The first route is the ingress of contamination through broken pipes or joints. Interruption of supply normally creates low pressures or even a vacuum condition in pipelines that last for a significant period of time. Consequently, potentially contaminated water, such as rainwater, sewage spills, latrine drainage, etc. may enter the system through the breaks in the pipe walls when supply is off.

It is difficult to keep proper chlorination level in the network since there are no constant hydraulic conditions with the repeated emptying and charging of the network. In order to deal with such situation it is normal to significantly increase chlorination which of course entails other dangers such as the potential creation of Trihalomethanes (THMs). Trihalomethanes are formed as a by-product predominantly when chlorine is used to disinfect water for drinking and result from the reaction of chlorine with organic matter present in the water being treated. The THMs produced have been associated through epidemiological studies with some adverse health effects and therefore limits are set on the amount permissible in drinking water. In addition excessive chlorination would not be acceptable to consumers as they would not be to deal with such high levels of contamination.

Inequitable distribution within a network

In distribution systems designed on the concepts of 24-hour supply flow depends on pressure head. When the network is charged much higher peak flows than expected will occur in the pipelines thus increasing pressure losses in the network. Consequently, consumers furthest away from supply points will always receive less water than those nearer to the source (Gottipati et al., 2014). This will also be associated with low supply pressures, particularly in high ground areas and/or areas furthest away from the source.

Water wastage

Consumers exposed to IWS conditions are likely to keep their taps open to obtain as much water as possible whenever the service resumes. In addition consumers usually remove the control valves that are installed in the ground and/or roof tanks in order to increase to remove any flow restriction hoping to get larger volumes of water in a shorter period of time. Under these circumstances consumers experiencing IWS are likely to waste more water than those who receive a 24/7 supply from the fear of not having sufficient water they will tend to store as much as possible which is usually replaced by the fresh supply of the next day. Unfortunately for the less fortunate consumers who do not have the means of installing ground and/or elevated tanks are forced to manage with the small quantities that they have managed to store in their individual containers.

Inconvenience and high coping costs for consumers

Inconvenient supply times mostly affect the poor, since consumers have to pay for storage and pumping. Alternatively, they will have to go to public taps, sometimes quite faraway and even during midnight, to collect water. Long distances and queues are typical problem of women and children from underprivileged areas, taking lots of productive time from them (Totsuka et al., 2004). Resulting from intermittent supply, the consumers have to pay the costs, so called coping costs, for additional facilities, such as storage tanks, pumps, alternative water supplies and household treatment facilities. The poor who cannot afford such facilities spend their time to fetch water from public taps or vendors at comparatively high total costs. Figure 18.2.2 (Chary, 2009) shows the direct costs that IWS inflicts on water consumers, rich people cope by spending money on water tanks, pumping systems and filters whereas middle-income groups spend less on capital equipment but more in terms of time and power. For the low-income group however the coping cost is primarily the opportunity cost of the time they must spend collecting water.

Meter malfunctioning and accelerated wear and tear

IWS would cause inaccuracies in meter registration. Meter registers might reverse due to vacuum conditions created during emptying of the network as supply is cut-off. Air expelled from the pipes during filling might drive meters at excessive speed during the charging stage after the supply has been resumed resulting in the accelerated wear and tear of the registration mechanism. Undesirable environment, such as repeated dry and wet conditions, would accelerate the performance deterioration of water meters. Meter malfunction brings difficulties for water providers to monitor the water use and collect accurate tariffs. Furthermore, it makes consumers sceptical to the accuracy of their water bills relating to the meter registration.

On the whole IWS has a detrimental effect on the network, results in ineffective supply and demand management, inefficient operations, increased difficulties in detecting and fixing leaks as well as greater number of illegal connections.

Myth busters

Over the years a number of misconceptions have been linked to IWS, particularly relating to leakage and customer consumption. Based on their own experiences as well as data and information provided by colleagues, the authors' set out below evidence which clearly shows that the "myths" build around IWS

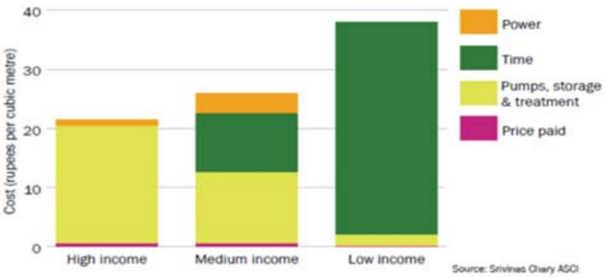

Figure 18.2.2 Coping cost of IWS. (Source: Author)

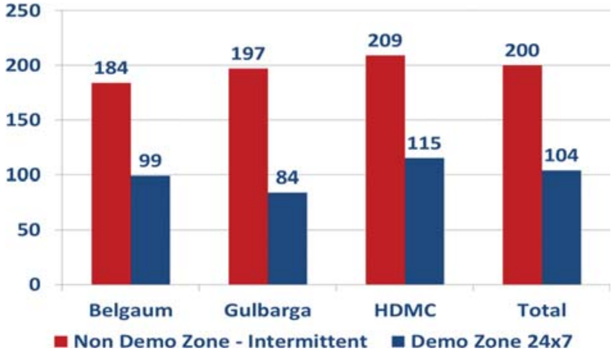

Figure 18.2.3 Water distributed in litres per capita per day. (Source: Anand Jalakam)

are just not true, such as under an IWS regime the NRW is lower compared to 24/7 supply or the volume of water distributed under IWS is less compared to 24/7 regime. Analytically the "myth busters" are presented below.

Is distributed water less under IWS?

It has been considered that under IWS conditions the volume of distributed water is less than the volume needed under a 24/7 supply regime. However, evidence from the Karnataka Demonstration Project (Jalakam, 2014) demonstrated that this is not the case as it can be seen from Figure 18.2.3.

The volumes of water which were distributed to the demonstration zones in each city were far less compared to the volumes that were distributed to the areas of each city under IWS. In fact the numbers show that on average for the 3 cities the volume distributed to the network under IWS was the equivalent of 200 litres per capita per day compared to 104 litres per capita per day for the demonstration zones which were under 24/7 regime, that is 50% less water on average was distributed under the 24/7 regime in the demonstration zones.

Is IWS an effective leakage reduction measure?

Data and information relating to leakage were collected and analysed for a distribution network which was operated over a two-year period under an IWS regime (Charalambous, 2012). Figure 18.2.4 shows the total

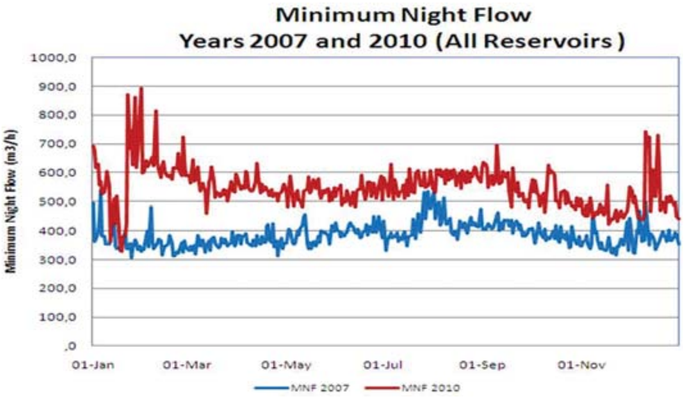

Figure 18.2.4 Minimum night flow before and after IWS. (Source: Author)

Table 18.2.1 Effect of intermittent supply on reported pipe bursts

Description	Number of Reported Breaks		
	Before (Year 2007)	After (Year 2010)	% Increase
Mains	14 per 100km	42 per 100km	200
Service Connections	15.5 per 1000	29.7 per 1000	100
20 DMAs: 373 km (45% of total length of the distribution network) IWS period 2008–09			

Minimum Night Flow before (blue colour) and after (red colour) the intermittent supply. It is evident that there has been a significant increase in the Minimum Night Flow which was attributed to the additional breaks which the network suffered during the two years of intermittent supply period.

Further analysis of case study data showed that there was a large increase in the number of reported pipe breaks during the period of intermittent supply. In order to quantify these a comparison was made for a large number of District Metered Areas, covering a length of network of 373 km corresponding to 45% of the total length of the distribution network, between the breaks reported in 2007, before the intermittent supply was applied, and those reported in 2010, the first year immediately after the measures were lifted and a 24/7 continuous supply was in place. The results are shown in Table 18.2.1 covering both mains and service connections.

This comparison showed that the number of breaks on mains increased from an average of 14 per 100 km of mains to 42 per 100 km of mains, an increase of 200%. Similarly the number of reported service connection breaks increased from an average of 15.5 per1000 connections to an average of 29.7 per 1000 connections an increase of approximately 100%.

Of course, in addition to the number of reported breaks in 2010, there were still a significant number of breaks, which required being located through active leakage control.

Is IWS an effective drought / water conservation measure?

Further evidence from the case study substantiating the increase in leakage due to the intermittent supply regime is given in Table 18.2.2 which provides data on System Input Volume and corresponding Customer Consumption. The Table shows that there was an increase of 12.8% in the System Input

Table 18.2.2 System input volume vs customer consumption

Year	System Input Volume	Customer Consumption
2007 Before Intermittent Supply	Base line 0%	Base line 0%
2008 Intermittent Supply	−17,5%	−9,2%
2009 Intermittent Supply	−9,1%	−8,9%
2010 After Intermittent Supply	+12,8%	−1,2%

Volume in the year immediately after the lifting of the IWS regime compared to the base year immediately prior to IWS. This increase could in fact be attributed to either increase in customer consumption or increase in leakage or both. In fact from the data examined the customer consumption was slightly less (1.2%) compared to the year before the intermittent supply measures were applied which clearly indicates that the additional volume in System Input Volume is attributed to leakage. It is also evident from Table 18.2.2 that the System Input Volume in the first year of intermittent supply decreased by 17.5% whereas in the second year by 9.1% indicating that the number of breaks in the network increased during the second year resulting in less water being saved. This is substantiated by the fact that the reduction in the customer consumption remained effectively the same for the two years' of intermittent supply, -9.2% in 2008 and -8.9% in 2009.

The challenge

While it is relatively easy to turn a 24/7 system to an intermittent supply, it is very hard to do the opposite. Water utilities that have fallen into the vicious cycle of IWS have major institutional, technical and financial issues and would definitely need to go through a reform process; moving to continuous supply requires often very difficult political and institutional choices that many water utilities/governments prove reluctant to make. A paradigm shift is therefore imperative to transition from IWS to 24/7 supply.

In order to improve operational, commercial and institutional efficiency the water utilities will need to strive towards reducing their water losses in the first instance coupled with an increase in the hours and days of supply until continuous supply conditions are achieved. A final step in this process once low water loss levels with continuous supply are achieved is to reduce and sustain the level of water losses to an economic level.

The need for a standardized approach

Before the first edition the IWA manual of Performance Indicators (Alegre et al., 2000) was published, there was no international attempt to standardize the water balance and water loss performance indicators. The IWA water balance and water loss PIs have meanwhile become international standard and are promoted by many regional and national professional associations around the world (including AWWA).

It is well known that expressing water losses (or NRW) in percentage of system input is misleading in the best case and doesn't work at all in IWS situation (No wonder that percentage water loss can be low if a utility has only a few hours water supply per day).

Water loss performance indicators, for example physical losses in litres/connection/day, always need to be adjusted to continuous supply (the acronym used is "w.s.p." – "when the system is pressurized").

For example: When in a system with 10 000 service connections and IWS of 4h/day physical losses are 3 000 m^3/d the correct performance indicator would be:

- 3,000 m^3/d /10 000 connections = 0.3 m^3/conn./d (300 l/conn./d)
- 300 l/conn./d / 4h x 24h = 1,800 l/conn./d (w.s.p.)

Only with this indicator (and the average operating pressure) the level of water loss can be understood and the transformation from IWS to 24/7 planned.

In summary, the IWA water balance methodology and the IWA water loss PIs can also be used in IWS systems – IF the supply time is properly taken into account.

Once the water loss situation is properly understood, forecasts can be made how much water will be required to supply the network in its present condition on a 24/7 basis and how much will be needed after network rehabilitation.

Transitioning from IWS to 24/7 will be different depending on the type of IWS:

- If the system was designed for IWS (like most in South Asia) one needs to start with pressurizing the system 24/7 on a zone by zone or DMA by DMA basis starting from the zone or DMA closer to the water source.
- In systems where IWS was not planned but became a reality in fringe areas of the system, water loss reduction (again, zone by zone) must be started in the part of the network with best supply and highest water losses and the water saved can then be pushed to the poorly supplied areas.

Details on the use of water loss PIs under IWS conditions and recommendations for transitioning to 24/7 will be published in the upcoming book on IWS to be available through IWA Publishing in the first half of 2017.

Conclusions/Key learning points

From the data and information presented in this paper which is based on actual data from distribution networks worldwide the following conclusions/key learning can be drawn regarding the use of IWS:

- IWS can easily be adopted by the water utility but it is extremely difficult to revert to 24/7 supply due to the damage caused to the network.
- IWS may seem to be a water saving measure however in the long run greater quantities of water will be lost through increased leakage and wastage compared to the quantities that may initially be saved.
- IWS has a detrimental effect on the structural integrity of the distribution network thus leading to quicker asset deterioration.
- IWS results in a substantial increase in the number of pipe bursts in mains and service connections thus increased leakage.
- IWS could create water quality problems which may be detrimental to human health and wellbeing.
- IWS has an adverse financial effect on the water utility resulting in lower water sales and higher costs due to additional O&M activities needed to run IWS.
- IWS results in customer dissatisfaction and reluctance to pay due to poor quality of service provided.
- IWS is not considered an appropriate intervention to drought/water shortage.

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Paper 3: The problem of leakage detection on large diameter mains

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Keywords: Acoustic, leaks, non-tethered devices, CCTV, Hz

INTRODUCTION

The authors of this paper are communicating the issues with transmission of noise created by a leak on larger diameter water mains and the issues involved with listening to such noise created by the leaks. The authors are also looking at the average frequency of leaks per km and the average losses from such leaks on large diameter mains.

Internal noise frequency from leaks on large diameter mains (greater than 500 mm) in some instances 50 m from the leak position can be as low as 1 Hz–10 Hz, a frequency that no human being regardless of sex or age can detect. For this reason the technology and associated software used today should be such as to identify if a leak is present and not merely relying if a noise can be heard or not. It has always been considered that if a noise cannot be heard then there would be no leak present. In the past this approach has been adopted using conventional and advanced acoustic leakage detection equipment. A modern internal tethered device has been adapted to do leakage detection in large diameter mains by showing CCTV, noise amplitude and frequency and yet even with this information the software graph is ignored if no sound is heard by the technician.

Acoustic noise generated at the point of a leak, regardless of pipe diameter or material, can be higher than 500 Hz, however these higher frequency noises are lost through the pipe wall and the water of the large diameter mains over distance leaving only the low frequencies 1–10 hz; it is these lower frequencies generally below the human threshold of hearing that can travel long distances in the pipeline, sometimes several km. It is for this reason that listening for noise on fittings or correlating is not always successful. Due to these circumstances the internal leakage approach, although may be more expensive, will have a higher degree of success in locating leaks on the larger diameter mains.

Other technology is also available today to indentify these extremely low frequency noises, however, some of this technology cannot locate the leak position but only identify if a leak is present or not.

Manufacturers are also seeking to find the solutions through correlators and to date some successes have been reported. The following section explains the importance of understanding the parameters involved in conducting leak detection on large diameter mains.

BACKGROUND

Human ear frequency range

The quality measurement for any noise heard is reliant on how well this noise sounds to the human ear. The human ear is extremely sensitive to noise and high volumes of noise can damage the range of hearing. This is

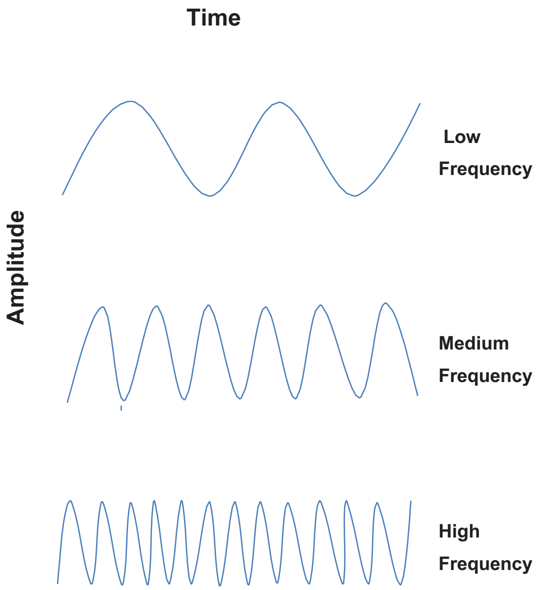

Figure 18.3.1 Example of frequency waves. (Source: Hamilton and Krywyj)

reflected in any time loud noises are listen to, as a ringing noise may be heard afterwards. This is an indication that some damage has been caused.

Hertz (Hz) is used as the measurement of the frequency of sound. For example, a low frequency sound, maybe something that is emitted from an instrument such as a large bass drum, whereas a high frequency sound would be a sound such as that which comes from a whistle (Figure 18.3.1). The Hertz sound range is different to how loud or how quiet the noise is, for instance, a load piece of machinery or a whisper.

The human ear has an average hearing range from a low of 20 Hertz (20 Hz) to a high of 20 000 Hertz (20 kHz); but it is the most sensitive to sounds that sit between the range of 1 kHz and 4 kHz. When a person ages their hearing starts to deteriorate and by the time they reach the age of eight, the deterioration has already started. For those that during the teenage years listened to loud music or went to games with loud noises, by the age of 20 they may have already be unable to hear the high tones. Thus the hearing ability has dropped 20 000 Hertz (20 KHz) to 16 000 Hertz (16 KHz). Then by the time the age of 30 is reached, it can be such that the ability to hear the high frequencies has dropped again.

Infrasound is the term used to describe any sound less than 20Hz (i.e below the human range of hearing). Sounds above 20 kHz are known as ultrasound (i.e above the human range of hearing). Animals as well as humans, have the ability to hear over a range of frequency:

- Dogs can sense frequencies as low as 50 Hz and as high as 45 000 Hz
- Cats can hear frequencies as low as 45 Hz and as high as 85 000 Hz
- Bats, as nocturnal creatures, need to rely on sound echolocation for navigation and hunting. They can pick up frequencies as high as 120 000 Hz.
- Dolphins are extremely sensitive to frequencies and can sense them as high as 200 000 Hz.
- Elephants, have an unusual ability to detect infrasound. They have an audible range of approximately 5 Hz to 10 000 Hz.

Table 18.3.1 Number of unreported leaks per km at average 40 m pressure 2001–2011

	KM	Leaks	Leaks/Km	Leaks/100 Km
North America	1259	1056	0.84	83.88
Europe	743	924	1.24	124.36
Asia	158	94	0.59	59.49
Middle East	24	6	0.25	25.00
Totals	2184	2080	0.95	95.24

CASE STUDIES

The data shown in Tables 18.3.1 and 18.3.2 is from case studies obtained from water companies from around the world and based on validated findings of unreported leaks. These studies show where these unreported leaks have been located at different pressures, diameters and in various materials. These case studies will indicate the type of leaks located in each material along with associated noise levels. Also reported in this section will be the number of leaks per km and the average size of the leak in m^3/hour.

It can be said that although many leaks have been located, not all were repaired as some were beyond economical repair, however these leaks should be regularly inspected as they are all potential catastrophic failures. To date there has not been sufficient data worked upon to identify the life of a leak and it is not known if the burst frequency/natural rate of rise calculation used in the distribution mains is applicable to the larger diameter mains however the authors suggest that recording the date of the survey and the time period measured between surveys can be used as base line data. This data against the age of the pipe will be an indicator to be used in future analysis.

LIFE OF A LEAK

Each leak has a life span and although there are technical terms available, as we are discussing the larger diameter mains the authors have at this point tried to explain them in simple terms. There are four parts to the life of a leak: weep – leak – burst – catastrophic failure.

Weep/Small loss – a small amount of water leaving a pipe from a small failure that is less than 5 litres per minute (1 imperial gallon per minute).

Leak/Medium loss – an amount of water that leaves a pipe through an orifice at an estimated flow of 90 litres per minute (20 imperial gallons per minute).

Table 18.3.2 Number of unreported leaks over mains diameter 2001–2011

Mains Dia mm	KM	Leaks	Leaks/Km	Leaks/100 Km
500	1139	1547	1.36	135.82
500–1000	987	515	0.52	52.18
1000	58	18	0.31	31.03
Totals	2184	2080	0.95	95.24

Table 18.3.3 Estimated flows from unreported leaks at an average pressure of 40 m (From over 2000 incidents) all flows in imperial gallons

Flow from a Leak	Weep	Leak	Burst	Cat. Failure
Gallons/hour	60	1200	4200	4200+
M^3/hour	0.27	5.4	19	19+

Note: leak flow lost increases with pressure.

Burst/Large loss – an amount of water that leaves a pipe from an orifice at an estimated flow of 315 litres per minute (70 imperial gallons per minute).
Catastrophic failure – a complete rupture of the pipeline.

In the initial request for data the question was asked if any of the leaks excavated for repair had their flows measured by some method. It was reported that only some of the repairs had in fact had flows measured albeit some very crude. This data was used along with the average pressure reported as the base line to estimate the volume lost from a Weep to a Burst shown in Table 18.3.3.

Further exercises have to take place to calibrate these figures as the method of measuring in many instances cannot be validated. The numbers used in Table 18.3.3 have been rounded to match losses in imperial gallons.

There was then a request to categorise all other repaired leaks into the following section to give the number of leaks by type as used in Table 18.3.4:

• Weep	0.27 m^3/hr
• Leak	0.27–11 m^3/hr;
• Burst	11 m^3/hr – 27 m^3/hr
• Catastrophic failure	>27 m^3/hr.

HZ – LEAK NOISE

It is noticeable that there is a varied range in Hz when listening to a leak noise, this can be due to many factors ranging from pipe material, pipe diameter, pressure and leak size however it can be seen that when the internal hydrophone passes the location of the leak regardless of the material of the pipe line the leak noise is greater than 300 Hz and can easily be heard by the operator. This is due to the fact that the maximum distance the internal tethered hydrophone is away from the leak is that of the pipe diameter. The leak noise in Hz drops over a distance and starts to go beneath the human range, in some instances this occurs as quickly as 30 m from the leak position. It can be seen in the figures below that when using internal tethered devices the operator hearing ability is not critical but should be a consideration. Today's

Table 18.3.4 Unreported leak categorisation

Leak Type	Weep	Leak	Burst	Cat. Failure
Total leaks identified	143	1,278	659	0

technology has software on the equipment which measures and reports these low frequency noises where as the operator may not be able to hear these.

Engineers have tried to use the frequency heard from a leak to estimate the size of the water leak. It is the authors' opinion that a leak cannot be measured as to the flow lost just by a noise measurement in Hz – there are too many other parameters which affect the range of losses.

The Figures 18.3.2–18.3.5 below show the frequency range observed over the distance measured in metres away from the various leaks.

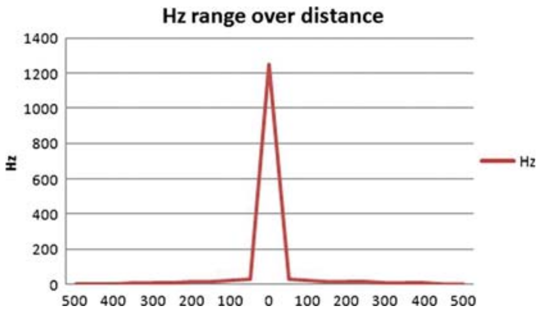

Figure 18.3.2 Noise in Hz 500 m from a leak on 300 mm cast iron pipe at 35 m pressure.

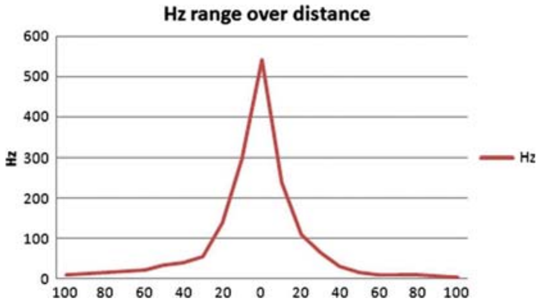

Figure 18.3.3 Noise in Hz 100 m from a leak on 500 mm cast iron pipe at 41 m pressure.

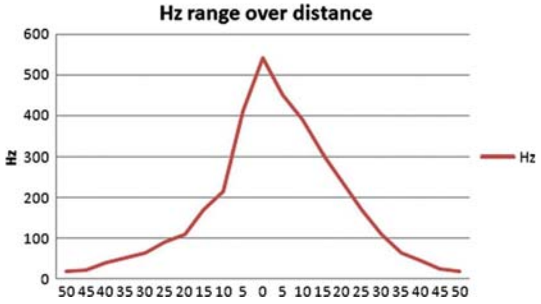

Figure 18.3.4 Noise in Hz 50 m from a leak on a 500 mm cast iron pipe at 41 m pressure.

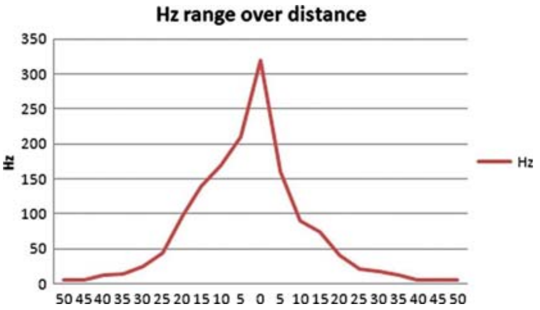

Figure 18.3.5 Noise in Hz 50 m from a leak on a 300 mm MDPE pipe 37 m pressure. (For Figures 18.3.2–5, Source: Author)

The process used was to stop the internal hydrophone at pre-determined increments prior to the leak, at the leak and after the leak to measure the noise in Hz at each point; the figures were then built from this data.

It should be noted that the leak noise changes in the frequency range depending on the material and mains diameter, it should also be noted that in Figures 18.3.3 & 18.3.4 although the figures are the same leak the frequency range changes over the time the survey was conducted and this may have been due to a pressure variation over the period.

Figures 18.3.2–18.3.5 show the leak noise in Hz when using internal an hydrophone drops below the threshold of human hearing within 40 m of the leak on metallic pipes and 25 m on MDPE pipes both with an average pressure of 35–41 m. Due to these observations it should be considered that leakage surveys are not completed on metallic mains diameter greater than 300 mm or non metallic mains regardless of diameter using traditional manual listening sticks.

If using some form of electronic listening devices as the means to identify leak noises these should be able to identify if a leak is present below the 20 Hz range of noise, if they do not have this ability then we now know that leaks may be missed (Figure 18.3.6).

This conclusion falls inside the guide lines reported by the IWA WLSG Acoustic Initiative group and the written manual 'Leakage Detection Methodologies including ALC Matrix' Ver. 4 January 2011.

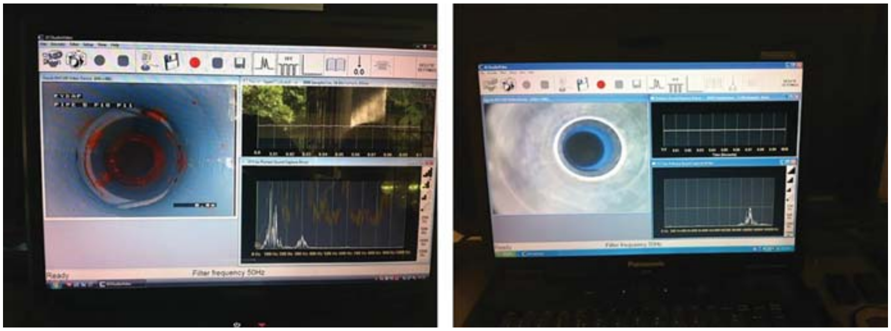

Figure 18.3.6 Screen dump from JD7 software showing of a leak inside a water pipe and the software showing the noise generated from the leak in Hz and Amplitude JD7AV software – version 1.1.0.10 developed 2012. JD7, Derby, UK. (Source: JD7 Ltd)

Table 18.3.5 Matrix is for leakage detection on all property and mains fittings with pressures greater than 10 m head or 15 psi. Fittings are at a minimum distance of 10 m apart and maximum 50 m.

Diameter	**mm**	***75***	***100***	***150***	***200***	***250***	***300***	***350***	***400***	***450***	***500***	***600***	***700***	***800***	***900***	***1000+***
	Inches	***3***	***4***	***6***	***8***	***10***	***12***	***14***	***16***	***18***	***20***	***24***	***28***	***32***	***36***	***40+***
Material																
Metallic all		A,B, C, D, F,G	A,B, C, D, F,G	A,B, C, D, F,G	A,B, C, D, F,G	A,B, C, D, F,G	A,C, D,E, F,G	A,C, D,E, F,G	A,C, D,E, F,G	C,D, E, F, G	C,D, E, F, G	C, D, E	C, D, E	D,E	D,E	D,E
Concrete all		A,C, D,F, G	A,C, D,F,G	A,C, D,F,G	A,D	A,D	A,D, E	A,D, E	A,D, E	E	E	E	E	E	E	E
Asbestos Cement		A,C, D,F, G	A,C, D,F,G	A,C, D,F,G	A,C, D	A,C, D	A,D, E	A,D, E	A,D, E	E	E	E	E	E	E	E
GRP		A,C, D,F, G	A,C, D,F,G	A,C, D,F,G	A,C, D	A,C, D	A,D, E	A,D, E	A,D, E	E	E	E	E	E	E	E
PVC		A,C, D,F, G	A,C, D,F,G	A,C, D,F,G	A,D	A,D	A,D, E	A,D, E	A,D, E	E	E	E	E	E	E	E
Polyethylene all		A,C, D,F, G	A,C, D,F,G	A,C, D,F,G	A,D	A,D	A,D, E	A,D, E	A,D, E	E	E	E	E	E	E	E

Notes: Method A – gas injection; Method B – traditional techniques with manual listening stick; Method C – non-intrusive acoustic techniques that is standard correlator, correlating noise loggers (accelerometers); Method D – intrusive acoustic techniques that is standard correlator or correlating noise loggers (hydrophones); Method E – inline inspection techniques (tethered & free-swimming); Method F – noise loggers (non-correlating), non-intrusive magnetic connection; Method G – electronic amplified listening ground microphone.

Table 18.3.5 shows one of the four matrices developed which show the best possible scenario and yet still does not promote manual listening on fittings for leakage surveys on any non metallic mains or metallic mains 300 mm and above.

It should also be noted that as a rule of thumb the noise frequency from a 100 mm non-metallic main has the same acoustic parameters as that of a 400 mm metallic main.

CONCLUSIONS

Conducting a manual acoustic sounding exercise on metallic pipelines 300 mm diameter and above with fitments more than 100 m apart or on any non metallic pipe work using human hearing alone is a non effective way of conducting a survey. The Hz range from a leak does not travel to the fitting high enough for the human ear to be able to hear the leak. If an electronic device has the ability to measure noise in Hz then this may be an option. On previous surveys it has been reported that listening devices on non metallic pipes were not effective unless they were attached to access points that were close to the leak – roughly within 5 m (16 ft).

Operators using headsets attached to leak-noise correlators are on many occasions unable to hear leak sounds. The thought process currently with engineers is if no noise is heard, then no leak should exist. Operators of the correlators have been surprised to be able to locate leaks using the cross-correlation of leak sounds that they could not hear.

The authors recommend that manual sounding on fittings for leak detection purposes on non metallic mains or on metallic water mains over 300 mm in diameter should stop as the operators may not hear any leaks present and an alternative approach for this type of routine operation should be considered.

The higher Hz range from the leak is lost very quickly in the pipe wall and the water of the larger diameter pipes leaving the lower frequencies that can travel long distances – it is these lower frequencies that can be problematic to the traditional correlator. Insertion technology is successful since the acoustic head is only the maximum distance from the leak as the pipe diameter it is in that is on a 500 mm diameter pipe the acoustic sensor (hydrophone) inside the pipe when passing the leak can only be a maximum of 500 mm from the leak position.

Advancements in correlators are changing and some are beginning to show successes in locating leaks using the low frequencies over the longer distances.

The average number of leaks that have been found over the 2184 km is 95.24 per 100/km with varied results over the 4 regions the data was gathered from. Some reasons for these varied results can be the pressure within the water main. Within Europe where the average pressure is 45 m (67.5 psi) 124.3 leaks/100 km have been located where as in Asia where pressure have been as low as 3 m (5 psi) only 59.49 leaks/100 Km were found. This is slightly below what has been previously estimated at 110 leaks per 100/km and this may be due to the increase of surveys being completed in the Asia & Middle East regions. It has to be commented on that the results from Asia have been very varied with the number of leaks per km and this should be investigated to understand why the variation has occurred.

For ease the authors have divided the leaks into 4 categories with these ranging from a weep to a catastrophic failure. The numbers of leak identified within these categories were: Weeps – 143, Leaks – 1,278, Bursts – 659 and Catastrophic Failures – zero. The greatest number of leaks was found in the 'Leak' category however the greatest volume of water lost per hour was from the 'Burst' category. The number of Weeps located was found to save little water and are also the most expensive to repair, the average loss from the weep of 0.27 m^3/hr is close to the current limit for background leakage (0.25 m^3/hr at 50 m pressure), these events are not normally repaired if they are considered 'beyond economic repair and become equivalent to background leakage' but as the authors have mentioned these have to be investigated with as they will progress to a Leak. The time scale of this life has not been looked into and is unknown but with soil analysis and NDT surveys undertaken then this life expectancy can be calculated.

The findings from this paper were taken from companies throughout the world and are based on the information given at the time. The volume of water lost from these leaks has been estimated and further research has to be completed to give more accurate findings. The paper also at this time has commented on Hz range from leaks heard and further research has to be completed to identify more accurate results.

The authors would more than pleased to receive further information and/or data in this particular field in order to establish a firm base on which to build futute methodologies and strategies for dealing with leakage on large diameter mains.

ACKNOWLEDGEMENTS

Data supplied by JD7 Ltd and several water companies/consultants that wish to remain anonymous.

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Paper 4: Technology – How far can we go?

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Keywords: Technology, Acoustic, Correlator, ALC, AMR, Pressure, Software

INTRODUCTION

The world's population is increasing at a tremendous rate, the world's renewable water resources are reducing rapidly, the gap between water supply and demand is widening with urbanisation and climate change making the gap even wider. This paper outlines the importance of technology and innovation, describes technologies available in assisting water utilities to save valuable quantities of water lost through leaky networks and highlights the way forward in developing appropriate technology.

To deal with such losses in an effective manner, particularly from networks in water scarce areas, water utility managers are increasingly turning to technology to reduce costs, increase efficiency and improve reliability. Companies that continuously invest in technology and innovation will see a positive return on investment in terms of improving daily operations and collection and analysis of network data for decision making and forward planning.

BACKGROUND

It is evident that times are changing and globalisation, information technology, innovation and sustainable development are part of our daily lives. Water utilities are considered to be extremely conservative especially when it comes to change. It has been the approach for many years that if something works do not change it. However, a number of water companies recognised the need to go forward towards a higher standard of performance.

Many water utilities are using Technology to improve reliability and to reduce costs. The need for change is becoming more and more pressing in order to facilitate and improve daily operations and to collect data for timely analysis and decision making as well as forward planning.

An important aspect that is usually debated is whether there is a positive return on investment in technology. In my opinion, there is a positive return on technology investment for companies that concentrate on enhancing system performance and focus on technological developments. This has certainly being the case with the technological changes which have taken place over the last 20 years in many water utilities around the globe. Now, is there a real need to continue developing technology to control water losses? Let us first have a look at some facts and figures:

- Currently there are 7 billion human beings on the earth and this is increasing by more than 2 people per second, 173.000 per day or 63 million per year, each extra life needs food, energy water and shelter. This rate of increase means that by the year 2050 the earth's population will be 9.5 billion human beings. Over the past 2000 years nature has controlled the earth's population. However, now with the impact of extending life by controlling diseases, the majority of today's teenagers will live until they become grandparents.

- The earth is called the blue planet because 70% of its surface area is covered by water. Only 2.5% of this water is fresh water of which just 1% is available for human consumption; the rest is locked up in glaciers and polar ice caps.
- Today more than 1 billion people lack access to safe drinking water and this will worsen.
- Predictions indicate that in the next 20 years as much as 50% of the world's population will live in areas of water stress.

Such chronic shortages are often a result of poor infrastructure, politics, poverty or simply living in an arid part of the world. For instance, one of the richest cities in the world benefits from heavy annual rainfall, it supplies 20 million inhabitants with water and yet every day at least 1 million people experience some sort of water shortage.

Therefore, it is imperative that problems of water shortage and scarcity are dealt with in an effective manner, especially in water stressed areas. Losses from water distribution networks are a major issue worldwide. It is known that water leakage varies from less than 10% of the water put into network systems in extremely good situations to greater than 60% leakage in extremely poor situations with the average NRW being 20%–30% of the system input volume.

WHAT IS TECHNOLOGY?

- Application of knowledge to the practical aims
- Changing and manipulating the way we think
- Includes the use of materials, tools and techniques to make life easier, more pleasant, increase productivity and to ensure that the problem that was impossible becomes possible.
- Technology began to influence human endeavor as soon as people began using tools.

It is evident that technology has an important role to play in order to deal efficiently and effectively with these high volume losses. So, where do we start and what do we have available? Well the very short answer is that technology is not moving fast enough to deal with these problems.

Methodologies are continuously changing to enable the best results to be achieved in the reduction of water losses. It is therefore imperative to move away from stock markets and profit making and to invest in the research and development of technology. Water companies and equipment manufacturers must work together in an effort to push current knowledge boundaries and to come up with improved and new ideas in order to complement current methodologies and together to provide solutions to reduce losses (Figure 18.4.1).

Figure 18.4.1 The continuous loop for product development. (Source: Author)

Some countries do encourage research to be carried out through government funded projects but this is nowhere near enough to meet the ever increasing challenges that we are currently facing. What is currently available and what is new to help combat the situation?

The IWA Water Loss Specialist Group identified the following methodologies which reduce real losses (leakages) as well as restrict apparent losses (increase revenues).

The methodologies for reducing Real Losses (leakages) are: Active Leakage Control, Pressure Management, Speed and Quality of Repairs and Renewal of Pipelines. Typical technology which is available in each one of these areas is briefly described below.

ACTIVE LEAKAGE CONTROL

Recent advances in equipment to help with location of leaks include correlating noise loggers, digital leak noise correlators with three sensors for better leak positioning and a ground microphone that can prioritise leaks by size and internal acoustic sensors for large diameter pipelines.

Internal tethered pipe technology is such that a cable can be inserted through a fire hydrant which has a head attached to the end. Within this head is a camera, hydrophone and location sonde. This system can go with or against the flow and has a maximum current range of 100 m, the ability here is to see the leak, hear the leak and to locate the head to pinpoint the position of the area of interest. This technology on the 300 mm and smaller metallic mains does not replace the traditional correlator however on the non metallic mains it has distinct advantages. This technology is used for internal condition pipe assessment showing tuberculation, unknown laterals, blockages and many other conditions. There is also a long range tethered technology available which can go distances currently up to 2000 m also the head combines a camera, hydrophone and location sonde. A company is in the process of attaching an ultra sonic internal condition assessment and pipe wall thickness measurement tool to the same head so it becomes a quadruple head.

Non-tethered devices range from a ball that rolls down the main locating leaks as it passes them, this device is captured by a net and retrieved from the main, this technology is restricted to 300 mm diameter pipe work and above. A completely new device available to the market in 2012 is a small 3 cm × 10 cm bullet shaped device which can be launched in a 75 mm and above diameter pipe work and contains a camera and hydrophone. This device can be launched through a fitting on the main or a through bore fire hydrant. This device can be retrieved if it is attached to a tethered braid or can be launched as a free swimming device and captured somewhere down stream in the water main.

A robot is being designed and will be in commission during the next 24 months and this will live in the water main reporting on leaks as they occur and may have the ability to repair the water leak from inside the main with some sort of sealant it carries with it.

Other non acoustic technologies to assist in the location of leaks in the distribution system are being developed. One of these is software to localise leak positions using pressure drops and pressure variants in the network to locate the leak positions. Another uses statistical analysis of past data to try to calculate when and where a leak will occur next.

Another new technology is a system that measures flows through either permanent or temporary flow meters in the distribution system to indentify the area where an increase in flow has occurred, indicating a potential leak. Acoustic devices can be attached to the meter to help locate the leak position.

There are several European Union co – funded research projects on technology currently in progress – with varying results and successes. Two such projects that have now been completed are '*Waterpip*e' and '*Leaking*'. The projects have similar objectives – to provide a non-intrusive leak location technology.

WATERPIPE

'*Waterpipe*' is a *system* where the leak is located by ground penetrating imaging radar. The objectives of the project were to investigate and develop a high resolution imaging ground penetrating radar for the detection of pipes, leaks and damages to underground infrastructure – and to provide imaging of the damaged region. A further enhancement was to produce an integrated system that will contain both the GPIR equipment and a Decision-Support-System (DSS) for the rehabilitation management of the underground water pipelines. This would use input from the inspections to assess, probabilistically, the time-dependent leakage and structural reliability of the pipelines and a risk-based methodology for rehabilitation

decisions that considers the overall risk, financial, social and environmental criteria.

Please see Bimpas *et al.* (2010) for the findings from 'Waterpipe' project.

LEAKING

'*Leaking*' had objectives to investigate and develop an innovative leak inspection equipment for water pipelines based on microwave technology (a Continuous Wave Doppler radar, a Frequency Modulated Continuous Wave radar and a radiometer), and a decision support system, that stores available data on the pipe network, and receives input from leak inspections. It should be able to perform condition assessment to determine residual life time of the pipeline in question.

There are many other internationally funded projects – all of them are trying to achieve the breakthrough that would change the way Active Leakage Control is currently carried out. These initiatives are funded by Governments, universities, manufacturers, partnerships and water companies.

The author considers that not enough initiatives are undertaken or sufficient emphasis is given to reach a breakthrough which eventually will happen but unfortunately seems not to be on the horizon at the moment but with continuous research and development it could happen at any time.

The findings from 'Leaking' project will be available some time in 2010.

PRESSURE MANAGEMENT

The use of pressure reducing valves is always investigated with regard to obtaining the best possible results. Current pressure control techniques available are Flow/Time Modulation, Multi Point Control (flow or pressure), Critical Point Control (real time or through self learning algorithms) all of which provide solutions to problems of excess or varying pressure thus reducing losses.

New ideas in this field are available, one of which is using advanced programming to regulate the pressure valve thus always maintaining the required pressure at the control points, thus saving water above that of the traditional pressure valve operation.

SPEED AND QUALITY OF REPAIRS

An idea that is currently being investigated is that of self repairing pipes or self healing pipes. The pipe repairs itself from the inside using small particles or chemicals that are induced into the pipeline. Other similar ideas, such as when a leak occurs on the water main to send a report to a control station notifying the water company of the leak and its position are also looked into.

At the moment there are only a handful of cities in the world which have invested in such equipment, other cities failing to do so normally use the high investment cost as the reason.

RENEWAL OF PIPELINES

A perfect solution to leakage would be a pipe that doesn't leak. The pipes used today are designed to last 50+ years and be leak free; however, there is a major problem in that any joint that requires any sort of human intervention is unfortunately a source of a potential leak.

The question is often asked: 'Why hasn't the industry developed a pipe that is leak-free'? Many companies are in fact addressing this question - pipelines that are better protected against corrosion and at keeping the water clean.

Other investigations deal with the insertion of sensors either constructed in the pipe or alongside the pipe others are where a fibre optic cable is laid alongside the pipe reporting on changes to noise/temperature conditions all of which report back to a central computer when a leak occurs. This technology has to be introduced during the renewal of the pipeline, the major issue being that investment will be made in a system to locate water leaks on a pipe line that is designed to last for 50+ years. But this should not be the reason to reject such ideas - if the pipe fails for any reason prior to the end of its life of the pipe this will also be identified.

METHODOLOGIES IN REDUCING APPARENT LOSSES

Methodologies in reducing Apparent Losses thus increasing water utility revenues have been developed. Technologies to accurately measure water consumption and to reduce under-registration have recently been introduced and provide cost effective solutions.

METER ERROR – METER UNDER REGISTRATION

The under registration of flows through a water meter is a source of revenue lost by the utility and many companies have developed and produced devices that allow very small flows to be recorded, meters that measure low flows and meters that have no moving parts. Other devices are available that can be added to an existing meter to allow for extremely low flows to be measured.

AUTOMATIC METER READING

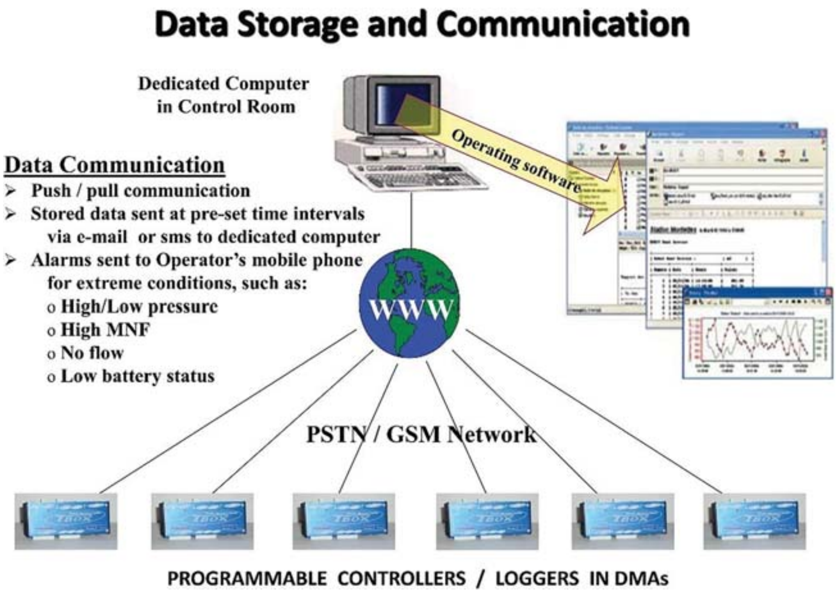
AMR is a way for the utility to read customer meters on a daily basis, sometimes continuously, allowing revenue to be collected using more frequent billing cycles. The company can also have a clear picture of the consumption by the household and indentify when a meter stops. This could indicate that the meter is broken or, for example, that a sole occupier is unwell. Conversely a higher than normal reading could indicate a leak on the service pipe.

Current technology allows transfer of data from the water meter by 'fixed radio network' or while a meter reader walks or drives past the meter. Software is available to produce a bill which is delivered by the utility employee while at the property.

One manufacturer has recently produced a drone aircraft that allows meters to be downloaded in remote locations by flying over the water meter. Noise loggers combined with water meters to allow both the meter flows and potential leaks being downloaded daily is another recent introduction.

SOFTWARE

In the area of water distribution network management advanced communication systems and software applications are playing an extremely important role in being able to take informed decisions timely and accurately.



Data Communication

- Push / pull communication
- Stored data sent at pre-set time intervals via e-mail or sms to dedicated computer
- Alarms sent to Operator's mobile phone for extreme conditions, such as:
  - o High/Low pressure
  - o High MNF
  - o No flow
  - o Low battery status

Figure 18.4.2 Typical set up for transfer of data collected and stored on critical site locations. (Source: Author)

COMMUNICATION SYSTEMS

The current trend is to apply solutions which combine information technology and telecommunications networks using the World Wide Web or GSM networks for the transfer of data which is obtained from site devices, such as water meters, pressures sensors, and so on.

Careful consideration and examination of the available technologies must be given in order to adopt an appropriate system with low capital expenditure as well as low operational and maintenance cost. A typical communication system for the storage and transfer of valuable information is shown diagrammatically in Figure 18.4.2 providing all the necessary information for the efficient and effective management of a water supply system.

SOFTWARE APPLICATIONS

Operating software provides an intelligent communication interface between the monitoring stations and the central control which exploit the power of the internet by receiving data from the monitoring stations and has the capability of transferring and exporting data to the majority of data bases. Most software incorporates powerful graphics to display data in the form of graphs and statistical tables as well as to Geographical Information Systems for further analysis.

The pressing need to efficiently manage water distribution networks has highlighted the need to develop software tools that would assist in the integrated and automated management of the networks. Such asset management tools should assist the network owners to evaluate the condition of the water distribution network, assess historical incident data (leakage or breakage) and risk of failure, visualise areas of high risk, propose "repair or replace" strategies and prioritise the work based on the inherent risk and cost of action.

The risk assessment and management ("repair or replace") system is based on analytical and numerical modelling techniques and supplemented with geographical distribution systems (GIS). The goal is to enable

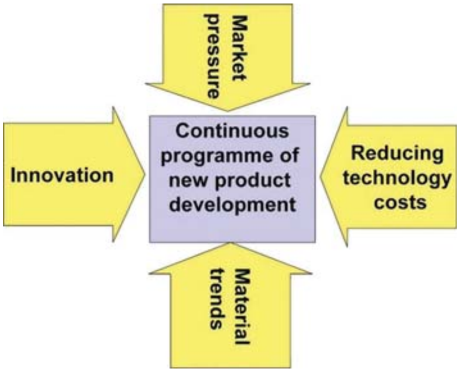


Figure 18.4.3 The four drivers on the manufacturer. (Source: Author)

water utilities to better manage condition assessment information, to process historical records with a number of analytical and numerical models, to identify underlying data patterns with artificial intelligence techniques and eventually to assess the corresponding risk of failure of each network element and to visually disseminate this information via geographical information systems.

INNOVATION IN THE FUTURE – CONCLUSIONS

The prime drivers needed for a continuous programme of new product development are shown diagrammatically in Figure 18.4.3. There is a market demand for new and improved technologies at affordable prices, but innovation and new products must be capable of delivering results in a cost efficient way. For this to happen a joint effort is needed by utilities, manufacturers, and researchers to develop the next generation of technology for the water utilities.

It is felt by the author that governments should encourage such investigations using grants and that water companies should be willing to partner with manufacturers to design the solution to the water loss problem. The water scarcity issue is getting no better and we cannot afford to wait much longer to start to look for solutions.

It is illuminating to consider how far technology has moved forward in the past 10 years in one particular field – mobile telephones. Nowadays there are options for sound, vision, SMS, MMS, E-mail, internet, camera and radio – all of these in a small hand held device. These enhancements were developed to meet a market demand, but were also fuelled by competition. It is this competition and forward driven thinking that is required in the water industry.

All stakeholders should be willing to invest in solutions today – ‘thinking outside the box’ is an apt expression for moving forward with innovative technology for saving precious water in today’s water scarce climate.

If we choose to cooperate can our intelligence and technology save us? It has to and we should be willing today to invest in the solution not wait for others to develop it tomorrow.

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