WATER LOSS DETECTIVES

Romanian leakage magazine
December 2017, year VII / no. 10
www.detectiviiapeipierdute.ro

WaterLoss 2018
7-9 May 2018
Cape Town - Africa de Sud

Global Leakage Summit 2018
13-14 March 2018,
London, UK

Water Loss Forum, Turkey
Istambul 29-31 March 2018

SUMMARy

www.detectiviiapeipierdute.ro

Apariţie anuală
ISSN 2457-6999
ISSN–L 2457-6999

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THE FUTURE BEGINS TODAY

Alin Anchidin

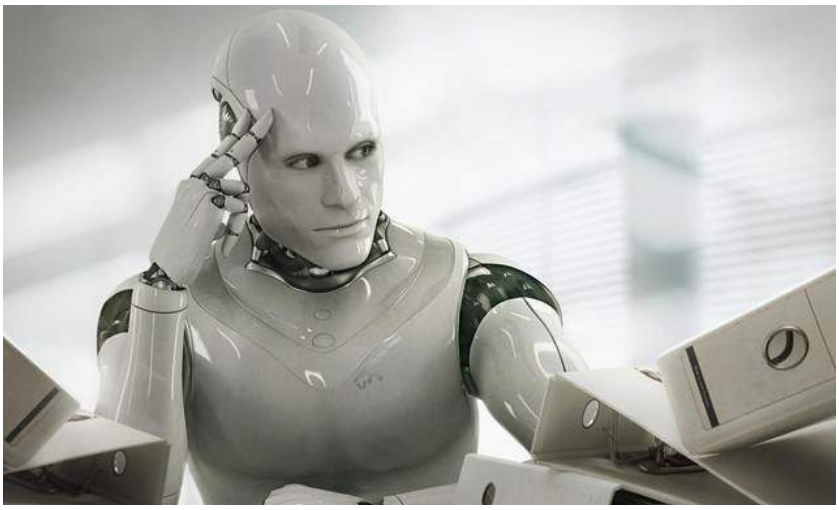
Recently, I read an interview with Mercedes CEO, Dieter Zetsche on how the world will change in the years to come. It's a vision of how the world will look over 5-10 years, about the trends and scale of the software industry.

Dieter Zetsche talks about where it is now, in this world of information technology and "predicts" the future of today's successful industries and companies that will have to adapt to new trends, from robots to 3D printers.

„Although Uber is a software, now is the best Taxi Company in the world. Airbnb is also the largest hotel company, although it has no property. Artificial intelligence becomes exponentially better.

This year, a computer has beaten the Go World's best player in the world. It was expected to happen, but in ten years. In USA, software applications give legal advice in a few seconds, with 90% accuracy. In the close future there will be 90% fewer layers. Computers have cancer diagnosis four times as accurate as humans, and Facebook has a facial recognition software better than we have, native. ", says Zetsche, concluding that by 2030, computers will be superior to humans.

According to Mercedes manager, the car industry will change complete starting with 2020, and our children will call a car at the door through an app. The car will come, of course alone and with no driver. An image worthy of a SF film, but comes packed with an optimistic outlook, tailored to the *share-economy* model. Nobody will have cars of their own, but we will all have access to them. Therefore, the parking area will also decrease. And much of the parking lot will become playgrounds. Autonomous cars will dramatically reduce the road death rate, which Zetsche estimates at 1 / 10,000,000 km in the future dominated by 100% of autonomous cars.



In terms of propulsion, this will obviously be electric: „Tesla, Google and Apple will revolutionize the industry, and the cities will be quieter, cleaner and easier to live in, because there will be electrical cars", says Dieter Zetsche.

It is also optimistic about resolving the crisis of renewable energy sources: "Last year, solar power plants were activated more than fossil fuels. Traditional energy companies are trying to limit access to the sun, but it's impossible because it's already happening individually. With free solar energy, my water comes cheap too. Its desalination costs 2kWh, or 0.25 cents per cubic meter (average global price)."

A well-known and probably passionate scholar of the SF universe, Dieter Zetsche is also aware of the revolutionary technologies in the medical world: "Tricorder X, a similar digital mechanism to Star Trek, will be launched this year. He analyzes through the smartphone the retina, blood samples and breathing. This is the future of medical analysis. Within a few years a significant part of the medical system will disappear, the harvesting and interpretation of medical analyses. 54 markers will give verdict on various diseases."

Some other predictions given by Zetscher: High performance 3D printers will be at 400-500% over 10 years. Business ideas need to necessarily work in agreement and relationship with the smartphone. We'll have $ 100-buddy robots who will work for us if we have microfarms. In 2020, 70% of people in the world will have smartphones, so access to quality education. In Africa and Asia are already selling 10-pound phones. By 2036, we should live on average for 100 years. Each year, the average lifespan increases by 3 months.

How the water world would look like, in the future seen by Dieter Zetsche?

It will certainly embrace new technologies. Required repairs will be made to 3D printers, there will be software-specific applications for all activities, we will constantly monitor networks to make algorithms to prevent damage, and who knows how many other great things. Perhaps we will get to teleport water.

Alin ANCHIDIN

Acoustic Leackage EXpert

EPISODE 6
ALLAN LAMBERT

It is elementary my dears; NRW as % of SIV just doesn't work.

Grafică: ***Mihai Bădilă***

Interview with Will Jernigan, MRW expert

To me the direction of the future isn't going to be dictated by the sophistication of the technology – though this can certainly play a part.

Will Jernigan

CAVANAUGH
Stewardship Through Innovation

Will Jernigan, P.E.
Director of Water Efficiency
Cavanaugh

Will Jernigan is a Director with Cavanaugh, and nationally recognized leader in Water Loss Management and Bioenergy. Will has 16 years in the industry, and was appointed in 2017 as the United States Expert to an international task force for developing the ISO Water Loss Standards.

Will actively serves with the American Water Works Association in several ways, including
- Chair of the Free Water Audit Software
- Secretary of the Water Loss Control Committee
- Co-Chair of the North American Water Loss Conference
- A principal contributing author on the M36 Manual for Water Loss Control, 4th Edition
- Trustee with the Distribution & Plant Operations Division

Will also serves as Project Manager for multi-year statewide Water Loss Technical Assistance Programs in Georgia and California, and has worked with over 1,000 utilities in North America to conduct water audits and water loss analysis. Will is a dynamic speaker who has presented technical papers all over the world. Will is a Registered Professional Engineer in multiple states.

1. A few words about you.. Where you were born, where you live, what schools have you done, where you work now

I was born in the foothills of the Appalachian mountains in North Carolina, and I currently live in in Asheville, North Carolina. With my work I travel across North America, so I always enjoy Asheville when I am home. I went to University at NC State, and studied Environmental Engineering.

2. Tell us something about your professional experience? How long you worked in the field of water loss? How did you get in touch with the water loss field? Who teach you this?

I am a managing partner with Cavanaugh, and have been with this company for 16 years now working on water loss for most of this tenure. Much of our focus on water loss stemmed from some leak detection work in Romania in the late 1990s, followed by a significant drought in the Southeastern US in the 2000s. My training and expertise was developed as a culmination of applying conventional civil engineering problem-solving to the water balance and water loss analysis. My original experience was honed on water system design and operation, before I moved into water audits & loss control programs.

3. What are the projects you attended? What conditions did you encounter?

In my career I have had the privilege of working with over 1,000 water utilities to conduct water audits with validation and water loss program development. They have ranged in size from a few dozen connections to several hundred thousand connections. While there are obvious differences in small and large utilities, I would argue they share a common thread of being resource-limited and the need to be diligent in their water balance validation practices. Data system sophistication and scale of program implementation are where the greatest variances lie.

4. What mentors did you have and what useful tips have you received? What books do you recommend?

I have been privileged to work with and learn from my expert partners at Cavanaugh, water loss experts in North America including George Kunkel, and international experts including Allan Lambert and Julian Thornton. I will say there is always a healthy amount of self-study needed in this ever-evolving field as well. Probably the most useful technical advice I've received is to always be aware of your context, and careful not to expend undue time on details that don't impact the big picture while neglecting details that do. And always maintain a good sense of humor.

5 In the US - California there is a water crisis. I understand that water police patrols have been set up to catch the water theft from hydrants. How could we reduce these thefts?

Interestingly, this is one of those details – at least in North America – that I would say is not moving the needle. Meaning theft from hydrants, while it does occur, is not a ubiquitous issue for most North American utilities, and even basic theft mitigation programs prove adequate for most utilities.

6. How do you see the current state of US water loss management?

That's a broad question for sure, but I would say that water loss management is becoming much more widely recognized and accepted as a practice versus 10 to 15 years ago, even within the last 5 years. One indicator I would point to are an increased number of specific water loss control program case studies coming up the North American Water Loss 2017 Conference – as compared to our inaugural event in 2015. Another indicator is the prevalence of companies that are coming to the North American market, from leak detection technologies to data analytics, the number of vendors seems to have exploded within just a few short years.

7. I understand you had collaborations in Romania. Can you detail this topic?

Cavanaugh was awarded two US AID ecoLinks grants to promote leak detection and loss abatement in Iasi, Romania. The short summary of our work with – at the time – Rajac Iasi (now Apa Vital) is that we delivered and demonstrated the value of leak loggers and moving their leak detection program from a reactive to proactive methodology. Further details can be found in the summary report from USAID, here: http://pdf.usaid.gov/pdf_docs/PDABW626.pdf

A brief write up can be found here – page 10: http://pdf.usaid.gov/pdf_docs/Pnada703.pdf

8. What do you think are the similarities and differences in terms of water loss between the US and Romania?

As this initial work was performed in 1999/2000, Romania was going through a privatization effort whereby they were bringing their management practices up to EU standards. Rajac Iasi was a very well run utility with proactive leak abatement practices. The volume however of unreported leaks that were not surfacing was tremendous. They needed a means by which to move faster through the system to discover and repair leaks before they surfaced. At the time of the project, the recovery of lost water had a direct impact on water supply, as well as energy savings.

This was more of a reduction of the backlog of leaks perspective then it was based on an economic intervention. There are areas of the US where scarcity and dependability of supply mirrors what we saw in Isai in 1999, in that any recovered loss could be made available for additional customer consumption. The vast majority of the US however, is fortunate to have abundant supply and the cost of water (variable production cost) is still relatively cheap therefore the catalyst for economically based action may not be as readily apparent.

Both Romania and the US have embraced the IWA/ AWWA best practices for Non-Revenue Water management and are beginning to break their losses down by their respective components and address them at economic levels.

9. You are in this year's second edition of the North American Water Loss Conference. Can you briefly tell us how this action started and how do you appreciate the impact of this conference for US / Canada specialists?

About 10 years ago, it was decided that the issue had gained enough steam to warrant a dedicated conference in the U.S. The first biennial event was held in Atlanta, Georgia in 2015. It took several years to marshal the bureaucratic and logistical support needed to make the non-profit event possible. An effort like this needs an organization willing to front it, be the face of it, and the planning committee works hand in hand with that organization. All of that took time but we were able to get there after several years of planning. For 2017, we are working with the California/Nevada Section of AWWA as the event host, and they have been tremendous. Other partners include the Alliance for Water Efficiency and US EPA. Overall the conference has been a significant milestone, drawing over 500 attendees in 2015. To me this is another indicator – a critical mass of utilities and practitioners with case studies to share, and enough demand for a large audience to be there to listen. I believe this perpetuates adoption of best-practices. We have been very happy with the interest the conference has generated so far, and we see a strong trajectory into the future – 2019 and beyond. We hope the international community of NRW stakeholders will consider joining us in San Diego, California this December - - www.northamericanwaterloss.org

10. How does AWWA involve in water loss management? Are there other professional organizations directly involved in this area?

AWWA is a key organization considered the authoritative resource for water loss management guidance in North America. Related to this, the Water Research Foundation has also been very active at producing research projects for many years related to water loss. Within AWWA, the Water Loss Control Committee (WLCC) is the second largest specialist group, and is responsible for key reference materials and tools used by the North American water loss industry. Specifically, these tools include the M36 Manual for Water Audits & Loss Control Programs (currently in its 4th Ed.), the Free Water Audit Software (currently in version 5) & its companion Compiler tool. The WLCC is very active, with 8 distinct subgroups that focus on outreach, business planning, real loss, apparent loss, regulatory practices, the M36 Manual and the Free Water Audit Software. Recently a Performance Indicators Task Force has been formed comprised of the WLCC leadership which will be examining the issue of an effective suite of metrics that can serve all stakeholders – technical and non-technical alike. The challenge of performance metrics is one that plagues the multitude of regulatory jurisdictions across North America. Some have a better handle on it than others, but fair to say none have come up with a truly effective performance benchmarking framework yet.

11. In the past, water losses were discovered by direct listening to the pipes, and now they are discovered using the drones and the satellites. What are the direction for the future? Will we be able to predict the loss of water using computer software?

It is an exciting time to be in the leakage management world, with innovations like those you mentioned, and others popping up like the use of electric currents to find leaks. To me the direction of the future isn't going to be dictated by the sophistication of the technology – though this can certainly play a part. The direction for leak detection I believe will be driven by the relationship between the cost-effectiveness of the technology and the utility's leakage cost mitigation. In North America, leakage remains relatively 'cheap' for many utilities – though this is changing as time moves on and resource availability/constraint enters a new era.

Regarding accurate desktop prediction of loss - - in theory, yes this is possible. But I believe we are a long time away from this becoming a widespread application, at least in North America. The real-time data requirements are going to be the barrier for 90% of North American water utilities. While the water sector is headed in this direction, the pace is decades – not years.

12. How can we become better in identifying, locating and reducing water losses?

I think the answer lies more in technique than technology. Regular, validated water auditing to understand volumes and values of disaggregated loss components, to set appropriate targets and guide interventions. This is the greatest area of improvement needed for 99% of North American water utilities. This includes, at a minimum, annual auditing and ongoing monitoring of nightflows at the greatest resolution a given utility's data will support, and optimal customer meter testing for revenue protection.

13. Using private companies to look for water losses would be a solution in reducing water losses?

I remain intentionally neutral on this question. If a utility can be most effective building internal capacity to execute and maintain a water loss program – that should be the chosen path. Outside help in some cases is the most cost-effective approach. Either way, the utility must take ownership in the water loss program for sustained results.

14. Water Loss Detectives know the magazine? What do you think?

I appreciate what you guys are doing to help bring attention to the issue. I do enjoy reading the publication whenever it comes out. Maybe I can get a tattoo of your mascot.

Operational vs. Financial Indicators in water losses assessment

Abstract: It is widely known nowadays that performance indicators are the base for decision making in utility companies. The whole process will yield good results in most cases, provided that the input data is highly accurate and the results have been given correct interpretations.

This paper will focus on less than perfect scenarios, where the erroneous input data can severely affect the end results and shift the company's policies in the wrong direction. One particular topic of interest is the accuracy of the input data, but the more subtle dangers come from a low degree of confidence of data, which often makes it impossible to determine a reliable accuracy margin.

Keywords: performance indicators, erroneous data, confidence margin

A Aldea

A Anton

INTRODUCTION

It is widely known nowadays that performance indicators are the base for decision making in utility companies. The whole process will yield good results in most cases, provided that the input data is highly accurate and the results have been given correct interpretations.

This paper will focus on less than perfect scenarios, where the erroneous input data can severely affect the end results and shift the company's policies in the wrong direction. One particular topic of interest is the accuracy of the input data, but the more subtle dangers come from a low degree of confidence of data, which often makes it impossible to determine a reliable accuracy margin.

Real life experience offers a number of situations that may seem exaggerated, but nevertheless real. As general rule, the World Bank Matrix takes into account differently the performance indicators for both developed and developing countries, but implies that the data accuracy is the same for both cases.

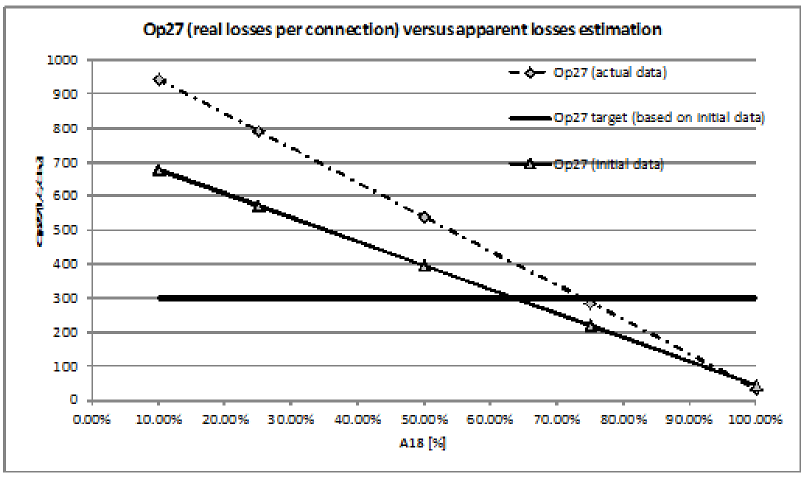


Fig. 1 Variation of Op27 versus apparent losses estimation (NRW remains the same). Case study Utility A

Combining the "top-down" and "bottom-up" methods for calculating the water balance is a must, especially since there is little information to start with. The data compiled from over 25 water networks and several water companies show that the underestimating the apparent losses is a common mistake and leads to unrealistic targets for performance indicators related to real losses. This problem is also amplified when the target is set to a water loss financial indicator (most common being the percentage of NRW), because the focus will be on the calculation of this particular indicator and thus neglecting the actual problems of the water network.

ERRONEOUS DATA AND ITS IMPLICATIONS

It is often the case when dealing with water utilities that had no previous experience regarding the IWA water balance or the performance indicators that the available data suffers from inaccuracies. The most common scenario met on the field is when the water utilities have to achieve a set of performance indicators calculated from erroneous data. Several examples are described below.

Overestimation of network length and number of connections

The example illustrated below refers to a target performance indicator (in this case real losses / connection) calculated based on initial inaccurate information. Regardless of the actual situation, the NRW level will be the same but for different reasons.

The figure below illustrates the variation of Op27 indicator versus the apparent water losses estimations A18 *(as percents of authorized consumption) in an attempt to provide a "what-if" scenario for a typical water* network. The initial and actual data sets refer to the number of service connections (a difference of 30% between both sets), the network length (a difference of 22% between both sets) and also a drop of 25% of billed authorized consumption

The conclusion drawn from the results analysis is that in this particular case the target performance indicator is less achievable in the real situation.

PERFORMANCE INDICATORS – UTILITY C						
FS	IWA	Performance indicator	UM	Initial	Actual	Target
2.5.1	A21	Total non-revenue water	m3/day	2500	316.55	1400
2.5.2	Fi46	Non-revenue water	%	54%	30.18%	45%
2.5.3	A19	Real losses in the network	m3/day	1700	172.91	1000
2.5.5	Op27	Real losses per connection	l/conn./day	114	426.94	103
2.5.8	Op29	ILI		3	7.84	3

Fig. 2 Utility C. Impact of wrong assessment for the number of connections over the performance indicators

A more simple but often case is the overestimation of number of connection. In the following example, Utility C is operating a water network that supply a large number of apartment blocks. The initial assessment considered that each apartment represents a connection, but in fact the client was the Owner Association for each block. The difference between the initial data and the actual data was quite huge: 3400 connections wrongly estimated in the initial data and only 405 connections in reality. One more remark for this case: the system input volume dropped by 40% and the billed consumption dropped by 25% compared to the initial situation in 2008.

It can be observed in the above table that the water utility managed to achieve the target for real losses (in fact it is several times less than the target indicator), but not the target indicators that required the number of connections in order to be calculated. Some additional interesting remarks can be made regarding the table in fig. 2:

the value in cubic meters / day for the non-revenue water is almost 4 times less than the target, but when converting these figures in percentages this difference doesn't seems so spectacular

the A19 indicator (real losses in the network) is almost 6 times less than the target value and this fact alone should indicates a great progress towards reducing water losses for the water utility, but when comparing the values of NRW% the difference don't delivers the same impact

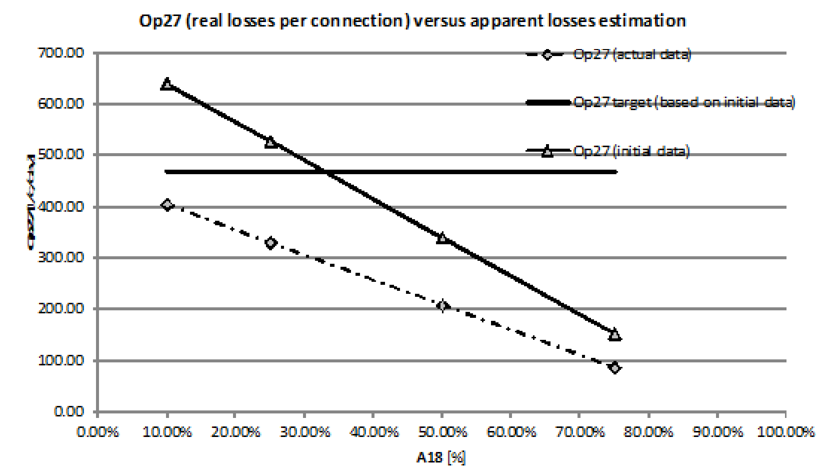


Fig. 3 Variation of Op27 versus apparent losses estimation (NRW remains the same). Case study Utility B

Underestimation of network length and number of connections

Of course, the initial assumptions can sometimes favours the water utilities, especially when underestimating these values. The next example refers to the same target performance indicator for another utility, but this time the initial assumptions were underestimated. The same remark applies also in this case, and that is the NRW level will be the same but for different reasons.

The figure below illustrates the variation of Op27 indicator versus the apparent water losses estimations A18 *(as percents of authorized consumption) in an attempt to provide a "what-if" scenario for a typical water* network. The initial and actual data sets refer to the number of service connections (a difference of 35% between both sets), the network length (a difference of 32% between both sets) and also a drop of 20% of billed authorized consumption

The conclusion drawn from the results analysis is that in this particular case the target performance indicator is more achievable in the real situation.

(IN)FAMOUS NRW INDICATOR

It is often the case for small network to be administered by a water utility or subsidiary along with other networks. In case there is no physical connection between these networks, one must be very careful when choosing which entity should be audited (water utility / subsidiary or distribution network). Usually, based on the available data and existing measuring equipment one have to choose between analysing the financial indicators of the utility / subsidiary or the operational indicators for the network.

	System input volume	Billed consumption	NRW [%]
Water utility	200	125	37.5%
Network A1	100	50	50%
Network A2	100	75	25%

Fig. 4 Comparison of NRW calculated for each network and for the water utility

In order to illustrate this concept let's take into consideration a very simple case: one water utility with two non-interconnected networks *A1* and *A2*. A1 have an input volume of 100 cubic meters with a billed volume of 50 cubic metres, while A2 have also an input volume of 100 cubic meters but a billed volume

PERFORMANCE INDICATORS – UTILITY D					
FS	Performance indicator	UM	Initial	Actual	Target
2.5.1	Total non-revenue water	m3/day	38	144	94
2.5.2	Non-revenue water	%	15%	42%	17%
2.5.3	Real losses in the network	m3/day	27	38	65
2.5.5	Real losses per connection	l/conn./day	21	25	23
2.5.8	ILI		3	1	2

Fig. 5 Non-revenue water (%) vs. ILI. Case study Utility D

Scenario	Distribution network			
	World Bank Matrix	National Operator Manual Matrix		
		NRW(%)	LKN (cm/yr/km.)	ILI
2012 – 0%	D	C5	C3	C4
2012 – 25%	D	C5	C3	C3
2012 – 50%	D	C5	C2	C2
2012 – 75%	C	C5	C1	C1
2012 – 100%	A	C5	C1	C1

Fig. 6 Same distribution network evaluated using two different matrices (note that NRW performance categories remain the same in every scenario)

of 75 cubic meters. A very rough water balance can then be calculated for the two networks and also for the water utility.

Note that if one would know only the values for the water utility, it will be impossible to assess the performance indicators for each network without additional measuring campaigns.

The table below illustrates a real-life example. It is a small utility with approx. 1500 connections and a network length of 34 km. Because is relatively new it can manage an ILI a little over 1 but suffers from apparent losses mismanagement. This detail could've not been seen if only the NRW indicator was calculated.

BENCHMARKING INCONSISTENCY

Depending on the evaluation matrix used, the water system can be considered acceptable or not, as seen in the table below. This fact alone will greatly affect the target PI's and will render the benchmarking process irrelevant if different matrices are used. The example below refers to the same networks in different"What If" scenarios of estimating the apparent losses as percentage of billed consumption.

Most important remarks drawn were the following:

Different set of measures for reducing the water losses depending of the evaluation matrix that was used
Under-evaluation of apparent losses will artificially increase the PI's for real losses
Necessity of combined "top-down" and "bottom-up" approach for calculating the water balance

CONCLUSIONS

There are several key conclusions that can be drawn from the previous case studies:

the overconfidence in the available data can result in severe over- or underestimations of the variables needed to calculate de performance indicators

the NRW indicator proved to be inadequate as a target PI because doesn't offer detailed information on the real problems

the choice of different benchmarking matrix can yields different strategies, so it is recommended to carefully chose the benchmarking matrix and then restrain to change it

the choice of assessing the performance indicators should follow this simple rule: financial indicators when dealing with a water utility / subsidiary and operational indicators when dealing with the actual distribution network.

Bibliography

H. Alegre, J.M. Baptista, E. Cabrera Jr. – Performance Indicators for Water Supply Services – 2nd edition, IWA Publishing, 2010

***, Manualul Național al Operatorilor de Apă și Canalizare (edițiile 2008 și 2010)

A. Aldea, Pierderi de apă - estimarea indicatorilor de performanță în rețele de mici dimensiuni, International Conference ARA , 16th edition, EXPOA APA 2014, Bucharest, Romania

M. Farley, S. Trow – Losses in Water Distribution Networks, IWA Publishing, 2003

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Fixed and Variable Area Discharges Update

How pressure influences N1, with updated calculations

Allan Lambert, Water Loss Research and Analysis Ltd

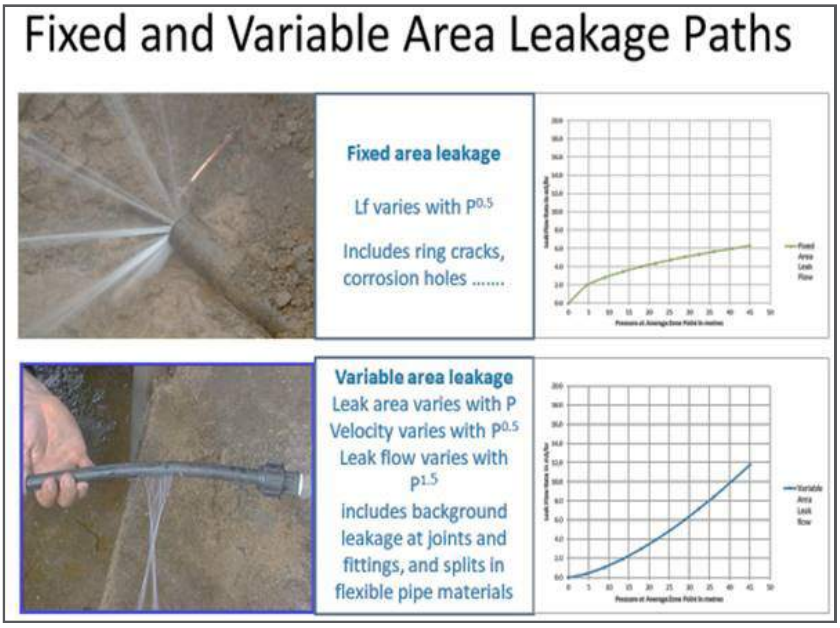
A Lambert

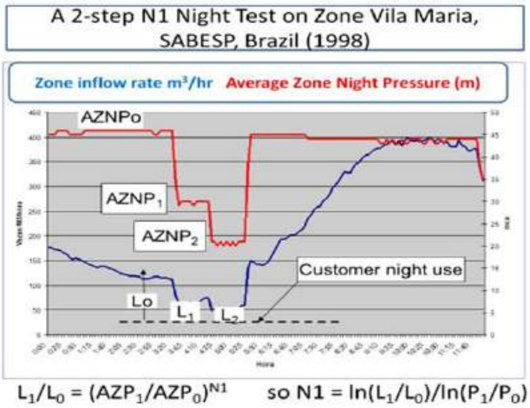
Management of distribution system pressures to reduce leakage and bursts, and extend asset life, is resulting in increasingly widespread reduction of excess pressures, and lowered pressures at times of low consumption. Recent research has enabled a more thorough application of FAVAD concepts in the practical methods used to analyse and predict pressure:leak flow relationships.

The original version of this article at http://www.leakssuite.com/favad-and-n1update/ provides additional links which are relevant to the updates.

The **Fixed and Variable Area Discharges** (FAVAD) concept, proposed by John May in 1994, reconciled Japanese (1979), UK (1980) and other international research data. The FAVAD concept considers the area of some leakage paths to be fixed, whilst the area of other types of leaks varies linearly with pressure. This explains why leak flow rates (volume/second) from most leaking pipes and distribution systems are more responsive to changes in pressure than leak velocity (distance/second), which only varies with the square root of pressure.

Since 1994 the N1 Power Law – a simplified approximate version of the FAVAD concept - has been widely used internationally for practical assessment of pressure-dependent leakage in water distribution systems. The Power Law assumes that leak flow rate varies with pressure to the power N1, where N1 is evaluated by field testing or assessed for a particular system. If the range of pressures is small, N1 is





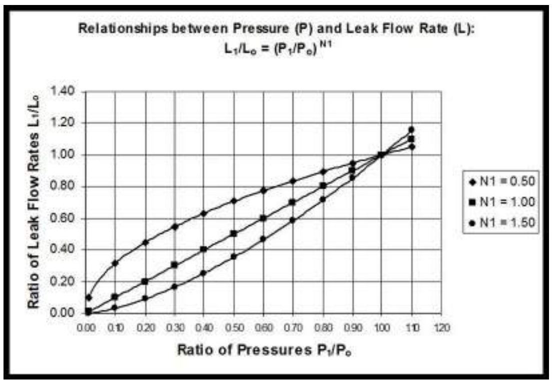
assumed for simplicity to be constant, but that would only be true if all leaks are fixed area (N1 = 0.5) or all are variable area (N1 = 1.5).

Zonal field tests to calculate N1 involve waiting until minimum night flow rate and average zone pressure (AZP) have stabilized, then reducing the pressure, observing the reduction in night flow, and deducting an allowance for customer night use to obtain the night leakage rates (Lo, L_1, L_2) and the corresponding average zone pressures (AZPo, AZP_1, AZP_2). The values for N1 can then be calculated from the equations shown below.

Once N1 is known, it can be used for predictions of how leak flow rates change with pressure. If AZPo and Lo are the initial average zone pressure and leakage rate, and N1 is known or can be predicted, then at a different average zone pressure AZP_1, leakage rate L_1 is predicted from the equation:

$L_1 = L_0 \times (AZP_1/AZP_0)^{N1}$ ....(1)

By 2005, NI values calculated from Zonal tests at night in the UK, Japan, Brazil, Cyprus, USA, Australia, New Zealand and Malaysia had shown that NI usually lay



between 0.50 and 1.50, with occasional values outside the 0.5 to 1.5 range (which may or may not be due to data or testing error). The limited published N1 data that exists is usually used by others without reference to, or knowledge of, the circumstances of the original tests. For example, one of the most frequently quoted N1 values (1.15) was originally based on field tests on around 2 km of metal mains and 300 service connections, almost 50 years ago. In two other series of tests, all detectable bursts were repaired before testing, and in one of these the N1 values include customer night use.

For practical purposes, a linear relationship (NI = 1.0) is often assumed to apply for large zones (as in the UARL formula), or where no specific evidence exists;

pressures at times of low consumption, particularly at night. Because variable leakage area reduces with pressure, when the average zone pressure for any particular system is reduced, the N1 value will also reduce, to a greater or lesser extent.

Research by Professor Kobus van Zyl and colleagues at University of Cape Town from 2012 to 2017 on cracks in different pipe materials has confirmed the validity of the assumptions in the FAVAD equation relating leak flow rate L to pressure P, which can be written as

L = Area x Velocity = (Af + Av) x (Cd $\sqrt{(2gP)}$) = (Af + mP) x (Cd $\sqrt{(2gP)}$) …………….(2)

Where Af is area of Fixed Area leaks, and Av is area of Variable Area leaks which increases linearly (slope m)

	N1 Night Test for	Anyzone				on	Sunday		7th	May	2017
Test	No. of Properties	1000	Population		2000	MNF		Night Use		Leakage Rate L	
Data	Start	01:30 to 02:15	AZNPo =	45.0	metres	20.00	m3/hr	2.00	m3/hr	18.00	m3/hr
	Finish	02:30 to 03:15	AZNP1 =	36.0	metres	15.50	m3/hr	2.00	m3/hr	13.50	m3/hr
Step 1	At Average AZNP =	40.5	metres N1 = $\ln(L_1/L_0)/\ln(AZNP_1/AZNP_0)$ =					1.29	Lave =	15.75	m3/hr
Step 2	Fixed Leakage Area FAL% = 1.5 -N1 =			0.21	Variable Leakage Area VAL% = N1 -0.5 =						0.79

i.e., a 10% reduction in average zone pressure will be assumed to reduce leak flow rate by 10%. Despite the approximations inherent in the Power Law equation, it has proved successful in introducing, to practitioners, calculations relating leak flow rates to average zone pressure in most distribution systems.

How is more extensive use of pressure management likely to influence values of N1?

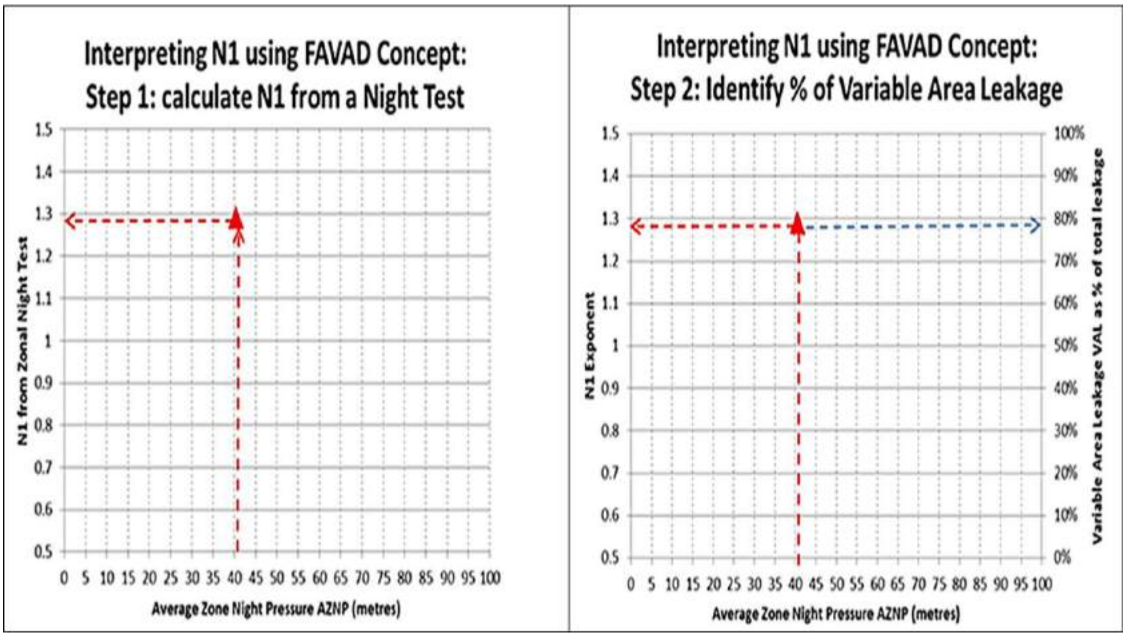
Improved understanding of pressure:burst frequency relationships and advances in valve control technology and data transfer have resulted in increasingly complex forms of advanced pressure management, with generally lower and more varied

with pressure. Cd $\sqrt{(2gP)}$ is the established equation for velocity of flow through an orifice.

Although the N1 parameter is now widely recognized and used in the international water industry, the more complex FAVAD equation (2) is not, and can appear intimidating to some practitioners.

Fast track Analysis of N1 tests shows how N1 varies with Average Zone Pressure

Lambert et al in Paper 2017L show how basic data from N1 tests can be rapidly and more thoroughly analysed using the principles of the FAVAD equation. A simple spreadsheet is used to calculate equations and graphs relating N1 and AZP, for practitioners to use. In the following excerpt from a WLR&A software, data



Step 3	Average Zone Pressure AZP when N1 = 1.0 is $AZP_{N1=1}$ = AZPave x FAL/VAL =		10.8	metres
	General Equation for N1 vs AZP is	N1 = AZP /(AZP + $AZP_{N1=1}$)	where units of AZP are in	metres
	Equation for N1 vs AZP is	N1 = AZP / (AZP +	10.8) where units of AZP are in	metres

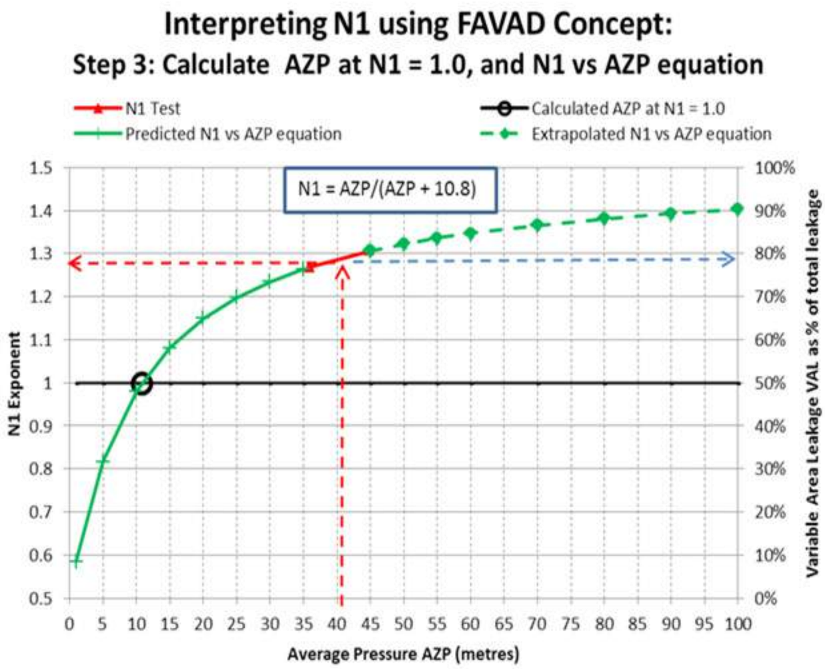
and preferred units are entered in the yellow cells, and pink cells show calculated outputs.

Step 1: Calculate the N1 value from the 'before' and 'after' AZP and Leak Flow Rates data

Step 2: Calculate %s of Fixed and Variable Area leaks at average AZP pressure in the N1 test

% of Variable Area Leakage = N1 – 0.5 = 21%; % of Fixed Area Leakage = 1.5 – N1 = 79%

N1 is plotted against the Average AZNP, and variable area leakage % is added to the graph



Because N1 varies with Average Zone Pressure, it is not sufficient to quote N1 (1.29) on its own; the Average Zone Night Pressure (AZNP = 40.5 metres) corresponding to the stated N1 must also be quoted at the same time. This leads to the calculation of $AZP_{N1=1}$ when N1 = 1.0, which is used in the equation relating N1 to AZP for this N1 test, calculated in Step 3.

Step 3: Calculate the equation relating N1 to AZP pressure, to predict how the zonal N1 from the test would vary with changes in Average Zone Pressures, and show this as a graph.

For this N1 test, it can be seen that:

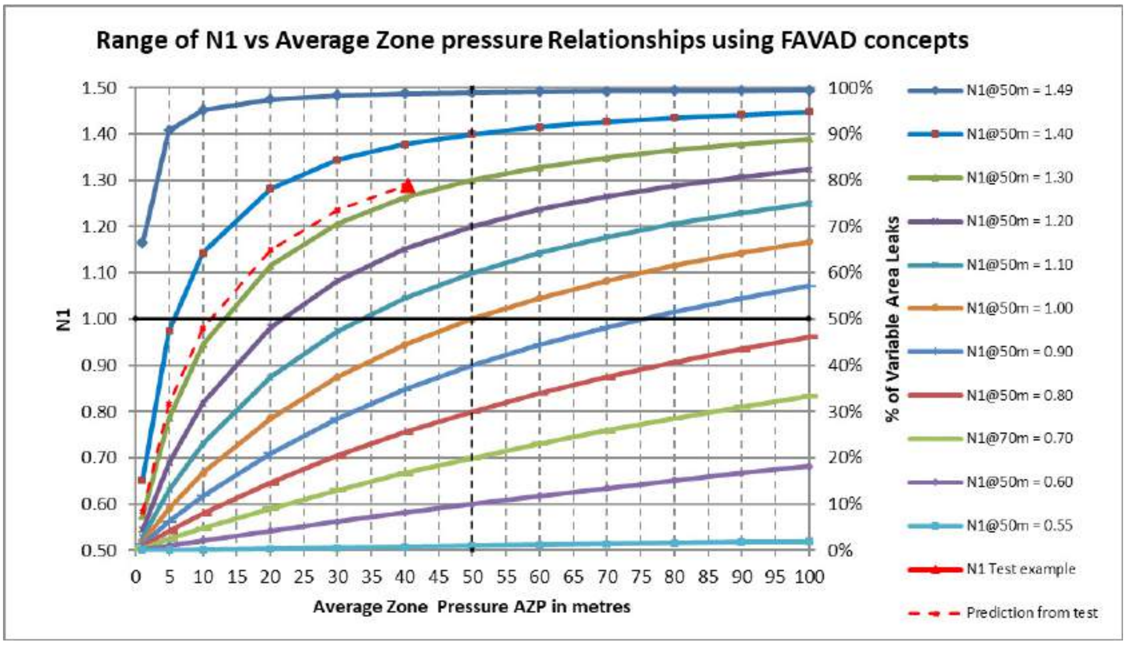
at the average AZP pressure during the N1 test (40.5 metres), the N1 was 1.29 and variable area leaks accounted for 79% (= N1 - 0.5) of the leakage paths

if the AZP pressure was to be reduced to say, 20 metres, the predicted N1 would reduce to 1.15, with variable area leaks accounting for 65% (= N1 – 0.5) of the leakage paths.

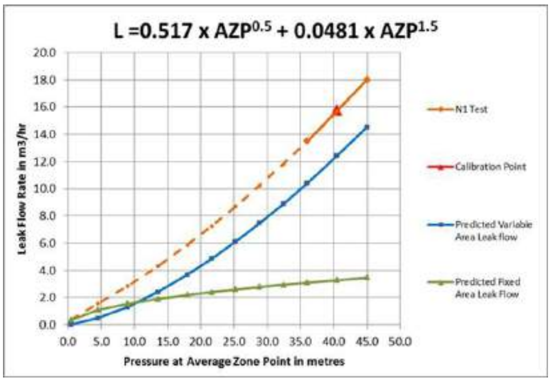
when AZP = 10.8 metres, N1 = 1.0, and areas of fixed and variable paths are equal

At AZP = 0, N1 = 0.5 and all leakage paths are fixed area, with no variable area component

CAUTION 1: If the N1 vs AZP equation is extrapolated to higher AZP pressures than the maximum AZP in the N1 test, there is the risk of creating new leaks which may change the N1 vs AZP relationship. However, if pressure is reduced (without causing significant pressure transients), the predicted reduced N1 values at lower AZP pressures should provide best estimates of N1 without causing additional leaks and bursts.



CAUTION 2: The N1 calculations and predictions in Step 1 to Step 3 above require that an N1 Test Protocol is followed. This includes systematic definition of an Average Zone Point (AZP) and measurements of pressure at the AZP during the N1 test. Pressures should always be reduced (not increased) during an N1 test. If you are not prepared to measure AZP pressures during N1 tests, or you do not follow the N1 Test Protocol, then don't bother with the tests; you will not only be wasting your time and resources, but the



results could not be relied upon. Updated webpages for Average Zone Point and N1 Test Protocol are being prepared and will be available on the LEAKSSuite website by 1st January 2018.

Individual N1 vs AZP equations from individual N1 tests should always lie somewhere within the general relationships between N1 and AZP pressure, as shown in the graph below for AZP pressures up to 100 metres.

It is expected that the above graph will be used for many different purpose, but perhaps the first and simplest is a quick check to assess if it is reasonable to assume that the value of N1 is almost constant for the situation being considered. This is most likely in Zones where:

the pressures at the AZP point do not vary greatly around the average daily value, and/or

the N1 vs AZP pressures lines have flatter slopes, which mainly occurs at higher pressures.

Just like a blood pressure test by a medical practitioner, even the most reliable N1 test by a leakage practitioner only gives a 'snapshot' value of N1, as (particularly in small Zones) the relative %s of fixed and variable area leakage paths in zones with mixed pipe materials can vary over time, as new leaks occur and existing leaks are repaired.

Fast track calculation of leak flow rate versus Average Zone Pressure

N1 values are useful for generally assessing how sensitive leak flow rates in a Zone are to changes in pressure, but practitioners also need to know the relationship between leak flow rate versus AZP. Because the studies by van Zyl and colleagues have confirmed the assumptions in the FAVAD equation, the FAVAD equation (2) can be rewritten simply as

$$L = A \times AZP^{0.5} + B \times AZP^{1.5} \quad \text{.........(3)}$$

where A and B are Zonal coefficients derived from an N1 test using any preferred combination of units for leak flow rate and AZP. The equations to calculate coefficients B and A are shown in Lambert et al Leak flow using fast track FAVAD, and can be used to calculate the L vs AZP equation directly from the N1 test.

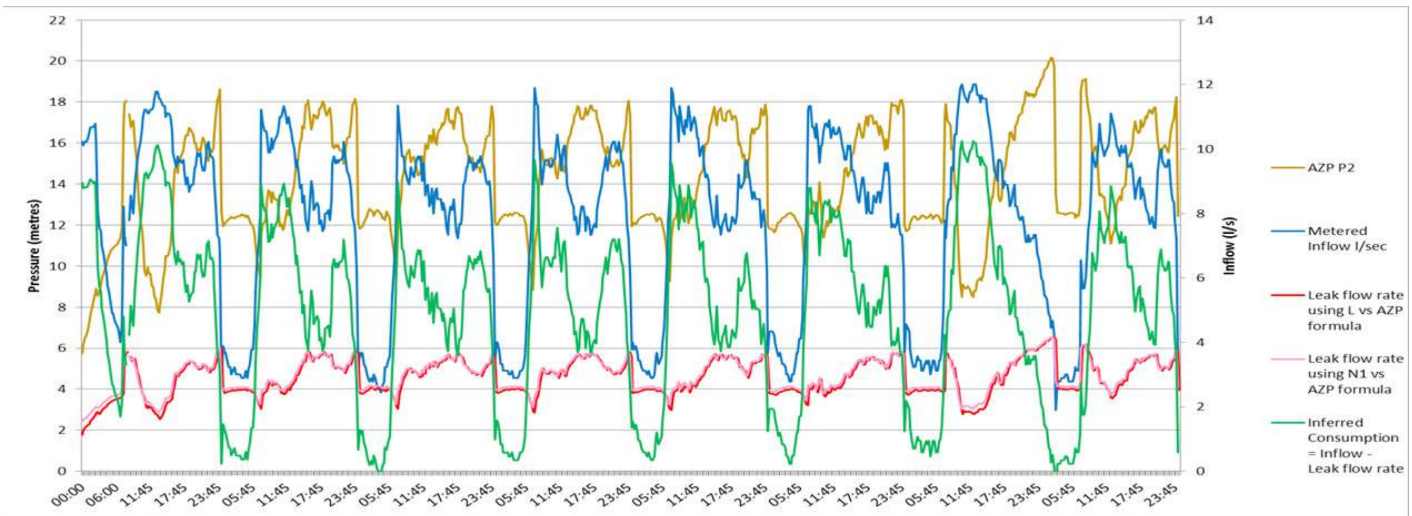
Continuous calculations of leak flow rates using recorded Average Zone Pressures

Utilities which establish continuous pressure measurement at Average Zone Points (which is best practice for most types of leakage calculations) will also be able to use reliable N1 test data to calculate and update equations (based on FAVAD principles) relating leak flow rate to AZP pressure, in their preferred choice of measuring units.

As the AZP pressure determines the instantaneous leak flow rate, measured AZP pressures can be used to calculate 15 minute, hourly and daily leak flow rates, allowing inflow rates to be split into leakage and consumption on a continuous basis. The example below is from a Mexican low pressure system with roof tanks, pressure reduction at night, occasional intermittent supply, and reliable N1 tests, analysed using a WLR&A software.

Influence of variable N1 on Night-Day Factors

Night leakage rate (volume/hour) can be converted to daily leakage using Night-Day Factor NDF (Hour-Day Factor HDF in the UK), which depends on variation of AZP pressure and assumed N1 value. Until now, a constant N1 value (either estimated or from N1 tests)



has been assumed, but as N1 varies with Average Zone Pressure, current methods of calculating NDF need to be reviewed.

NDF calculations can become quite detailed, and not many practitioners understand the complexities, so Water Loss Research & Analysis Ltd has applied the corrections for variable leakage paths that expand with pressure, and developed a simple approach for quick calculations of NDF, see http://www.leakssuite.com/night-day-factor-update/ . The method initially calculates NDF using the common (but approximate) assumption that N1 is constant at 1.0, then applies a correction for variable area leakage using a Correction Factor CF. CF depends on the ratio of average AZP/AZP at the hour of minimum night flow (AZPave/AZPmnf) and N1. The equation for NDF is

NDF (hours/day) = CF x 24 x AZPave/AZPmnf

Step 1: for a particular Zone, calculate AZPave/AZPmnf : e.g. AZPave/AZPmnf = **1.50**

Step 2: Approximate estimate of NDF, if N1 is constant at 1.0, = 24 x 1.50 = **36.0** hours/day

Step 3: get values of CF at AZPave/AZPmnf = 1.50 from the graph below.

CF for N1 = 1.0 is 0.98, so true NDF at N1 = 1.0 = 0.98 x 24 x1.50 = **35.3** hours/day

Step 4: CF max at AZPave/AZPmnf = 1.22, so NDFmax = 1.22 x 24 x 1.50 = **43.9** hours/day;

CF min at AZPave/AZPmnf = 0.82, so NDFmin = 0.82 x 24 x 1.50 = **29.5** hours/day

Step 5: carry out N1 test, define N1 at the Average AZP for the Zone, finalise NDF estimate

The above approach has the advantage that it starts from a method which is already being widely used (calculate NDF assuming N1 = 1.0), and is readily adaptable to automatic data processing of recorded AZP pressures, with periodic N1 tests.

Alternatively, the NDFs can be read directly (but less accurately) off the graph of NDF vs AZPave/AZPmnf below, for different values of N1 at the average zone pressure. This graph has also been adjusted for fixed and variable leakage areas.

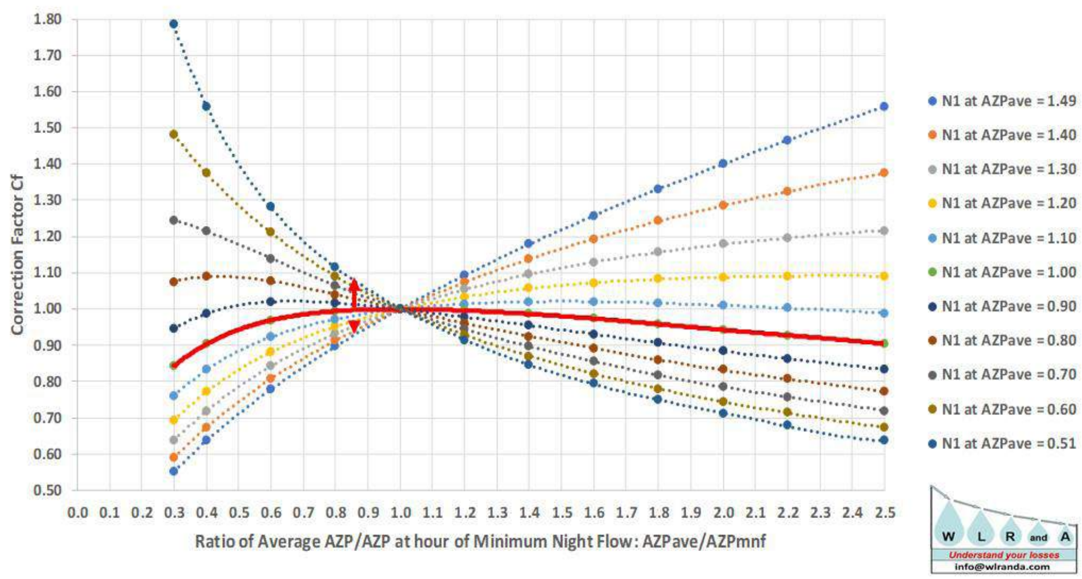
Summary: this article has provided an outline of the some of the basic fast track additional calculations that can be carried out by leakage practitioners when the FAVAD concepts are applied to the data from a reliable N1 test.

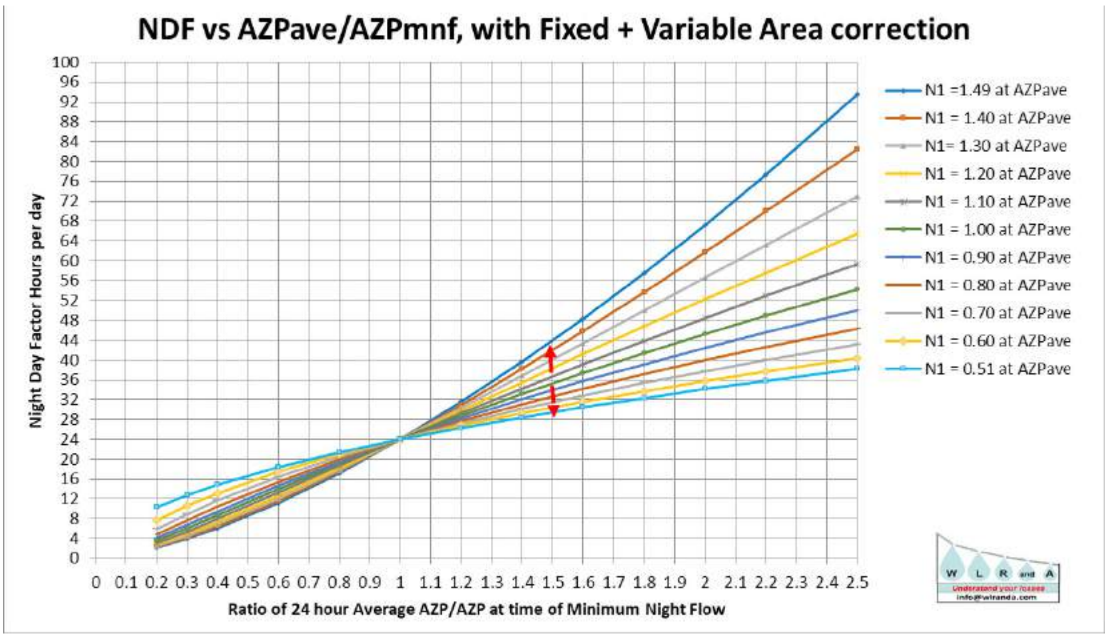
Acknowledgements: Kobus van Zyl, Mark Shepherd, Marco Fantozzi, Julian Thornton

For further information on the methodology, equations, look-up tables etc, described in this article, and options for training in their use, contact Water Loss Research and Analysis Ltd. info@wlranda.com

1st December 2017

Figure 4: Night Day Factor = CF x 24 x AZPave/AZPmnf





Can we go below ILI=1?

Keywords: Leakage management, Infrastructure Leakage Index, Noise logging, Correlation

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Background

The Infrastructure Leakage Index (ILI) was developed by the Water Loss Task Force (as it was then) (Lambert & et_al, 1999) as a measure of leakage performance in a network. The concept of ILI is to express current level of leakage as a ratio to what is referred to as the "unavoidable" level of real losses (UARL) on a network of the same size and operating at the same pressure. The UARL is deemed to be the level of losses that could be expected on a system that is in good condition and well managed. The estimate of UARL was based on a survey of operating practices and characteristics of many networks in 21 countries across the world. The IWA Water Loss Specialist Group (as it is now termed) recommends the use of ILI to compare leakage management performance.

In that the ILI is the ratio of actual losses to the UARL then one could expect that the lowest level of ILI that could be achieved is ILI=1. Only if the UARL could be bettered would the ILI be less than 1. Now that ILIs have been derived and monitored for over 14 years, the data set has grown significantly (Lambert & et_al, 2014). It can be seen that a very limited number of operators have been able to achieve a value of ILI<1.

Estimate of unavoidable losses

The estimate of UARL was developed using the component loss approach, originally referred to as Burst and Background Estimate (BABE) of leakage (Lambert & Morrison, 1996). For the purposes of building a component loss model of leakage, the distribution system is split into three components based on the asset type (mains, connections to edge of street (EoS) and connections from the EoS). Leakage on each of these asset types is then built up from three components – background leakage, burst leakage from reported leaks and leakage from unreported leaks. Background leakage is the leakage from leaks below the level of detection. Reported leaks are those leaks that come to the attention of the operator through customer contact and reports. Unreported leakage is the leakage from those leaks that have to be found by proactive leakage control. There is thus a three by three matrix of components used to estimate leakage from the distribution system. The basis of the calculation and the assumptions used in the estimation of the unavoidable losses are provided in the IWA Aqua Paper (Lambert & et_al, 1999).

The estimate of UARL assumes a number of key factors, namely:

- The burst frequency on mains, connections to EoS and connections from EoS (normalised for the length of mains and number of connections)
- The split of these between those that are reported and those that have to be found by proactive leakage control
- The average flow rate of leaks
- The average run time of leaks
- The level of background losses (unit losses per length of mains, per connection to EoS and per connection from EoS)
- The values for these factors were derived by reference to a number of utility operators around the world. The "standard" values for flow rates and background losses are expressed at 50m pressure. These are then adjusted to take into account the actual operating pressure.

Experience has shown that the estimate of UARL is very robust because it is only in a few circumstances that operators are reporting levels of leakage less than the unavoidable estimate. In many cases values of ILI<1 can be due to erroneous data recording or other situations such as revenue meter recording lag in times of changing demand patterns. In fact the ILI is often used as a first screening for data errors.

It is only in a very few situation that values of ILI less than 1 have been confirmed as valid. These situations are when:

- A higher proportion of total leaks are reported by the public than the proportion assumed in the UARL calculation. Analysis has shown that this is due to geological circumstances which mean that more leaks come to the surface and are reported
- There are fewer bursts/leaks than that assumed. This will be due to exceptionally new infrastructure
- Response times are faster than those assumed in the calculation of UARL due to exceptional circumstances (e.g. a drought)

The exceptional circumstances above have resulted in values of ILI of perhaps as low as 0.6, but generally around 0.8. However it must be emphasised that these are exceptions. The first circumstance is a function of the geology and underlying strata and therefore beyond the control of the operator of the network. In an established system, the second circumstance would require inordinate expenditure in terms of mains and connection replacement. The last factor will require a major increase in detection resources and would therefore be significantly more expensive.

This could only be justified against the risk of major restrictions or interruptions to supply, and is therefore usually only for a short period of time while these circumstances pertain.

The introduction of new technology, however, may be challenging the economics of the current approach to proactive leakage control and therefore may lead to faster response times.

The proactive leakage detection process

As mentioned earlier, proactive leakage control is the process which is used to identify and locate leaks that would otherwise not come to the attention of the operator. Without proactive leakage detection these leaks would accumulate on the system and leakage would continue to rise.

Proactive leakage control - Regular sounding

The "oldest" form of proactive leakage detection is a process referred to as "Regular Sounding". The process involves sweeping across the network at a regular interval, usually something of the order of about once per year or once every other year. The problems with this technique are that:

it is relatively inefficient in areas where leakage detection has been in operation for many years as large areas of the network with no leaks will be swept both mains and connections have to be sounded

there is no guarantee that a leak has not been missed

run times will be long - for example a leak will run on average for 180 days with annual sounding or 360 days with biennial sounding

Proactive leakage control – Responding to changes in flow

It is possible to improve the efficiency of regular sounding by only carrying out a survey in response to a rise in flow into an area, say, monitored by a district meter or flows from a service reservoir.

The advantages of using a district metered area (DMA) or other flow data, as opposed to regular sounding, are that it:

- means that the search is only in response to a leak or leaks breaking out
- localises the area of the search (be it to some 1000 to 3000 connections or more depending on the size of the DMA or area fed by the service reservoir)
- provides a way of confirming that the leak has been found

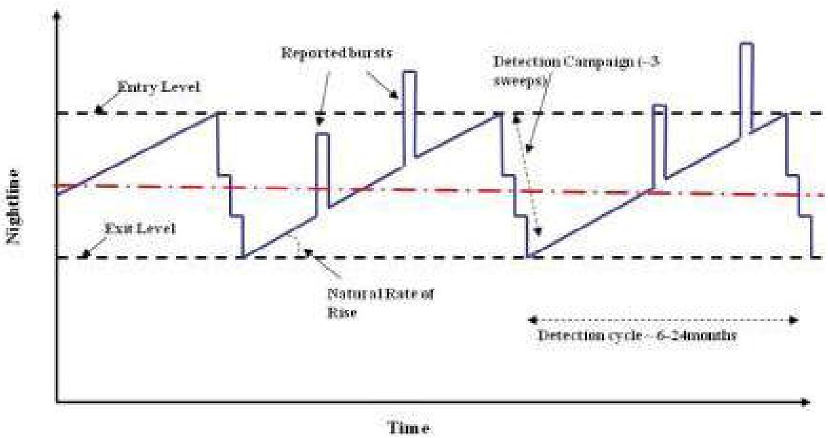

Figure 1 DMA Entry and Exit Levels

If the flow into an area is monitored, for example in the case of a DMA, the need to carry out a survey is usually triggered when the night flow exceeds a threshold value, known as the entry level. Detection is then meant to find leaks so that the night flow returns to the minimum achieved level, referred to as the exit level. This process is shown diagrammatically in Figure 1 DMA Entry and Exit LevelsFigure 1.

The value of the entry level can be assessed using economic analysis (Lambert, et al., 1998)). This analysis is akin to economic inventory management. The entry level will be a function of the size of the area to be surveyed. As the area becomes larger the entry level is higher because the time taken to carry out the survey increases. Often an intervention is usually triggered when more than one leak has accumulated on the system. A more technically robust methodology to establish the economic level of intervention is to intervene when the value of water lost since the last intervention equals the cost of carrying out the survey (Rizzo, 2002).

One might ask whether it is not possible to react to each and every leak as it breaks out. There are a number of reasons why such an approach is not feasible:

- One is responding to a change in flow rather than knowledge that it is a leak. It is often necessary to wait several days to confirm that it is a likely to be a leak and not just some short term fluctuation in demand.
- Initially it may be difficult to discern the change in flow above the general background noise and fluctuations of flow into the area. Depending on the size of area and the type of leak this may take several days or even weeks to have this clarity.
- It usually takes several man days to survey a DMA in order to locate the leaks, ranging from say to 6 man-days for a small DMA of 1000 connections to 16 man-days for a large DMA of 2500 to 3000 connections.
- A single survey may not be sufficient to find small leaks and bring the night flow down to the exit level and this cannot be confirmed until all leaks that have been found have been repaired. Additional surveys would then be required to find the illusive leak.
- The combination of uncertainty, effort and elapsed time, means that other leaks will have broken out in another DMA before the leaks have been cleared from the first DMA. It would require an inordinate and uneconomic level of resources to respond to each possible rise in flow.

It is common for the economic intervention period, using this methodology, to be of the order of anything from 6 months on an area with a high natural rate of rise of leakage (high burst frequency) to 24 or possibly

36 months on an area with a low natural rate of rise of leakage. This means that on average a leak will run for anything from 3 months to 18 months before being located.

If the confidence that it is a leak can be improved and the time, and hence cost, needed to locate and pinpoint a leak can be reduced then it may be economical to intervene in response to each suspect leak. This would mean that the response times would be better than those assumed in the unavoidable level of loss calculation. Recent developments in technology are now offering that opportunity.

Technological developments in leakage detection

Virtually all leakage detection techniques are predicated on identifying the sound made by water escaping from the pipe. Initially this sound was detected using listening sticks and then ground microphones (Pilcher, 2003). In the 1970's the leak noise correlator was developed. This equipment used the principle of the speed of the sound travelling in the pipe to estimate the location of a leak by sounding at two points along the main. This reduced the time taken to survey a main.

Acoustic Loggers

In the 1990s solid state technology was developed that allowed the sound to be recorded in a device that could be attached to a fitting (seeFigure 2 Acoustic logger deployed on a valve spindle (Courtesy Gutermann) Figure 2) and was small enough to fit within a normal valve or hydrant chamber. These loggers could be deployed, record the noise overnight and be interrogated the next day. The noise pattern could be analysed to give an indication if there was a leak in the vicinity. This equipment was then developed so the processing was carried out in the logger and therefore the logger did not need to be retrieved. The logger could be interrogated from a vehicle as it passed close to the logger.

These noise loggers are only deployed in response to a rise in night flow on an area as discussed earlier. The loggers are deployed on valves and hydrants on the system usually at a density of 100m or so depending on the availability of fittings. The whole of the DMA has to be "flooded" with loggers. After they have been left in the ground overnight they are then interrogated. The loggers indicate that a noise is in the vicinity of the logger, referred to as an Area of Interest (AoI). Those that are indicating a possible leak are left in the ground whilst the others are retrieved for use elsewhere. Sometimes it may be possible to say the leak is between two or three loggers. The leak noises are then investigated in more detail by looking at the frequency, constancy and level of the noise. If a leak is suspected then "normal" leak detection techniques are used to localise and then pinpoint the leak. Any leak that is found is then repaired. The loggers are left in the ground to confirm that all suspect noises have been resolved. Once the leaks have been repaired and no further noises identified, the loggers are retrieved and deployed elsewhere. This operation is referred to as "lift and shift".

This equipment and process helped reduce the cost of leakage detection for three reasons:

- the placing and removal of loggers could usually be carried out by a single person whereas previously it was common to use a two man team for leakage detection
- the placing and removal of loggers could be carried out during the day rather than at night when leakage detection was often carried out
- the loggers would localise a leak to within a few hundred meters rather than having to sweep the whole of the DMA

Permanent deployment of acoustic loggers

By the mid-1990s the cost of loggers was reducing due to technological improvements in miniaturisation in circuitry and construction and also due to the volume of manufacturing. It was therefore considered that perhaps the cost justified permanent deployment of the loggers. A number of utilities looked at the economics of this type of operation, but at the time it was considered that the "lift and shift" type of operation was still the most cost effective.

Correlating loggers

By the late 1990s, some manufacturers were starting to look at the possibility of being able to use the noise from adjacent loggers to localise the leak with greater

Figure 2 Acoustic logger deployed on a valve spindle (Courtesy Gutermann)

Figure 3 Correlating noise logger secured to a hydrant (Courtesy Gutermann)

resolution using the correlation principle described earlier (seFigure 3 Correlating noise logger secured to a hydrant (Courtesy Gutermann)e Figure 3). In order to carry out correlation the time clocks in the loggers have to be synchronised. The more accurate the clocks are synchronised and the more stable in terms of drift, then the more accurate will be the correlation. In order to achieve the synchronisation it was common to synchronise the clocks in all the loggers by connecting them to a computer prior to deployment.

The reliability and accuracy of these systems have improved significantly over the last ten years and the costs have reduced. Time synchronisation is now becoming feasible by connection to accurate time clocks through GPRS for example.

Cost of permanently deploying loggers

The cost of permanently deploying loggers is reducing and the performance is improving every year as:

- The capability, reliability and cost of the technology within the loggers improves
- The unit cost of manufacture reduces as more systems are deployed worldwide
- The cost of transmission systems reduce with the deployment of 3G and now 4G mobile phone networks as well as local radio systems
- The coverage and strength of the mobile phone network continues to improve
- Systems to provide very accurate time clock synchronisation become available at more reasonable cost
- The cost of holding, processing and interpreting the data from the loggers reduces with the widespread adoption of "cloud" technology

Because of this reduction in cost and improvement in capability, a number of operators have started to look at deploying loggers permanently thereby avoiding the cost of the lift and shift operation. A number of significant trials and deployments are now in operation around the world.

There are three main generic types of loggers, namely:

- pure noise logging
- noise logging with some secondary verification functionality, such as frequency and noise level information in order to improve the interpretation of the AoI
- as (2) above but with the addition of correlation functionality.

As the level of functionality increases then there is a need to transmit more data. This means that some loggers cannot be supported by simple SMS

Figure 4 Data collector connected to wi-fi network (Courtesy Gutermann)

transmission. The more comprehensive systems require local wi-fi/radio systems (sFigure 4 Data collector connected to wi-fi network (Courtesy Gutermann)ee Figure 4). Table 1 shows the matrix of logger functionality and transmission method.

Modelling the impact on leakage

In order to carry out a cost-benefit or return on investment assessment to justify permanent deployment of loggers it is necessary to estimate the benefit in terms of leakage reduction. Leakage can be modelled using the component loss approach mentioned earlier.

The use of permanently deployed loggers can not affect many of the parameters in the component loss model mentioned earlier. For example permanently deployed loggers:

- cannot affect the burst frequency on mains or services
- would not normally affect the proportion or the run time of leaks that are reported by the public – unless they identify leaks faster than the public
- would not reduce background leakage – as by definition these are below the level of detection – unless they can detect leaks at a lower threshold
- will not reduce repair times as these are a function of repair policy and provision of repair resources
- would not reduce the average flow rate of leaks although it might be argued that they are found earlier. But it is only a proportion of leaks that grow with time.

The main impact that permanently deployed loggers would have is in reducing the run time of unreported leaks. This can be significant in the overall balance of the leakage components. Because of the long average run times described earlier, unreported leakage is usually of the order of 30% to 40% of total leakage despite the fact that the number of unreported leaks is usually only of the order of 20% to 30% of total leaks. If the run time can be reduced significantly this

Generic Type of Logger	Transmission Method	
	SMS	3G/4G/GPRS Local Radio
Noise logging	þ	þ
Noise logging & secondary verification	x	þ
Noise logging, secondary verification & correlation	x	þ

Table 1 Matrix of noise logger functionality and transmission method

will result in considerable savings in leakage and this may justify the cost of deploying loggers over the entire network.

Permanently deployed loggers give this opportunity as they provide:

- greater confidence that a leak has broken out as they are responding to a noise rather than a change in flow
- immediate localisation of the leak avoiding the need to sweep a whole DMA
- the opportunity to improve the resolution of this localisation to a matter of a few meters if correlating loggers are used

The provision of this localisation can mean that the effort needed on site to locate, confirm and pinpoint a leak can be reduced to a matter of 1 or 2 man-hours rather than several man-days mentioned earlier. This reduction in the location effort needed changes the economics of leakage detection entirely. Rather than waiting for the flow into an area to increase to a predefined entry level and then having to sweep the whole area, the loggers will indicate where the leaks are and a team can be deployed directly to that location. If the time on site is low enough then this becomes a queuing problem rthaer than an inventory management problem.

Queuing theory

Queuing theory (Adan & Resing, 2002) is a relatively well developed science having originally been developed as part of the research into the sizing of telephone exchanges in the late 19th century. It was then realised that the theory can apply to many systems – for example queues at bus stops, at shops, airports etc. The theory can be used to calculate the average waiting time in a queue, the average length of a queue, the average deployment of a "server". The main parameters are the arrival rate (e.g. people arriving in the shop or restaurant) and the average serving time. Both these aspects will have stochastic variability – for example people arrive intermittently at the shop. It is found that almost invariably that the time between arrivals in any system with a very large number of independent arrivals (be it telephone calls or people arriving at a shop) follow an exponential distribution (the number of arrivals per unit time will follow a Poisson distribution). It has been shown that leaks breaking out on a water distribution system follow this process be it with seasonal variation (Goulter & Kazemi, 1988). There is also a stochastic variation in the time taken to serve (travel, localisation and pinpointing). This serving time also usually follows an exponential distribution. Various serving disciplines can be modelled but the most common is "first in first out" (FIFO). Multiple servers can be modelled as well as multiple queues (e.g. passport control at an airport). In the most complex cases simulation has to be used but for simpler cases solutions have been developed using the properties of the mathematical distributions involved. A standard nomenclature depicting the type of system that is being modelled has been developed (Kendall, 1953). For example, the M/M/1 queue is a simple model where a single server is servicing jobs that arrive according to a Poisson (Markov) process and have exponentially distributed (Markov) servicing times.

Modelling the cost/benefit benefit of permanently deployed loggers

The author has used queuing theory in order to model the leakage detection process when permanently deployed loggers are deployed. The break out or "arrival" of leaks was modelled using a Poisson distribution with the mean arrival rate equal to the average annual burst frequency. The servicing time was modelled as an exponential distribution with an average serving time to represent travel to site and the time taken to pinpoint the leak. The average waiting time was then calculated as a function of the number of servers (i.e. detection teams) deployed.

There are three main factors that will impact on the cost effectiveness of the approach, namely:

- The level of false positives
  It is possible that a logger may pick up a noise which is not due to a leak. Some of these "false positives" can be filtered out by the software in the logger depending on the functionality of the logger. For example, a logger that records the frequency as well as the volume of the noise can be used to identify if the noise is from a street light rather than a leak because the noise will have the frequency of the mains power (50hz in the UK). As the period over which the noise is sampled increases then the greater is the confidence that extraneous noise sources can be filtered out. Even so there will be a small proportion of noises which do not turn out to be leaks but which cause detection resources to be deployed to the location.
- The level of false negatives
  Similarly, it is possible that some leaks may not identified – for example those on long supply pipes or leaks on materials that absorb the noise rather than transmitting to the nearest logger. These situations are referred to as "false negatives". The level of false negatives can be improved by logging over a longer period. Leaks which are not picked up by the logger will gradually accumulate on the system and will eventually have to be found by the traditional detection techniques following an increase in the night flow on the district.
- The resolution and accuracy of the localisation
  The time spent on site to confirm and pinpoint the leak will depend whether correlating or "simple" acoustic loggers are being used. If "simple" acoustic loggers are being used then it may be necessary to correlate and sweep 2 or 3 streets to localise the leak. If correlating loggers are being used, the leak should hopefully be located to within 2 or 3 meters but the accuracy of the indicated location will depend on the precision of the synchronisation, the accuracy of the GIS records (material, diameter and layout of the main) and whether this information is integrated with the loggers.

The detection process, including modelling false positives, false negatives and time on site, was built into a model that estimated leakage using the component loss approach. The overall time that a leak will run will be a function of the length of the queue which can be influenced by the number of resources deployed on detection. The model included evaluating the economic level of resources using the same approach as the normal ELL process i.e. the leakage cost curve was derived and the economic level of resources found where the marginal cost of detection equalled the marginal cost of water.

The model also evaluated the "traditional" active leakage control process for comparison. Again the model calculated the economic level of leakage by evaluating when the marginal cost of leakage detection equalled the marginal cost of water.

The modelling assumed the same pressure, that minimum achieved leakage levels had been reduced to background level of leakage (Pearson, 2009) in both cases. They assumed the same marginal cost of water.

Results/Key influences/Sensitivity analysis

A number of major logger manufacturers were contacted and supplied information about their experiences. They provided information on the three key sensitivities:

- Level of false positives
- Level of false negatives
- Precision of localisation of leaks

The results are summarised in Table 2.

The actual time to resolve a point of interest (and hence the run time of a leak) will be higher than values in the last column in Table 2 Range of key sensitivities by generic logger typeTable 2. Firstly travel time has to be taken into account. This is likely to be of 1 to 2hrs at the most. What is more significant, however, is the time that may be required to collect more data to improve the confidence in the interpretation of the AoI. This may take up to three or more separate nights of noise collection. Thus the run time of these leaks may go to 80 or more hours.

The model was run with this data and Monte Carlo simulation used to sample from the indicated ranges. The model predicted the level of ILI in each case. The results are summarised in Table 3.

The analysis showed, as expected, that in all cases leakage was lower with the use of permanently deployed loggers. With normal leakage detection

Generic Type of detection	ILI
Traditional detection	1.6
Noise logging	1.3 - 1.5
Noise logging & secondary verification	1.0 – 1.3
Noise logging, secondary verification & correlation	0.8 – 1.0

Table 3 Range of ILI by generic logger type

techniques the economic level of leakage was equivalent to an ILI of 1.6. This will vary depending on the cost of detection and the value of water. Using "simple" acoustic loggers the economic level of leakage reduced to between 1.3 and 1.5 depending on the assumptions on the false positives and negatives. This was with comparable costs of detection and value of water. With secondary verification the ILI range reduced to1.0 to 1.3. However with correlation the range was 0.8 to 1.0. So with permanently deployed correlating noise loggers it is feasible to reduce leakage below an ILI of 1 possibly as low as 0.8. At this level unreported leakage is virtually eliminated and background leakage makes up 85% of total leakage (85%).

The level of leakage detection resources required is significantly lower (less than 10%) of those needed with traditional techniques. In deciding whether to proceed with a network of permanently deployed loggers it will be necessary to look at the business case of whether the reduction in the cost of detection resources together with savings in water production costs justify the cost of purchasing and maintaining a network of loggers.

Conclusions

The study has shown that:

- The use of permanently deployed correlating loggers provides the opportunity to drive leakage levels below the level of the unavoidable losses used in the calculation of ILI. This is because their use changes the economics of the leakage detection process to such an extent that the run time of leaks can be significantly reduced
- Leakage could be driven down to values of an ILI of about 0.8 compared to 1.6 on a comparable basis i.e. a 50% reduction
- These levels of leakage can only be achieved if background leakage has been reduced the minimum achievable
- The key sensitivities to the achievement of this level of leakage are;

Generic Type of Logger	Level of False Positives	Level of False Negatives	Resolution of Localisation	Time to confirm and pinpoint
Noise logging	50% - 90%	50% - 90%	80 - 300m*[1]	2 - 4hrs
Noise logging & secondary verification	10% - 40%	10% - 40%	80 - 300m*[1]	2 - 4hrs
Noise logging, secondary verification & correlation	0% - 10%	0% - 10%	1 - 20m*[2]	1 - 2hrs

*[1]*Dependent on spacing of loggers* *[2]*Dependent on integration with GIS*

Table 2 Range of key sensitivities by generic logger type

- The level of false positives
- The level of false negatives
- The resolution of the localisation

- The modelling has shown that the adoption of permanently deployed loggers would shift the leakage detection process to one of queues rather than inventory management
- There could well be a business case for the establishment of a network of permanently deployed correlating loggers, essentially establishing a SMART distribution network

This deployment of permanent correlating loggers therefore provides the industry with the opportunity of a paradigm shift in leakage performance.

Acknowledgements

The authors would like to thank the following companies and employees for their support in the preparation and providing information for this paper:

- Uri Gutermann, Gutermann AG
- Mike Tennant, HWM-Water Ltd
- Roger Ironmonger, Primayer Ltd
- Michael Buerger, SebaKMT

References

Adan, I. & Resing, J., 2002. *Queueing Theory.* s.l.:Eindhoven University of Technology.

Goulter, I. C. & Kazemi, A., 1988. Spatial and temporal groupings of water main pipe breakage in Winnipeg. *Canadian Journal of Civil Engineering Vol 15 No 1,* pp. 91-97.

Kendall, D. G., 1953. Stochastic Processes Occuring in the Theory of Queues and their Analysis by the method of the Imbedded Markov Chain. *The Annals of Mathematical Statistics Vol 24 No 3,* p. 338.

Lambert, A. & et_al, 2014. *14 Years Experience of using IWA Best Practice Water Balance and Water Loss Performance Indicators in Europe.* [Online] Available at: http://www.leakssuite.com/outreach/

Lambert, A., Myers, S. & Trow, S., 1998. *Managing Water Leakage - Economic and Technical Issues,* s.l.: UK Financial Times Business Ltd.

Lambert, A. O. & et_al, 1999. A Review of Performance Indicators for Real Losses from Water Supply Systems. *IWA Aqua Vol 48*, pp. 227-237.

Lambert, A. O. & Morrison, J. A. E., 1996. Recent Developments in Application of Bursts and Background Concepts for Leakage Management. *Water and Environmnet Journal Vol 10 Issue 2,* pp. 100-104.

Pearson, D., 2009. *Residual Leakage Reduction - The Fifth Dimension.* IWA Water Loss Conference, Cape Town, s.n.

Pilcher, R., 2003. Leak detection practices and techniques: a practical approach. *Water21 Dec,* pp. 44-45.

Rizzo, A., 2002. *Tactical Planning for Effective Leakage Control.* IWA Water Loss Conference, Limassol, World Bank.

ADVANCED HYDRAULIC ANALYSIS FOR WATER DISTRIBUTION NETWORK MANAGEMENT

Keywords: Leakage management, Infrastructure Leakage Index, Noise logging, Correlation

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Brief background on classical hydraulic models for network analysis

In the early decades of the last century, water distribution networks (WDN) were built for many water-related reasons, such as human health and well-being, but also to support economic development, industrial activities and provide fire protection to cities. This condition required the definition of some analytical criteria to validate the WDN projects, with particular reference to the WDN hydraulic capacity to meet (statistically) water demands of different users (residential, commercial and industrial) and, in some particular cases, fire protection requirements. The energy balance equations for pipes and mass balance equations at nodes of the network gave shape to the first models for hydraulic simulation of WDN.

In this context, the hydraulic analysis of WDN has been developed in order to calculate pressures at nodes given the internal pipe roughness and constant water requests at nodes (statistical water demands of various types of users). Therefore, project verification consisted in the evaluation of nodal pressures with respect to a minimum value for a proper service to users (generally related to the height of buildings) and, with references to fire protection standards, in the assessment of flow rates and minimum residual pressures for a correct hydraulic performance of the fire hydrants. In the beginning, the analyses were referred to small or very simplified (skeletonized) networks considering only the main pipelines. The first algorithm for WDN hydraulic analysis/simulation was invented by Cross in the 1930s (Cross 1936). It allowed manual calculation as strictly possible at that time. In later years, until the end of the millennium, with the massive spread of computers with increasing computational capabilities, and the complication of WDN hydraulic models, due to the need to consider more devices such as pumps, valves, etc., several WDN simulation algorithms were developed to achieve efficiency, robustness and accuracy of solutions. In 1979, Todini invented the Global Gradient Algorithm (GGA) based on the Newton-Raphson method, which was able simulate also any device in 1988 (Todini and Pilati 1988), and becoming the "hydraulic engine" of EPANET, a software for WDN hydraulic simulation developed by Rossman (1994), and released in the first version in the early 1990s. Current software packages are generally based on the same EPANET "hydraulic engine" with rare exceptions, as in the case of INFOWORKS, which algorithm is derived from the Linear Theory. The main difference between the EPANET and INFOWORKS algorithms is in the higher accuracy of the former, while the latter shows higher convergence velocities for lower accuracy, as discussed by Rossman and Todini (2013).

All classic WDN hydraulic simulators are based on the assumption of constant nodal water demands in order to represent the statistical requirements of water of various types of users. Fire hydrants, however, are implemented as free orifices for fire protection requirements testing. Therefore, classical WDN analyses are performed with algorithms that are called "demand-driven", that is, the calculated nodal pressures are "driven" by the statistical water demands that are defined hourly by specific multipliers (demand patterns) of a base demand value. Therefore, the calibration of these WDN hydraulic models is related to pipes roughness, assuming that the internal pipe diameter is known, and with particular reference to fire protection requirements. In fact, under these conditions, the water velocity can reach even 10 m/s, therefore, the roughness has a decisive influence on evenly distributed load losses and on the residual pressure/flow at the fire hydrants of the hydraulic system.

Development of hydraulic models for advanced management and analysis

Over the years, WDN have become more and more large, complex and obsolete; therefore, new management needs have arisen with respect to water quality, water losses, network reliability, energy optimization, rehabilitation, etc.. Todini (2003) firstly poses the problem of defining a model for WDN that allows calculating the "actual" water demand that can be supplied to users, especially at some nodes that are under pressure conditions lower than the minimum level for a proper service. He pointed to Wagner et al. (1988) model as the most appropriate pressure-demand function:

$$d(i,t)=\begin{cases} d^{req}(i,t) & P(i,t)\geq P^{ser}(i) \\ \dfrac{d^{req}(i,t)}{\sqrt{P^{ser}(i)-P^{min}(i)}}\sqrt{P(i,t)-P^{min}(i)} & P^{min}(i)<P(i,t)<P^{ser}(i) \\ 0 & P(i,t)\leq P^{min}(i) \end{cases}$$

(1)

As in Figure 1, and expressed by Eq. (1), the Wagner et al. model sets a constant demand $d(i,t)$ at the i-th node at time t, equal to the statistical user-required water demand $d_{req}(i,t)$ for pressures higher than $P_{ser}(i)$, the minimum pressure for a proper service; null water demand for pressures lower than the tap elevation $P_{min}(i)$; and the actual water demand for intermediate pressures according to Torricelli's law, i.e. under pressure-deficient conditions as indicated by Giustolisi and Walski (2012). Therefore, the model is hydraulically consistent, and correctly represents the real functioning of a WDN, where users statistically control the flow rates from the taps as long as the pressures are sufficient, while drawing the maximum allowed flow (i.e., Torricelli law validity for fully open orifices) under low pressure conditions, see Giustolisi and Walski (2012) for more details.

Later on, Giustolisi et al. (2008a) firstly developed a robust and accurate algorithm for the simulation of WDN under pressure-deficient conditions, including in the WDN hydraulic model the hydraulic component related to background leakages (Giustolisi et al. 2008b), which are considered as evenly distributed

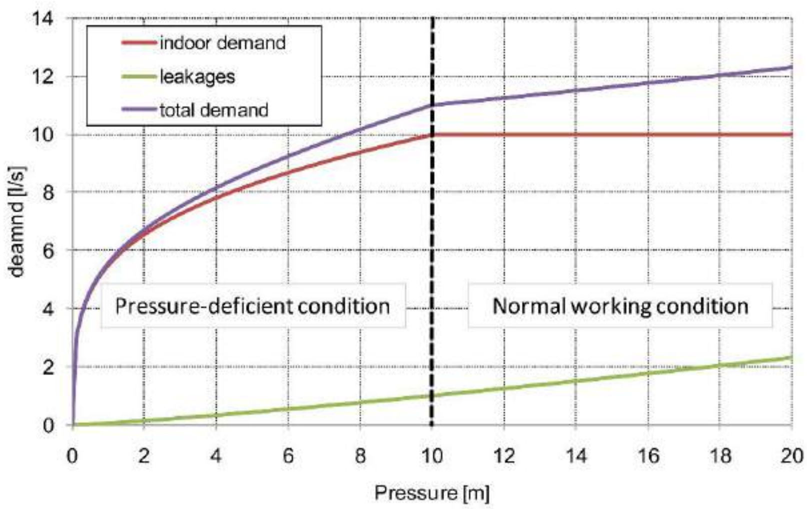

Figure 1. Pressure-demand diagram (Wagner et al. 1988) including residential water demands and water losses due to background leakages.

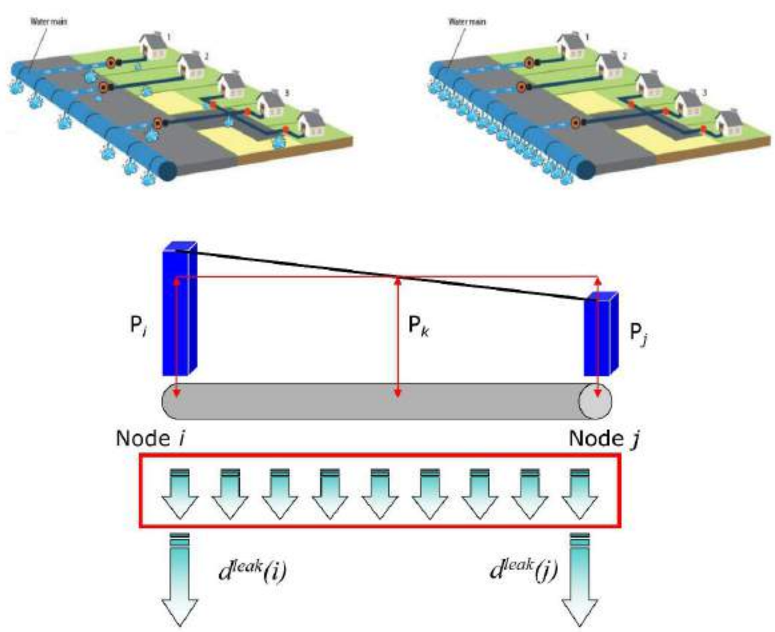

Figure 2. Background leakages and their representation in the hydraulic model.

along the pipes length. This demand component was associated with water losses as dependent on the average pressure on the pipes, as specified in the next paragraph.

Background leakages in WDN hydraulic models: concepts and management utility

As above mentioned, Giustolisi et al. (2008b) developed the representation in WDN hydraulic models of the hydraulic component of background leakages along the pipelines. The aim was to consider an ever-existing water demand component into the hydraulic simulation of a WDN, consisting in small water leaks along the pipelines (including those related to user private connections) and bigger losses not yet detected and repaired. Giustolisi et al. (2008b) adopted the classic model for water leakage simulation proposed by Germanopoulos (1985), representing the water loss demand at nodes *i* and *j* of the *k*-th pipe, as related to a deterioration factor β(*k*) and the mean pressure *P*(*k*), see Eq. (2).

$$d^{leak}\left(i,P(k,t)\right)=\begin{cases}\dfrac{\beta(k)L(k)P(k,t)^{\alpha}}{2} & P(k,t)\geq 0\\ 0 & P(k,t)<0\end{cases}$$

(2)

The sum of leakages on pipes that are confluent into a node provides the water demand component in each node of the WDN, which is added to the users water demand as previously reported in Figure 1. The exponent (α) in the Germanopoulos model depends on the rigidity of the pipe material (Giustolisi et al., 2008b) and can generally be assumed equal to one, as first approximation.

Figure 2 shows what is modelled in Giustolisi et al. (2008b). Pipes water losses are assumed to be evenly distributed, also including those existing along the user private connections. Water losses in a single pipe are then related to the average pressure as reported in Eq. (2). For modelling reasons, during hydraulic simulations, leakage water demands are concentrated in nodes, Eq. (2), without errors on mass balance, but with an error on the energy balance, generally negligible compared to the system uncertainties (Giustolisi and Todini 2009; Giustolisi et al. 2016). The overall scheme allows relating background leakages with the average pressures of each pipe, using a unique deterioration factor (β), usually in the order of magnitude of 10^{-8}. It is a global indicator of deterioration for single pipes (including the effect of any connections) that is very useful at management level (Giustolisi et al. 2016), both for planning of interventions, e.g. districtualization and rehabilitation, and for network operation, e.g. calibration and optimization of pumping, also considering leakage reduction (Berardi et al., 2017).

In fact, the simulation of pipe water losses is crucial for planning management operations such as: (1) optimal districtualization both topological and in terms of water leakage mitigation (Laucelli et al., 2017); (2) planning of pressure reduction valves locally controlled or at the critical node (Giustolisi et al. 2016; Giustolisi et al., 2017); (3) optimal rehabilitation; etc.. In addition, an advanced calibrated hydraulic model is definitely irreplaceable to support all the above-mentioned tasks since their initial stages related to implementing strategies and management processes. It is noteworthy that representing water losses with hydrants, eventually with an exponent different from 0.5, deployed in all nodes in the network, makes the hydraulic simulation calculation inaccurate from different points of view (Giustolisi et al. 2016), loosing the information at pipe level and, hence, the information on the pipe deterioration and any connections, which is, for example, essential for an optimal rehabilitation. Finally, as above mentioned, classical hydraulic simulators are demand-driven, i.e. nodal water demands are fixed a priori, while water losses cannot be fixed a priori, because they are dependent on the average pressures of the pipes, through nodal pressures that are the unknowns of the problem. Therefore, WDN simulation for management purposes always requires a pressure-driven analysis approach (i.e. nodal water demands are not fixed a priori, but driven by pressure) due to the presence of background leakages and pressure-deficient conditions for users water demands, see Figure 1. Following the works of Giustolisi et al. (2008a;b), Giustolisi et al. (2011) developed a software package for WDN analysis, planning and management named WDNetXL. The accuracy of WDNetXL compared to other pressure-driven analysis approaches is much higher than standard commercial products since its "hydraulic engine" has been designed to be originally pressure-driven.

References

Berardi, L., Simone, A., Laucelli, D. and Giustolisi, O. (2017) Feasibility of Mass Balance Approach to Water Distribution Network Model Calibration. *Procedia Engineering*, Elsevier, 186.

Cross, H. (1936) Analysis of flow in networks of conduits or conductors. *Bulletin n. 286*, University of Illinois Engineering Experimental Station, Urbana Illinois, USA.

Germanopoulos, G. (1985) A technical note on the inclusion of pressure dependent demand and leakage terms in water supply network models. *Civ. Eng. & Env. Syst.*, Taylor & Francis, 2(3).

Giustolisi, O., Kapelan, Z. and Savic, D.A. (2008a) An algorithm for automatic detection of topological changes in water distribution networks. *J. Hydr. Eng.*, ASCE, 134(4).

Giustolisi, O., Savic, D.A. and Kapelan, Z. (2008b) Pressure-driven demand and leakage simulation for water distribution networks. *J. Hydr. Eng.*, ASCE, 134(5).

Giustolisi, O. and Todini, E. (2009) Pipe hydraulic resistance correction in WDN analysis. *Urban Water Journal*, Taylor & Francis, 6(1).

Giustolisi, O., Savic, D.A., Berardi, L. and Laucelli, D. (2011) An Excel-based solution to bring water distribution network analysis closer to users, Proceedings of Computer and Control in Water Industry (CCWI), Exeter, UK.

Giustolisi, O. and Walski, T.M. (2012) Demand Components in Water Distribution Network Analysis. *J. Water Res. Plan. and Management*, ASCE, 138(4).

Giustolisi, O., Berardi, L., Laucelli, D., Savic, D. and Kapelan, Z. (2016) Operational and Tactical Management of Water and Energy Resources in Pressurized Systems: Competition at WDSA 2014. *J. Water Res. Plan. and Management*, ASCE, 142(5).

Giustolisi, O., Ugarelli, R., Berardi, L., Laucelli, D. and Simone, A. (2017) Strategies for the Electric Regulation of Pressure Control Valves. *Journal of Hydroinformatics*, IWA Publishing, 19(5).

Laucelli, D., Simone, A., Berardi, L. and Giustolisi, O. (2017) Optimal Design of DMAs for Leakages Reduction. *J. Water Res. Plan. and Management*, ASCE, 143(6).

Rossman, L.A. (1994). Epanet User's Manual. U.S. Environmental Protection Agency, Cincinnati, OH.

Todini, E. and Pilati, S. (1988) A gradient method for the solution of looped pipe networks. *Computer Applications in Water Supply*, Wiley & Sons, 1.

Todini, E. (2003) A more realistic approach to the "extended period simulation" of water distribution networks. Advances in Water Supply Management, Maksimovic C., Butler D. and Memon F.A. (eds), A.A.Balkema Publishers, Lisse, The Netherlands, 173-184.

Todini, E. and Rossman, L.A. (2013) Unified Framework for Deriving Simultaneous Equation Algorithms for Water Distribution Networks. *J. of Hydr. Engineering*, ASCE, 139(5).

Wagner, J.M., Shamir, U. and Marks, D.H. (1988) Water distribution reliability: simulation methods. *J. Water Res. Plan. and Management*, ASCE, 114(3).

EVALUATION OF WATER LOSS AND THE EFFECTIVENESS OF THEIR REDUCTION - ECONOMIC LOSS LEVEL

ABSTRACT: Water losses are one of the most frequently cited indicators in assessing the quality and efficiency of water system operation. The assessment and reporting of water losses is different across different countries, but it is rather traditional to indicate losses through the proportion of water produced to its implementation. Currently, the standard for water companies in the Czech Republic is also to use other indicators such as unit leakage, water loss at the connection, or the indicator of Infrastructure Leakage Index (ILI), which is recommended and the methodology of its determination is further developed by the International Water Association (IWA). However, a different way of reporting losses can mean a different loss reduction priority in the same part of the water system. It is therefore necessary to take into account also the economy of water losses or the costs of their reduction as a decision criterion on the loss reduction priority. The paper focuses on the economic aspects of water loss and shows a possible approach to assessing and determining an economically acceptable level of water loss.

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INTRODUCTION

Traditionally, in the Czech Republic, water losses are based on *non revenue water*, which is most often reported as a percentage proportion of the *system input volume*. The non revenue water itself is then divided into *authorised consumption* and *water loss*. As a better indicator of the technical state of the water distribution network the *unit leakage* indicator is more often used. Here, however, the attention needs to be paid to how the unit leakage is calculated. Mostly, water losses or the entire non-revenue water volume is converted to km of network length per year. Many water companies calculate the unit leakage for the so-called equivalent profile DN 150, or even for trunk mains and connections, but their lengths are multiplied by different coefficients.

This paper briefly describes one of the possible methodology of the comprehensive technical audit of the water distribution networks particularly the part focused on the water loss. This methodology is called TEA Water and this is a method which permits a preliminary assessment of the technical condition of the water supply infrastructure so as to enable not only to efficiently identify hot spots and parts of drinking water supply systems. It is based on practical experience, discussions with various domestic as well foreign operators and knowledge gained from international projects and grants. This paper describes the *Economic Loss Level* (ELL), which takes into account the economic losses caused by water losses.

METHODOLOGY

As it was mentioned above, the water loss assessment is carried out within the TEA Water methodology, which is described in more detail, for example, in (Tuhovcak, 2016). The draft methodology of preliminary assessment of the technical condition of the water supply system components is based on the general method, the FMEA. The FMEA method (Failure Mode and Effects Analysis) allows for semi-quantitative assessment of the relevant system and its components. To assess the water supply systems using the FMEA is necessary to establish specific technical indicators for each of the water supply system component and structure. For each technical indicator we must subsequently define their determination method, necessary input data, physical dimensions and method of assessment and presentation. The proposed methodology has been also developed as a web application at http://tea.fce.vutbr.cz

In order to assess the various components of WSS, the methodology is, just like the water supply system, divided into separate modules – water resources (TEAR), water treatment plants (TEAT), water transmission mains (TEAM), water tanks (TEAA), pumping stations (TEAP), ***water distribution network (TEAN)*** and water mains (TEAS).

The total assessment of the relevant structure or components of the assessed WSS by the relevant module is based on the evaluation of two basic parts of each structure or component of the WSS:

- Structural Technical part (ST)
- Technological Operating part (TO)

Compared to the standard FMEA method, the proposed methodology is expanded by another level - factors (F). Technical indicators are not assessed directly, but their evaluation is based on a set of factors proposed for each technical indicator. For each and every factor we have a uniform 4-point rating assessment system with specifications and recommendations for the specific score for each factor. Each factor and each technical indicator also comes with a **weight**, which reflects the importance of the relevant factor, indicator in the proposed assessment system. The factors are the only level, which is assessed on the basis of defined input data. Assessment made at higher levels (indicators, parts of structures, structures) are calculated based on the relevant indicator factor assessment.

The point ranking of factors is as follows:

0 – factor not assessed, insufficient input data to assess the relevant factor

1, 2 or 3 – where the value of 1 is the most favourable condition, while the value of 3 is the least favourable condition of the factor assessment

Structure	Part	Indicator	Description of assessment
A+, A, A-	A	1	optimal condition, no measures to change the assessment of this structure are required (indicators)
B+, B, B-	B	2	Very good condition of the structure (indicator), no major immediate measures are required
C+, C, C-	C	3	average assessment, no immediate solution is required, but the structure (indicator) should be monitored in the near future
D+, D, D-	D	4	critical assessment of the condition, planned measures should potentially be implemented promptly to address the condition
F	F	5	undesirable condition calling for an immediate solution to improve the condition of the structure, its part or relevant indicator
N	N	N	Insufficient input data to assess the structure or its part or indicators

Table 1 Assessment categories

Technological Operating part weight		
Technological Operating indicators		0,60
TO1 – Burst rate		0,40
F1-	Average yearly pipe burst rate [pp. km-1.year-1]	0,50
F2-	Burst dynamics	0,50
TO2 – Water losses		0,25
F1-	NRW percentage	0,30
F2-	Unit NRW [m3.km-1.year-1]	0,30
F3-	Minimum night flow	0,20
F4-	Economic loss level (ELL)	0,20
TO3 – Quality of water in the network		0,25
F1-	Water age time in the network [hours]	0,30
F2-	Incrustation impact	0,30
F3-	Transported water quality	0,20
F4-	Effect of pipe materials	0,20
TO4 – Pressure conditions in the zone		0,10
F1-	Maximum hydrostatic pressure [m]	0,40
F2-	Average hydrodynamic pressure [m]	0,30
F3-	Hydrodynamic pressure fluctuation [m]	0,30

Table 2 Structure of indicators and factors and their weighs in the TEAN module in the TO part

Based on the assessment, the assessed structures, their ST and TO parts and their indicators may fall within the following assessment categories:

This is a multi-criteria assessment. The proposed methodology is based on the weighted sum method. For this method it is particularly important to set the weights of the individual factors and indicators. The sum of the weights of various factors of the relevant indicator equals one. The same applies to the weight of indicators in the ST or TO parts of the structures. The proposed methodology is used to set the weights based on the knowledge and experience of the research team obtained also during discussions with water utility technicians. We also performed a sensitivity analysis of the influence of the proposed weights of the factors and indicators for real and fictitious water supply systems for all 7 modules.

TEAN Module

Water losses are assessed within the TEAN module in the Technological Operating Section. As it can be seen from Table 2, water losses are included in the TO2 technical indicator.

TO2 – Water losses			
F1 – NRW percentage		F2 – Unit NRW (m3.km-1. year-1)	
0	Not assessed.	0	Not assessed .
1	< 12	1	< 3000
2	12-20	2	3000 - 7000
3	> 20	3	> 7000
F3 – Minimum night flow		F4 – Economic loss level (ELL)	
0	Not assessed.	0	Not assessed.
1	Qmin ≤ theoretical Qt,min	1	< 0,8
2	Qmin < 1,25*Qt,min	2	0,8 - 1,3
3	Qmin ≥ 1,25*Qt,min	3	> 1,3

Table 3 Example of the point assessment of TO2 Water losses indicator factor

For this indicator we propose 4 factors expressing various water losses indicators in the relevant water supply network and the borders of the point ranking.

Economic loss level

What is the most important for the operator of the water systems is to determine the economically acceptable values of water losses indicators. These are values the further reduction of which is not economically efficient for the operator. The Economic Loss Level (ELL) values can be determined using the following simple relation.

$$ELI = E \cdot L \qquad [-]$$

where **EI** - economical index can reach the following values

1,5 - water in the audited system is treated in a two-stage process and pumped to a minimum height of 50 m of water column.

1 - water in the audited system is treated in a two-stage process but it is conveyed to the system by gravity, the water for the audited system requires only disinfecting, i.e. simple treatment, but it must be pumped into the system

0,5 - water in the audited system requires only disinfecting i.e. simple treatment and it is conveyed to the system by gravity

LI – losses index is based on the following relation

$$\mathbf{L} = \frac{\mathrm{UNRW}}{3600} \qquad [-]$$

where **UNRW** – Unit Non Revenue Water

The UNRW = 3600 [$m^3.km^{-1}.year^{-1}$] value represents the recommended value of the unit leakage indicator for networks that are in a very good technical condition. For evaluating water losses using the ELL indicator, the following simple methodology was prepared

If **ELL > 1,3** it is a pressure zone where the water losses cause significant economic operating losses and where it is desirable that the operator should focus intensively on their reduction.

pressure zone	F1 NRW percentage		F2 Unit NRW		F4 Economic Loss Level		TO2 Water losses
	%	category	$m^3.km^{-1}.year^{-1}$	category	-	category	
101	8	1	3060	2	0.9	2	2
111	21	3	1760	1	0.5	1	2
112	36	3	2208	1	0.6	1	2
113	5	1	49	1	0	1	1
121	55	3	5412	2	2.3	3	4
122	81	3	4358	2	1.2	2	4
123	77	3	5163	2	1.4	3	4
124	51	3	6309	2	1.8	3	4
125	11	1	5108	2	2.1	3	3
131	14	2	919	1	0.4	1	2
141	38	3	1643	1	0.5	1	2
142	78	3	2161	1	0.9	2	3
211	10	1	3288	2	0.9	2	2
221	33	3	8962	3	3.7	3	5
222	6	1	2390	1	0.7	1	1
231	27	3	1557	1	0.6	1	2
232	24	3	6043	2	2.5	3	4
233	14	2	883	1	0.2	1	2
234	22	3	6932	2	2.9	3	4
235	7	1	429	1	0.1	1	1
236	5	1	1911	1	0.5	1	1
237	5	1	2389	1	1	2	1
241	25	3	3554	2	1	2	4
242	37	3	2910	1	0.8	2	3
243	52	3	293	1	0.1	1	2
311	14	2	6999	2	1.9	3	3
312	5	1	9561	3	4	3	3
341	8	1	318	1	0.1	1	1

Table 4 Evaluation of pressure zones using the water losses sub-indicators

0,8<ELL<1,3 it is a pressure zone where the present water losses do not cause any major economic operating costs

ELL < 0,8 it is a pressure zone where the water losses are adequate in technical and economic terms and execution of further measures focusing on losses reduction would not be economically efficient

CASE STUDY

The proposed methodology was applied to a case study in the regional city in the Czech Republic. Approximately 160 thousand inhabitants are connected to the water network in the case study. Evaluation of the technical conditions of the individual pressure zones seen from the point of view of pressure losses and the values of sub-indicators for each pressure zone are shown in Table 4.

This case study was chosen to demonstrate the possibility of evaluating the pressure zone in terms of water losses even without a complete set of data. In this case, the minimum night flows were not considered. The overall TO2 evaluation for each pressure zone is determined by the weighted average, without considering the weight of the non-evaluated factor.

As regards water losses, one pressure zone is evaluated as being in „unacceptable condition". This is zone 221. As it can be seen from the table above within the Factor F1 - NRW percentage the evaluation of the factor is 3 for 15 pressure zones. On the other hand, within the Factor F4 - Economic loss level, only 6 zones of the same pressure zones have got the evaluation of the factor 3, indicating that a high percentage of non revenue water does not always mean high economic losses. For example, for the pressure zone 243, the evaluation of the non revenue water percentage is 3 (57%) is evaluated, but the two remaining factors are evaluated by 1. This example demonstrates the need to consider the water loss assessment as a multi-criteria assessment.

CONCLUSION

Over the past decade, the water supply system in the Czech Republic has undergone significant changes in terms of the proprietary relations and the reliability for drinking water supplies and the quality of services. The issue of water losses has been one of the key problems encountered by the operators in the Czech Republic and handled by the management of water companies. Auditing of the technical condition of the water networks in water supply systems using a uniform methodology makes it possible to define the hot spots in the system and it is also used as a background for the Active Leakage Control (ALC) and planning of water mains reconstructions. The presented methodology and its implementation in one of the biggest water companies in the Czech Republic has suggested a possibility of using various indicators of water losses including the data required for their determination.

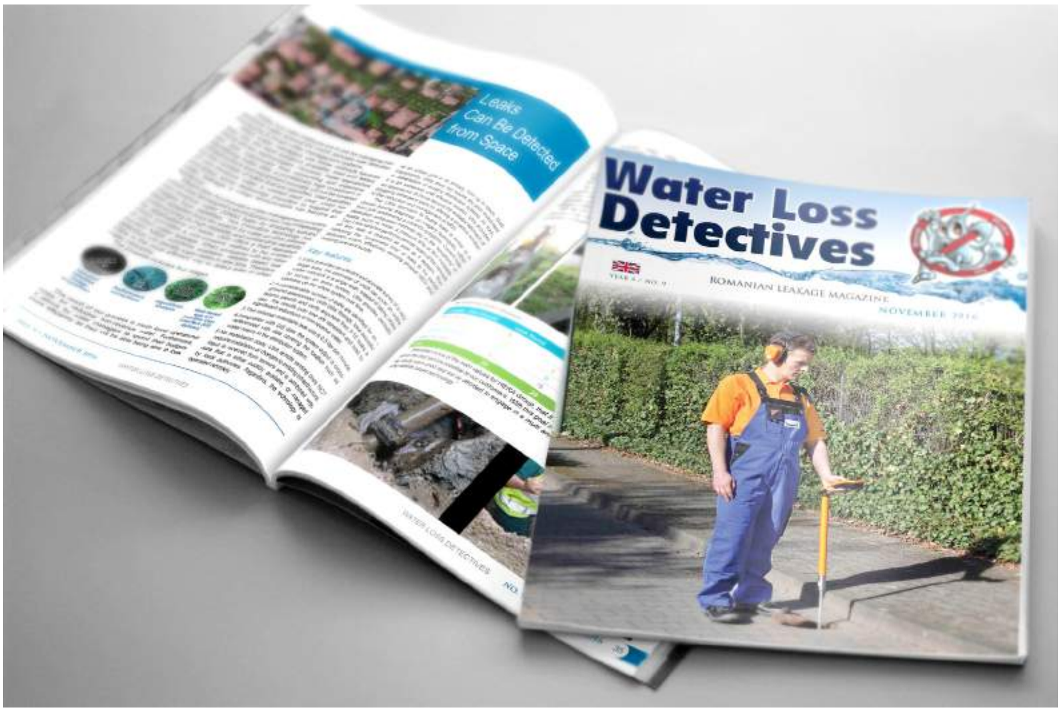
In general, the level of losses should be reduced to the lowest possible level, but the attention should be also paid to the economic effectiveness of leakage reduction. In particular in cases, where the capacity of the water, the water treatment and the distribution networks are sufficient and, even in the view of the projected water needs, there is no need for further investment in expanding the existing system and increasing of its capacity, the operators of these systems should pay attention to the economic efficiency of spending on reducing of water loss. The aim of this effort should be to determine the economically acceptable level of values of the water loss indicators used. Based on these values, a program of technical and operational measures, including the assessment of their economic complexity and a timetable, which will lead to their achievement, should be drawn up. Meanwhile, the effectiveness of spent resources in this way should be evaluated on a continuous basis. One of these tools is the TEA Water preliminary assessment methodology, which assesses water losses in a multi-criteria way, and introduces an indicator of the cost of production and transport of water - the Economic Loss Level (ELL).

ACKNOWLEDGMENT

The article was created in the framework of the project of specific research project of Brno University of Technology FAST-J-17-4384 *Influence of boundary conditions on optimization of pressure conditions in water supply networks* and FAST-S-17-4643 *Modelling of selected indicators and processes in drinking water supplies*.

REFERENCES

TUHOVCAK, L.; KUCERA, T.; SUCHACEK, T., Preliminary assessment of the technical condition of water supply infrastructures, příspěvek na konferenci 2nd EWaS International Conference, ISSN 1877-7058, Elsevier Ltd., Philadelphia, USA, 2016



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Loss Leader: The Next Wave of Water Loss Management in North America

Will Jernigan

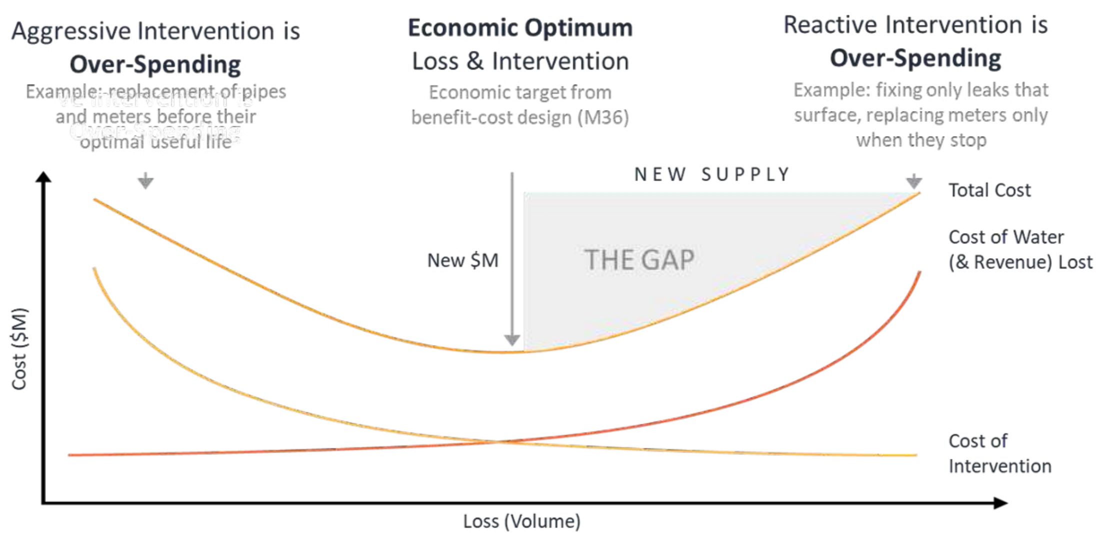
Will Jernigan is a water loss expert having worked with over 1,000 water utilities in North America. Will is a Director with Cavanaugh, and is Co-Chair for the North American Water Loss 2017 Conference.

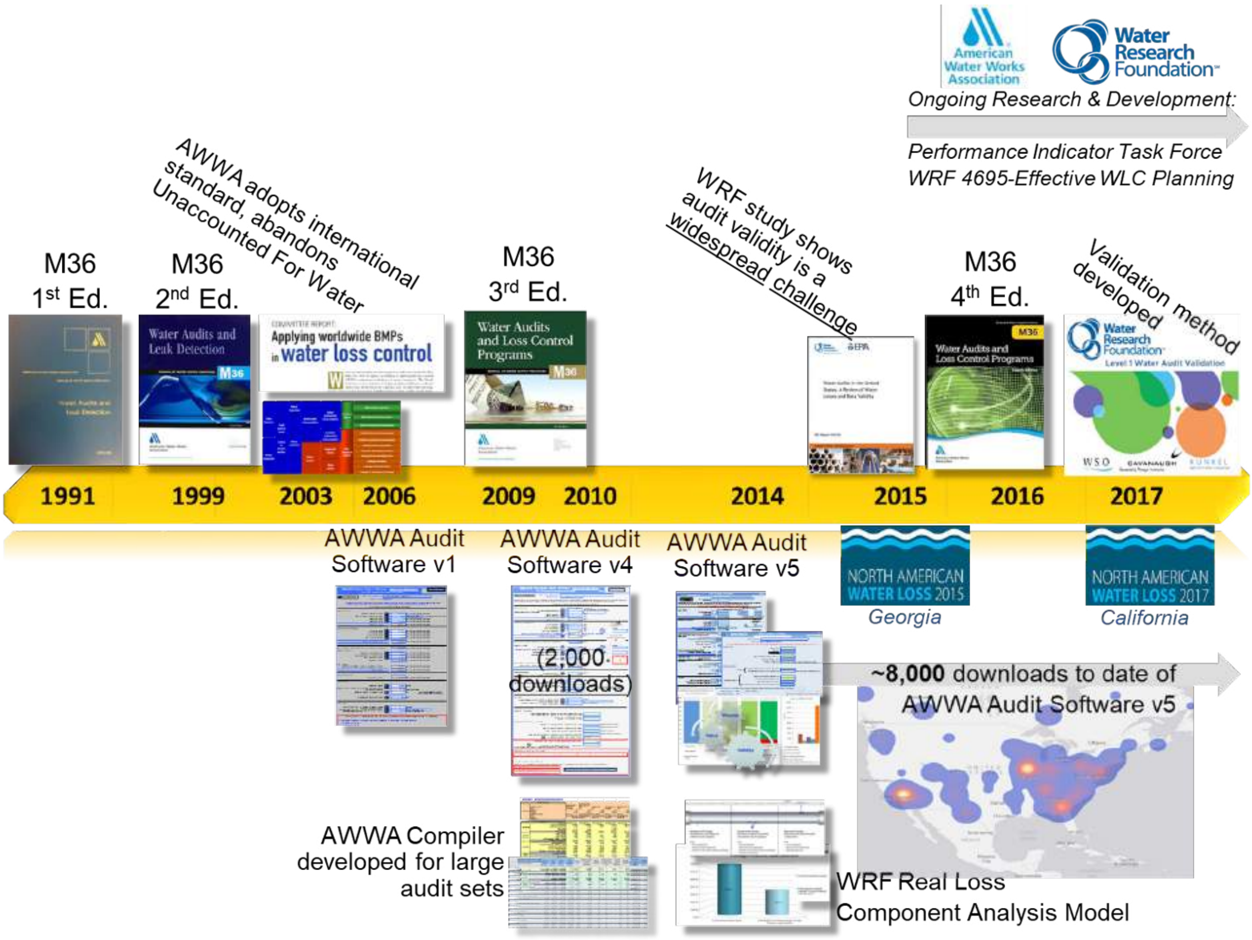
So much has happened in the North American field of Water Loss Management in the past 10 years…. even the past 2 to 3 years have brought significant new developments. Though this field is ever-growing and refining, a validated water audit to disaggregate volumes and values of all loss components remains the essential first step to mitigate water losses and positively impact your utility's bottom line. The goal is to reduce water loss in a way that is economically sustainable, both for your utility and your ratepayers. Climate change, extreme weather events, conservation rate structures and regional population shifts are changing the face of business as usual in the water industry. It's time to get with the program.

It's an exciting time to be in Water Loss Management. In its basic sense, water loss is a resource opportunity waiting to happen. The culmination of the last 25 years has taken water loss from an after-thought to a driving force for policy and management in water utilities across North America. We sit today on the cusp of widespread adoption for standard annual water auditing, validation and economically-driven water loss programs. The AWWA Free Water Audit Software (now in its 5th generation) recently turned 10 years old, and the current version at over 8,000 downloads has far eclipsed its predecessor (2,000 downloads). The M36 recently came out in its 4th edition…interesting the first edition (1991) of this anchor reference manual was entitled 'Water Audits and Leak Detection"….a testament to how far the industry has come. In fact, AWWA's water loss brain trust - - the Water Loss Control Committee, bore this same name as its original moniker. George Kunkel is an integral member of the Water Loss Control Committee and former long-time manager for Philadelphia's water loss program (longest running in the US). George was an inaugural member of the committee in 1991, rumored to have showed up and asked so many questions that they made him the committee chair. A lot has happened in the preceding years, and the Water Loss Control Committee has largely been the driving force.

Then and Now

Fast forward to 2017. Multiple states around the US are adopting the AWWA M36 standard. Presently regulations in 11 areas (California, the Delaware River Basin, Georgia, Hawaii, Indiana, New Hampshire, Pennsylvania, Tennessee, Texas, Washington, and Wisconsin) require utilities to report water loss with AWWA M36 terminology. Water Research Foundation (WRF) projects have proven out widespread challenges with audit data reliability, and established formal guidelines for water audit validation. Those widespread challenges, by the way, have very little to do with direct human error. While there will inevitably be a miscalculation here and there, and an ever-improving understanding of the basic audit process, the WRF studies suggest that 'getting the math wrong' is not what we are up against. The water industry is staffed with highly competent professionals with which we entrust our public health. What we are up against are systematic gremlins that endeavor to introduce error into the underlying data we rely upon to develop the water balance and conduct the annual water audit. These gremlins live in the supply

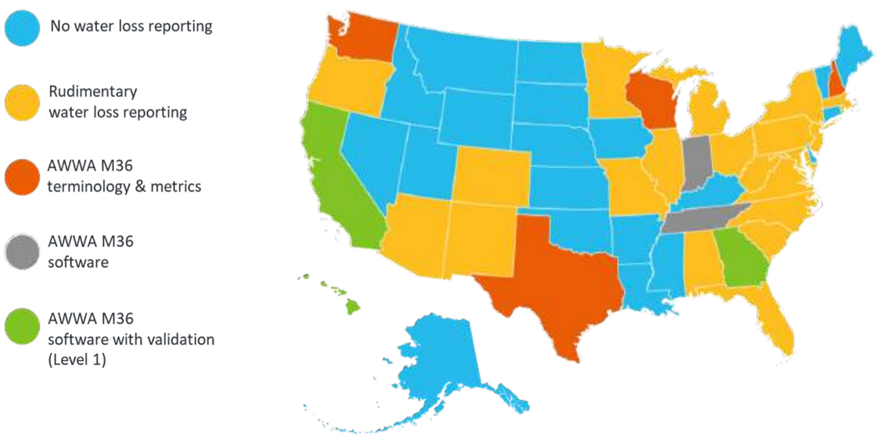


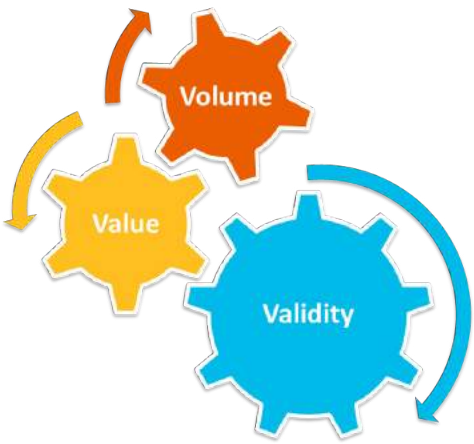


measurement systems – through meter wear, poor meter siting/installation, and conversion/transfer/ archival error. They can live in our consumption measurement systems – through data transfer, archival and coding error. Largely these issues stem from the original system design rather than system operation – which means the root cause traces back years and even decades to when the systems were first put in. Like many problems that are long in the making - - they don't get solved right away. But the industry's level of awareness, and the toolkit to address these gremlins continues to gain steam through the work of AWWA and its expert volunteers, the increased focus on water loss research from WRF, and the ever-changing water loss regulatory landscape.

Validation Versus Auditing

Validation can occur at graduated levels of effort and outcomes. As defined by Water Research Foundation project 4639 (2016), Level 1 validation is an examination for correct application of the audit methodology including errors evident in summary data and to confirm data grading applications. Level 2 investigates raw data and archived reports at a deeper level to ensure the best sources of data





have been used. Level 3 focuses on bolstering data reliability through instrument accuracy tests, pilot leak detection studies and similar field tests. Currently in California, Georgia and Hawaii, Level 1 validation is required for annually submitted AWWA water audits. California is presently under way with the largest water audit validation program in the nation – involving ~450 urban water systems across the state. A Level 1 validated water audit provides the foundation for developing an economically sound water loss control program focused on the true nature and extent of a system's losses and their financial impact on utility operations. To validate an audit, a water loss expert reviews the data entered and the associated data grades, and discusses business and operational practices with the audit preparation team. Validation does not make data inputs or grades "right" or "wrong" but merely aligns them with the actual conditions that occurred in the operation of the utility for the audit year. Any discrepancies noted during validation are discussed between the audit team and the validator, and documented in a validation report. The initial outcome of Level 1 validation is a documented understanding of the data and business practices informing the water audit. Tangible examples of this include:

- Systems discovering a billing error during its audit validation, subsequently correcting thousands of dollars of lost revenue
- Systems identifying a source metering configuration creating inaccurate measurement of the volume of water entering the system
- Systems using the water audit to communicate the need for, and value of, a targeted leakage detection and monitoring capital project, resulting in millions of gallons of water saved

A validated water audit provides *useful insight* into a system's profile of water loss components – expressed in validity, volume and value, known as the '3Vs'. This level of understanding is essential for a utility program to be *cost-effective*, addressing central questions of how much loss exists by type, what is it costing us, and is my data sufficiently reliable and actionable?

The Next Wave

Utilities that embrace the M36 methodology, and use their validated water loss audits to pursue an economically based water loss control program are true stewards of the resource. Primacy agencies around the US and Canada have begun to adopt this perspective, even where a mandate for auditing and validation does not yet exist. Many states are leveraging their State Revolving Fund (SRF) programs to provide direct technical assistance to utilities in auditing, validation and program implementation, in pursuit of strategic goals for capacity building. And research and development continues. At WRF, project 4695 is developing guidance on implementing an effective water loss control plan. The outcome of this project (2018) will be a guidance manual on reducing water loss economically in a way that aligns with your utility's strategic goals, local circumstances and financial parameters. This work is being complimented by efforts under way at the AWWA Water Loss Control Committee (WLCC). One key effort in play is a newly formed Performance Indicators Task Force, comprised of the WLCC's leadership, which is evaluating the and acceptability of historically applied and recommended best practice performance indicators (PIs) for assessment of water loss. The PI Task Force will issue its recommendations by June 2019. In parallel with these efforts, the WLCC is also developing the next generation (version 6) of the Free Water Audit Software (2019), which will embody insights gained from the version 5's adoption in *thousands* of systems across North America. Moving forward, key elements to watch will be regulatory developments and new research & development from AWWA and WRF. The field industry charges ahead with new developments in leak detection and data analytics technology. But the tools for auditing, validation and economic planning remain the cornerstone for effective water loss control. To find the tip of the spear, come join us in San Diego this December for the North American Water Loss Conference. www.northamericanwaterloss.org

Sidebar: All Call for NAWL

The 2nd biennial North American Water Loss Conference (NAWL 2017) will be held December 3rd-5th in San Diego this year, marking another significant step forward in the water loss industry in North America. NAWL 2017 will be hosted by the California-Nevada Section AWWA, in partnership with the Alliance for Water Efficiency, AWWA, and the US EPA. The event is expected to draw over 1,000 attendees. The inaugural NAWL, held in Atlanta in 2015, drew over 500 attendees from 37 US states, 3 Canadian provinces, and 15 countries around the world. NAWL 2017 is expected to double that attendance.

The conference will be held at a Paradise Point Resort, a destination hotel on Mission Bay in the heart of San Diego. The conference schedule includes Sunday social activities to welcome attendees, followed by 2 days of densely packed industry leading speakers and sessions on developing water loss policies, water auditing & validation, economic target setting, reducing apparent losses, controlling leakage, optimizing network pressure, and tracking performance. Over 100 speakers will present on the latest North American water loss practices including utility, consultant and regulatory perspectives. The program will also include innovative Learning Modules designed for those seeking more of a classroom learning environment. The conference will also feature an Exhibit Hall with 55 leading technology and service providers for water loss management.

Keynote speakers will include Peter Grevatt, Director of US EPA Office of Groundwater and Drinking Water, and Felicia Marcus, Chair of the California State Water Resources Board.

Registration is open! Exhibit space and sponsorships are also still available. Make your plans to join NAWL 2017 in San Diego at www.northamericanwaterloss.org.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