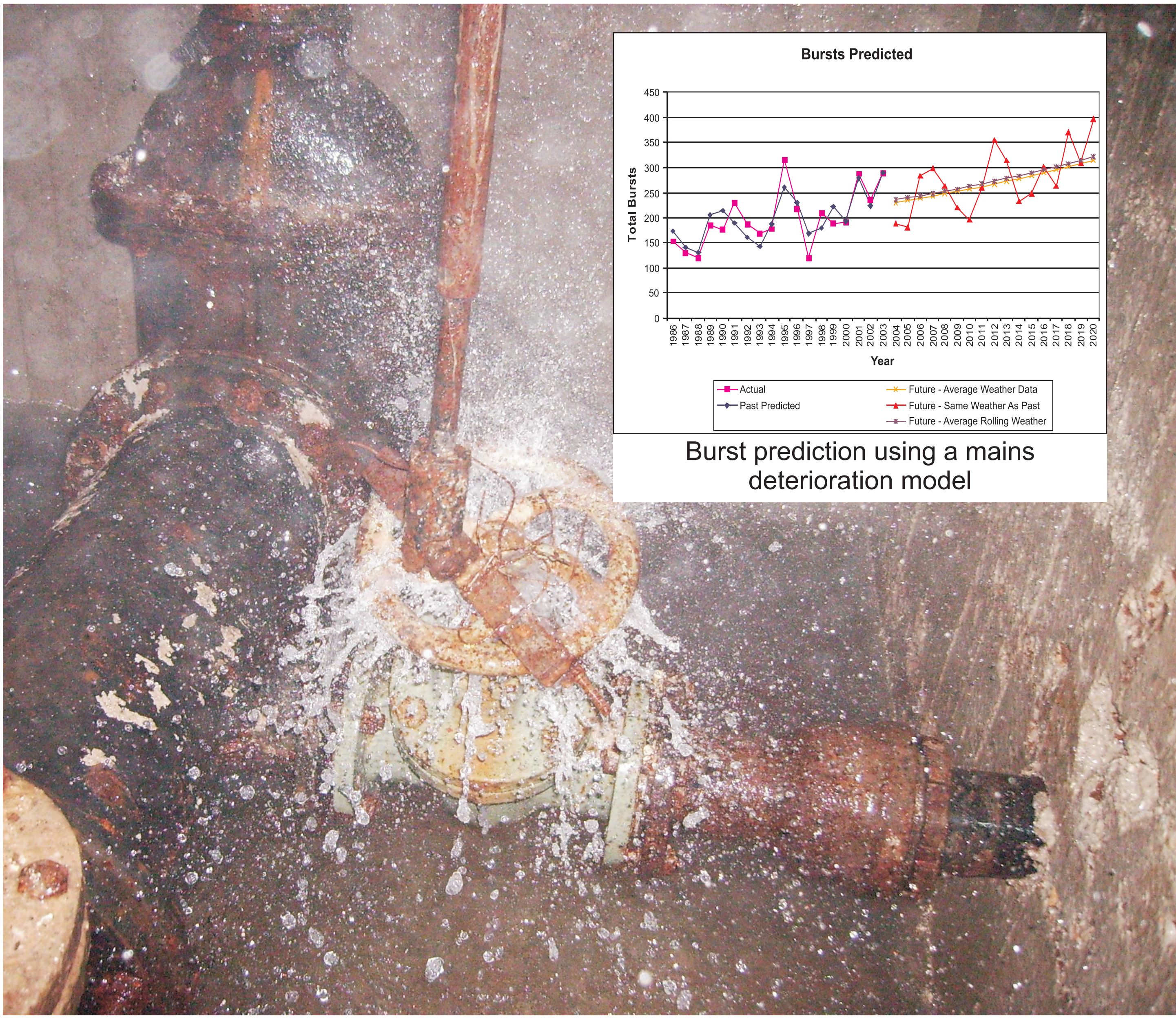
Water Loss 2007

23 - 26 September

Conference Proceedings
Volume II

Bucharest - Romania



Burst prediction using a mains deterioration model

International Water Association

Specialist Group
Efficient Operation and Management
Water Loss Task Force

ASOCIAȚIA ROMÂNĂ A APEI
ROMANIAN WATER ASSOCIATION

IWA International Specialised Conference
23 – 26 September 2007
Bucharest, Romania

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Foreword

One of the major challenges facing many water utilities around the world is a high level of water losses either through real losses (leakage) or apparent losses (meter under-registration, theft of water). This difference between the amount of water put into the distribution system and the amount of water billed to consumers is known as "Non-Revenue Water" (NRW). According to a recent World Bank discussion paper[1] the total cost to water utilities caused by NRW worldwide can be conservatively estimated at $15 billion/year.

Not understanding the magnitude, sources, and cost of NRW is one of the main reasons for insufficient NRW reduction efforts around the world. Only by quantifying NRW and its components, calculating water loss performance indicators, and turning volumes of lost water into monetary values can the NRW situation be properly understood and the required action taken.

For the last ten years the Water Loss Task Force (WLTF) of the IWA's Specialist Group on "Efficient Operation and Management of Urban Water Systems" is developing and advocating new concepts and methodologies that can help water utilities to reduce water losses more efficiently.

A part of the WLTF's efforts is the organisation of specialised conferences and the biggest so far was "Leakage 2005", an event that took place in Halifax, Canada in September 2005. More than 50 high quality papers were presented during this three day event.

Source: Water and Sanitation Program of the World Bank

Two years have passed since and the global water industry is showing even more interest in the work of the WLTF – and especially in the WLTF's 2007 conference: "Water Loss 2007" in Bucharest, Romania where some 90 papers from around the world will be presented, the majority of them included in these proceedings.

I like to take the opportunity to thank the members of the Scientific Committee (Francisco Cubillo, Prof. Anton Anton, Bambos Charalambous, Tim Waldron, Mary Ann Dickinson, Malcolm Farley, Marco Fantozzi and Dewi Rogers) for reviewing close to 120 abstracts and helping me to put the program for "Water Loss 2007" together.

However, it would not have been possible to organise "Water Loss 2007" and publish these proceedings without the enormous efforts of ARA, the Romanian Water Association. I would like to thank the Management and the Staff of ARA for all the hard work, in particular Cristina Popescu, Eugenia Demetrescu, Silviu Lacatusu, Daniel Zaharia and Vasile Ciomos.

In June 2007 I had the opportunity to visit SABESP, the water utility of São Paulo, Brazil. One of their leak detection specialists showed me the Leakage 2005 proceedings – downloaded from the Internet and nicely printed and bound. He referred to it as the "best water loss management publication". I sincerely hope that the "Water Loss 2007" proceedings will be considered an equally useful reference document for water loss management professionals around the world.

Roland Liemberger
Chair, Scientific Committee

[1] The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries - How the Private Sector Can Help: A Look at Performance-Based Service Contracting, WSS Sector Board Discussion Paper #8, World Bank, 2006, by William D. Kingdom, Roland Liemberger, and Philippe Marin

VOLUME 1

VOLUME 3

Relationship between Water Losses and Financial Elements – Study Case - Romanian Water Sector

Augustin Boer

augustin.boer@bdo.ro

Keywords: Benchmarking indicators, investment planning, non-revenue water and financial performances

Introduction

Romania is in full process of evaluating the investment needs and preparing long-term strategies in order to assure compliance with the European Directives and sustainable development of municipal services.

Apart from evaluating the investment needs and preparing long-term strategies the Romania water sector record important institutional changes as part of the process of merging the individual water operator in order to create larger regional operators. This process of creating regional operator is part of the national strategy according to the Operational Sectoral Programme (SOP Environment) approved by the Romanian Government and agreed with European Union. The regionalization process is based on the following 3 main items:

- Intercommunity Development Association (ADI) (association of municipalities) allowing the local authorities to associate in order to implemented a common integrated strategy for water and wastewater development. ADI has the overall responsibility to arrange for and control the water and waste water services in the county or region;
- Regional Operating Company (ROC) that is owned by the municipalities in the region and which is responsible for the management and operation of water services delivery in the county or region;
- Management Delegation Contract that is established between the ADI as „granting authority" (on behalf of the municipalities) and the ROC as operator and that specifies the scope and the level of water and waste water services to be provided in the region.

In this context, a more intense attention is set on the financial and operational performance improvement programmes (FOPIP). Currently, almost all the operators from Romania are benefiting or will benefit in the near future of technical assistances in this respect. An important part of the process of improvement of financial and operational performances is the development of a benchmarking strategy. The development of benchmarks started in Romania in late '90 as part of the MUDP programme (Municipal Development Utilities Programmes) and was continued by the Romanian Water Association (ARA) in the last 5 years. Currently a new benchmarking strategy is developed and discussed with all involved stakeholders by FOPIP I Technical Assistance (implemented by Royal Haskoning - Louis Berger – BDO Consortium) and the calculation of ratios, under the testing period, covers with data more than half of the Counties of Romania.

The role of benchmarks will become more and more important in the following years in the context of the regionalization process and direct delegation of services to the regional operator. The delegation contract contains a set of performances indicators and, by having a detailed benchmarking system for the sector, there will be an extra pressure on the management teams of the operators.

From the performance indicators point of view, the level of non-revenues water becomes one of the most sensitive issues for the stakeholders (mainly for the local authorities) and any strategy regarding tariffs, investment planning and business planning will have to consider it.

Considering the context presented above, the present paper analysed the impact of the level of non-revenues water and its evolution from the last years on the decisions regarding the tariff adjustments and investment planning. The link between the water losses and the elements presented above overpasses the direct impact (financial, economical and technical) and is becoming more a political tool that is used by the local authorities to take decision that based on electoral promises and not on efficiency reasons.

Relationship between the investments performed and the non-revenue water in the last 10 years

In the last years the water operators from the main cities of Romania recorded important improvement of their financial and operational performances mainly as result of international financed investment projects. For the purpose of this analysis, we selected 4 water operators (presented in the report by using the name of the cities) that were part of the MUDP II investment programme. Under this programme, the operators implemented important investments (financed from loans, grant and own sources), benefited by technical assistances for improvement their financial and operational performances and recorded important improvement of their financial performances.

However, if we analyze the evolution of the level of losses from the last years we will see that no important achievements were recorded at first sight. The following table presents the evolution of the level of non-revenue water between 1997 and 2006 considering the level of non-revenue water declared by the companies in 1997 (as part of the assessment analysis for EBRD performed by BDO Conti Audit) and 2006 (as part of the benchmarking exercise conducted by the FOPIP I TA in 2007:

Table 1.1: Evolution of non-revenues water (in %) 1997 vs. 2006

City	Non-revenues water	
	1997	**2006**
Arad	34%	39%
Bacau	55%	40%
Oradea	40%	44%
Bistrita	33%	47%

Source: BDO Conti Audit Internal Data Base

At least at declarative levels, the percentage of non-revenue water did not record any decrease in 3 out of 4 cases. In some cases it even recorded a significant increase (in Bistrita). This is due mainly of poor recording of the level of non-revenues water in 1997 mainly as result of low level of metering (close to 0%). In 1996, the main part of the invoiced water was based on standard norms and was not related to the actual water consumption. However, in the official documents, the level of non-revenue water for 1996 was the one presented above.

It is important to analyze from the quantitative point of view the evolution of the level of non-revenues water recorded in the last 10 years by the above mentioned water companies. This evolution is presented in the following table:

Table 1.2: Evolution of water losses – quantitative approach (in m3/year) 1997 vs. 2006

City	Water production (m3/year)		Water consumption (m3/year)		Water losses (m3/year)	
	1997	2006	1997	2006	1997	2006
Arad	67,928,718	23,125,054	45,078,600	14,175,658	22,850,118	8,949,396
Bacau	66,000,000	19,455,830	29,380,000	11,746,627	36,620,000	7,709,203
Oradea	51,088,333	25,736,470	30,653,000	14,342,653	20,435,333	11,393,817
Bistrita	33,636,000	12,597,984	22,452,000	6,697,323	11,184,000	5,900,661

Source: BDO Conti Audit Internal Data Base

The above table actually shows that the level of non-revenues water in quantitative terms decreases significantly in the last years. However, this decrease is also partially accurate because the accuracy of the figures from 1997 is questionable due to low level of primary and secondary metering.

The level of non-revenues water from 2006 is based on a more accurate recording considering that the level of metering is close to 100%.

Considering the elements presented above, the Water Companies have to be very careful in presenting these evolutions mainly from public relation point of view considering the relationship between the management team and the shareholders (the local authorities represented by politicians). The evolution of the data (even if the data sources from 1997 are questionable) can question the ability of the management team of the water companies in implementing an efficient water loss decrease strategy.

A possible risk from public relation point of view is represented by the tendency to present the level of the non-revenues water as percentage. In our case, even if the level of non-revenues water decreases as quantity, the percentages increased creating a possible impression of lack of efficient management.

A possible risk in questioning the performances of the management team in this respect is the correlation between the evolution of non-revenues water and the investments performed in the last years. The following table presents an estimation of the investments performed by the selected operators in the analyzed period:

Table 1.3: The level of investments 1997 vs. 2006

City	Investment performed during the period (in USD)	Investments under implementation (ISPA) (in USD)
Arad	15,510,032	23,400,000
Bacau	15,087,955	63,940,500
Oradea	47,119,037	34,320,000
Bistrita	15,881,920	29,250,000

Source: BDO Conti Audit Internal Data Base

The politicians are arguing (this is happened to a number of water managers from water companies in Romania) that important amounts of investments were performed in the last 10 years and that no impact on the level of water losses is recorded.

The reason for the limited impact of the investments on the level of non-revenue water is determined by the following reasons:

- The low accuracy of data from 1996;
- The main part of the investment were focused on water quality improvement (water treatment plans refurbishments) and environmental aspects (wastewater treatment plants);
- Only a small part of the investments were focused on water network rehabilitation;

Considering that in the context of development of a benchmarking strategy for the system and that the non-revenue water most probably will be a performance indicator in the delegation contract, the management team of the operators will have to develop the new investment strategies taking into consideration these elements.

Relationship between the level of tariffs and the non-revenue water in the last 10 years

The relationship between the tariffs and the level of non-revenue water can be assessed at two levels:

- The impact of the high level of non revenue water on the operating costs (through additional energy and material costs) leading to higher tariff requirements;
- The political level, the bodies responsible with approving the tariff increases (in the case of Romania being the local authorities) arguing that the high level of water losses should not be covered through tariffs.

The first element is important and should be considered in developing the new investment strategies for the following years in order to increase the efficiency. However, in the following years, as result of Romania's accession to EU, most probably the investment project will focus mainly on the compliance with the EU requirements meaning mainly investment in increasing the water quality, treatment of wastewater and extension of sewerage networks (the last 2 being mainly environmental investments).

The second element is very important mainly from public relations point of view. Most of the members of the local council are looking at the following two elements regarding the water and wastewater activity:

- If the customers are receiving quality water 24 hours per day and are benefiting from sewerage services;
- The level of tariff (to be maintained at low levels);

One of the most used arguments of the members of the local councils in the process of refusing tariff adjustments for the water operators is the high level of the non-revenues water (as percentage) and that the non-revenues water should not be financed through the tariff but through increase of efficiency. However, you can not achieve decrease of non-revenues water without investment and the investment might be channelled to other areas leading to a circular reference.

A comparison between the evolution of non-revenue water and the evolution of tariff increases for the 4 selected water operators from the last 10 years is presented in the following table:

Table 1.4: Tariff adjustment vs. non-revenue water

City	Non-revenue water		Tariff increase in real terms	Affordability ratio evolution	
	1997	2006		1997	2006
Arad	34%	39%	442.7%	1.9%	1.7%
Bacau	55%	40%	617.4%	2.5%	1.9%
Oradea	40%	44%	387.9%	3.0%	1.8%
Bistrita	33%	47%	318.2%	2.4%	1.5%

Source: BDO Conti Audit Internal Data Base

Even if the last 10 years the tariffs increase in real terms by more than 300%, the level of the affordability ratio calculated as percentage of the water and wastewater bill in the average household income decreased. This is the result of the following effects:

- Decrease of individual consumption from level around 250-350 litres per capita per day in 1997 (mainly set according to the consumption norms) to levels around 100-125 litres per capita per day in 2006-2007.
- The increase of household average revenues;

However, during the analyzed interval, for short periods of time, the level of affordability ratio exceeded 4% mainly due to important tariff increases in real terms from the last years of the ’90. The tariffs from 1997 were set at the level of just covering the operating costs (in fortunate cases) while the important tariff increases from the last 10 years were performed for assuring the repayment of loans contracted for investments, coverage of all operating costs and assuring investment funds from own sources.

These important tariff increases from the last 10 years had an important indirect effect on the non-revenue water due to the following cascade effects:

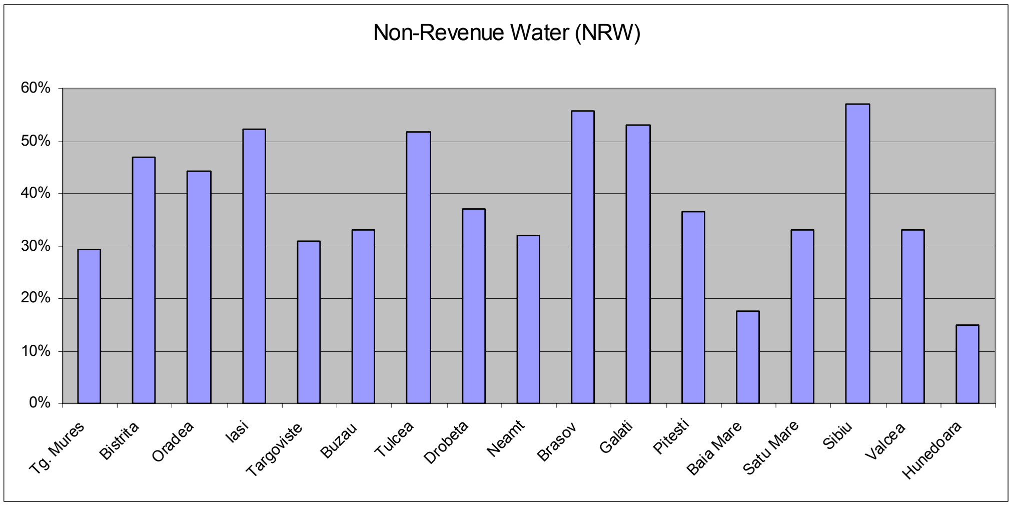
- The operators were able to contract loans for financing investments having as components primary metering of the systems leading to more accurate calculation of the level of non-revenue water;
- The high levels of the tariff increased the level of the monthly water bill (the affordability ratio exceeding 4%) making aware the consumers about the importance of secondary metering and elimination of waste of water. This actually happened, in the last 10 years in the analyzed cities, the level of secondary metering currently being around 90%;

By these effects, even if the percentage of non-revenue water slightly increased in most of the cities, the actual quantity of non-revenue water decrease due to more accurate data recording system and decrease of water waste mainly by domestic customers. This had a direct effect on the decrease of energy consumption and materials related to the water and wastewater treatment activities. This increased the financial performances of the operators allowing them to perform the investments presented in the above chapter.

Present Level of Non-Revenues Water in Romania

The level of Non-Revenues Water presented in this chapter is the result of the first benchmarking exercise conducted by the FOPIP I Technical Assistance (implemented by Royal Haskoning - Louis Berger – BDO Consortium) performed in March 2007. The level of non-revenues water for a number of 17 Water Operators from Romania (presented considering the names of the cities or regions where they operate) is presented in the following Figures:

Figure 1.1: Level of Non-Revenues Water in 2006



Source: FOPIP I Benchmarking Exercise Results, March 2007

From the presented results it can be seen that even today, when the degree of primary and secondary metering in the analyzed cities is high, there are still recorded very low reporting on the level of non-revenues water (below 20% in Baia Mare and Huneadoara) mainly from cost management consideration. This raises an important question on how should be the level of non-revenues water be calculated.

Most of the water operators present the results based on the metered quantity of distributed water into the water system and the level of invoiced water. However, in the case of Baia Mare and Hunedoara, the level of non-revenues water is calculated not based on the level of actual water distributed into the water system but based on the level of raw water actually paid to Romania Waters (the management authority of the water sources) according to the contracts, corrected by the technological losses. The level of raw water considered in this case is not based on metering but on an agreement of the management of the company with Romanian Waters with the intention of cost consideration (to the decrease the costs with raw water).

In the context of setting up regional operators and implementation of benchmarking strategies for the Romanian Water Sector, this approach is very risky for the management team of the companies from Baia Mare and Hunedoara. If they will include in the delegation contract as performance indicators the level of non-revenues water according to the approach presented above considering only the cost decreases motivation on short term, in the future they might face important “performance” problems when these “arrangements” with Romanian Water will not be possible and they will have to record the real levels for non-revenues water.

Conclusions

In the context of regionalization and conclusions of new delegation contract according to the national strategy presented in the Sectoral Operational Programme, the role of performance indicators is becoming more and more important. And one of the most appreciated performance indicator by the local authorities (the shareholders of the water companies and the entities responsible with the service supply) will be the level of non-revenues water.

Even if in the past the water operators from Romania calculated this ratio in different ways and using different set of data (more or less accurate) in order to achieve some short-term reporting objectives, in the near future the attitude has to change significantly.

The implementation of a benchmarking strategy at the level of the water industry will allow the stakeholders to make relevant comparisons between operators and any “anomalies” (as the ones from the charts presenting the level of non-revenues water discussed above) will be immediately identified.

All water operators has to be aware that they should all start to calculate the level of non-revenues water based on real figure and supported by full metering of the systems on order to be sure that in the future their performances will be measured starting from a correct base.

Considering the importance that the local authorities are allocating to the level of non-revenues water, the water companies have to consider this element in designing the development strategies for the following years:

- The investment strategies, even if the main elements will be focus on compliance with EU Directive, should also consider investments in improving the level of non-revenues water;
- The formula of non-revenues water that will be considered as performance indicator has to be carefully explained to the performance monitoring entities in order to do not lead to misleading conclusions in the future;
- Clear explanation presented to all relevant stakeholders on the relationship between the level of non-revenues water, investment programmes, tariff levels and development strategies.

The following 10 years will record major changes in the Romania Water Sector starting from institutional issues (creation of large regional operators), following with technical and operational issue (improve of performances due to large investment for meeting the EU standards) and ending with financial performances (monitoring of performances, increase of efficiency, etc). In this context the non-revenues water will become one of the most important performance indicator and the water companies will have to treat it accordingly.

References

Royal Haskoning, Louis Berger and BDO Conti Audit Consortium, “Technical Assistance for Institutional Strengthening of ISPA Final Beneficiaries in the Water and Wastewater Sector – FOPIP I”, “Benchmarking strategy”, 2006-2007

Ministry of Environment and Sustainable Development, Sectoral Operational Programme Environment (SOP Environment), version June 2007, approved by European Union in July 2007.

BDO Conti Audit SRL internal data base for water and wastewater sector.

MEASURES FOR REDUCTION OF WATER LOSSES FROM THE DISTRIBUTION NETWORKS OF THE LOCALITIES FROM CONSTANTZA COUNTY

Eng. Aurel PRESURA, Technical manager

Dr. Eng. Nicolae PITU, Technical Counsellor

1. General presentation of the water supply system

RAJA S.A. Constantza is a joint-stock company which ensures the exploitation of the water supply and sewerage system from Constantza county, providing the following services:

- drinking water supply in 11 towns and 46 rural localities;
- collection and discharge of domestic and rain waste in 22 towns and communes;
- treatment and discharge of the waste water in the receiving water bodies;
- production, maintenance and repair of plant and installations specific for water supply and sewerage activities;
- control of drinking water and waste water quality in own laboratories.

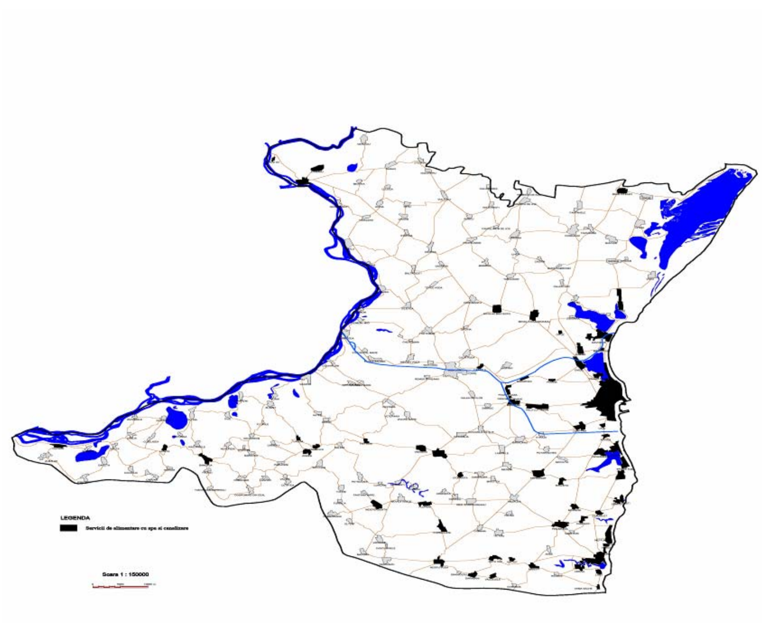


Figure 1.1. Localities where the water supply and sewerage system is operated by S.C. RAJA S.A.

The water supply systems from Constantza County are zonal interconnected systems in the Black Sea costal area and the Danube-Black Sea Channel area and isolated or micro-zonal systems in the other areas.

1.1. Existent capacities for the water supply system

- 38 depth sources, with a total number of 306 wells, total installed capacity of 8,530 l/s;

- 1 water catchment from Danube-Black Sea Channel, - total installed capacity of 4,514 l/s;

- the length of the network is of 2000.31 km, out of which:

    - 795.09 km supply network;
    - 1205.22 km distribution network.

- materials used for the network: steel, cast iron, PREMO, asbestos-cement, HDPE,

  ductile cast iron;

- wearing degree – ~ 40%;

- 98 storage tanks, total stored volume of 278,260 m³;

- 41 pumping stations, total capacity of 107,341 m³/h;

- 1 surface water treatment station (Palas), treatment capacity of 3.75 m³/s.

1.2. The structure of the drinking water supply and distribution network, depending on the material and age

Table 1.2

Type of the pipe	**SUPPLY**			**DISTRIBUTION**		
	Length km	%	Age years	Length km	%	Age years
Steel	399	40	15 - 40	664	55	40
Plastic (HDPE, PVC, etc.)	3	1	<10	14	1	<10 ; 20
Cast iron	10	2	70	143	12	70
Pre-stressed concrete	241	48	20 - 45	-	-	-
Asbestos-cement	139	8	40	384	32	40
Ductile cast iron	3	1	<10	-	-	-
Total	**795**		**15…70**	**1205**		**1..70**

1.3. The deficiencies of the water supply system are as follows :

- numerous damages of the water supply system due to the old age and the operational lifetime especially for the steel and asbestos cement pipes, resulting into a high number of supply interruption which generates a discomfort for the consumers;
- high losses in the water distribution network which generate high costs for water pumping at the sources and re-pumping stations;
- the water resulted from damages infiltrates into the basement of the buildings causing;

- the water infiltrates into the sewerage network causing the increase of the inlet flow in the WWTP;
- the unjustified increase of the water abstracted from the ground-water layer;
- unreliable operation of the closing valves from the distribution network also results into: high water losses from the network when the damages are remedied;
  - the impossibility to insulate the water network sectors in order remedy the damages.

A particularity of the water supply activity for the costal area, which concentrates ~ 80 % of the water distribution activity of the company, is the seasonality and the existence of an interconnected system.

The interconnected system(figure 1.2) along the shore line from Midia to Vama Veche, to which are connected the drinking water sources of the areas located at distance from the shore, ensures a higher exploitation flexibility and a higher security for providing the water for this populated area of Constantza County.

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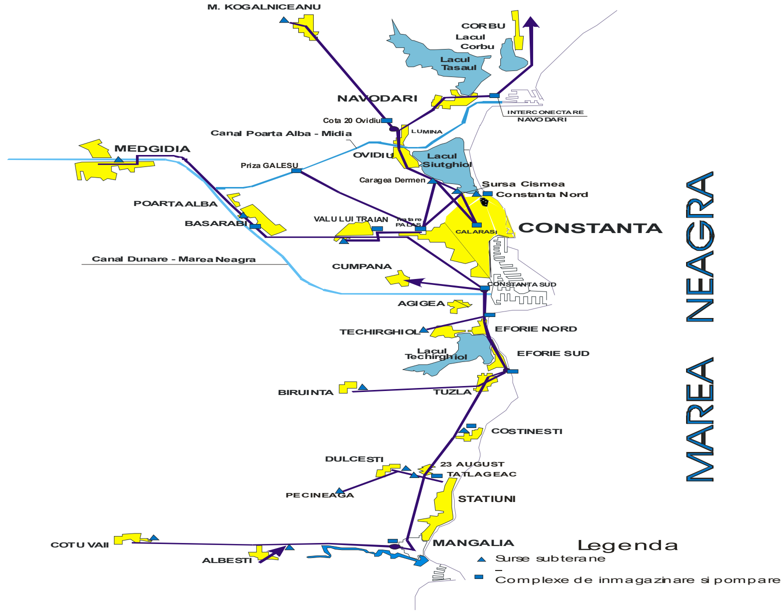


Figure 1.2 Interconnected water supply system "Litoral'

Taking into account the touristic feature of the majority of localities on the seashore, results another important characteristic of the water supply system – the seasonality of water distribution. The system has been designed to ensure the water supply for the peak season, when the population on the costal area increases significantly (at least by 50 %).

The inlet water quantity increases in the summer period (May – September) by ~ 40% (figure 1.3). More significant increases are registered for the industrial units, by ~ 85 % due to the touristic activity and for the households by ~ 100-130 %, due to unorganized tourism and the use of drinking water for irrigations.

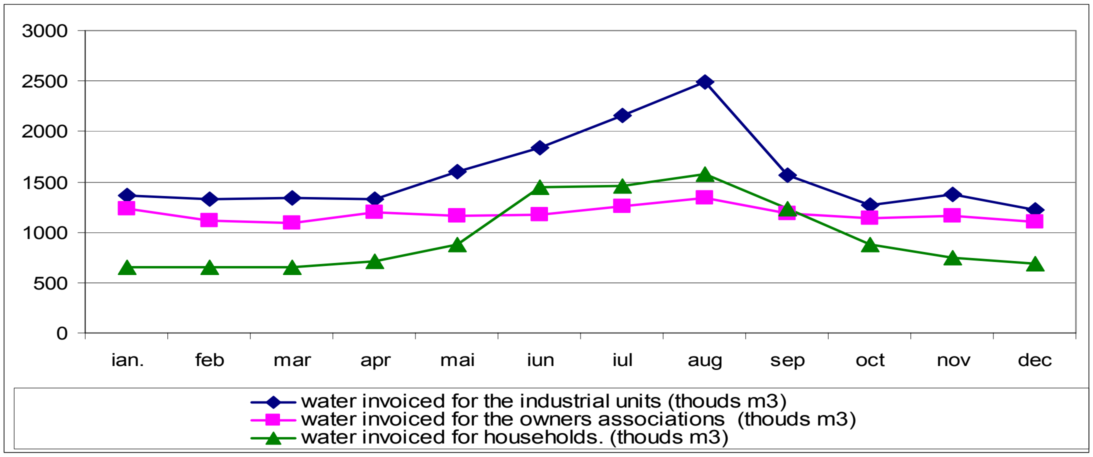


Figure 1.3 Monthly variation of the invoiced water depending on the consumers' categories in 2006

This monthly variation is more visible in case of resorts as Mamaia (figure 1.4) and Neptun (figure 1.5) and less obvious for touristic localities as (figure 1.6), which has a high number of permanent inhabitants.

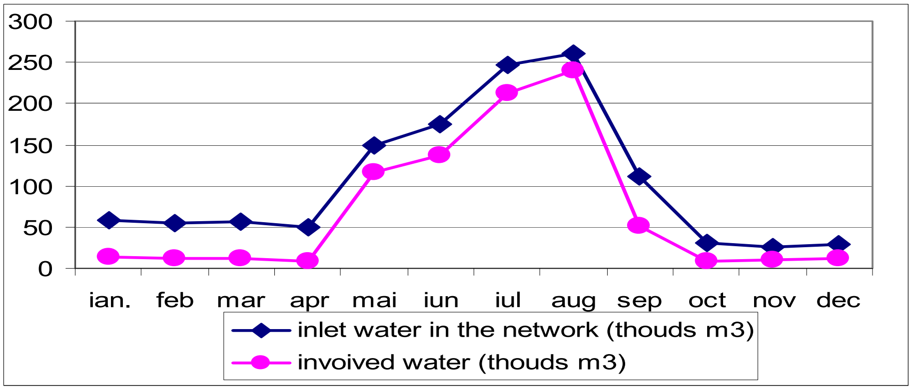


Figure 1.4 Monthly variation of the water consumption in Mamaia resort in 2006

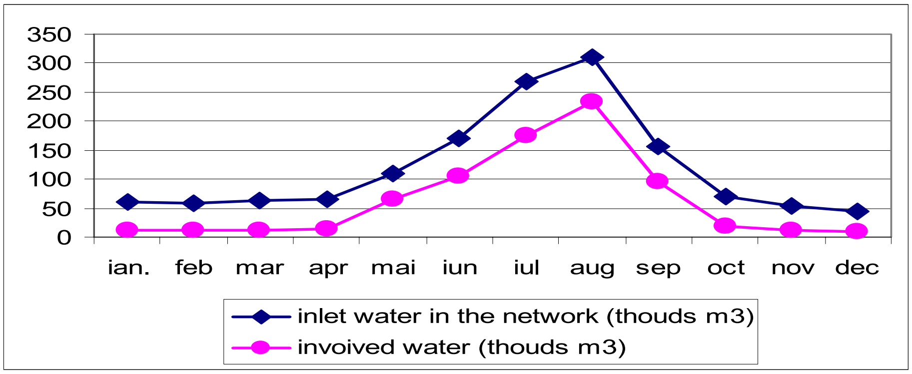


Figure 1.5 Monthly variation of the water consumption in Neptun resort in 2006

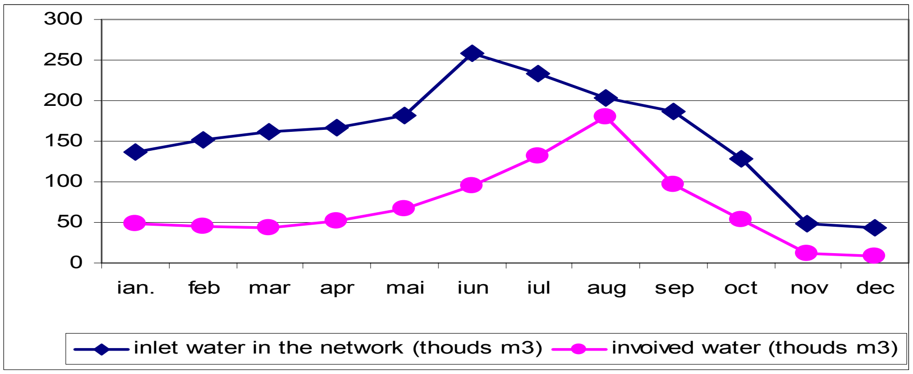


Figure. 1.6 Monthly variation of the water consumption in Eforie locality in 2006

The seasonal character of the water supply activity in the costal area presents a number of disadvantages related to the losses from the distribution network due to the necessity to maintain it pressurized in the resorts with a low level of consumption, resulted only from maintenance and security of objectives. The technical losses being constant, the percentage of the water losses as ratio between the inlet water of the resort and the invoiced water increases, reaching 80-85 % (figure 1.7).

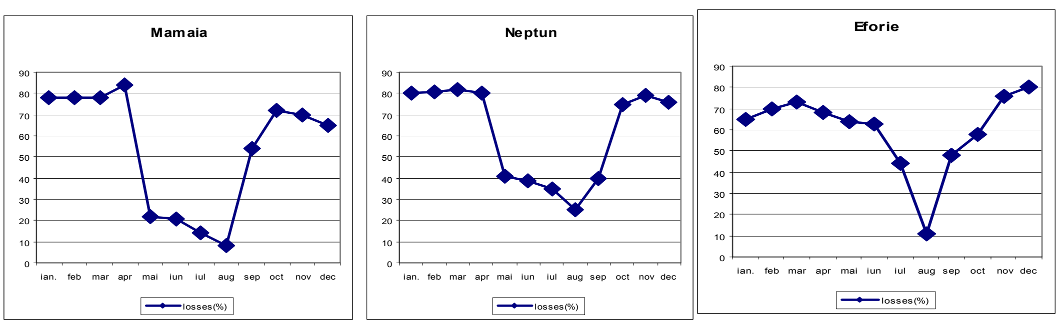


Figure 1.7 Water losses evolution in percentages for Mamaia, Neptun and Eforie resorts

2. Measures for water losses reduction, taken in the period 2006-2007

The water losses from the systems operated by S.C. RAJA S.A. Constantza are important, registering an average of 60-62 %, sometimes with significant variations from one area to the other and from season to season, generated by a number of factors, the most important being as follows:

Technical factors:

- old age of the pipes and the high degree of wearing of the majority;
- inadequate operation of the closing system;
- over- dimensioned metering.

Economic factors:

- incomplete metering;
- non-compliance with the checking programme established for the meters;

- water thefts, by different means (illegal connection to the network, meter interventions);
- misconduct of the employees in establishing the water consumptions.

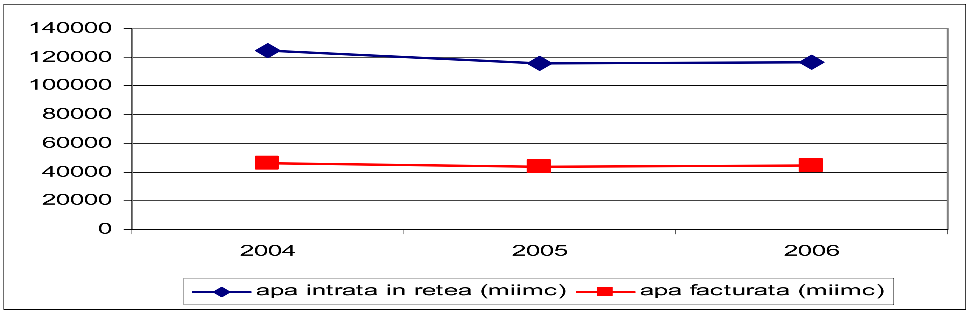


Figure 2.1 The inlet and invoiced water in the period 2004 - 2006

In order to reduce the water losses, S.C. RAJA S.A. Constantza established short-term, medium-term and long-term measure programmes. For the short-term measures, applied from 2006, we mention:

2.1 Metering with Class C water meters the pipe branches which supply the thermal plants and the blocks of flats with more than 4 levels, by hydrophores mounted in the thermal points;
2.2 Re-dimensioning of the meters mounted on the pipe branches of the F+2 – F+4 level blocks;
2.3 Completing the metering activity for the industrial units, with Class C meters;
2.4 Division into sectors of the water networks of Constantza town;
2.5 Replacement of the distribution networks presenting a high degree of wearing and damages;
2.6 Intensifying the checking activity for the cold water meters.
This paper analyzes the measures taken in Constantza, which represent over 60% of the water consumption registered by the company, but we underline that these measures have been taken for all the localities and the water supply systems operated by RAJA S.A.

2.1. Metering of the pipe branches which supply the thermal plants and tower blocks of flats

In order to perform this activity, the water meters of the thermal plants and tower blocks of flats have been re-dimensioned and replaced with Class C meters. A number of 711 water meters have been replaced, diameters ranging between 32 - 100 mm.
For this micro-systems, the water losses decreased by 10% (graph in figure 2.2).

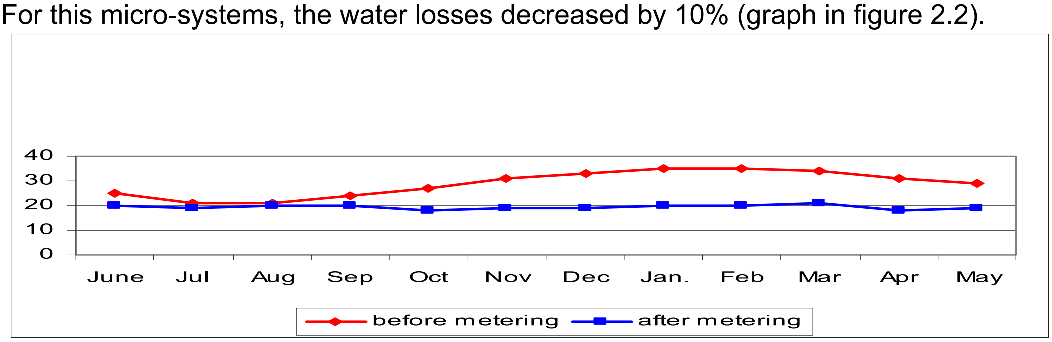


Figure 2.2 Evolution of water losses after applying the measure 2.1.

2.2. Re-dimensioning of the meters mounted on the pipe branches of the F+4 level block of flats

In order to perform this activity, the water meters of F+4 level blocks of flats have been re-dimensioned and replaced with Class C meters. A number of 3379 have been mounted, diameters ranging between 20 - 100 mm.

The water volume additional valorised for a year period was of 803 000 m³ (graph in figure 2.3).

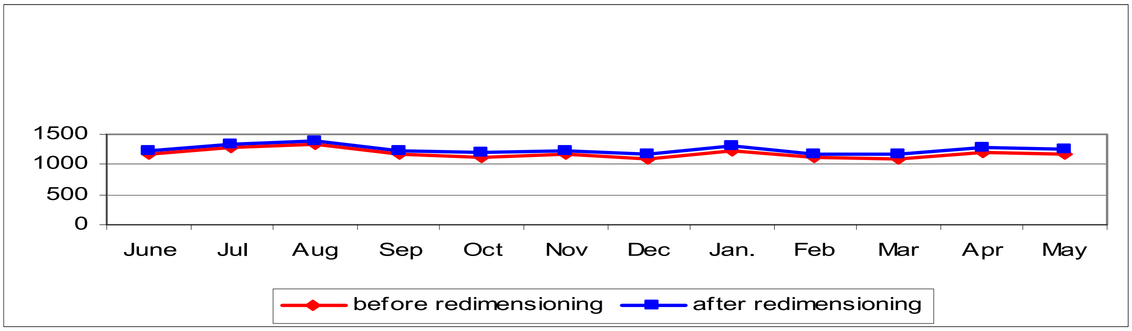


Figure 2.3 Evolution of water consumption after applying the measure 2.2.

2.3. Completing the metering activity of the industrial units with Class C meters

In 2006, out of a total number of 4,858 registered industrial units a number of 3,822 have been metered with Class C meters, the rest already being adequately metered.

An average increase by 8% of the water consumption has been registered for this consumer category. The invoiced water volume for the industrial units being before of ~18,000 thouds m³/year, the 8% represents 1.400 thouds m³/year additional valorised.

The activity did not imply additional investments for the company, the metering being performed on the industrial units expenses.

2.4. Division into sectors of the water network in Constanta

Represents one of the important measures the company is seeking to take in order to reduce the water losses. The measure allows an assessment of the water losses for limited sectors of water network, applying measures to discover the technical and economic losses, monitoring and assessing the efficiency of each measure.

Practically, the measure consists in separating the distribution network of the city into sectors, taking into account the its existing configuration and mounting water meters for each sector to measure the inlet water quantity in the respective sectors. By comparison with the invoiced water, the volume and the percentage of water losses of the respective sector are determined.

The measures envisaged and applied for reduction of losses in each sector comprise:

- discovering the illegal consumers by a serious control of the consumers;
- re-dimensioning of the meters if applicable;
- checking the meters according to the legal provisions, replacing the defective ones and completing the metering;

- discovering by means of the water losses detecting equipment the hidden damages in the sector's networks and repairing it;
- as final measure, replacing the water networks presenting a high degree of wearing.

Applying the measure implies for many cases mounting valves for separating the network and installing additional pipes to ensure the operation of the system.

2.4.1. Stage I

In Constantza a number of 12 sectors have been delimited and metered in the firt=st stage 2005-2006, which represent ~ 8% of the inlet water in the city's network. For the sectors, the above mentioned measures have been partially applied and monitored.

The comparative situation of the water losses in the area divided in sectors and not divided in Constantza, is shown in table 2.1.

Table 2.1-Production indicators achieved in Constanta in 2006

Indicator		Constantza	
	Total out of which:	**Divided in sectors**	**Not-divided in sectors**
Inlet water into the network (thouds m³)	74268	4850	69418
Invoiced water (thouds m³)	26833	2551	24282
Water losses (thouds m³)	47435	2299	45136
Water losses (%)	64	47	65

It results a water losses reduction in this area of 47%, compared to the average losses per town of 64%.

For a few sectors, the evolution of the water losses in 2006, is shown in graphs of figure 2.4.

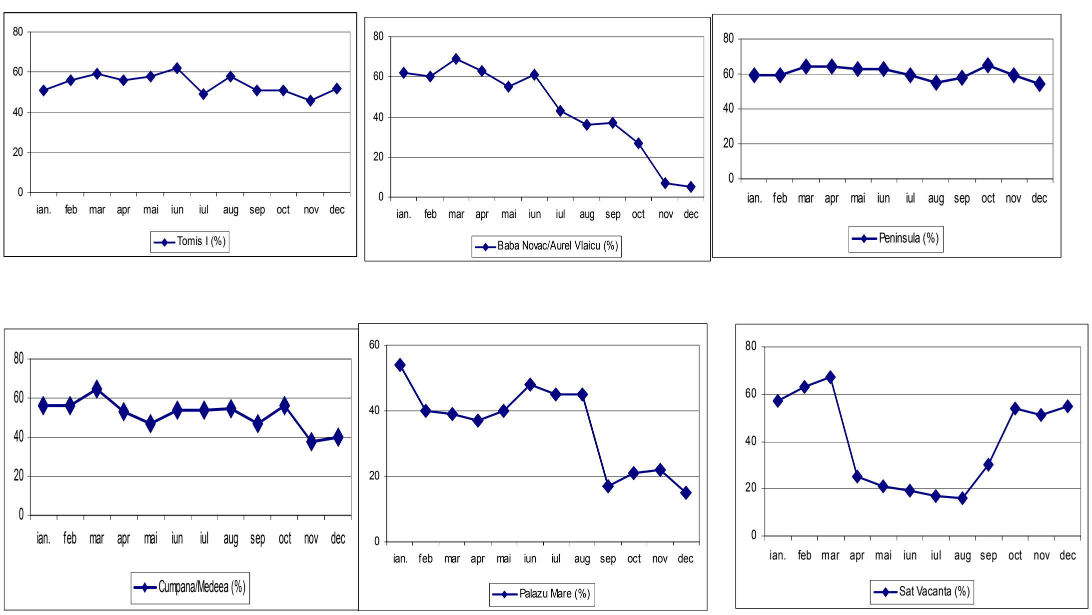


Figure 2.4. Evolution of the water losses for some delimited area from Constantza

2.4.2. Stage II

In order to develop the division of the distribution network of Constantza, in stage II another 50 network sectors (figure 2.5) have been delimited, for which a project has been drawn up, comprising the necessary works for delimiting: manholes for meters, valve manholes and other necessary works and a cost-benefit analyze of the project.

Bases on preliminary determinations, it has been assessed that the complete division into sectors of Constantza city would lead to the reduction of water losses from 64% to 58% , thus to a physical reduction of ~ 4 500 thouds m³/year.

A reduction of the percentage of the water losses of 58% and not 47% has been considered, percentage which represents the losses registered in the 12 delimited areas in the first stage as:

- the length of the transport and distribution networks is bigger than the length of the existing networks in the first stage areas, so the efficiency of the delimitation will be more reduced;
- the areas comprised in stage II comprise the distribution networks with high diameters and their replacement incurs high costs, difficult to sustain in this stage ;
- the age of the water networks differs from one area to the other.

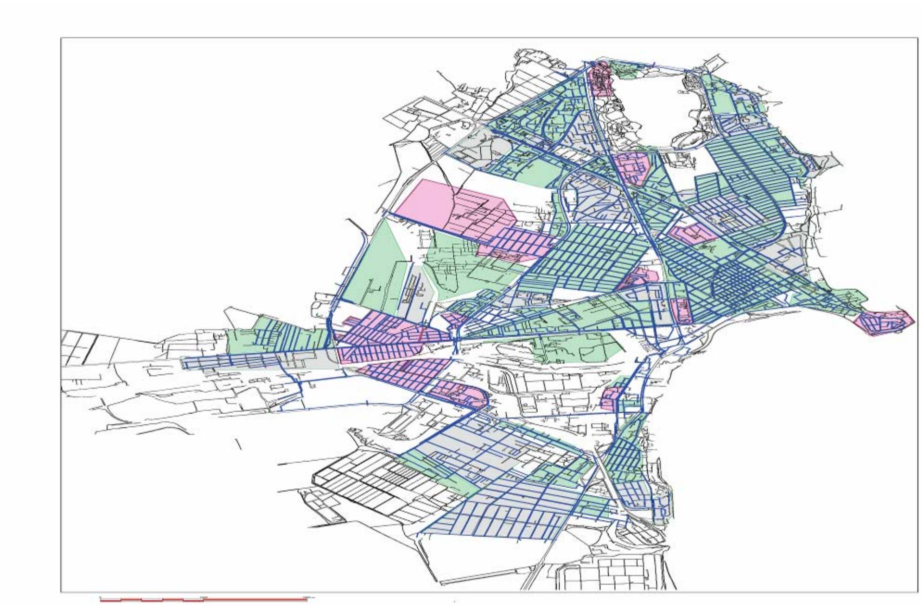


Figure 2.5. Drawing of the existent and designed network sectors in Constantza

2.4.3. Cost-benefit analyze of the delimiting into sectors project in Constantza
(extract from the delimiting project)

The implementing costs of the project have been calculated taking into account the works necessary for the extended division in sectors in Constantza :

- execution of 63 valve manholes, equipped with : valves, water meters, compensators;
- replacement and completion of the water networks for delimiting the measurement areas.

The estimated value of the works is of ~ 1,500,700 lei, value depreciating in 1 year and 12 months, taking into account that a 6 % reduction of losses represents an annual reduction of the operational costs by 1,200,000 lei.

3. CONCLUSIONS:

Delimiting the network sectors in Constantza town ensures the possibility of an efficient control of the losses on small network segments, establishing with accuracy the nature of the losses (technical or commercial) and the necessary measures to reduce them.

The delimitation allows an attentive monitoring of the losses evolution in aech sector and assessing the efficiency of the taken measures.

The measures comprised in the sectors project are to be extended for all the localities supplied from S.C. RAJA S.A. Constantza's system.

Advanced Pressure Management via Flow Modulation; the Dartmouth Central PMA

Carl D. Yates, P.Eng., Halifax Regional Water Commission, P.O. Box 8388, Stn. A, Halifax, Nova Scotia, Canada B3K 5M1 carly@hrwc.ca
Graham D. MacDonald, Halifax Regional Water Commission, P.O. Box 8388, Stn. A, Halifax, Nova Scotia, Canada B3K 5M1 grahamm@hrwc.ca

Keywords: Pressure Management Area; Flow Modulation; Background Leakage

Background

The Halifax Regional Water Commission [HRWC] has documented success in water loss control through adoption of the methodology promoted by the Water Loss Task Force of the International Water Association [IWA]. HRWC put the methodology into action in 1999 and formally adopted it as a best practice in April, 2000. By March 31, 2006, HRWC reduced leakage in the distribution system by 34 million litres/day with a corresponding plant output reduction from 168 to 134 million litres/day. The total leakage reduction of 34 million litres/day is reflected in an Infrastructure Leakage Index [ILI] reduction from 9.0 to 3.0 and annual savings of $550,000. In addition to direct savings, the customers of HRWC see increased public health protection [a leaking system has more potential for contamination], less service disruption and reduced property damage, as leaks are now found in a proactive manner through early intervention. Water loss control at HRWC is holistic in nature and benefits greatly from a distribution network that is subdivided into permanent district metered areas [DMAs]. The HRWC has over 65 DMAs and a robust supervisory control and data acquisition [SCADA] system. These tools are used in tandem for night flow analysis for leakage assessment and to determine best achievable benchmarks in system flows. A typical DMA incorporates a zone in the distribution system with a maximum pipe length of 30 km, 150 hydrants or approximately 2500 customer connections.

Pressure Managed Area Operation

Objectives

Selection

As part of its holistic approach, pressure management through fixed outlet control has been actively pursued by HRWC to ensure pressure within the distribution system is optimized for customer service and kept at levels to minimize leakage. Building on the successful installation of DMAs, flow modulated pressure control was installed in a typical sector in Dartmouth to further control and manage leakage. The Dartmouth Central DMA indicated in Figure 1 was selected to evaluate advanced pressure management as a leakage management tool for AwwaRF Project 2928, "Leakage Management Technologies". By reducing system pressures during periods of low demand, flow rates through background and active leaks were expected to be reduced. Improved control of system pressures would also reduce or eliminate pressure surges that can occur within the DMA. The HRWC chose the Dartmouth Central DMA for several reasons; the DMA is supplied by two recently constructed in-ground pressure reducing and metering chambers, providing new control valves and accurate metering. Dual supplies into the DMA offered the challenge of modulating two control valves in geographically differing locations, to achieve the desired system pressure in response to the changing demand. Finally, following regular active leakage detection, the

Reaching optimum level of looses in the distribution network – a balance between the rehabilitation measures and the supportability of the consummers

Gabriel Racovițeanu*, Sandu Marin**

* Technical University of Civil Engineering of Bucharest, Sanitary Engineering and Water Protection Department, Lacul Tei Bvd., No. 124, Sector 2, Bucharest, Romania, e-mail: rgabriel@utcb.ro

** Technical University of Civil Engineering of Bucharest, Head of the Sanitary Engineering and Water Protection Department, Lacul Tei Bvd., No. 124, Sector 2, Bucharest, Romania, e-mail: msandu@utcb.ro

Keywords: Distribution network, looses

Abstract

Decreasing the level of looses in the distribution network is determined by structural measures for rehabilitation of the existing components of the network but also by improving operation of the distribution system, including measures as pressure management.

How far we can go with looses reduction is a matter of technical and economical balance which is reflected in several parameters including the capital and operating expenditures related to the level of supportability and the local habits of the population.

The paper present which are the findings in Romania related to the levels of looses in the distribution networks and which are the proposed targets for the water looses, determined after technical and economical analyses of the rehabilitation measures balanced by the effects on the supportability of the consumers.

The analysis is based on an evaluation of more than 20 urban centers in 5 counties of Romania in the past years and the targets for the next 20 years.

Introduction

After accession in the European Union, 1st of January 2007, Romania is focusing on rehabilitation of it's infrastructure. One important issue is represented by rehabilitation of the water and wastewater sector.

The Ministry of Environment and Sustainable Development selected several consulting companies to develop Master Plans, Feasibility Studies and Application for Co-financing under Cohesion Funds from the European Union.

For the project "*Technical Assistance for Project Preparation in Drinking Water and Wastewater Sector in Romania*", EuropeAid/119083/D/SV/RO-2003/RO/16/P/PA 013-04, it was selected the consortium consisting of the following companies: CES Consulting Engineers Salzgitter from Germany, the GFA Consulting Group and the Technical University of Civil Engineering of Bucharest – UTCB.

The mission of the consortium is to prepare several projects to the point where they can be proposed for EU co-financing. The localities in which rehabilitation of the water and wastewater infrastructure will be realised are presented in the next table.

Table 1. Localities components of the project PA 013-04.

Item	County	Locality	Number of inhabitants (year 2002)
1	Brasov	Brasov	284,596
2		Fagaras	36,121
3		Sacele	29,915
4		Zarnesti	25,299
5		Codlea	24,286
6		Rasnov	15,456
7		Victoria	9,059
8		Rupea	5,759
9		Predeal	5,615
10		Ghimbav	5.100
11	Calarasi	Calarasi	70,039
12		Oltenita	27,213
13		Lehliu Gara	6,562
14		Fundulea	6,691
15		Budesti	9,702
16	Ialomita	Urziceni	17,899
17	Giurgiu	Giurgiu	69,345
18		Bolintin Vale	11,702
19		Mihailesti	7,490
20	Teleorman	Alexandria	50,496
21		Turnu Magurele	30,089
22		Rosiorii de Vede	31,849
23		Zimnicea	15,672
24		Videle	11,987

Status of the distribution networks

One of the most important components in each locality is the distribution network. Practically all the distribution networks will suffer an important rehabilitation and extension process in the following years.

The milestones in Romania's development were considered the following periods:

- Period 2008 – 2010 – the process for rehabilitation will start;
- Period 2010 – 2013 – the process will reach it's maximum intensity; in year 2013 a first audit will be made by the EU;
- Period 2010 – 2015 – the process will keep it's high intensity; in year 2015 a second audit will be made by the EU;
- Period 2015 – 2018 – finalising the process for agglomeration larger than 10.000 inhabitants; in year 2018, it is supposed that Romania will be compliant;
- Period 2018 – 2026 – working on agglomeration below 10.000 inhabitants.

The findings related to the current situation of the distribution networks revealed in most of the cases the following:

- Poor stage of the networks;
- Corroded steel pipes and important quantities of asbestos cement;

- Insufficient connection rate;
- High number of damages and bursts;
- Frequent interruptions in the water supply;
- Low metering rate;
- High individual consumptions;
- High looses.

The main indicators of the efficiency of the networks are briefly discussed in the following.

Lengths of the networks

The length of the distribution networks has been analysed from the prospective of two parameters: physical length of the networks and specific length (meters of networks /inhabitants).

As it can be observed, most of the localities analysed are in range of below 50.000 inhabitants. Only 3 municipalities have over 50.000 inhabitants (Alexandria, Giurgiu and Calarasi) and only one (Brasov) has over 100.000 inhabitants.

The evolution of the length of the distribution networks in the next years (see next figure) revealed a general increase, due to necessary investments to connect different consumers, who for the moment does not benefit for the water service.

Two stages of development have been defined:

- Stage 1 – until year 2015 in which the extent of the distribution networks will reach the necessary length to cover all the needs of the localities;
- Stage 2 – after year 2015, when the investments will focus mainly in rehabilitation of the networks.

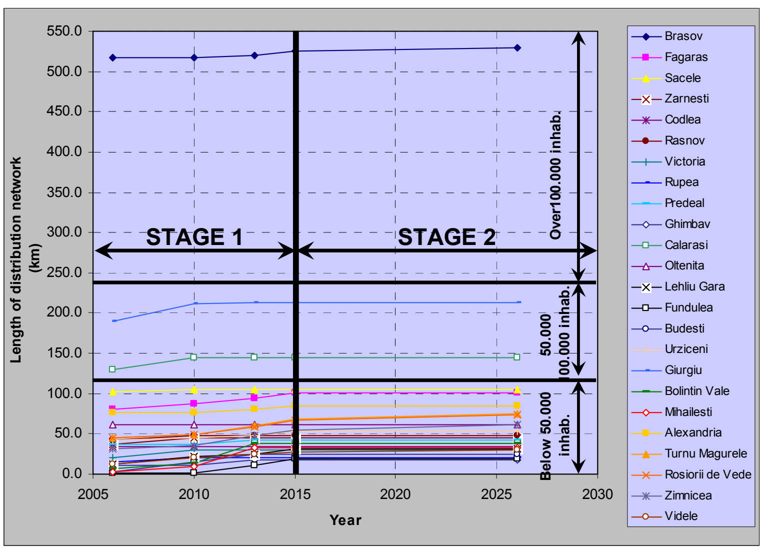


Figure 1. Evolution of the lengths of the distribution networks.

If looking at the specific length (meters of pipes divided by the number of inhabitants), a classification of the networks can be made as follows (figure 2, table 2):

- Over loaded networks, in which the number of inhabitants connected to the distribution network is very high; most of the cases here are coming from over crowded localities (Brasov, Calarasi, Alexandria, Zarnesti, Codlea);

- Distribution networks in which the load is in average range; most of the localities are in this category;
- Distribution networks low loaded; in this analyse, only Predeal is in this category, due to the fact that it is a very spread mountain resort and the stable population is quite low.

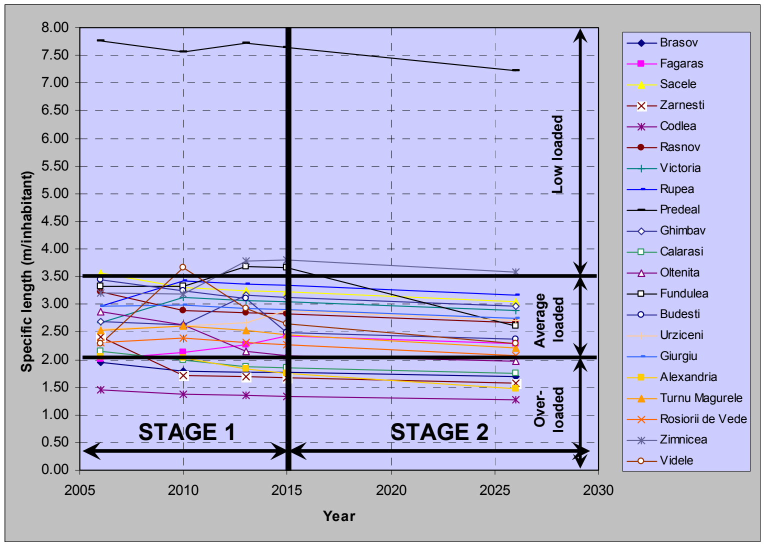


Figure 2. Evolution of the specific length (m/inhab.) of the distribution networks.

Table 2. Classification of the distribution networks according to the specific length**.**

Item	Type of the distribution network	Range of the specific length (m/inhab.)
1	Over loaded networks	< 2.0
2	Average loaded networks	2.0 – 3.50
3	Low loaded networks	> 3.50

Connection rate

The evolution of the connection rate to the public distribution networks in the analysed localities revealed an important expected increase in the next years. Practically, all the localities will have connected over 75% of the total number of inhabitants until year 2015, while it is expected that until year 2026 all the population to be connected. The following classification is proposed related to the connection rate.

Table 3. Classification of the distribution networks according to the connection rate (%).

Item	Connection rate	Values
1	Low connection rate	<50%
2	Average connection rate	50% – 80%
3	High connection rate	> 80%

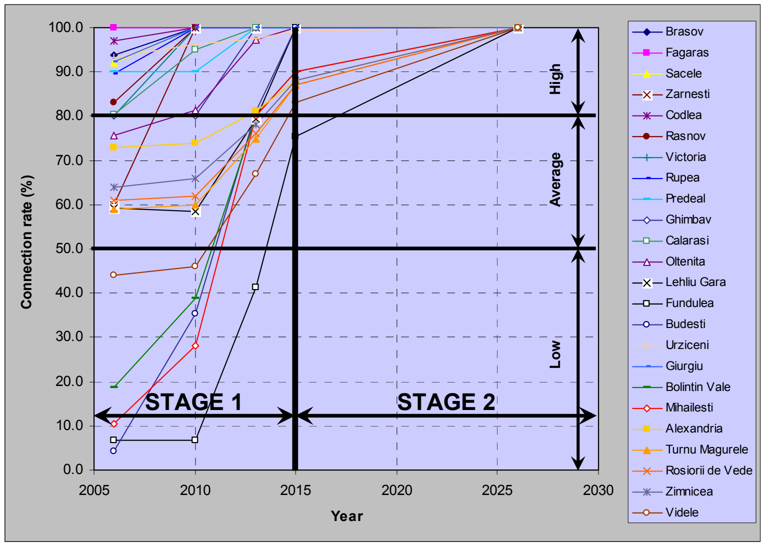


Figure 3. Evolution of the connection rate (%) to the centralised distribution networks.

If analysing the connection rate as a ratio between the units and the number of inhabitants. another classification can be made, according to figure 4 and table 4.

The analyse revealed that most of the localities are in an average range of the connection rate. Only in one case (Victoria) the connection rate is in a high value, while there are only 2 cases (Brasov and Ghimbav) in which the connection rate is in the low range. The explanation is provided by the fact that the localities in the low range have a high number of blocks of flats, while in the average range there is a mixture of blocks of flats and individual houses.

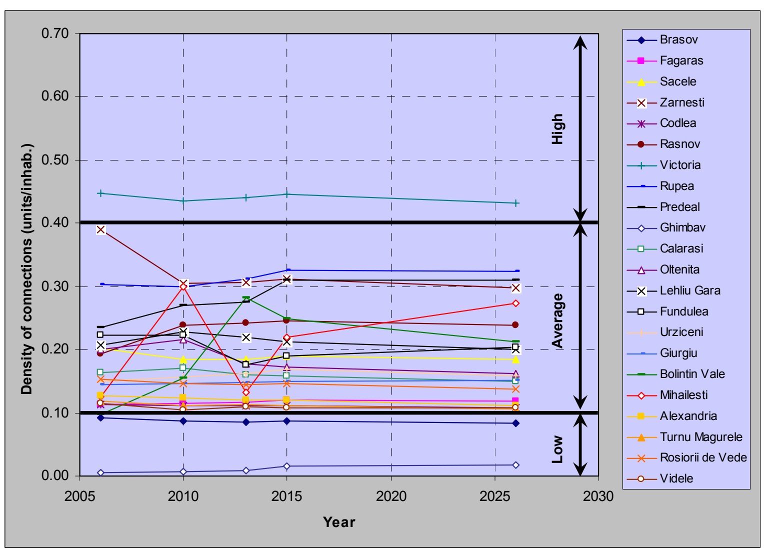


Figure 4. Evolution of the connection rate (m/inhab.) to the distribution networks.

Table 4. Classification of the networks according to the connection rate (m/inhab.).

Item	Connection rate	Values
1	Low connection rate	<0.10 m/inhab.
2	Average connection rate	0.10 – 0.40 m/inhab.
3	High connection rate	> 0.40 m/inhab.

Materials for pipes and damages in the networks

The forecast on the evolution of the materials for pipes is revealed in the next figure.

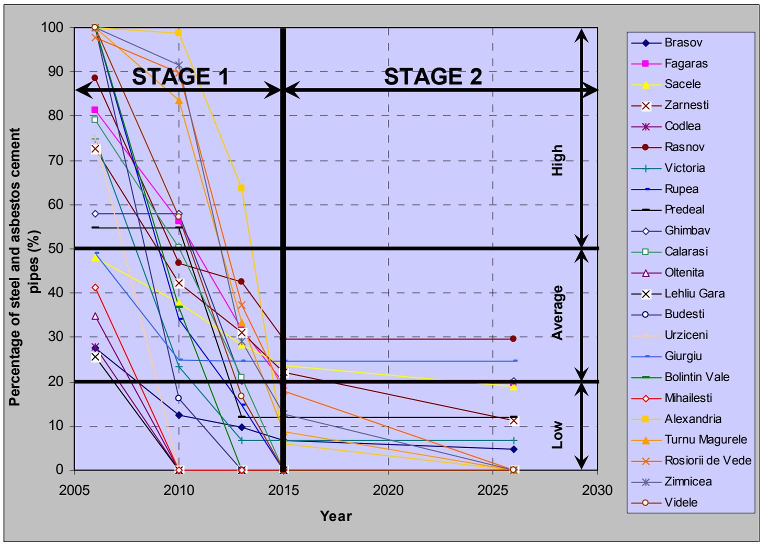


Figure 5. Evolution of the connection rate (m/inhab.) to the distribution networks.

As it can be observed, the high percentage of steel and asbestos cement pipes existing today will decrease dramatically in the next year in the favour of the plastic materials (especially HDPE), due to corrosion and related risks on human health.

Still in some cases, steel and asbestos cement pipes will remain as components of the distribution networks, but mainly in a low percentage (below 30%).

The rehabilitation of the distribution networks by replacing old and corroded pipes will consequently determine a decrease of the damages, as presented in the next tables and figure.

Table 5. Classification related to the percentage of steel and asbestos cement pipes.

Item	Composition of the network	Values
1	Low steel and asbestos cement percentage	<20%
2	Average steel and asbestos cement percentage	20% – 50%
3	High steel and asbestos cement percentage	> 50%

Table 6. Classification related to the number of damages/km/year.

Item	Number of damages	Values (damages/km/year)
1	Low number of damages	<2.0
2	Average number of damages	2.0 – 5.0
3	High number of damages	> 5.0

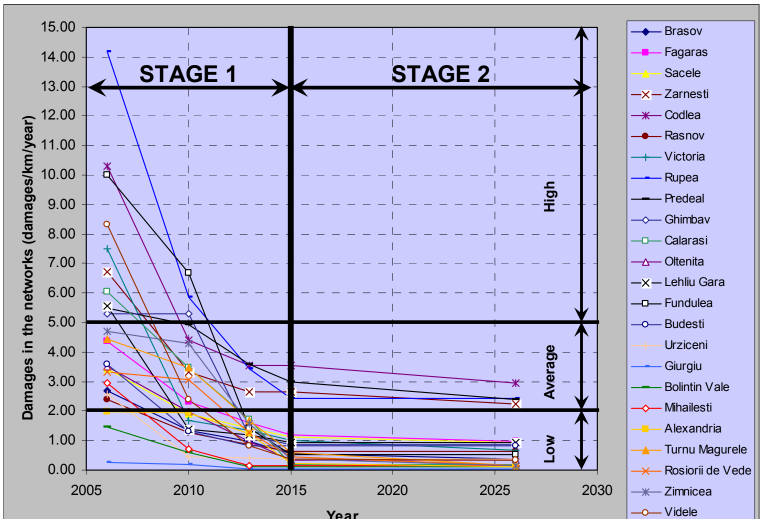


Figure 6. Evolution of the damages index in the distribution network

Physical looses

The forecast on the physical looses in the distribution networks revealed a positive expected evolution (see next figure) in which reduction of physical looses due to replacements in the distribution networks will be reduced until year 2015 to normal and reasonable values (in the range 25 - 35%) related to the today situation (40 – 65%).

This percentage can be considered still high, but the analyse was made considering only the replacements of the pipes. If applying non-structural methods like pressure management or other, further decrease is expected.

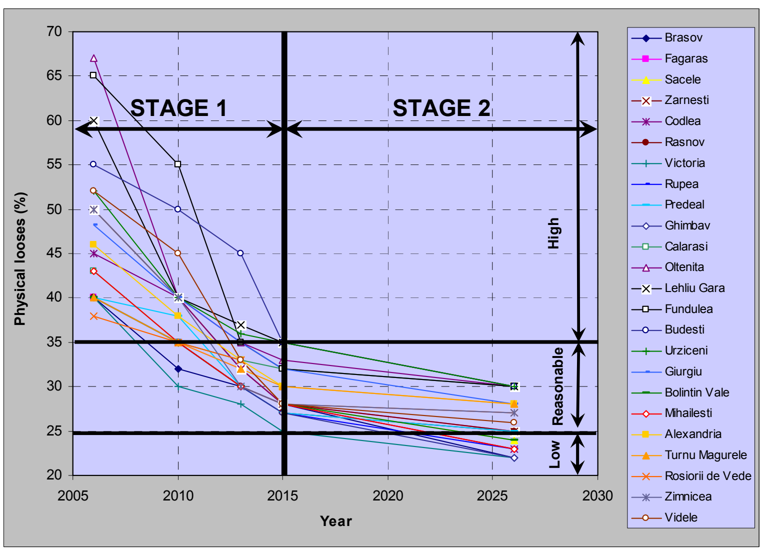


Figure 7. Forecast on the evolution of the physical looses.

A specific analyse was made on the efficiency of the investment expressed in the ratio Investment per meter of rehabilitated pipe and percentage of expected reduction of the looses.

The next figure reveal 3 stages in the next years:

- Stage 1 – until year 2013 – in which large investments will determine rehabilitation of the distribution networks;

- Stage 2 – between years 2013 and 2015 in which the investments will still continue, but the reduction of the percentage of the physical looses will become stagnant;
- Stage 3 – after year 2015, when the investments in rehabilitation of the distribution networks will start to decrease and the reduction of the physical looses will be lower, consequently.

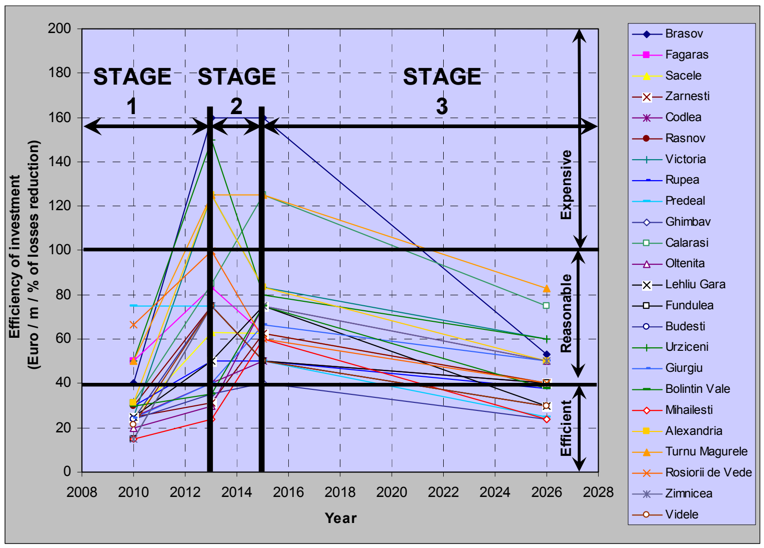


Figure 8. Evolution of the efficiency of the rehabilitation measures.

If looking strictly at the efficiency of the investments to be made for rehabilitation of the distribution networks, the following classification can be made.

Table 6. Classification related to efficiency of investments.

Item	Efficiency of the investments	Values (Euro/m/% of reduction of looses)
1	Efficient investment	20 – 40 Euro/m/%of reduction
2	Reasonable investment	40 – 100 Euro/m/%of reduction
3	Expensive investment	> 100 Euro/m/%of reduction

As it can be observed from the figure, most of the distribution networks are in the category of reasonable investment to reduce percentage of looses. In some cases, though, the necessary investments will still be made, even the costs are high.

After applying these structural methods for rehabilitation of the distribution networks, meaning and physical looses reduced to a reasonable percentage, the reduction can continue more by applying other types of measures like public awareness, pressure management, etc.

Conclusions

The necessary investments in the rehabilitation of the distribution networks will determine the following:

- Increase of the connection rate;
- Decrease of the percentage of the steel pipes;
- Decrease of the percentage of the asbestos cement pipes;
- Decrease of the damages in the networks;

- Lowering the level of the physical looses.

The analyse on the efficiency of the investments revealed that in all cases on the first slope of the graph (in the first years) the measures will determine important decrease of the percentage of the looses.

The level of the looses will still continue to decrease after large proportion of the investment have been realised, but with a lower rate.

Anyhow, in all cases, even the investments proved to be expensive, the investments has to be made in order to reduce waste of one of the most important resource: water.

The investments to be made in rehabilitation of the distribution networks are strictly related to the suportability of the consummers through the following items:

investment cost, which at least partially has to be supported by the consummers,

the disorder created by the construction works;

interruptions of the existing water supply, even in most of the cases this is unsafe.

It is always a balance between the pressure of the necessary rehabilitation and the supportability of the consummers. In our opinion and experience, decreasing the looses in existing systems only by replacements of the pipes has to reach the target of 25 – 28%. According to several calculation, decreasing the level of looses only through replacements to lower values than 25% determine very high investment costs.

It is recomandable to stop the replacements when the physical looses reached values around 25% and to continue fighting against looses with other type of measures.

Selective References

Cioc D., Anton A. – *Hydraulic networks: calculus, optimisation, safety*, 2001, Editura Orizonturi Universitare, Timişoara.

CES, GFA, UTCB – *Technical Assistance for project preparation in the wastewter and drinking water sectors of Romania* **–** Proiect ISPA, EuropeAid/119083/D/SV/RO–2003/RO/16/P/PA 013-04, 2006.

IWA – *Losses from Water Supply Systems: Standard Terminology and Recommended Performance Measures*, October 2000.

Lai, C., C. - *Eaux Perdues et Economie de la Detection de Fuites* - IR1 - Congres IWSA, Copenhaga, 1991.

Ministry of Environment and Sustainable Development –*Operational Sectorial Plan for the Environment*, Bucharest, 2006.

Sandu M., Racoviteanu G. – *Manual for sanitary inspection and monitoring of the water quality in the water supply systems* – Editura Conspress Buchurest, 2006.

Stoica, S. – *The management of the urban water supply and sewerage systems* – Ph.D. Thesis, UTCB, 2007.

GIS Acoustic Mapping in Ottawa

Kenneth J. Brothers, P.Eng.

City of Ottawa Utility Services Branch, 110 Laurier Avenue West, Ottawa, Ontario, K1P 1J1 Canada, Ken.Brothers@Ottawa.ca

Keywords: Acoustic Noise Mapping, Active Leak Detection, Noise Clusters, Acoustic Survey, Leakage Run-time, ILI

In 2005, the City of Ottawa moved away from reporting water losses through unaccounted water percentages, to utilizing the IWA methodologies and performance measurements, including the Infrastructure Leakage Index (ILI) and reporting volumes and values of lost water in the system. The IWA Water Balance was also used to focus the attention to the various categories of water use, loss, and potential for recovery of lost water and additional revenues by undertaking a more rigorous assessment of the overall accounting of water in these areas.

The City of Ottawa water system incorporates 2,700 km of distribution and transmission watermains, providing drinking water and fire protection services to approximately 800,000 people in the metropolitan area.

The City calculated an ILI of 6.4 in 2005, after undertaking the Standard Water Balance. 263 litres per service connection per day of real losses were calculated from this water loss assessment in the system with an average pressure of 43 metres. This figure contrasts to the previously reported 25% Unaccounted For Water used in the past.

With a focus on reducing real losses, the City reviewed it's Active Leak Control (ALC) program. The City was using a suite of noise correlators and electronic acoustic leak detection equipment to conduct broad system wide leak detection surveys. The City had recently implemented a systematic approach of ALC by utilizing noise correlation equipment to undertake both the survey and pinpointing activities of the program.

Through discussions with staff, it became apparent that the process of utilizing noise correlation equipment would take approximately 5 years to complete the comprehensive survey of the Ottawa system. This was based upon the staff resources available and in consideration of the extreme cold weather conditions during winter months during which the program could not cost effectively be implemented.

The water loss control team reviewed their equipment and procedures with the goal of reducing the leakage runtime by adopting the "Noise Mapping" procedure in the metallic pipe serviced areas. The Noise Mapping procedure can be applied to all rigid pipe, including cast iron, duct tile iron, copper, brass and asbestos cement systems. Acoustic noise mapping, and other sounding techniques, are not generally effective on PVC or elastic piping systems due to the limited transmission of leak noise propagation through this material.

To focus on where to implement the noise mapping procedure first, a bottom-up approach of the large sectored metered zones in Ottawa was undertaken. The bottom-up approach comprised of assessing the night time flow rates in large sectors compared to the calculation of background losses for the system size, and an estimated 6% toilet/cistern use by population equivalence calculation, in night time use between 2:00-4:00 a.m. determined from a cistern size equivalent to the plumbing standards in the sector. This approach resulted in identifying 3 major zones that experienced much higher differences in calculated bottom-up water use loss compared to the night time system input flow to the sector. Not surprisingly, the real loss areas were in those systems with the highest system operating pressure, located along the river front, and which also comprised of the oldest piping systems in the City.

The City leak detection staff were brought together to review and standardized the equipment to be utilized in the field for the acoustic noise mapping of the system. The equipment reviewed included high quality leak detection equipment, ground microphone sensors and standard equipment setup to ensure team-to-team consistency of acoustic noise mapping, and leak noise intensity documentation used in the pre-survey of above ground fire hydrants, valves and property isolation service valves.

The acoustic noise mapping procedure follows the standardized approach of acoustically sounding direct contact points on a metallic piping system to determine the presence or absence of system generated noises. Fire hydrants are typically spaced at 150 metres apart in North America, and provide excellent access points to the metallic piping systems to undertake acoustic soundings of the system to determine leaks on mains and services.

The acoustic procedure includes using ground microphones (transducers) and positioning these on top of fire hydrants, or valve keys, to provide the most direct access point to the metallic distribution system. The operator acoustically listens to the noise on the system and determines whether there is a presence of noise, and utilizes an acoustic "legend" to further describe the type of noise heard on the system. The standard legend that's applied in Ottawa includes:

1. Presence or absence of noise;
2. Intensity of noise (0-100 relative scale);
3. Mechanical noise on system;
4. Transformer noise;
5. Consumption Noise: Variations in noise intensity and pitch;
6. Pump noise; and,
7. High pitch noise: Typified a hydrant "seat" leak that is distinctively different than other system leak noises.

Utilizing this approach of acoustically sounding the equally spaced fire hydrants, or providing acoustic sounding points intermediate valves, the operator provides an acoustic array of information that determines the presence or absence of noise, and further characterization of noise by way of intensity and further descriptors to further assist the manager in assessing the potential type of leak, or leaks, monitored in the system.

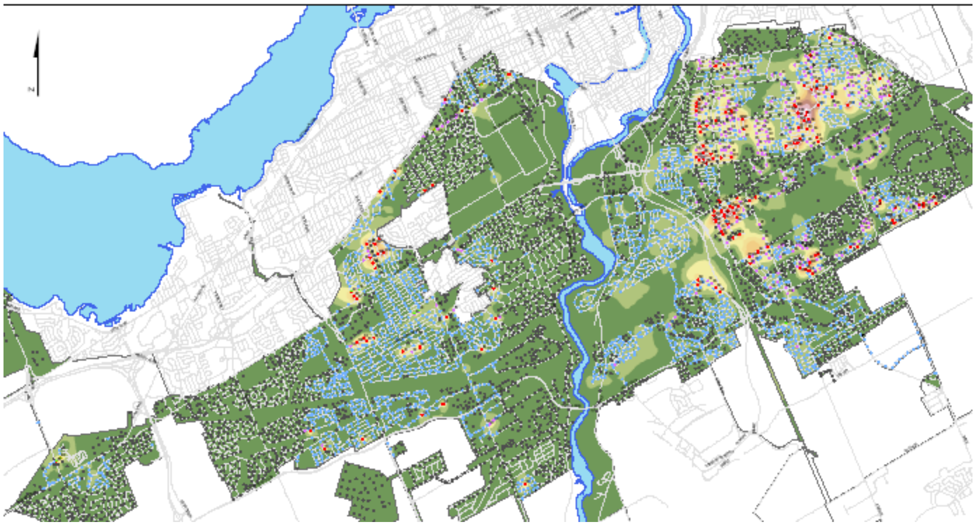
With this information in hand, the operator can use a typical water plan of the system to graphically present the noise of each leak sounding while on route. This information can be transposed to a GIS and Excel spreadsheet system for further tracking of the repairs and leak detection recheck follow-up after repairs. On the GIS system, the plotting of the leak noise and intensity provides for a full view of the leak noise color pattern, which provides for a full graphic depiction of the leak noise for review and assessment to determine the number of potential leaks in the zone.

The City is currently using handheld computer devices to document other operational and maintenance information on fire hydrants, valves and other system information. The City will be implementing data capture devices to input the acoustic noise information directly down to palm held devices, which can be uploaded into the GIS system on a daily basis, without the further transfer information from hard copy sheets.

The aforementioned documentation of leak noises, and its presentation on system maps, can provide an overview of the “acoustic mapping“ of noises heard through metallic systems. The intensity of noise has been scaled to a color scheme that shows the area of the noise plotted on the GIS mapping of the water system. With an

Ottawa : Sector 2W2C: 1,240 km Metallic Pipe – Noise Mapping

2006 - 2W2C



intensity provision, it can clearly see the rise and fall of leak noises as monitored throughout the system. The acoustic noise mapping technique provides a visual display of the potential leak locations, as well as multiple leaks that can occur within the cluster of leak noises that are monitored from the City distribution system. The use of color and the relative noise intensity figure posted to the attribute (hydrant or valve) provides for a detailed sonic view of the leak.

Ottawa: Noise Intensity Clusters Demonstrate Multiple Leaks

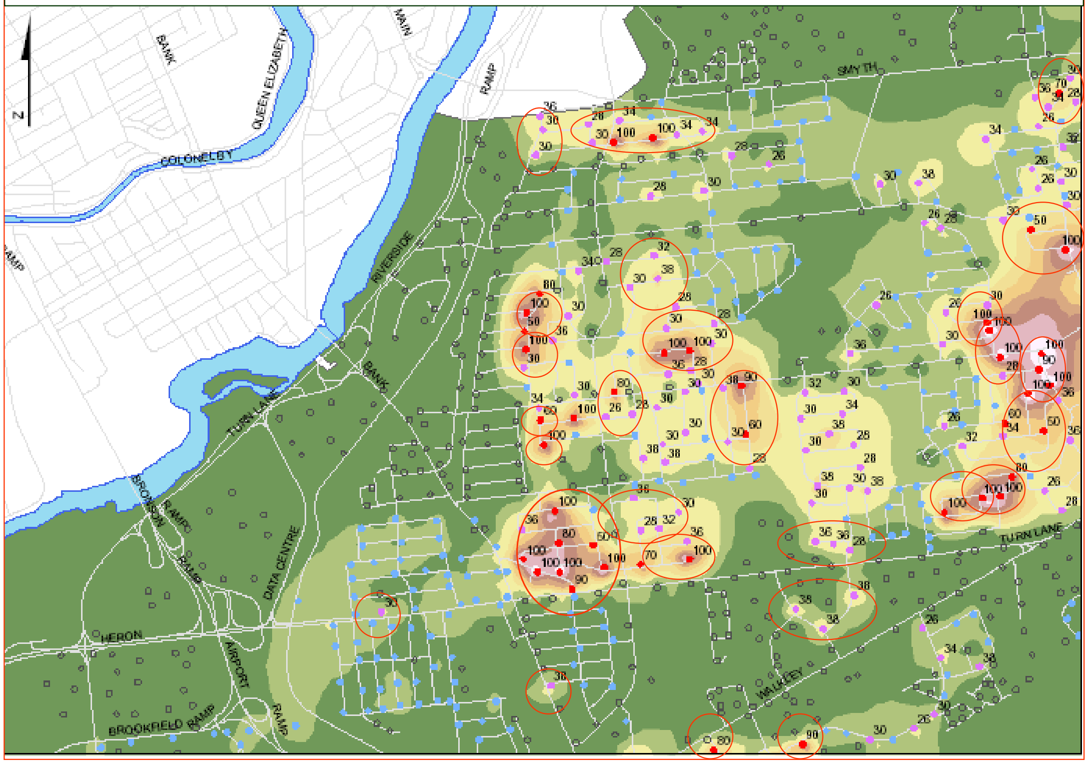


Figure #2

The Figure #1 depicts sector 2W2C comprising of 1,240 km of metallic pipe. Acoustic noise mapping was undertaken in this area and is seen on Figure #2, the GIS system plotted the acoustic noise intensities, with a variance in colour, to visualize the noise mapping and corresponding intensity of noises (leak noises) in the system. The lighter toned areas, along with the corresponding noise intensity figures, are plotted on the map. Upon review, it is evident that multiple leaks are occurring in clusters, through the assessment and profile of leak noise intensities in the various noise present areas. The noise intensity rises and falls, in groupings of high noise clusters. The corresponding reduction of noise in peripheral areas, illustrates that several leaks can be present over a very small area, and that the noises generated from each leak tend to overlap.

The acoustic noise mapping procedure, through a standardized equipment and documentation setup and description of leak noise intensity, clearly demonstrates that prior to any further leak investigation, that leak clusters (or multiple leaks) are present in many areas that have high losses. The acoustic noise mapping procedure can be used to focus pinpointing procedures for several leaks in a noise cluster area which can result in a greater number of leaks to be found and repaired more quickly than other active leak control programs and techniques. The acoustic noise mapping procedure can have a significant effect in reducing the overall leakage runtime of multiple leaks clustered in distribution systems of poor or in average condition.

The Ottawa system comprises of 1,900 km of metallic watermains. The initial survey of this system contemplated approximately a 5 year timeframe to cover the entire system. After review of the acoustic noise mapping system, staff had targeted approximately 18 months to complete the 1,900 km of metallic pipe. The process of acoustic noise mapping started in April 2006 and the 1,900 km of main was completed in 9 months. It is anticipated that this timeframe can be reduced by another 3 months as leak crews become more confident and competent in the acoustic noise mapping procedure.

The City reduced real losses by 12% in the first year of Noise Mapping procedures. More importantly, unreported leak repairs increased to 20% of all main break repairs in 2006. It was also found that 40% of the noise clusters identified in the Noise Mapping procedure were found to have one or more leaks that were repaired. The City anticipates further improvements in the percentage of unreported leaks found in the system, and realize further reductions in the volume of water lost through the reduction in leakage run time.

The Infrastructure Leakage Index has also been reduced from 6.4 in 2005, to and ILI equals 5.2 in 2006. This decrease in real losses by 12% of the system input, is estimated at 3.1 million cubic metres per year of system input.

Based upon the City's extensive watershed area and access to the Ottawa River sustainable water supply, staff have targeted a short term goal of an ILI = 4.0. A further evaluation of an economic target level of leakage will be undertaken when this goal is achieved. The City's low marginal cost of water at 6.0 cents per cubic metre will have a bearing on the economic level of leakage calculated by the City.

Conclusions

1. The acoustic noise mapping technique is a best practice for active leak control detection of unreported leaks on metallic or other rigid piping systems.
2. In systems with high leakage or infrastructure in average or poor condition, multiple leaks can occur in clustered areas.
3. Leak noises emanating from noise clusters provide an overlap and can be discerned through appropriate documentation of leak noises, intensity and noise characterization descriptions.
4. The plot of noise and intensity or a GIS format provides a successful diagnostic test to determine multiple leaks exist before pinpointing procedures and repairs occur.
5. The City of Ottawa has reduced it's real losses by 12% in the first year of the noise mapping actively controlled technique, and completed system surveys in half the planned leak detection survey timeframe.

Using an AMR System to Aid in the Evaluation of Water Losses: A Small DMA Case Study at East Bay Municipal Utility District, USA

Andrew Chastain-Howley*, P.G., Water Prospecting and Resource Consulting
David Wallenstein, P.E., East Bay Municipal Utility District

* WPRC, Water Gardens Place, 100 E 15th Street, Suite 310, Fort Worth, Texas, 76102, USA.

Abstract

This paper outlines the development and evaluation of two small residential District Metered Areas (DMAs) within the East Bay Municipal Utility District service area in northern California. The two areas have significantly different non-revenue water characteristics. The District evaluated the system usage through analysis of hourly SCADA, reservoir level data, and customer consumption using Automatic Meter Reading (AMR) systems recording on hourly intervals. This data was recorded, validated, and analyzed to better define the non-revenue water and the variation of apparent and real losses in both systems.

This is one of the first projects of its kind that evaluates water losses by using all the data integrated in close to real time. It adds a further dimension to the possibilities of district metering by allowing the District to assess the changes in system flows on an hourly basis rather than just during the low-flow minimum night flow periods. As will be noted in the paper, there are still issues, errors, and estimates in this data. However, this provides insight into the nature of the meters and enables the District to improve metered data accuracy and assess the minimum night flow usage at the same time.

The paper details the technology of AMR utilized, the results obtained, and the knowledge gained during the analysis.

Introduction

In 2005 EBMUD embarked upon an extensive pilot program to evaluate the conservation benefits of AMR systems within its service area. EBMUD conducted field studies with mobile and fixed-network systems each equipped with data-logging capabilities. The results of the mobile network system used on the Holly and Round Hill Pressure Zone were the subject of this analysis. The Holly Pressure Zone was selected based on its high discrepancy between billed consumption and water delivery to the zone. The Round Hill Pressure Zone was selected because of its relatively low discrepancy. Currently EBMUD is developing additional pressure zone balance studies with fixed network AMR technology.

WPRC, in cooperation with EBMUD, has completed detailed audits of the pressure zones in order to determine the true nature of lost water — leaks, flushing, fire flow, system meter error, customer meter error, theft, leaks from one zone to another, or any combination thereof. The tools and data used in these audits were hourly consumption from AMR- and data-logging-equipped customer meters, hourly operations data from SCADA system historian of pumping plants flow rates and reservoir level indicators, acoustic leak-detection equipment, and customer-meter testing equipment. Both locations and equipment had some issues with installation and/or operation; however, all data from each meter was available for this study. It should be noted that EBMUD meters 100% of its customers.

Background

The Round Hill Pressure Zone consists of the Round Hill Pumping Plant and Reservoir, and approximately six kilometers (4 miles) of primarily 200 mm and 150 mm piping. The majority of piping was installed in 1981 and is a mix of steel and asbestos cement. At the time of the study, the Round Hill Pressure Zone had 137 affluent customers with large homes and very large landscapes, two (2) irrigation-only accounts, and two (2) homes under construction. The meter size distribution is shown on the following table.

Table 1. Round Hill Meter Information

Meter size	Number of meters	Average Daily Use (l/conn/d)*
15 mm (5/8-inch)	116	3713
19 mm (3/4-inch)	6	7,211
25 mm (1-inch)	4	8,301
38 mm (1.5-inch)	15	5,984
Total	**141**	**4,175**

*2004 annual consumption (from bimonthly billing records)

Actual water usage in these homes is much higher than typical single family homes and averages more than (1,600 gallons) per day in the summer months. Some of the homes use as much as (37,500 litres) per day during summer months. The resolution of these meters ranges from 0.1 cubic feet to 10 cubic feet (2.83 litres to 283 litres) depending on the size and manufacture of the meter register. Based on a review of historical bi-monthly billing records the zone customer demand tracks well although the losses are comparatively high due to the very high usage (approximately .250 litres/connection/day, or 6% of total production) compared to supply records.

The Holly Pressure Zone consists of the Holly Pumping Plant and Reservoir. There are approximately four (4) miles of piping ranging in size from 150 mm to 400 mm in diameter. This piping is primarily mortar-lined steel which was installed between 1988 and 1995 with a small amount of plastic (PVC) piping installed in 1998. At the time of the study, the customer breakdown in the Holly Pressure Zone was as follows: 62 fourplexes, 62 single-family homes, 19 estates, 15 irrigation-only, and two (2) apartment buildings. The meter size distribution is shown on the following table.

Table 2. Holly Meter Information

Meter size	Number of meters	Average Daily Use (l/conn/day)*
15 mm (5/8-inch)	13	4,603
19 mm (3/4-inch)	0	-
25 mm (1-inch)	13	5,470
38 mm (1.5-inch)	127	2,805
50 mm (2-inch)	6	25,730
76 mm (3-inch)	1	101,373
Total	**160**	**4,630**

*2004 annual consumption (from bimonthly billing records)

The resolution of these meters ranges from 0.1 cubic feet to 50 cubic feet (2.83 litres to 1,415 litres) depending on the size and manufacture of the meter register. Based on a review of 3 years of historical bimonthly billing records the zone demand tracks poorly (greater than 25% loss – 1150 litres per connection per day) compared to supply records.

Aside from the 19 large estates in the Holly Pressure Zone, the rest of the services are part of a senior-living community. Homes in the senior center consist of separately metered single-family homes, townhouses connected as fourplexes with a common meter, and several apartments. In the center, all landscape and irrigation services are provided by one of several homeowners' associations and paid for through association fees. Water supplied to the fourplexes is also paid for by the homeowners' fees. All but 12 of the fourplexes and all of the single family homes in center are connected to 1.5-inch or 38 mm meters as required to meet flow requirements of fire sprinklers in each of the homes. However, because all of the demand on these 38 mm meters is from indoor uses, a significant percentage of their usage is at the bottom end of or below the AWWA-recommended operating range of $1^1/_2$ to 120 gpm (5.7 to 454 litres per minute).

Pressure Zone Audit and Balance Process

Audits of the pressure zones were first conducted by comparing billing records based on bimonthly meter reads and average supply rates from SCADA system records. After a supply vs. demand discrepancy was identified the audit process was formally begun in the following steps:

1. **Demand Data.** Hourly data was downloaded from AMR-equipped customer meters.
2. **Demand Calculation.** Hourly AMR data was summed to determine total customer demand.
3. **Supply Data.** Hourly pumping plant and reservoir operating data from EBMUD's SCADA historian was extracted and added to the database. Neither of these zones had regulated subzones so there was no bulk outflow.
4. **Supply Calculation.** Hourly system supply was calculated from hourly pumping and changes in reservoir storage.
5. **Calibration.** SCADA data was corrected for system anomalies, loss of signal, and calibration errors. Pump-flow meters were calibrated to pump curves and reservoir fill rates . System accuracy was rechecked once the typical loss rate was established.
6. **Time Shift.** When necessary, AMR data was shifted by one hour to accommodate for daylight savings time to match SCADA records.
7. **Averaging.** A three-hour rolling average was used to compare hourly demand as measured by the SCADA system and hourly demand as measured by the AMR system.
8. **Statistical Analysis.** Statistics were developed to measure the loss percentage as a function of month, pumping plant operation times, overall demand, several large-user demands, and various other factors.
9. **Meter Testing.** A small number of meters with extensive usage history and/or known excess usage along with new/unused meters were shop-tested for accuracy at flows ranging from much below design flow rate to much above design flow rate.

10. **Pipeline Leak Detection.** Acoustic leak detection equipment was used to identify any distribution pipeline or valve leaks.

11. **Audits.** Customer audits were completed to ensure that there was no unmetered use.

Authorized Uses

Authorized uses in both pressure zones are shown mainly by the billed consumption data. There were no known fireflows (testing or otherwise) during the project. Water quality flushings did not occur during the periods examined. Furthermore, there were no known contractor or other authorized hydrant uses. The Round Hill Pressure Zone had several lateral repairs but the loss was minimal and accounted for. Therefore, the data can be evaluated as it is organized with little known interference from other factors.

Leaks

A surprisingly large percentage of total water usage discovered by the AMR systems in Round Hill Pressure Zone was customer-side leaks. These leaks were identified by the absence of any zero consumption hourly readings over a 24 hour cycle. 40% of the customers had leaks which were recorded as a continuous flow of water use. Typical leaks averaged between 0.5 litre and 1 litre per minute, which is typical of a small toilet leak and amounted to a total of 91 gallons (340 litres) per household per day or approximately 12,500 gallons (47,300 litres) per day for the whole pressure zone. A 0.5 litre per minute leak equals approximately 1 cubic foot per hour consumption, which is the minimum unit recorded by most AMR-equipped meters. Ninety percent of the meters in the zone recorded 1 cubic foot or better resolution.

By comparison, only a small number of customer leaks (12%, or 19 of the 156 properties) were found by the AMR system in the Holly Pressure Zone, although the authors contend the actual leakage rate was much higher. Two of the 19 meters with recorded leaks were measuring water consumption in apartment buildings where the total leakage rate was 0.5 and 2.5 gpm (2 litres and 9.5 litres per minute) respectively. The other 17 meters that recorded leakage were associated with accounts on 15 mm (5/8-inch) and 25 mm (1-inch) meters. None of the 127, 38 mm (1.5-inch) meters recorded any leakage. However, all 12 of the fourplexes connected to 25 mm meters recorded leaks. There are two likely reasons the smaller meters were able to record the leak rates and the 38 mm meters were not: 1) the AWWA lower accuracy range of 15 and 25 mm meters (1 and 3 litres per minute) is lower than 38 mm meters (5.5 litres per minute); 2) the resolution of the electronic registers was 0.1 cubic foot (3 litres) vs. 1.0 cubic foot (28 litres) of the 38 mm size.

The Round Hill Pressure Zone has considerably smaller meters than the Holly Pressure Zone. This enabled more precise measurement of leaks because the AWWA Standard accuracy range of the meters themselves was lower (1 to 75 litres per minute). However, the resolution of the majority of the electronic meter registers in the Round Hill Pressure Zone was 1.0 cubic feet, thus requiring a continuous leak of at least 0.5 litre per minute to register. Several reasons led the authors to believe that customer leaks in the Holly Pressure Zone 38 mm meters were at least as prevalent as Round Hill even though they were not being measured by the majority of the meters:

1. The presence of 40% leaks in Round Hill where the homes were of similar age and location.

2. All 12 of the 25 mm (1-inch) meters in the fourplexes in the senior center subdivision of the Round Hill zone recorded leaks.
3. Both apartment buildings in the senior center had identifiable leaks.
4. Since the study has been completed, the senior center management has completed a toilet testing and repair program, which found and repaired numerous leaks.

EBMUD conducted a basic distribution system leakage survey in each pressure zone and found no major leaks. EBMUD maintains a GIS record of all recorded main breaks and none were reported during the study period.

Study Findings

During the study, the losses were significantly different between the two areas. The Holly Pressure Zone has significantly more measured supply-side water loss than Round Hill both in percentage terms (20% vs. 8% of total system input) and per connection (545 litres per connection per day (lpcd) in Holly, and 242 lpcd in Round Hill over the periods of record). However, both zones do have significant customer-side leakage that was metered in Round Hill but undetected in the Holly zone.

Round Hill Pressure Zone

The results of the analysis for the Round Hill Pressure Zone suggest that the SCADA system is the main source for the recorded apparent losses and the system appears relatively tight overall once this error is removed. The study also helped identify several high use meters that were no longer working which were suspected after review of graphs similar to Figure 1 which shows a marked difference between the peak supply and peak demand on certain days. These meters were most likely damaged by excessive flow over a period of time. However, there are still customer-side leaks that need to be addressed to improve the water use efficiency of this zone.

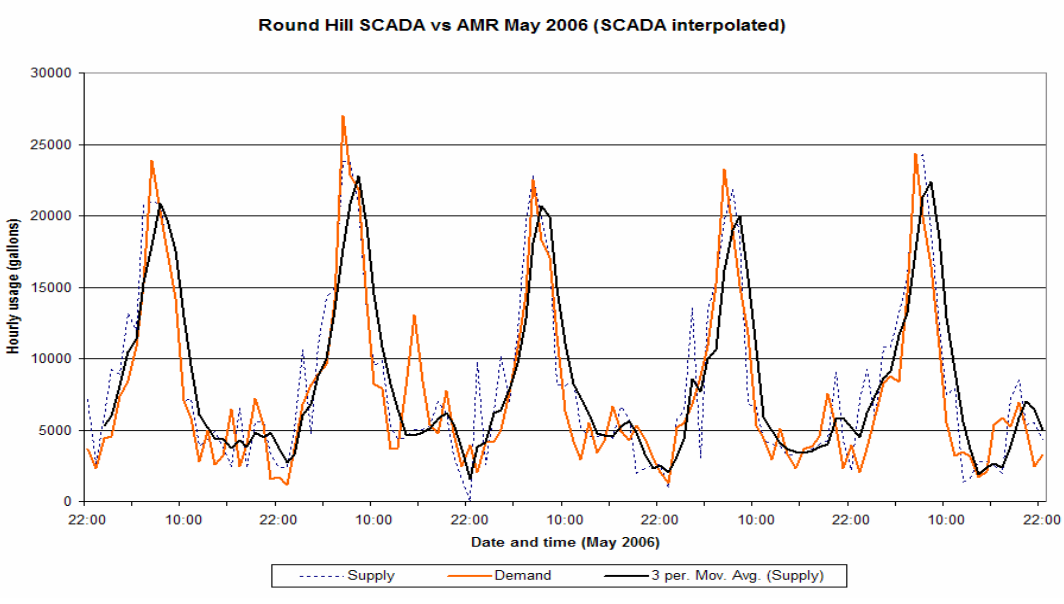


Figure 1. Round Hill supply versus demand graphs.

Holly Pressure Zone

The results of the analysis for Holly Pressure Zone appear to show a good correlation between meter accuracy and water system losses. The problems appear to be greatest above and below the AWWA accuracy ranges. The low-flow periods have significant losses. However, the largest volume problems appear to be during the highest flow conditions at the upper end of the meter flow accuracy ranges. It is quite likely that just a couple of major users are pumping far beyond the accuracy range of the in-place meter. For example, one user is constantly pumping 4.9 l/s as recorded by the AMR system (the property manager who maintains the pumping plant indicated it may actually flow much higher) in the summer months to feed their system – all through a 25 mm (1-inch) meter.

The high flow conditions only occur during the irrigation season during which time there is a massive variation in flow on a daily basis. Figure 2 outlines the demand pattern of the Holly zone, which is very peak-driven due to the irrigation systems. Other than a short time in February when the area received a few days of very warm weather, the irrigation systems were mainly started in late April.

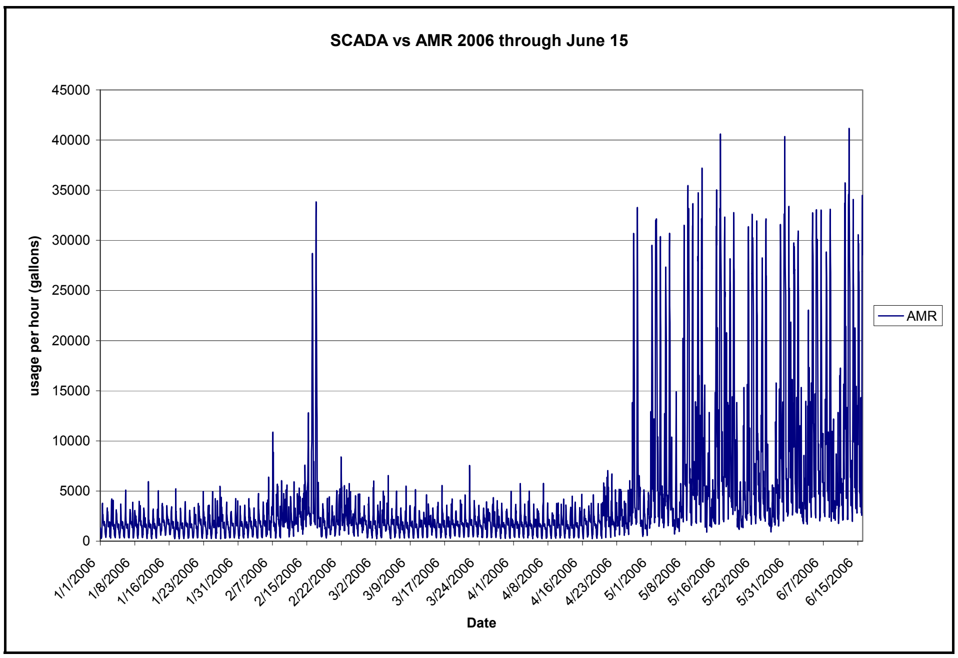


Figure 2. Holly Billed Usage from January 1 through June 15, 2006 showing peak demand for irrigation).

The data shown in Figure 3 outlines the effect of the top ten users on the Holly zone supply and outlines some of the variations between production and billing which are further discussed and explained in Figures 3 and 4.

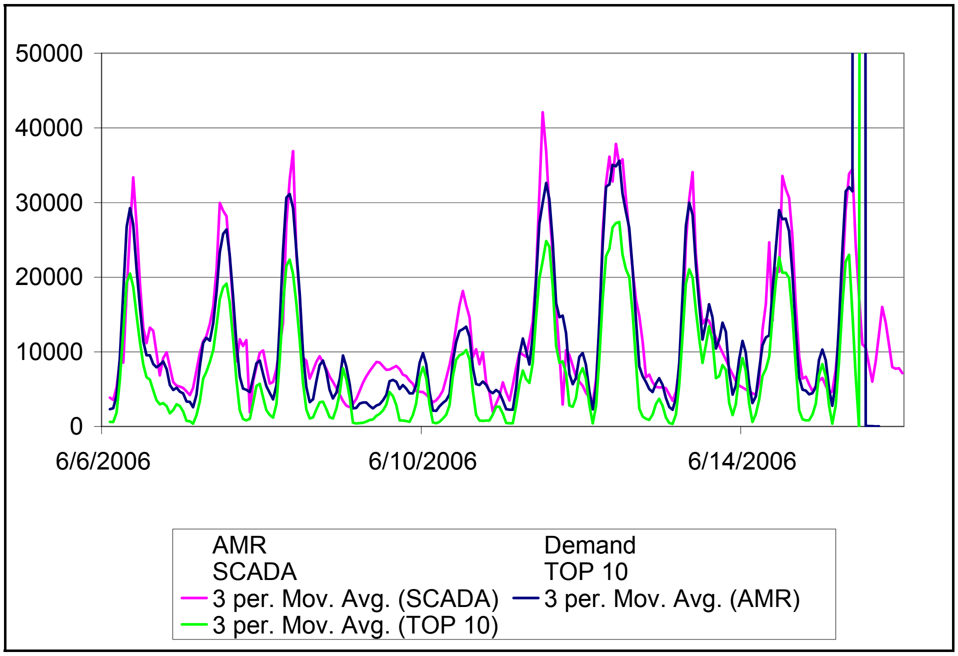


Figure 3. Ten-day production versus billed usage review

Figures 4 and 5 below outline the differences between January and June hourly averages within the project time period in 2006 when more detailed review was conducted. What appears evident is the following:

- January data shows the consistent loss throughout the day associated with the low-flow meter inaccuracy.
- June data shows the highly variable losses throughout the day associated with the high-flow meter inaccuracy.
- There is a very large variation between average and peak water use which will almost certainly cause significant stress on the distribution infrastructure, and meter performance.
- Water losses in June appear to be greater in the early morning hours when lawn irrigation is at its peak.
- The largest 10 result in more than 60% of the peaks in this pressure zone. These users drive the system demand, and the apparent losses.

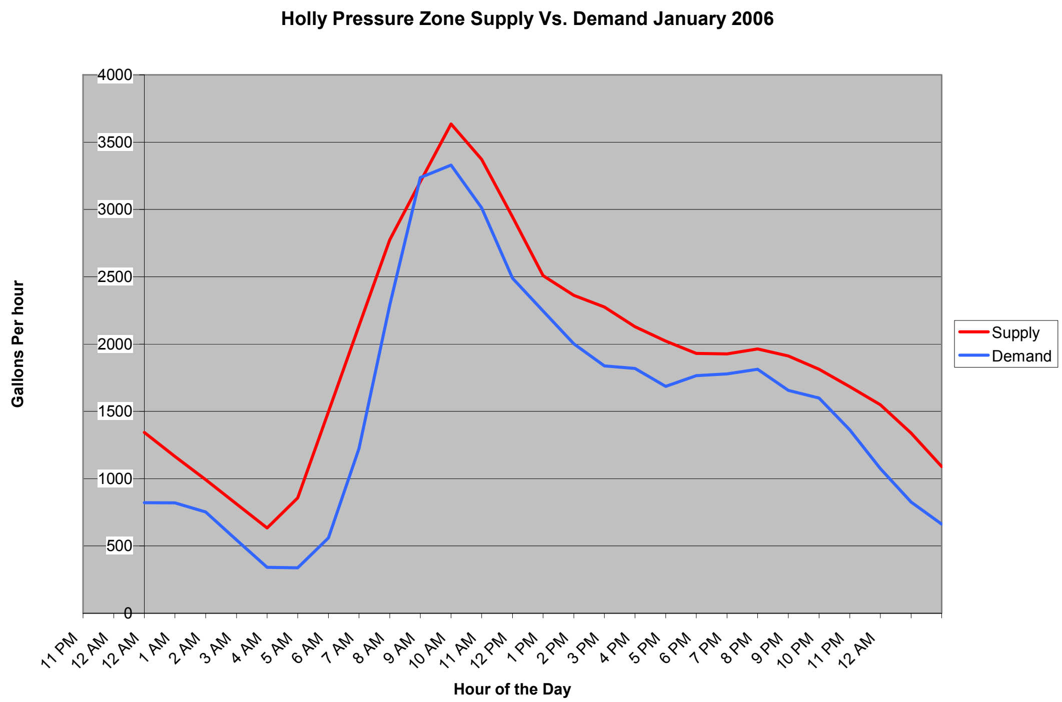


Figure 4. January 2006 average hourly data supply versus demand on Holly Pressure Zone in January 2006 showing apparent water loss from low flow leaks.

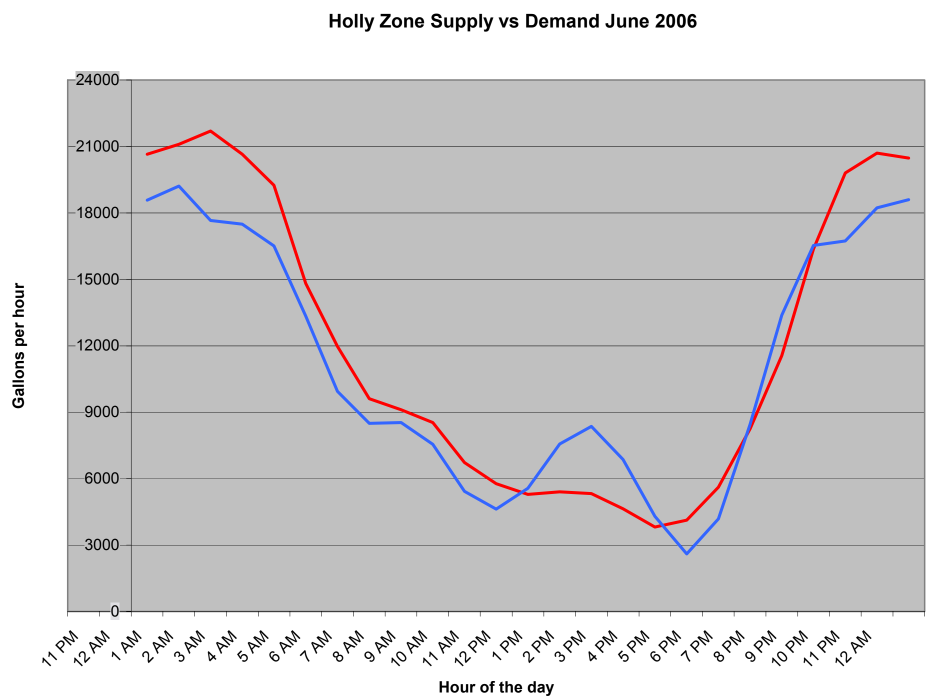


Figure 5. June 2006 average hourly data supply versus demand on Holly Pressure Zone in June 2006 showing apparent water loss from high flow meter inaccuracies.

Meter Testing Results

EBMUD completed a number of different tests on meters outside of normal operation as part of this study. However, EBMUD's meter-testing laboratory was designed to test meters in normal operating range and therefore limited tests were completed at various stable low-end flow rates, which were not easily repeatable.

The first tests EBMUD completed were on new meters with the following results:

- New 15mm (5/8-inch) meters were 99% accurate at flows as low as $^{1}/_{2}$ litre per minute (lpm) and as high as 110 lpm. Magnetic disconnect occurred at flows approaching 190 lpm.
- New 25 mm (1-inch) meters were found to be 96% accurate at 1 lpm and 100% accurate at 375 lpm.
- New 38 mm (1.5-inch) meters were found to be an average of 94% accurate at 1 lpm; however, low-flow rates could not be tested.

The second round of tests was completed on used meters from the study area with the following results:

- Six 15 mm (5/8-inch) meters were selected for testing.
  - One meter with more than 2.3 million reported cubic feet (65 million litres) on it was slipping badly and only reporting about 2% in AWWA ranges.
  - Another meter with more than 1.2 million cubic feet (34 million litres) of recorded consumption broke at 75 litres per minute.
  - The remaining four meters were tested at $^{1}/_{2}$ lpm and found to be between 90% and 103% accurate, and at 1 lpm they were between 95% and 98% accurate.
  - These meters were also tested at AWWA standard ranges and found to be within targets.
  - One of the 15 mm (5/8-inch) meters was tested to 144 lpm (38 gpm) and found to be 96% accurate.
- One (1) used 25 mm meter that had more than 700,000 cubic feet (20 million litres) put through it in 16 months was 70% accurate at ½ litre per minute (0.135 gpm) and 84% accurate at 1 lpm (0.25 gpm).
- A number of different tests were completed on 38 mm (1.5-inch) meters:
  - Three (3) used 38 mm (1.5-inch) meters were tested at 0.65 litres per minute (0.171 gpm) and found to be 10%, 45%, and 60% accurate.
  - Another three (3) were tested at 0.72 lpm (0.19 gpm) and found to be 38%, 75%, and 80% accurate.
  - Additionally, a field test was conducted on an in-service meter at a very low 0.15 lpm ($^{1}/_{25}$ gpm) and 0.76 lpm ($^{1}/_{5}$ gpm). The meter showed no registration at the lowest flow rate and only 69% registration at 0.76 lpm.
  - The accuracy of these meters generally increased with flow rate. Without actually completing the testing at these rates, the authors felt it was a conservatively reasonable generalization to assume that used 38 mm (1.5-in) meters were less than 50% accurate at a slow leak rate of $^{1}/_{2}$ lpm ($^{1}/_{8}$ gpm).

Case for Meter Error

As explained above, it appears that used 38 mm (1.5-inch) meters are less than 50% accurate at 1/2 lpm. The authors further believe that 40% of the 62 single-family homes and assuming all of the 50 fourplexes with 38 mm (1.5-inch) meters have system leaks that are only being recorded at a 50% rate. Based on these assumptions, at least

Equation1: = % of metered connections leaking × ½ lpm (1/8 gpm) ×50% accuracy

$$(0.40\times(62 + 50)) \times 0.5\times 1440\times 0.50 = \textbf{16,128 litres per day (0.19 l/s)}$$

is lost in the pressure zone from demand (customer) -side low flow leaks on these 38 mm (1.5-inch) meters alone. This does not include meter errors in any of the remaining 48 meters with or without slow leaks.

Conclusions

- Data analysis can be time consuming especially if the AMR and SCADA system data do not match with respect to their timesteps.
- Overall in this case, there was a fair amount of manual analysis and organization of data, but it was not overly onerous.
- Round Hill Pressure Zone has relatively low losses which are mainly due to the SCADA calibration and several individual meter failures. In addition, there are a number of demand (customer)-side leaks but these are being metered and are therefore not supply-side water loss).
- The Holly Pressure Zone has significant issues with the low-flow and very high-flow recordings of its meters.
- The top 10 users drive the demand and also create the greatest stress on the infrastructure. Compound meters would be helpful to capture the entirety of the flow range.
- Once the data issues are addressed, this is an excellent method of determining variations in apparent water losses.
- Apparent losses are evident from detailed analysis of the graphics.
- The leakage survey suggested that there were no significant distribution system leaks evident within the pressure zones during the project.
- Slow demand (customer)-side leaks, especially on larger meters, are a sleeping giant of system loss within these pressure zones.

Managing London’s Leakage – How London’s other water company achieves its leakage targets

J Parker

Watershed Associates, Little Cuppers, Rushmere, Leighton Buzzard, Bedfordshire, LU7 0DZ,

UK. jparker@watershedassociates.co.uk

Introduction

London, the capital of the England and the UK is situated in the South East of the UK. This area is densely populated and has relatively low rainfall compared with areas to the north and west such that rainfall per head of population is very low and comparable with areas generally considered arid. Water supplies come from both surface water, and in particular the River Thames and ground water. A number of hot dry summers and dry winters have meant that water resources have sometimes been stretched such that some limited water use restrictions were implemented in 2006, although these have since been lifted.

The restrictions, coupled with Thames Water’s failure to meet the leakage targets set by the water regulator, OFWAT, lead to leakage becoming far more high profile in the south east, with national newspapers running articles and even featuring cartoons related to leakage.

Much of London is supplied by Thames Water, one of 8 private water companies supplying water and sewerage services. However, the north and west of London is supplied by another company, Three Valleys Water, which has no sewerage responsibilities. The company was formed from a number of predecessor organisations, the very earliest being established in the 19th century. Besides the London area, Three Valley supplies parts of the surrounding counties of Hertfordshire, Essex, Buckinghamshire, Bedfordshire, and Surrey. The total number of connections is over 1 million serving a population of just under 3 million. The company produces in excess of 900 Ml/d.

The company owns over 14,000 kilometers of mains. Some of these mains are the original cast iron mains laid in the 19th century. The network also includes spun iron, grey iron, ductile iron, asbestos cement, PVC and polyethylene mains. A large proportion of the mains, particularly within the densely populated parts of London are laid in London clay, which is very reactive to changes in soil moisture content and which is also very aggressive to ferrous mains.

Leakage Regulation in the English water industry

The Water Services Regulation Authority, commonly known as OFWAT, is responsible for providing regulation on financial and customer service levels for the English and Welsh Water Companies. Scotland and Northern Ireland water and sewerage services have not been privatised and are regulated by different bodies.

Water companies are expected to meet targets for their leakage each year which are based on the Economic Level of Leakage (ELL). This is calculated via an agreed approach which is laid down in the Tripartite report published in 2002 , which was developed jointly by OFWAT, DEFRA and the Environment Agency (the environmental regulator for England) (OFWAT 2002). Provided companies are shown to have robust calculations for their ELL then they can set their own targets showing a gradual reduction to that level over a period of time. Many companies in South East

England are already at or even below their ELL (Environment Agency 2004) including Three Valleys Water.

Targets for each year are quoted in average level of leakage over the regulatory year running from April 1st given in Ml/d. Water companies calculate their leakage using both a ‘top down’ approach which is then cross checked with a ‘bottom up’ approach using minimum night flows measured in DMAs. This helps overcome the problem that only around 25% of properties in England are metered. The calculations of each water company’s leakage submitted to OFWAT are audited by engineering consultants employed by OFWAT. Targets include leakage from unmetered customer supply pipes such that most water companies offer subsidised repairs to these pipes, although they are the responsibility of the property owner.

Leakage targets for Three Valleys are shown in Table 1 (OFWAT 1999, 2000, 2001, 2004, 2006) and although leakage levels have sometimes been above the targets, leakage has been brought under control and was within the leakage target for the last 2 years published reports. A particular increase was observed in 2001/2 which was immediately after an extremely wet year with widespread flooding, which may have damaged the mains infrastructure. A recalculation of the ELL for the 2004 business plan submission to OFWAT identified that the ELL was indeed higher and the targets were revised.

This process has been assisted by a detailed ELL model based on hydraulic zones. The average delivered water cost is calculated in each hydraulic zone and the cost of alternative supplies to each zone is also calculated. Leakage detection and repair costs allocated to DMAs so that they can be collated into hydraulic zones costs. The ELL in each zone is then calculated using the APLE software, with the Three Valleys system being one of the most extensive and detailed to use this approach.

Table 1 OFWAT targets and actual leakage in Ml/d

Year	**94-5**	**95-6**	**96-7**	**97-8**	**98-9**	**99-0**	**00-1**	**01-2**	**02-3**	**03-4**	**04-5**	**05-6**
Target				160	157	145	142	141	140	140	150	150
Actual Leakage	187	199	199	172	157	145	140	157	152	152	149	149

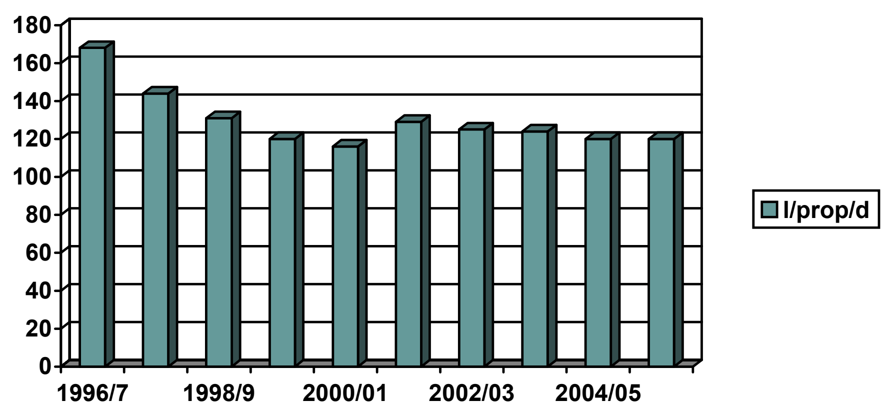


Figure 1 Leakage levels in Three Valleys from 1996/7

The ILI is not generally used in the UK for leakage comparison between companies. However, Three Valleys maintains an ILI of just over 2, comparing well with other water utilities both in the UK and overseas.

Three Valleys approach to leakage

The IWA Water Loss Task Force has developed a model of four different aspects to managing leakage as shown in Figure 2.

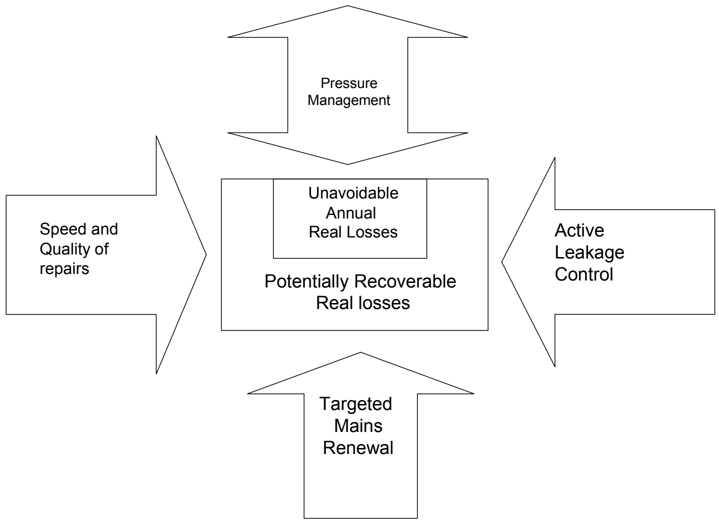


Figure 2 The IWA Water Loss Task Force Approach to leakage control

Three Valleys Water has always been active with all four aspects of leakage control, although each poses challenges for the water company due to the nature of the distribution system.

A particular strategy which underlies all the leakage control activities is the configuration of the network. DMAs have been established in the company for some time and in fact some of the predecessor companies were pioneers of this approach. However, more recently the company has been through an initiative to establish larger control zones with a clear hierarchy of these zones. The network is divided into 6 of the largest areas, resource zones. These define clear areas with a very limited number of trunk transfers between the zones. The zones are generally fed from supply sites which are similar in nature. They provide a basis for high level reporting of performance within the company (see Figure 3).

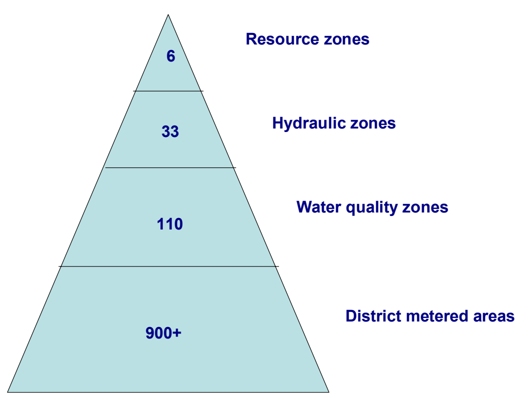


Figure 3 The hierarchy of zones in Three Valleys Water

These resource zones are further divided into 33 hydraulic zones which still have minimal interconnections and which provide a more detailed level for reporting. The detail level below this provides a structure for the drinking water quality sampling regime as the zones provide the largest areas where a consistent quality of water is obtained. The 110 areas are therefore called water quality zones. Below this there are DMAs established which serve an average of slightly more than 1000 properties each.

A substantial amount of time has been devoted in to ensuring that boundaries of all the zones are clearly defined and overlay each other. They are defined via the GIS system and hydraulic zone valves have all been fitted with Wizkeys, a device which automatically records the status of the valve, such that any changes in the network configuration are identified automatically on the GIS system. DMA valves are all clearly marked and all valve operations not using the Wizkey system are recorded via GIS. The network hierarchy and maintaining the integrity of the DMAs and larger zones underpins the whole leakage system as will be described later.

Active leakage control

Leakage is monitored through the Leakage Management and Reporting System (LMARS) which was developed just after the turn of the millennium, and which replaced an earlier system which integrated data from telemetered district meters across the company.

This system is linked to GIS such that any changes in network configuration automatically update the LMARS zonal configuration. DMA information can be accessed via the geographical location or through a known code for the DMA (Figure 4)

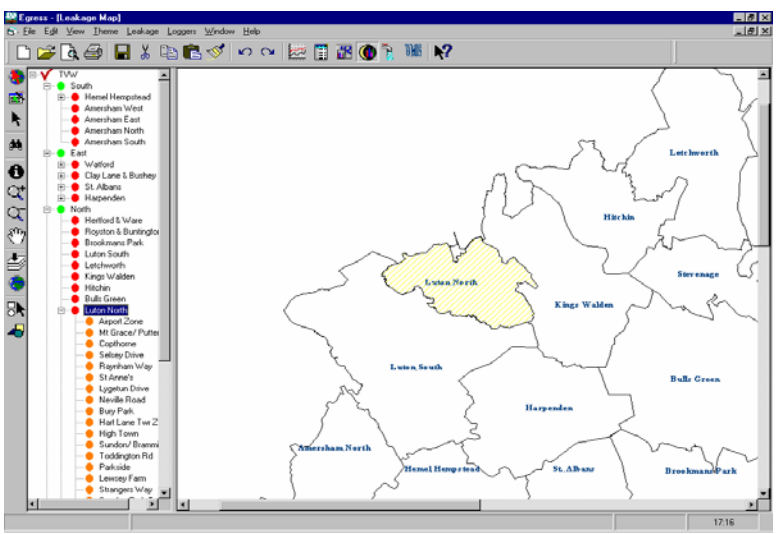


Figure 4 Typical screen showing geographic access to a zone

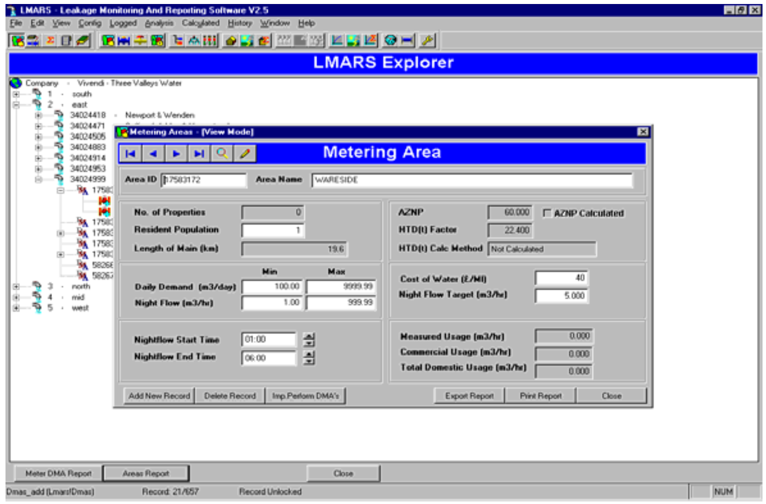


Figure 5 Zonal information available from the LMARS system

Information about meter installations and about each DMA is stored on LMARS including the cost of water, length of mains and AZNP as well as the flows and pressures within each DMA. These can be totalled for hydraulic areas as in figure 6 which facilitates high level monitoring, reporting and target setting.

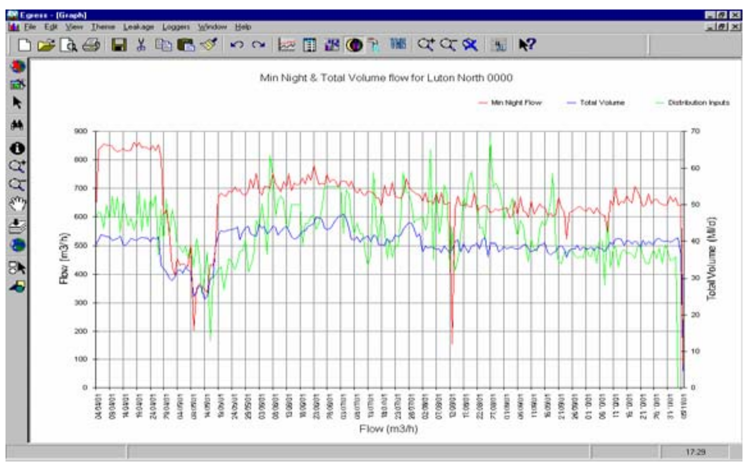


Figure 6 Total flow information for a hydraulic zone

In addition to the usual facility to monitor DMAs to identify increases in minimum night flows, some additional facilities have been provided within the system. Leakage per property per hour can be calculated automatically and DMAs ranked to facilitate prioritisation. Alert levels are set for all DMAs and e mails are sent automatically to leakage team leaders where leakage has gone above the alert level. This ensures that new leaks are identified as quickly as possible.

Three Valleys has always placed great store in using the latest available leakage location equipment and has participated in trials of equipment such as the early versions of the correlating noise loggers introduced at the start of the millennium. Correlators, simple noise loggers, drive past loggers and correlating loggers are all used, with different geography and network characteristics driving the choice of equipment, since different methods of locating leaks suit different types of conditions.

Speed and quality of repairs

The area includes some of the most highly trafficked roads in the UK. Therefore managing leakage repairs requires constant attention to minimise the time a detected leak runs. Apart from using technology to optimise the time taken to repair leaks, developing god relationships with local authorities is essential as they have responsibility for co-ordinating street works, with new responsibilities introduced under the recent Traffic Management Act passed in 2004.

The time taken for leaks to be repaired is monitored for each leak and monthly management reports are submitted. Repair progress is monitored through the company work management system which is linked to LMARS as shown in figure 7

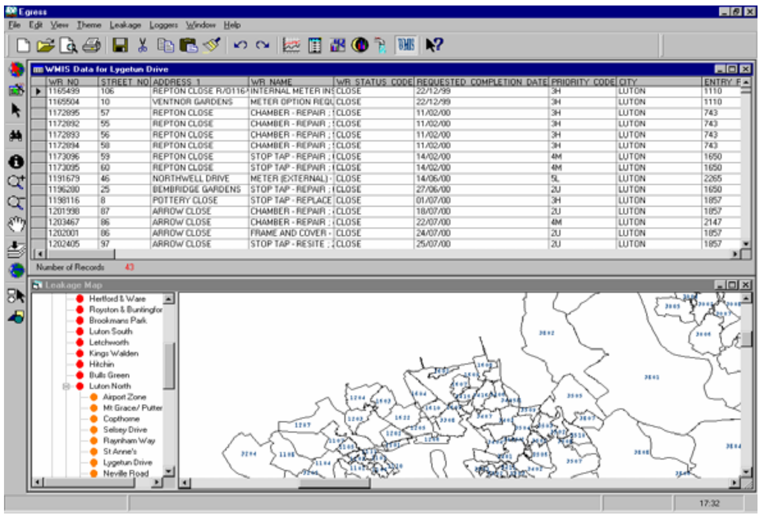


Figure 7 LMARS showing the link to the work management system

A resource optimisation system ensures that gangs' travel times are minimised with all gangs, whether directly employed or contractor using field information systems that allow job details plus related information such as other utility plans to be available to the gangs without the need to return to their base.

Mains renewal

As mentioned earlier, much of the Three Valleys region lies within an area of London clay. This is very aggressive to ferrous mains and due to the high levels of corrosion on some mains, the company has a high burst rate compared with other parts of the country.

Capital investment is funded form the water charges and a case must be made to OFWAT in order to be allowed to raise water charges to cover this investment. In order to build the case for additional funding to replace the old mains, Three Valleys has developed mains deterioration models. These are based on over pipe 2000 samples collected over a number of years which have been analysed for corrosion such that the likely rate of failure can be determined as a result of different replacement rates. An example of a predicted burst rate using a deterioration model is shown in Figure 8

The models need to take in to consideration a wide variety of factors, including pipe data such as date laid, material, burst history and operating pressure, soil conditions including corrosivity and fracture potential pus weather information such as temperature, rainfall and soil moisture deficit.

Different models are built for the different groups of pipes, e.g. cast iron pre and post war, spun iron, ductile iron etc.

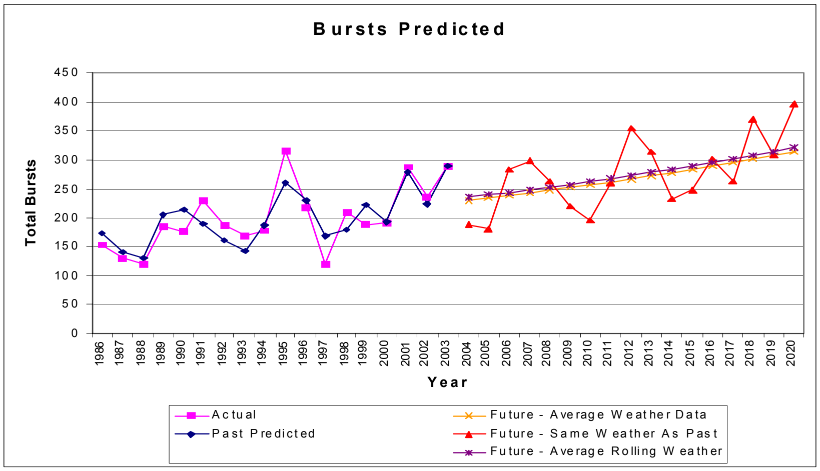


Figure 8 Burst prediction using a mains deterioration model

Renewal locations are also identified and prioritised based on this analysis to ensure that investment is optimised to deliver the maximum benefit with the improvement in customer service as well as reduction in leakage being taken in to account.

Pressure Management

Three Valleys has practiced active pressure management of much of the system for a substantial amount of time. Many zones have pressure control, which not only reduces leakage, but also helps extend the life of pipes. Flow modulated and time controlled valves are used across a variety of installations which range from small local control areas to one of the largest in the country, controlling pressures throughout much of North London as shown in Figure 9.

This system uses pressure reducing valves at 8 different locations, with settings which are controlled and monitored remotely by PLC to prevent ‘hunting’ of the PRVs. This system has reduced leakage dramatically in the North London area, which has the most vulnerable mains in the area due to the age of the mains and the aggressive clay soil. Failures of the system are relatively rare and through fail safe systems and well defined procedures, major problems such as widespread outages or trunk main failures have been avoided. It shows that complex pressure reducing systems can be made to work with the appropriate control systems.

Involvement of the Public

With leakage being so high profile, particularly in the London area, it is essential to keep customers informed of the measures being taken to reduce leakage. Leakage activities are regularly featured in the local press with displays available for local carnivals and other events. This ensures that the message to conserve water is supported by the companies own efforts to manage its own water wisely.

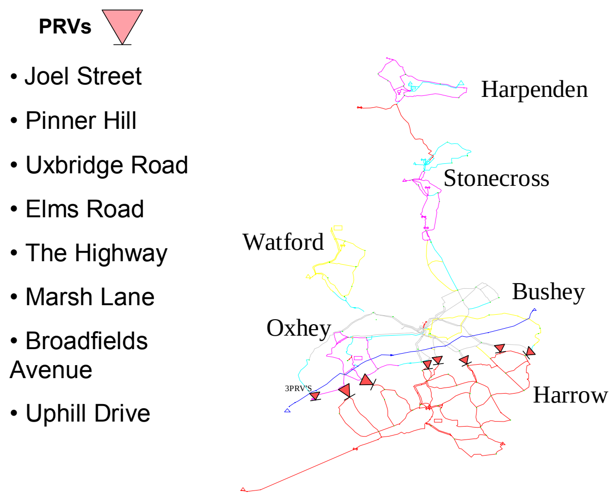


Figure 9 North London Pressure Reducing System

Conclusions

Managing leakage in the London area does without doubt have particular problems. The aggressive clay which reacts severely to changes in moisture and temperature combined with the density of population, an old mains network and heavy traffic do require constant vigilance to reduce and maintain leakage.

Nevertheless, by considering all four aspects of the IWA leakage control model, and through the appropriate investment in technology, leakage in these conditions can be controlled and maintained at an economic level which is as low as many water utilities achieve with rather less demanding conditions.

References

Environment Agency Report 'Maintaining Water Supply' July 2004.

OFWAT 'Leakage target setting for water companies in England and Wales: an investigation by WRc with Stone and Webster Consultants for the Tripartite Group of the Department for Environment, Food and Rural Affairs, the Environment Agency and Ofwat' 2002.

OFWAT Leakage and the Efficient Use of Water 1999 - 2000 report

OFWAT Leakage and the Efficient Use of Water 2000 – 2001 report

OFWAT Security of Supply, leakage and water efficiency 2003-04 report

OFWAT Security of Supply, leakage and water efficiency 2005-06 report

Leak Location and Repair Guidance Notes and….. The Never Ending War against Leakage

Richard Pilcher

Halcrow Group Ltd, Rocfort Road, Snodland, Kent ME6 5NQ, United Kingdom

email – pilcherr@halcrow.com

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Abstract

The Water Loss Task Force (WLTF) is part of the International Water Association's Specialist Group on Efficient Operation and Management of Urban Water Distribution Systems. The aim of the WLTF is to "provide leadership in the field of Water Loss Management through effective and sustainable international best practices".

The WLTF has various focus teams whose objectives are to develop best practice and disseminate the information on all aspects of water loss. The Leak Detection Practices, Techniques and Repair Team is one of these and this paper outlines one of their key activities which has been to produce a set of Guidance Notes. The main objectives of these Guidance Notes are to introduce newcomers to leakage reduction and control i.e. the process of identification, location and repair of leaks and to make experienced leakage practitioners aware of new and recently developed techniques. This document is now available on the IWA's website and describes how leak detection methods have developed over the years leading to those now available to 21st century practitioners. Publishing these Notes on the website provides the flexibility for giving details of new techniques and case studies and it is the intention to update them on a regular basis.

During the preparation of the Leak Location and Repair Guidance Notes the author was reminded that the reduction and control of leakage is a never ending war. The second part of this paper describes the main battlefield and asks the question – do we have the right weapons to win the war and are we fighting it the right way?

Introduction

The reduction and control of water loss is becoming more vital than ever in this age of increasing demand. Many utilities have developed, or are developing, strategies to reduce losses to an economic or acceptable level in order to preserve valuable water resources. These strategies have, and will, inevitably include modern leakage management techniques. One key activity is Active Leakage Control (ALC). ALC can best be described as a proactive strategy to reduce loss by the detection of non-visible leaks and their prompt repair by highly trained engineers using specialized equipment.

The Guidance Notes are intended as an introduction for leakage practitioners to the process of identification, location and repair of leaks. They are aimed at staff with little or no experience of leak detection and location techniques and practices. It has drawn on the experience of international leakage engineers to pull together the key best practice essentials and outline technical understanding behind this vital activity.

Today's leakage practitioners have a range of good equipment and techniques that have been developed to assist them tackle the four basic leakage management activities of pressure management, ALC, repair of leaks and mains replacement. The document essentially focuses on ALC or leak location and repair.

Factors that Influence Leakage

Before examining the equipment and techniques used by leakage engineers and technicians the main factors that influence leakage should be considered:

- Infrastructure condition
- Pressure
- Service connections - number, ownership and location of customer meters
- Length of mains
- Annual number of new leaks (reported and unreported) on mains
- Annual number of new leaks (reported and unreported) on service connections
- Average run-times of reported and unreported leaks

The frequency at which new bursts and leaks occur is subject to the overall condition of the infrastructure and how well the pressures in the distribution system are managed. Dependent upon the specific ground type there will always be a proportion of leaks and bursts that do not appear on the surface i.e. non-visible or unreported leaks.

Components of Real Losses or Leakage

Real losses or leakage are made up of three components

- Reported leaks and breaks **-** typically high flow rates, short run-time often notified to the water utility by customers etc
- Unreported leaks and breaks - typically moderate flow rates, long run-time located by active leakage control
- Background leakage (mostly at joints and fittings) - flow rates too small to be detected if hidden, generally < 250 litres/hour, but run continuously

Reported leaks are usually:

- Phoned in by the public
- Visible
- Found following complaints of low pressure or no supply
- Observed by meter readers and maintenance teams

Unreported leaks are usually:

- Non-visible
- Found by Active Leakage Control

Depending upon the type of leak, the fitting on which it is occurring and the pressure in the system bursts and leaks will have different typical flow rates. Time also makes a difference – the longer a leak runs the greater volume of water that is lost. Figure 1 shows the three key factors in the amount of water that is lost from an individual leak or burst - awareness time (A), location time (L) and repair time (R).

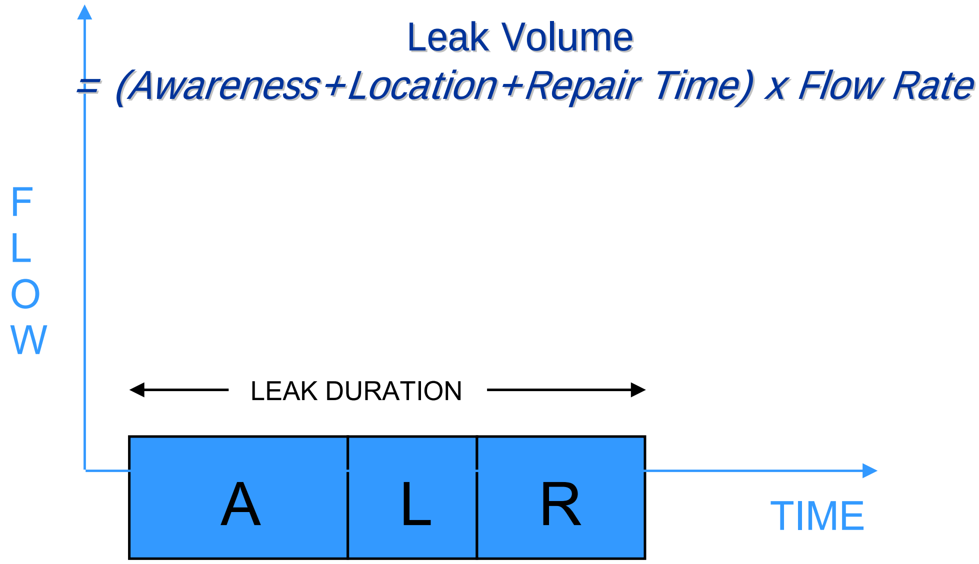

Figure 1 Leak Duration and Volume

It is often assumed that the largest volume of real losses or leakage arises from large visible mains bursts because of their high flow rates. However, component analysis shows that in most well managed systems reported mains bursts account for less than 10% of the annual real losses volume. The largest components of real losses are from:

- background leakage
- long-running unreported leaks and bursts
- long-running reported leaks which the water utility does not bother to repair

From a practical point of view it is the unreported or non-visible leaks and bursts that most utilities need to locate and repair. If the leaks and bursts are non-visible then there is a degree of difficulty in precisely pinpointing their location in order to repair them.

The Four Basic Methods of Managing Real Losses

In respect of real (leakage) losses there are four basic leakage management activities. These activities are pressure management, ALC, pipe materials management and speed and quality of repairs. These activities are shown diagrammatically in Figure 2.

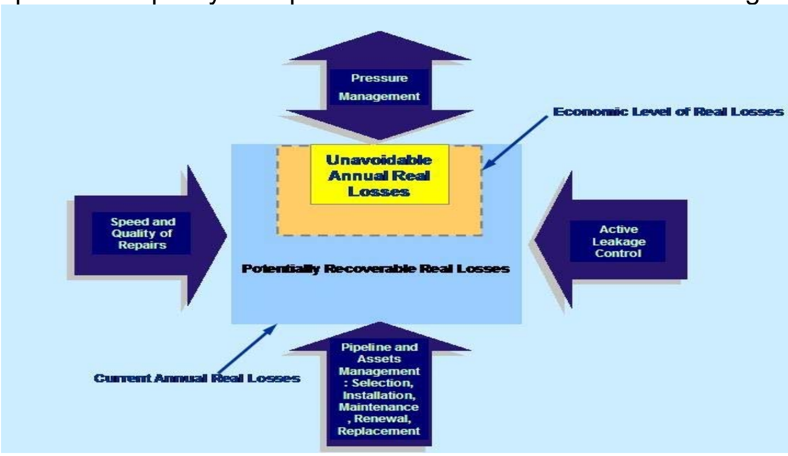

Figure 2 The four basic leakage management techniques

It is recognised that pressure management and pipe replacement are two important activities in respect of water loss reduction. The focus of the Guidance Notes is Active Leakage Control. Leakage cannot be eliminated completely. The lowest technically achievable level of physical losses for a well managed system is known as the Unavoidable Annual Real Losses (UARL), represented by the smaller rectangle in Figure 2 and only changes in pressure will influence these background losses. UARL consists of:

- undetectable small hidden leaks (background leakage)
- volumes lost from reported and unreported leaks with well-managed short run-times, for well-maintained infrastructure in reasonably good condition

Modern Leakage Management Techniques

In the last twenty years leakage management techniques have been successful by the application of the activities associated with Figure 2. However, in order to fully optimise leakage management resources the monitoring of flows is essential. The most efficient utilities are those that monitor night flows and are able direct the leakage teams to that part of a network where most leakage is occurring.

Leakage Monitoring Principles

The technique of leakage monitoring requires the installation of flow meters at strategic points throughout a distribution system, each meter recording flows (and often pressures) into a discrete sector or district which has a defined and permanent boundary. Such a district is termed a District Meter Area (DMA)

The design of a leakage monitoring system has one main aim:

- To divide the distribution network into a number of sectors or DMAs, with the minimum number of meters (to improve accuracy of MNF), so that the night flows into each district can be regularly or continuously monitored, enabling non-visible bursts and leaks to be identified and located more efficiently.

In February 2007 the WLTF published a set of DMA Guidance Notes on its website and these provide comprehensive detail on the philosophy and practice of leakage monitoring.

Leakage Reduction and Control

Night flow data from DMAs provides the information that enables the prioritization of the leak location effort. This effort is divided into two separate activities, leak localising and leak location.

Leak Localising

The most beneficial leakage activity is the implementation of a process that “cuts down the process time” from assessment to the repair of the leak. One of the most time consuming activities in the process is the “leak localising” phase

Leak Detection or localizing by means of a step test or acoustic logging survey enables the practitioner to narrow down the location of the leak to an individual road or length of main. There are two techniques used today, ‘step testing’ and acoustic logger surveys. ‘A step test’ is an activity whereby the area such as a DMA is subdivided by the systematic closing of valves during the period of minimum night flow. The flow data is analysed to determine the areas of suspected leakage. Leak location or the pinpointing of leaks was then carried out in the section of the waste meter area that had high night flows.

Acoustic logger surveys are used to define the general area in which leaks are located - normally a DMA or part of a DMA. However they can be used independent of a DMA Structure and any type of distribution network. They are installed on pipefittings by way of a strong magnet and are programmed to listen for leak characteristics. By recording and analysing the intensity and consistency of noise, each logger indicates the likely presence (or absence) of a leak. Deployment of noise loggers can be done on a “Strategic” basis or a “Tactical basis”

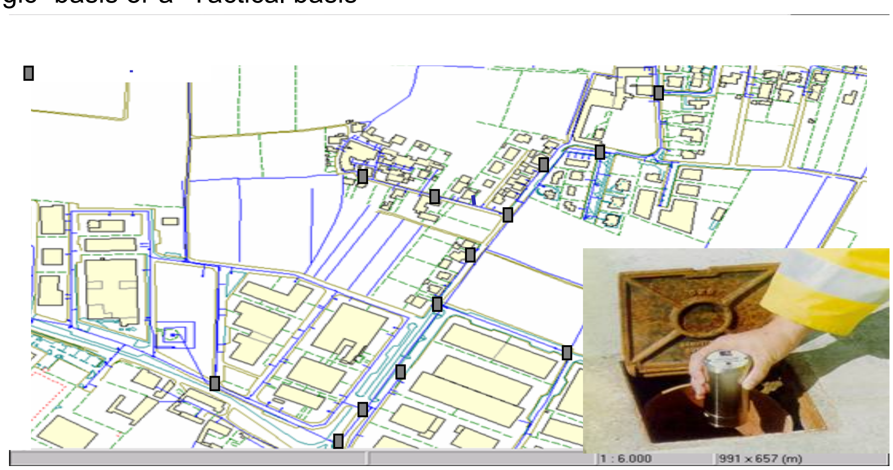

Figure 3 Acoustic logger placements in the distribution system

STRATEGIC- In this method the operators look at permanent or semi-permanent deployment of the loggers into a DMA or into areas where no DMA structure exists. The advantage of the noise logger system is that as it only detects noise so no preparation of areas is necessary other than to establish positions of suitable fittings and access to the fittings. Operators look at the integrity of network and the “natural rate of rise" of leakage within the network to determine if permanent or semi-permanent deployment is necessary. Areas that are difficult to access for traditional methods of leak detection are also prime areas for consideration of permanent monitoring (city centres etc).

TACTICAL- This is the use of the acoustic loggers in survey mode using the mobile teams to deploy loggers, locate leaks and move loggers into new areas. Fast deployment and redeployment of quantities of loggers by dedicated teams are part of a tactical approach to "crisis" or "short term" needs of a utility.

Existing Leak Location Techniques

Following a leak localising exercise the next activity for the leakage engineer is to precisely locate or pinpoint the position of the leak and mark the point clearly on the ground surface where the repair teams will have to excavate. There are several methods that can be utilized to pinpoint the leak and as new pieces of equipment are developed techniques change and evolve. Some pieces of leak location equipment work better on some distribution systems rather than others. None of the methods are totally infallible and the skill, motivation/experience of the leakage engineer in the pinpointing of a leak cannot be underestimated. All the methods that are described in the Guidance Notes depend upon the leak making a noise with the exception of ground radar and a technique that uses gas to trace the leak.

Direct Sounding

The most common method for determining the position of a leak is by direct sounding. The leakage engineer listens for the characteristic sound of the leak by placing a listening device onto a fitting such as a sluice valve, hydrant or stopcock

Surface or Indirect Sounding

Surface or indirect sounding is a method whereby acoustic listening is made on the surface directly above the line of the pipe to determine the location of the maximum sound intensity. The maximum sound is often directly above the leak and is a method to verify the pinpointing using another technique

Equipment used for Sounding

There are several pieces of equipment used for detecting the sound created by a leak or burst. There are two traditional types of instrument used for the location of leaks, the stethoscope or listening stick and an electronic amplifier and detector. In the last twenty years the leak noise correlator has developed to become the most common method of pinpointing leaks.

Figure 4 Leak Noise Correlation

Non Acoustic Techniques

Three methods of locating leaks that emit little or no noise are described in the Notes and they are ground penetrating radar (GPR), tracer gas and Infrared thermography

Repair of Leaks

A key component in water loss management is the speed and quality of a leak repair. This chapter covers the types of leaks encountered in different water supply networks, how specific leak types are repaired and the techniques used in carrying out repairs.

Leakage can occur due to corrosion in mains and service pipes that are metallic. This corrosion is caused by ageing pipes, chemicals in the water and soil make up. Another type of leak that occurs on metallic pipe is cracks and splits. These occur due to ground movement, increases in water pressure (sometimes after nearby repairs), vehicular traffic and ageing. A leak caused by a crack or split will have significantly greater leakage than a leak caused by corrosion. Leaks on fittings such as hydrants and valves are visually identifiable most of the time. Competent repair teams should have appropriate equipment and training to deal with the leaks on their particular system.

Non-metallic water main leaks are similar in leakage nature as the above metallic pipes. However they are harder to pick up with leak detection equipment due to the low conductivity of sound. Corrosion generally doesn't occur in non-metallic mains; but it is not unusual to encounter faulty products that lead to the mains splitting. Also with a non-metallic main; other contractors working on underground services are able to easily damage the pipe leading to large leaks caused by excavators and the like. With PVC mains the ground movement can cause the pipes to easily crack and often lead to damaged joints.

Figure 5 Typical repair of a leaking joint

Other Chapters in the Guidance Notes

New and Emerging Techniques

The pace of the development of new technology has accelerated in the last ten to fifteen years as the goal of many water utilities around the world to reduce water loss has become a priority. One problem with detailing with new and emerging leak location technologies is that they are evolving rapidly and the equipment mentioned in this section could be out of date within 12 months and therefore details must be regularly updated.

Training

The need for a sustainable and competently trained workforce is central to the success of any organization. In respect of leakage management and in particular detection and location this is especially true. A suggested training programme is described in the chapter

Glossary of Terms

A glossary of terms is included in the Guidance Notes to provide clarity and avoid confusion.

Case Studies

Three case studies are featured in the Guidance Notes. They are from places as far apart as Canada, Greece and Malaysia. These case studies are in the form of papers that have been written and presented by members of the Leak Location and Repair Team.

The Never Ending War on Leakage

An experienced leakage practitioner once stated that the reduction and control of leakage is a never ending war. Individual battles are fought and won (often in DMAs) but the war goes on. So what is the leakage practitioner's greatest enemy or where and how often do leaks occur.

Consider a water balance of a typical water utility 20-25% of losses are apparent or commercial i.e. customer meter under-registration or theft of water. The other 75-80%

is real loss or leakage. The leakage may be from reservoirs or transmission mains but most of the leakage is from the distribution system. Data from many different systems around the world point to the main enemy, the humble service or house connection.

Figure 6 Leaking service pipes

Tables 1 and 2 below shows the size of the problem. Overall, the number of leaks that occur on service connections range from 65 to 90% by number and 60 to 70% by volume.

Table 1 Percentage of leaks from networks by number

Percentage of leaks from networks (recorded numbers of leaks)

Country of Utility	Service Connections	Mains
Brazil	90	10
Latvia	79	21
England	75	25
Ireland	71	29
Malaysia	68	32
Greece	67	33
Malaysia	68	32
Poland	65	35

Table 2 Percentage of leaks from networks by volume

Percentage of leaks from networks (recorded volumes of leaks)

Country of Utility	Service Connections	Mains
Ireland	70	30
New Zealand	69	31
Australia	68	32
USA	63	37
Malaysia	60	40

Why is the Proportion of Service Pipe Leakage So High?

In a typical urban network the length of service pipes may approach or exceed the length of the mains. Although the diameter of the service pipe is small (12mm to 25mm) and any leak will run with a lower flow rate than a main but the duration of the leak can be much longer. Typical flow rates used in a study in the U.S.A. in 2002, for detectable leaks from service pipes and mains at 50m pressure are shown in figures 7 and 8.

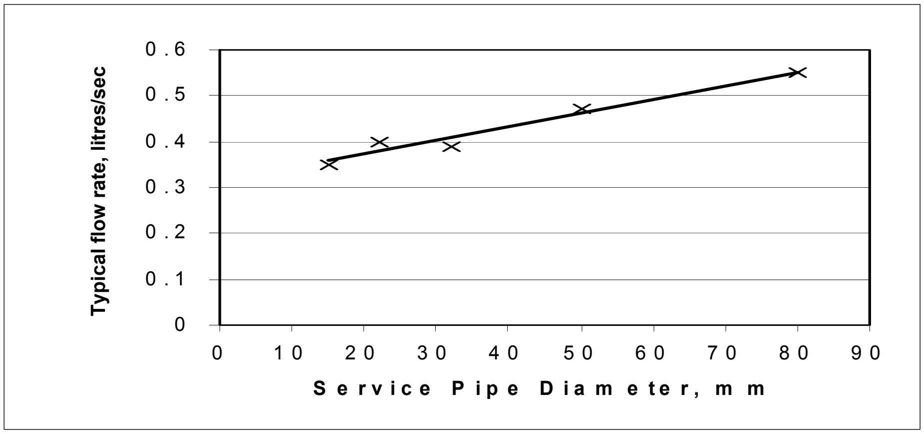

Figure 7 Typical service pipe burst at 50m pressure

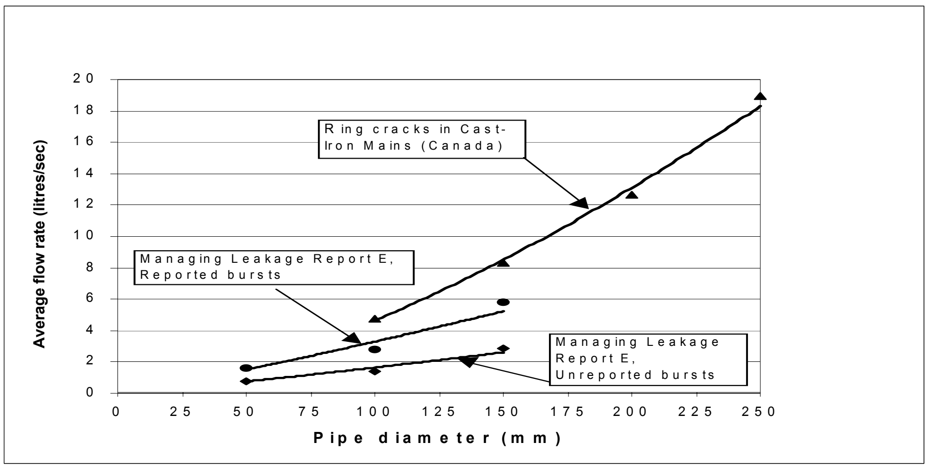

Figure 8 Examples of mains burst flow at 50m pressure

Service pipe leaks however, contribute significant volumes to overall leakage, particularly as the leak may be on customer premises and run undetected for a long period. Also much of leakage on service pipes is considered as background and often undetectable in terms of being able to locate the leak with the current location equipment.

	Background Leakage ML/year	Reported Bursts ML/year	Unreported Bursts ML/year	Total ML/year
Mains	5920	3882	7776	17578
Service Connections	10656	11080	22193	43929
Total	16576	14962	29969	61507

Figure 9 Components of real loss from a water utility in the UK

Other factors that contribute to the high losses that occur on the service connections are the number of joints, often as many as seven or eight and the type of pipe material. There is such a range of materials used for the service pipe from galvanised iron to polyethylene and in some countries the quality of manufacture may not be as high as in others. On occasions the service pipe can be laid by builders where the quality of workmanship may be questionable. Another observation is that often a water utility will replace water mains without the corresponding replacement of the service pipe.

What is the Solution?

- Should the water industry develop a new material that is more robust than the current selection available?
- Should manufactures be encouraged to develop equipment that would locate more leaks on service pipes?
- Or will automated meter reading (AMR) provide a solution whereby suspected leaks on individual service connections are flagged up?

Conclusions

There is little doubt that in the fight to reduce and control leakage one of the main battle grounds is the service or house connection. Certainly the development of a better material for the service pipe would provide a solution whereby 'prevention is better than cure'. Tim Waldron, in his 2005 paper posed the question "Where are the Advancements in Leak detection?" Tim made some very good suggestions as to how we may go forward to produce better leak location equipment Are these suggestions being taken up?. As AMR technology advances is it possible that improvement to the customer's meter that will provide a solution for beating the unseen enemy below our feet?

Note – The Guidance Notes can be downloaded free of charge from the web site of the Water Loss Task Force (www.iwaom.org/wltf).

References

Leakage Management and Control – A Best Practice training Manual, (WHO (2001).
Thornton J, (202) Water Loss Control Manual, (McGraw-Hill...
Farley M and Trow S, (2003) Losses in Water Distribution Networks, (IWA Publishing).
Warren R, (2005, The Service Pipe – A Forgotten Asset in Leak Detection – Conference Proceedings from Leakage 2005.
Pilcher R, (2006), Modern Leak Detection Practices and Techniques for Reducing Losses in Water Distribution Systems Leakage Conference Macedonia.
Waldron T, (2005), Where are the Advances in Leak Detection? - Conference Proceedings from Leakage 2005.

Water Loss Management for Utilities in Low Income Countries: Case studies from Four African Water Utilities

S.M. Kayaga[1] and I.K. Smout

Water, Engineering & Development Centre (WEDC), Loughborough University, Leicestershire, LE11 3TU, UK.

Abstract

Keywords: water loss management; water utilities; low-income countries

The rapid increase in global population coupled with escalating climate change has led to a serious water scarcity in the world. The problem is more pronounced in urban areas and UN Habitat estimates that the proportion of the world's population living in urban areas had grown to at least 50% by early 2007. Therefore, instead of focusing on supply management, urban water managers need to also adopt demand management. Water loss management in the distribution network will not only reduce demand, but has other important benefits. This paper describes a project by Water Utility Partnership (WUP) of Africa whose objective was to reduce non-revenue water (NRW) in four water utilities in sub-Saharan Africa. The project's approach was based on the premise that NRW is only a consequence of deep-seated utility management challenges. Hence, through capacity-building partnerships, key staff in the participating utilities were facilitated to develop performance improvement plans (PIPs), which included establishment of pilot District Meter Areas (DMAs) for effective water loss management (WLM). The results of this project show that iterative and incremental pilot WLM projects could be an effective way of convincing uncertain senior managers of cash-trapped utilities in low income countries to allocate more resources for water loss management.

Introduction

The global population has continued to increase rapidly, despite the fact that the overall growth rate and net additions are decreasing. According to the most recent UN world population prospects report, the world population will reach 6.7 billion by mid July 2007, 5.4 billion of whom will live in the less developed regions (United Nations, 2007). It is estimated that 804 million people, accounting for 12% of the world population currently live in 50 least developed countries. Assuming a declining fertility rate, the world population is projected to increase to 9.2 billion by 2050, which increment will mainly be absorbed by less developed regions, with 19% of all the global population living in least developed countries (ibid).

Yet the water resources have not only remained constant but have increasingly been polluted by the growing population. The rate of abstraction of freshwater has grown rapidly in tandem with human population growth. For example human water use increased by a factor of six in the past century (Andresen, Lorch & Rosegrant, 1997). It is estimated that global water withdrawals will increase by 35% between 1995 and 2020 (ibid). As a result, per capita water availability is steadily declining. The water scarcity situation is compounded by the major impacts of climate change on the water resources, namely shorter duration of the precipitation seasons and increase in hydrological extremes.

[1] Corresponding Author, email: s.m.kayaga@Lboro.ac.uk

The water scarcity situation will get worse in the world's urban areas where over 50% of the world's population have lived since the beginning of 2007 (UN-HABITAT, 2006). Between 2000 and 2030, it is projected that there will be an increase of urban population of 2.12 billion, with over 95% of this increase expected to be in low-income countries (UN-HABITAT, 2004). Parallel with this growth in population, the demand for drinking water has been increasing rapidly in urban areas of developing countries. Yet the number of viable water resources in any country is limited and has to serve competing requirements such as domestic, industrial, irrigation, fishing, navigation, tourism, recreational, ecological and waste disposal/assimilation.

There is a need therefore for water sector policy makers and professionals to have a shift in the way they manage water resources in urban areas. Instead of focusing on only supply-side options, there is need to apply water demand management (WDM) tools both at the utility and end-user sides. Managing water losses in the distribution network is a critical aspect of water demand management. It would be easier for the utilities to promote the concept of demand management for end uses, if they can demonstrate that they have reduced the level of losses in the water distribution network to an economic level of leakage. At utility level, water losses may be categorised as physical losses (or real losses) and commercial losses (or apparent losses). Physical losses are as a result of water leakages from pipes, joints, fittings and reservoirs. On the other hand, commercial losses consist of unauthorised water use and metering errors.

There are several benefits that will come out of effective and efficient water loss management by water utilities. Reduced leakages will lead to higher system pressures, which will in turn lead to less likelihoods of having suction pressures in the pipeline. High system pressures will reduce the risks of pollution of the system flows, and ensure that no air-blocks are formed in the pipeline. Less water losses and high system pressures will also ensure that customers receive better service levels in terms of pressure, continuity, reliability and aesthetics. Furthermore, availability of more water in the distribution system will lead to higher allocative efficiency between different sections of society, for the benefit of the urban poor, and will result in a delay in expansion of water works infrastructure, hence freeing the much needed capital expenditure for network expansion. Efficient water loss management will also lead to lower production costs in terms of energy, materials and staff costs.

This paper describes an action research project that was conducted with urban water utilities in four countries in sub-Saharan Africa in the period 2000 to 2005. The overall objective was to improve the performance of water and sanitation utilities through improved management, and enable expansion and enhancement of services to customers living in low-income settlements. The remainder of this paper briefly describes the scope and methodology of the capacity building project, outlines existing practices in water loss reduction, describes how pilot DMAs were set up and finally highlights challenges faced by water utility professionals in low-income countries in managing water losses.

The WUP Capacity Building Project

Scope and Objectives of the Project

The action research project on reduction of non-revenue water was conducted as of one of the capacity building projects under the auspices of Water Utility Partnership of Africa (WUP). The Water Utilities Partnership (WUP) of Africa was established in 1996 with the goal of building a partnership among African water supply and sanitation utilities and other key sector institutions, and creating opportunities for sharing of experiences and capacity building. The activities of WUP are centred around four key interrelated programmes. The subject of this paper is the programme on utility management and reduction of non-revenue water. The others are (i) reform of the water and sanitation sector; (ii) performance indicators of African water utilities; and (iii) provision of water and sanitation services to the urban poor.

Funded by Swedish International Development Agency (SIDA), the project on reduction of non-revenue water kicked off in mid-2000, and ran until July 2005. The first activity was the development of an audit manual, which was designed, piloted and subsequently utilised to map the performance of the participating utilities. The utilities were selected on the basis of size (medium, serving not more than 500,000 people), geographical spread (representing all regions of the sub-Saharan Africa) and willingness of the top management to participate in the programme. The selected utilities were (i) Societe Nationale d'Eau du Benin, Cotonou, Benin; (ii) Societe Nationale de Distribution d'Eau, Brazzaville, Congo; (iii) National Water and Sewerage Corporation, Entebbe, Uganda; (iv) Kisumu Water and Sewerage Company, Kisumu, Kenya; (v) Mwanza Urban Water and Sewerage Authority, Mwanza, Tanzania; and (vi) Water and Sewerage Authority, Maseru, Lesotho. However, this paper reports on activities in the last four utilities located in English-speaking countries.

As already stated, the overall aim of the project was to improve the performance of water and sanitation utilities through improved management, and enable expansion and enhancement of services to customers living in low-income settlements. The specific objectives of the project were (Mugabi et al, 2007a; Mugabi et al, 2007b): (i) improve management skills of the water professionals in participating utilities; (ii) Provide support in preparation of performance improvement plans for the utilities, based on the principles of strategic planning; (iii) train participants and sensitize them on the importance of reducing non-revenue water; (iv) prepare and develop pilot district water areas for effective water loss management; (v) raise operational and management standards for participants to operate with financial autonomy; and (vi) disseminate good practices to other African water utilities.

Methodology

The project was executed through a capacity building partnership between Severn-Trent Water International (STWI), a UK private-sector water utility; the Water, Engineering and Development Centre (WEDC), a Loughborough University research institute that also specialises in training and capacity building of professionals working in the water and sanitation sector of developing countries; independent water utility management consultants working in Africa; and key staff in the participating utilities. The project team aimed at having a participatory approach, which maximised ownership of the project objectives by staff of the participating utilities. Additionally, the international project team acted as facilitators, while staff from the participating utilities planned and produced the outputs.

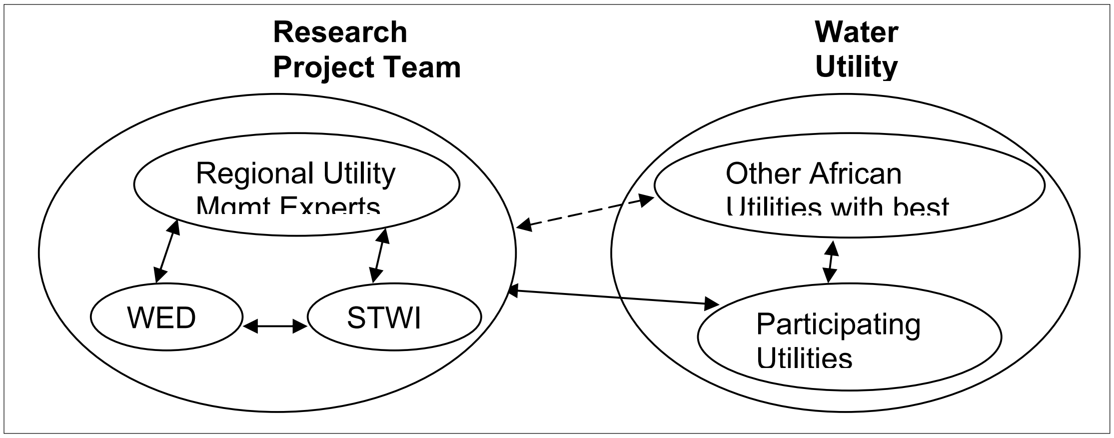

Figure 1 Capacity building partnership framework for the WUP Project (Source: Mugabi et al, 2007b)

Figure 1 shows the partnership framework that is based on the premise that staff of the participating utilities know the operating environment (both internal and external) of their utilities better than outsiders. On the other hand, the external partners have more knowledge of good practices and experiences from different parts of the world (Mugabi et al, 2007b). The partnership approach brought on board experiences from the international arena (through experts from STWI and WEDC) as well as from local utility management experts. Furthermore, this approach ensured that there was cross-fertilisation between the various participating utilities, as well as with other utilities under the WUP umbrella known to have good practices.

After mapping out the existing situation in the participating utilities, a training needs analysis was conducted, on which basis training materials were developed. A two-module course was delivered, which mainly covered best practices in commercial, technical and customer-orientated water utility management. The project team then supported the utility staff to develop generic performance improvement plans (PIPs), including reduction of non-revenue water. PIPs were developed based on a solution-oriented planning framework derived from the basic strategic model that aims to answer four central questions (Bourgeois, 1997; Wilson and Gilligan, 1997): (i) where is the utility now? (ii) where does the utility want to be? (iii) how might the utility get there? (iv) how does it ensure success?

Non-Revenue Water – Existing Situation

An outstanding challenge during the implementation of the project was to obtain data on the operations of the utility. In spite of the first phase of the project that was dedicated to mapping the existing situation of the utilities, it was difficult to obtain baseline data on the magnitude of non-revenue water, due to the following major problems: (i) there was inadequate bulk metering in the reticulation network; (ii) not all service connections were metered; (iii) even for existing meters, the meters had not been calibrated or replaced for a long time, and therefore the accuracy could not be easily assessed; (iv) many staff responsible for pipe network maintenance were unaware of the importance of, and/or incapable of carrying out a water balance, (v) there were different conflicting definitions of Unaccounted-for-Water (UFW).

The guiding philosophy of this action research was that the technical efficiency of a utility cannot be isolated: it is intertwined with other organisational dimensions such as the institutional setup, leadership qualities, commercial orientation, customer orientation and organisational culture (Kayaga & Zhe, 2007; Jacob & Lefgren, 2005). Therefore the action research sought to scan the overall performance of the utilities so as to get a full picture of the technical efficiency, as depicted by the level of non-revenue water. With the facilitation of the research team, key staff from each utilities carried out a participatory situational analysis. The results are presented in the following sub-sections.

Kisumu Water and Sewerage Company (KIWASCO), Kenya

KIWASCO is an autonomous limited company wholly owned by Kisumu Municipal Council, providing water and sewerage services to an estimated 2004 population of 350,000 people. KIWASCO has two conventional water treatment plants with a total throughput of 18,500 m^3/day, and, at the beginning of the project, was reported to have 11,500 customer accounts, out of which only 5,300 accounts were active. Assuming that all this water was available to the households, this works out at about 50 litres per resident per day. Yet, as of July 2003, the non-revenue water was estimated to be 70% of the total systems input, a big fraction of which was presumed to be in form of water theft and illegal connections (Kayaga et al, 2006). It is therefore no surprise that during the project period, KIWASCO was providing intermittent water supply services to the consumers.

At the beginning of the project, senior and middle managers of KIWASCO were facilitated to carry out a situational analysis of the internal and external environments of their organisation. The assessment was fully participatory, and utilised the Strengths-Weaknesses-Opportunities-Threats (SWOT) and Problem Tree Analyses. Through the SWOT Analysis, the key strengths and opportunities highlighted were: (i) autonomy of the company from the Municipal Council; (ii) experienced dedicated staff; (iii) inexhaustible raw water supply; (iv) eligible for international loans/grants; (v) water policies being upgraded; and (vi) existence of a gravity raw water source.

However, the lists of weakness and threats were much longer. They were classified into three categories of management, technical and financial related aspects. Table 1 shows the classified issues. It is clear from the table that most of these issues either directly or indirectly impact on the capacity of the utility to carry out efficient water loss management. Although some issues were categorised as technical and financial in nature, all of them are dependant on the management competencies that are available in the organisation.

Table 1 Classification of key issues perceived as weaknesses and threats to KIWASCO (Kayaga et al, 2006).

Management Issues	Technical Issues	Financial Issues
• Poor org. structure • Lack of transport • Slow procurement system • Poor MIS • Poor public relations • Lack of protective clothing • Staff is irrationally deployed • Poor communication • Staff attrition • Weak HR capacity development system • Lack of processes, procedures & guidelines • Lack of skilled manpower in key areas	• Illegal connections • Low production levels • Inadequate infrastructure • Frequent bursts • Frequent pump breakdowns • High treatment costs • Poor O & M practice • High levels of breakdown of meters • Old network • Drawings of existing network not updated	• Late payment of salaries • Low rate of debt collections • Poor cash flow • Inadequate tools and equipment • Poor stock management • Non-payment of internal and external liabilities • Filling of vacant positions • Non-remittance of statutory deductions • Disparity in salary scales

A closer look at the Technical Department showed that the existing hard copy distribution network maps had not been updated for decades. A lot of maintenance activities relied on the personal memory of two technicians that had each worked for the utility for over 30 years. Isolating valves and other fittings could only be traced through a resource-intensive trial-and-error process. The department let alone the company did not have any transport facilities, but relied on the use of bicycles owned by magnanimous staff. Maintenance of the piped network was done on breakdown-orientated procedures, and quite a few reported bursts remained un-repaired for weeks or even months due to lack of materials and fittings. Staff interviewed could not remember when they last went on refresher courses, not to mention the fact that many of the staff were of very low skills. In summary, the internal environment in KAWASCO was far from being conducive for carrying out active water leakage management.

Mwanza Urban Water and Sewerage Authority (MWAUWASA), Tanzania

To enhance autonomy of water service provider in Mwanza, the Government of Tanzania created MWAUWASA as a semi-autonomous agency in July 1996. The mandate of MWAUWASA is to '…provide reliable, adequate and sustainable water and sewerage services in an environmentally friendly manner to Mwanza City (with a 2002 population of 375,000 people) at affordable and cost effective tariffs' (Mihayo & Njiru, 2006, p196). The institutional reform immediately paid off dividends, as key performance indicators showed a positive trend. For example, Non-revenue water improved from 76% to 57%, while the customer base increased from 8,000 to 14,515 customers between 1996 and 2003. The WUP project, which aimed at consolidating these efficiency gains, kicked off with a situational analysis carried out by middle and senior managers of the organisation. Table 2 shows an abridged version of the SWOT analysis dated August 2003.

Table 2 A SWOT analysis by senior and middle staff of MWAUWASA, Mwanza - Tanzania

Strengths

- Good internal control
- Reliable (good) billing system)
- High fraction of metered customers
- Well qualified senior staff
- Good (large) customer base
- New sewerage infrastructure
- Participatory management
- Good revenue collection

Weaknesses

- Inadequate revenue collection
- Poor water distribution network
- Poor water quality
- High percentage of UFW
- Inadequate tools and equipment
- Inequitable salary structure
- Inadequate treatment capacity
- Long connection lines to customers
- Poor motivation of staff
- Lack of pipe network maps
- Inadequate infrastructure & transport

Opportunities

- Being a monopoly
- Reliable & cheap source of raw water
- Reliable waste water receiving body
- Increasing industrial growth
- Relatively high level of autonomy
- Topography allow the construction of optimal reservoir sites
- Good transport links to/from Mwanza
- Eligibility for external funding
- Opportunity for outsourcing
- Ability to attract grants

Threats

- Political interest
- Geology - high excavation costs
- Topography - high pumping costs
- High potential of raw water pollution
- Difficult procedures to recover debts
- Low willingness & affordability to pay
- Water theft & meter tempering
- Intermittent power supply
- Low public health awareness
- Inadequate supply of materials
- Poor city planning

As shown in Table 2, MWAUWASA has got an array of opportunities and strengths, which could easily be utilised to improve their performance in water loss management. Notable examples are an increasing level of autonomy that has enabled the utility to recruit well qualified senior staff, and institute good internal control mechanisms. Furthermore, the increasing goodwill from international development and financing organisations enabled MWAUWASA to access international funding for expansion of the network. Another unique opportunity, which was transformed into a strength was the decentralised nature of utility services in the urban centres of Tanzania. This independence and self-determination meant that once the utility leadership bought into the programme, they were able to make budgetary provisions for it without reference to higher authorities.

Water and Sewerage Authority (WASA), Maseru - Lesotho

WASA was formed as a semi-autonomous parastatal company in 1991 to provide water and sanitation services to the urban centres of Lesotho. The WUP project was limited to only Maseru, the capital city, with an estimated population of 320,000 people at the start of the project. The 2003 production capacity of Maseru water treatment plant was about 28,000 m3/day, which was supplied to the customers through about 18,000 service connections. Maseru has been experiencing a high industrial growth rate since the new millennium, and by the start of the project, there was a shortfall of about 10,000 m3/day of water supply. Hence, a reduction in non-revenue water from the estimated 37% at the start of the WUP project was a highly desired outcome. Aware that a high level non-revenue water is only a consequence of other root problems, the project kicked off with a SWOT analysis to map out the existing situation. Table 3 shows an abridged format of the SWOT analysis carried out by the middle and senior managers of WASA in November 2003.

Table 3 A SWOT analysis by senior and middle staff of WASA, Maseru – Lesotho (Sekhonyana et al, 2006)

Strengths	**Weaknesses**
• Staff with good sector knowledge • Financial stability • Links with other institutions • Highly-skilled technical staff	• Weak leadership & corporate governance • Low level of revenue • High level of UfW and illegal connections • Old infrastructure & inaccurate meters • Poor customer service • Poor performance, corruption and fraud • No HIV/AIDS programme
Opportunities	**Threats**
• Monopoly status • High demand • Donor assistance • Benefits of proximity to South Africa • Available good quality water • Enactment of Environmental Act	• Droughts and inadequate water resources • Low autonomy & privatisation of utilities • High level of unemployment and crime • Environmental pollution • Legal impediments & industrial disputes • High mortality rates

Through a problem tree analysis, the staff in WASA identified challenges to be mainly linked to the root causes of low organisational autonomy, inadequate financial resources and poor leadership skills. The staff who participated in the discussion pointed out that these root causes eventually lead to a high level of non-revenue water through the following key mediating factors: (i) low commitment by managers; (ii) low staff morale and poor attitude to work; (iii) lack of teamwork; (iv) poor remuneration of staff; (v) collusion of staff in making illegal connections; (vi) long procurement processes; (vii) poor maintenance practices; and (viii) inadequate resources for the technical staff e.g. vehicles and tools.

National Water and Sewerage Corporation (NWSC), Entebbe – Uganda

NWSC is a government-owned corporatised utility that provides water and sewerage services in Entebbe and 17 other major urban centres of Uganda. Although the target population in Entebbe at the beginning of the project was estimated at about 110,000 people, the service coverage was about 60%, due to low production capacity of the water production plant. As part of NWSC, Entebbe has benefited from the performance improvement programmes initiated by the new corporate leadership since 1999, which have resulted in positive performance improvement trends in overall service delivery. For instance, between 1998 and 2001, percentage of non-revenue water has reduced from 44% to 30%; bill collection efficiency increased from 74% to 96%, while service coverage increased from 3,000 to 3,400 service connections (Tumuheirwe et al, 2006). Therefore, the WUP project sought to consolidate these efficiency gains.

Despite the performance improvements registered by NWSC Entebbe by the start of the WUP project, a SWOT analysis carried out in October 2003 identified the following major weaknesses concerning non-revenue water (Tumuheirwe and Lutaaya, 2006; Tumuheirwe et al, 2006): (i) an organisational structure that does not fully address water loss management needs; (ii) inadequate management information systems; (iii) weak asset management procedures; (iv) inadequate application of planning tools; (v) lack of district meter areas (DMAs) and inadequate bulk metering (vi) inadequate meter maintenance/replacement policy; (vii) no active leakage management; (viii) weak network management procedures; and (ix) an old pipe network prone to frequent leaks and bursts.

Pilot DMA Action Plans for Water Loss Management

A key section of the PIPs developed by the utilities was on setting up pilot DMAs for improved water loss management. Through training sessions participants were sensitized on the need of knowledge on (i) how much water is being lost; (ii) where it is being lost from; and (iii) why it is being lost. Water loss management (WLM) is therefore a process that involves stages of measurement, validation, identification and rectification. A training module covered the following major topics: (i) terminologies frequently used; (ii) the IWA Water Balance; (iii) classification, estimation and measurement of physical and apparent losses; (iv) conducting a network and operational audit to identify why water is being lost; (v) factors affecting water loss rates; (vi) strategies for reducing water loss; (vii) setting up DMAs; and (viii) pressure reduction strategies. Different utilities had different levels of human and financial resources, and this project aimed at responding to the needs of all utilities. The depth and breadth of the water loss strategy depended on the technical, institutional and financial capacity of the utility. For instance, whereas some utilities could afford to purchase leak noise correlators, others made do with just basic listening sticks.

After the training course, WLM units were set up in each utility, basically composed of the following key staff: (i) a data analysis/team leader to coordinate WLM activities, analyse and evaluate data from the DMAs; (ii) 2-3 leakage technicians to conduct passive and active leakage detection surveys and support repair crews; (iii) a record technician to update network plans, produce and maintain a graphical display of location of leaks/bursts. The consultants worked with these units to set up pilot DMAs.

The process of setting up the pilot DMA were simplified as much as possible, so as to minimise costs and maximise impact, in line with the 80:20 Pareto principle. Identification of the pilot areas was based on factors such as (i) potential for a single meter feed; (ii) minimum number of boundary valves required; (iii) areas with old mains and properties; (iv) high pressure areas; (v) minimal range in ground level contours; and (vi) about 1500-4000 properties. At least two pilot DMAs were set up in each utility.

The preliminary activities in the pilot DMAs were to (i) carry out inspections to minimise visible leaks; (ii) carry out a survey to minimise illegal connections; and (iii) analyse available technical and billing data to establish inaccurate meter readings. Thereafter, boundary valves and meters were installed, and a basic components analysis carried out. Where possible step tests were carried out to identify sub-zones with high water losses. Leak detection activities were then concentrated on these sub-zones, using available leak detection equipment. Minimum night flow measurements were conducted in the pilot zones established in only one utility. By the end of the project, the other three utilities could not conduct minimum night flows either because of the perceived security risks in these zones, or due to lack of the necessary equipment.

Although we could not measure the leakage as accurately as we could have wished to, we were able to establish the zones that acted as a nucleus for (i) carrying out a six-monthly routine leak detection pass using available equipment, (ii) carrying out effective and timely repair of leaks; (iii) continuous verification of customer accounts to minimise water theft, (iv) setting up an MIS and continuous updating of records for various WLM parameters; and (v) initiation of a programme for meter calibration and renewal. For other utilities like Entebbe, they were able to use these pilot DMAs to integrate the WLM parameters in the CUSTIMA billing software, decentralise the network management to these DMAs, and synchronise DMA management into their performance management systems (Tumuheirwe and Lutaaya, 2006). Table 4 shows that by the end of the project, the measures taken by NWSC management in Entebbe successfully reduced water losses in these zones. However, it is not clear if these gains were maintained even after the project ended.

Table 4 Performance of NRW management in NWSC Entebbe's pilot DMAs (Tumuheirwe & Lutaaya, 2006)

		Dec 2004	Jan 2005	Feb 2005	March 2005
Zone 2	Number of Accounts	3401	3784	3827	3896
	Billing Efficiency (%)	61	63	80	89
	NRW (%)	39	37	20	11
Zone 3	No of Accts	1608	1717	1844	1919
	Billing Efficiency (%)	73	80	86	71
	NRW (%)	27	20	14	29*

*During road repairs in March 2005, a number of mains and service lines were severed

Key Challenges of WLM in Utilities of Developing Countries

As already mentioned, the participating utilities had different capacities as far as their human and physical resources were concerned. However, some challenges were common across all the utilities, although to different levels. A key challenge was to convince top managers in utilities in developing countries of the benefits of water loss management. Senior management are not prepared to invest in any programme unless they are convinced of the tangible benefits. The onus is on the professionals to make a cost benefit analysis of the interventions. Often, however, there is inadequate data in utilities of developing countries to make such an analysis. It may therefore be necessary to do a pilot study of a well identified small area in order to collect data for making the case.

Related to the challenge described in the above paragraph, there may be the problem of inadequate organisational capacity. A utility may have a fairly reasonable financial capacity, but may not figure out how strategically important water loss management is to the overall corporate mission. Hence, the department in charge of WLM is not availed all the critically required human, material and financial resources. But another key challenge is inadequate continuous professional development. These concepts are normally available to water professionals through exposures in international conferences, workshops or subscription to journals and magazines. Such options may not be available to professionals working in utilities of developing countries, who must produce results in difficult scarcity-prone environments.

Contrary to the common perceptions held by some water utility managers that reduction of water losses is a purely technical issue, successful water loss management requires concerted efforts from all corporate elements. A reduction in water losses on the side of the service provider requires integrated actions to address technical, operational, institutional, planning, financial and management issues (Vairavamoorthy & Mansoor, 2006). Engendering a integrated approach in a water utility is by no means an easy task, particularly in low-income countries, where disposable corporate resources are limited, and highly contested for by different functions.

Conclusion

The non-revenue water component for some water utilities in middle- and low-income countries is over 50%. For instance, the estimated NRW for four utilities in sub-Saharan Africa that participated in the SIDA-funded WUP project on reduction of NRW ranged between 70% and 30%, a big fraction of which was suspected to be physical losses in the distribution network. Reduction of water loss in the water distribution network is not only important for financial accountability, but also reduces the risk of water re-contamination, improves service quality, and contributes to overall economic/environmental sustainability. The conceptual framework used by this project is that NRW is only a consequence of deep-seated management and organisational challenges in the utilities. As a result, the scope of the project extended to all aspects of water utility management.

Pilot DMAs set up as part of the utilities' PIPs can be an effective way of introducing the concepts of WLM to the utilities. Such iterative and incremental methods ensures that efficiency improvement tasks are matched with existing capacities and create a process-based learning environment. Furthermore, the success stories of pilot projects, if well communicated, could convince the otherwise uncertain top management to allocate more resources for water loss management.

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References

Andresen, P.P., Lorch, R.P. and Rosegrant, M.W. (1997) *The World Food Situation: Recent Development, Emerging Issues, and Long-term Prospects*, Food Policy Report, International Food Policy Research Institute, Washington D.C.

Bourgeois, L. J. (1996). *Strategic Management: From Concepts to Implementation*. The Dryden Press, Fort Worth, TX.

Jacob, B.A. and Lefgren, L. (2005) Principals as Agents: Subjective Performance Measurement in Education. *National Bureau of Economic Research Working Paper No. 11463*, available at http://ksgnotes1.harvard.edu/Research/wpaper.nsf/32181f04b09f9d158525694d001bc47d/077362d64c6fabdc85257026005c6d49/$FILE/Principals%20as%20Agents.doc; accessed on 13 August 2006.

Kayaga S, Itiko, Onyango-Owino, J and Njiru, C. (2006) "Improving Utility Management: Case Study from Kisumu, Kenya", *31st WEDC Conference Proceedings*, Loughborough University, UK.

Kayaga, S. and Zhe, L. (2007) Analysis of public-private partnerships for China's water service, *Proceedings of the Institutions of Civil Engineers – Municipal Engineer* , 160(1), 7-15.

Mihayo, Z. and Njiru, C. (2006) "Improving utility management: cases study of MWAUWASA, Tanzania", *31st WEDC Conference Proceedings*, Loughborough University, UK.

Mugabi, J., Kayaga, S. and Njiru, C. (2007a) Strategic planning for water utilities in developing countries, *Utilities Policy*, 15(1), 1-8.

Mugabi, J., Kayaga, S. and Njiru, C. (2007b) Partnerships for improving water utility management in Africa, *Proceedings of the Institutions of Civil Engineers – Municipal Engineer* , 160(1), 1-6.

Sekhonyana, S., Pholo, M.T. and Fisher, J. (2006) "Improving utility management: cases study from Lesotho", *31st WEDC Conference Proceedings*, Loughborough University, UK.

Tumuheirwe, S. and, Lutaaya, M. (2006) "Challenges of managing non-revenue water: Expereince from a water utility in Uganda", *31st WEDC Conference Proceedings*, Loughborough University, UK

Tumuheirwe, S., Lutaaya, M. and Kayaga, S. (2006) Improving utility management through partnership and capacity building - the case study of NWSC, Entebbe", *31st WEDC Conference Proceedings*, Loughborough University, UK

UN-HABITAT (2004) State of the world's cities, 2004/05, UN-HABITAT Report, Nairobi, Kenya

UN-HABITAT (2006) *State of the World's Cities 2006/7*, Nairobi, Kenya.

United Nations (2007) *World Population Prospects: 2006 Revision,* Department of Economic and Social Affairs, Population Division, New York, USA.

Vairavamoorthy K and Mansoor, M.A. (2006) "Demand management in developing countries" in Butler, D. and Memon, F.A. (eds) *Water Demand Management*, IWA Publishing, London.

Wilson, R.M.S. and Gilligan, C., (1997). *Strategic Marketing Management*, 2nd edition, Butterworth-Heinemann, London.

A Case Study of Leakage Management in Medellin City, Colombia

F Garzon-Contreras*, C Palacio-Sierra **

*Javeriana University, Cali, Colombia. fgarzon@puj.edu.co

**Empresas Publicas de Medellin, Medellin, Colombia. cpalacis@eeppm.com

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Introduction

There has been a recent development of reforms in Colombia with the objective of improving the performance on the water sector. Among those measures, it should be stressed the economic regulatory process adopted, based on a yardstick competition (YC) approach. YC consists in the regulation of an operator with the performance evaluation as a basis for the remaining operators in the same sector. La Comisión de Regulación de Agua Potable y Saneamiento Básico (CRA) defined the criteria and methodology to find out the Colombian Water and Sewerage Services tariff system, where one of the most important is the economic efficiency of water undertakings.

Considering this issue, the tariff structure has water losses as one of main parameters. But in this methodology the water losses are defined as a percentage of volume input (or water production); although in the literature it was extensively discussed that this indicator is very misleading (Lambert, 1999; Liemberger, 2002). Despite this, the economic regulator had fixed in the tariff structure a 30% value for water losses, when the average value for this indicator in Colombia is about 40%, with the objective of improving the general performance of the water sector.

The analysis of the results of water loss control, in the last ten years, showed that Colombia has not made significant progress in this field. For example, for the group of the country's biggest water utilities, water losses have been reduced by less than 1 point, from 40.3% in 1990 to 39.4% in 2001. And, for medium sized water utilities there was an increase from 42% in 1990 to 45.5% in 2001 (Fernandez, 2004). It is very important to note that the difficulty in reducing this performance indicator is explained to great extent by the significant reduction in the water production volume, as a result of reduction in consumption and, as a consequence of the increase in water rates and the expansion of coverage of customers metering; however, this indicator does not allow the utilities to show the reduction in the volume of UfW that they had to manage in order to keep the current levels of UfW. This framework puts water utilities in a difficult position, because the water losses have a direct relation with the rate of return of the operators, and the water loss reduction is linked with the investment made, which influence the OPEX as well as the capital expenses, becoming this a key issue for the utilities.

Recently, the Research Group in Advanced Urban Water Management (GIGAAU) has joined with Empresas Publicas de Medellin (EPM) in a research and validation project sponsored by EPM. It is important to note that EPM is one of the most important Utilities in Colombia and it supplies water to more that 700.000 customers at Medellin's metropolitan area, located in the Antioquia Department, at Colombia's central part zone. The objective of the project was to take a step forward in leakage control in Colombia and it seeks to support EPM with choosing leakage management strategies suitable to their specific needs based on world's best practices.

In this way, the project focused on developing a decision support tool that guides the user in choosing appropriate methodologies and technologies to take leakage to sustainable levels. This system is a web-based system, suited with a set of key principles and related technologies to be followed by the operator when developing a strategy for water loss reduction taken from best practice adapted to Colombian environment, that are connected with tools for calculating IWA Water Balance, IWA Performance Indicators, Economic Leakage Level, Analysis of Night Flows, and Econometric Model for Pressure Management.

To assured that the products of this project were applicable to a diverse range of conditions, the tools were tested and validated on a trial zone in the EPM system. This paper describes, in full detail, the processes and results of this project that shows to be useful for the water loss control for Colombian conditions.

The EPM Water Supply and Distribution System

Medellin's Metropolitan Area is conformed by three interconnected major subsystems: La Ayura, Manantiales and Piedras Blancas; and two minor subsystems: San Cristobal and La Cascada. The Ayura subsystem is feed by the De La Fe reservoir (12.1Mm³); Manantiales by the Rio Grande II reservoir (152 Mm³); and Piedras Blancas by a reservoir with the same name (1.2 Mm³). The interconnected subsystems are connected by six treatment plants with an installed capacity of 16,8 m³/s. Additionally, there are other four small plants with only 0,42 m³/s of installed capacity that are independent of the general system. It's important to note that the actual demand is only 52% of the total capacity.

The raw water transmition system is conformed by four pumping stations; 25,6 km of tunnels; 9,5 km of channels; 6,7 km of pressure conduits; and 35,6 km of pipes that convey water to treatment plants. From this facilities, drinking water is transported to 97 storage tanks (418 000 m³) through 29 booster stations and 256 km of pipes.

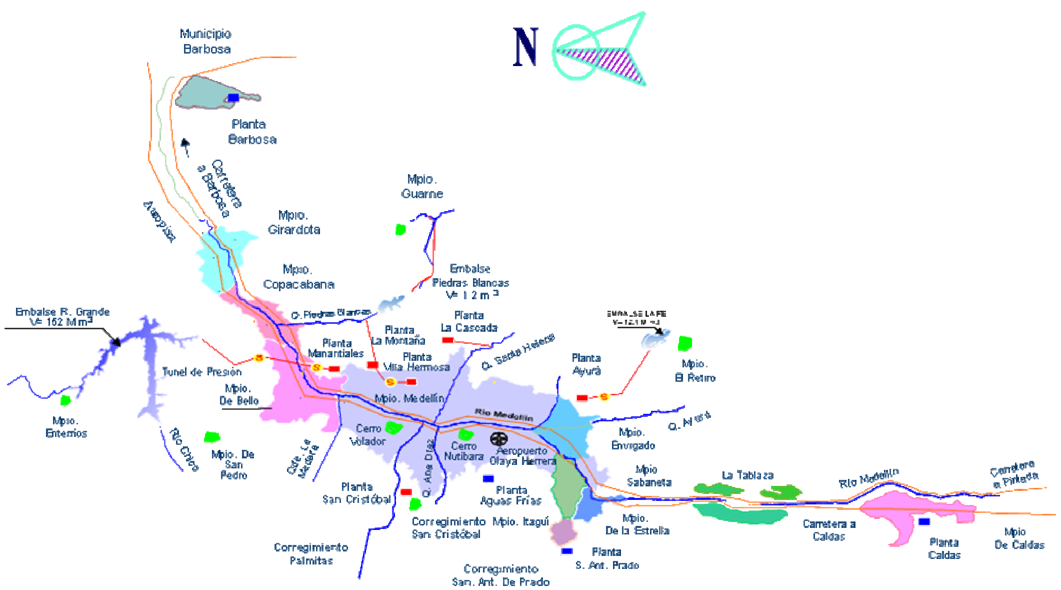

Figure 1. Water Supply Area of Metropolitana de Aguas

The system zoning is based on the location of the storage tanks. So the system now counts with 85 DMAs, and 379 subDMAs. The distribution system has installed 26.369 valves, 4.546 hydrants, 410 PVRs, and 3.159 km of pipes. The composition of pipes by material is: 35% cast iron, 27% ductile iron, 21% UPVC, 6% asbestos cement, 5% PCCP, and the other 6% in other materials. The diameter variation is from 2,5 m to

25 mm, but the diameters are mainly 75 mm (34%), 100 mm (30%) and 150 mm (16%).

EPM Leakage Reduction Program

Assessment of Water Loss for EPM System

During the last decade and before the current project, EPM has been used a variety of approaches to identify how much water was lost. In 1999, EPM started to use the water audit methodology proposed by AWWA Manual M36. Two years later, EPM intended to adopt the water balance calculation methodology developed by Institute for Water Technology (Cabrera et al. 1999). For this period of time, the level of water losses was expressed as a percentage of distribution input, just like is asked by Economic Regulator. Figure 2 shows the evolution of this performance indicator during this period.

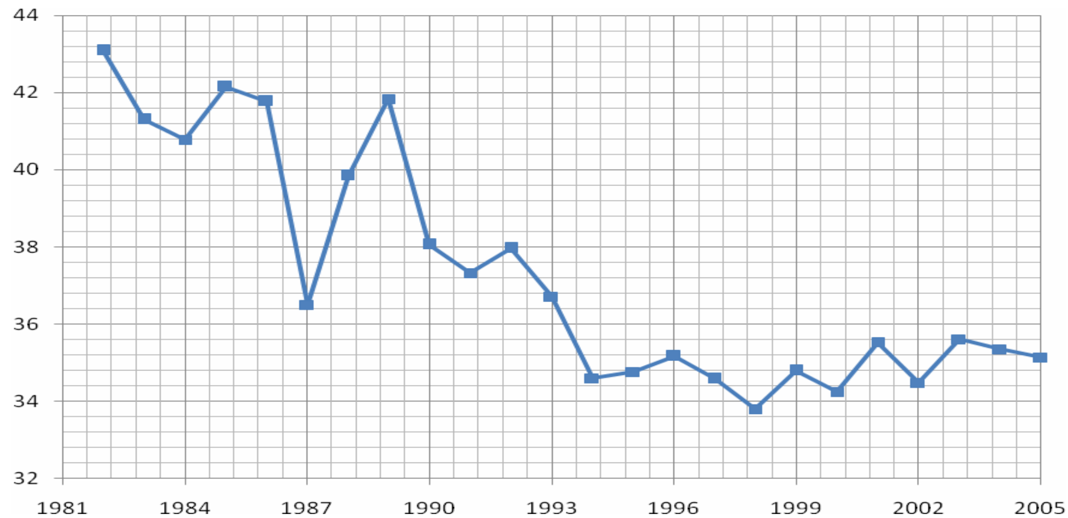

Figure 2. Time Evolution of UfW (% of input volume)

The results of water loss desegregation for the year 2001 showed that the major component was real losses, with 57% of the total water losses, while apparent losses were estimated at 43%. The level of unauthorised use, i.e. illegal connections and water theft accounted approximately for 25% of the total water losses.

Water Loss Reduction Strategy adopted by EPM System

On the basis of water loss assessment, EPM adopted key actions focused on reducing the real water losses:

1. Enhance the bulk metering system.
2. Update information about the system DMAs, and rezone 34 sectors.
3. Implementation of SCADA system for DMAs with minimum night flow calculation.
4. Reduce response time to costumer complains about visible leakage.
5. Start an intensive non-visible leak detection program for the entire distribution network.

6. Reduce the water distribution system maximum pressure from 125 m head to 60 m. (205 PVRs installed)
7. Renovate almost 690 km of mains (cast iron and asbestos cement) in poor condition.
8. Implement a replacement programme for iron and uPVC service pipes.

The Research Project

In general, in Colombia as in other Latin American countries, the advance on leakage evaluation and control made in the last couple of decades, especially in England and Wales and later by International Water Association's Water Losses Taskforce, is rather unknown. The main cause for this situation is associated with the low level exposure of our utility personal to the best management practices, due to lack of information since there is a vast amount of publications in English, and it is rare to find some state-of-the-art literature about this topic in Spanish, related with our local conditions.

Considering this fact, the GIGAAU Research Group under the Innovation and Development Program of EPM carried out a research project aimed to disseminate Best Practices on water loss management in a wide scale in Colombia. It is important to emphasize that this project is not aimed to develop new tools, but rather to find new ways of applying existing methodologies and tools within the decision support methodology, focused on finding an efficient way to meet water leakage problems.

This project considered two related parts. The first one was the development of a Decision Support Tool based on the analysis of available technologies, procedures, and methodologies to reduce leakage in water distribution networks. The other part of the project was the practical field testing of some of these procedures in one test area of EPM's water distribution system.

Decision Support Tool

The DST is a leakage management specialised software, that supplies information on a wide range of topics directly relevant to today's water service provider and allowing the practitioner to take informed decisions by customising the decision support responses to his/her local needs. The DST is designed to interact with the other project tools: benchmarking and econometric tools.

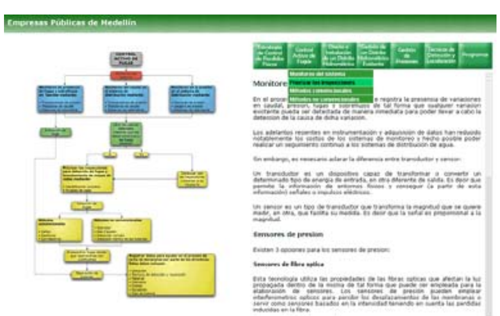

Figure 3. Details of Decision Support Tool

The structure of DST considers that in selecting an appropriate leakage management strategy, the water operator needs to take into account its own sustainability requirements, institutional structure and resources. In fact the water company will establish its leakage target having those factors in mind. But before defining leakage targets, the water company will need to define its current position, i.e. how much water is actually lost from the water system and how this leakage level compares with other systems. For this purpose the DST has a benchmarking tool that integrates the IWA standardised water balance that takes into account the reliability of the data used in the water balance calculation; the component analysis; and IWA Performance Indicators. For the users in which the leakage level is defined by night flow measurements the DST has a tool for minimum night flow calculation based on UKWIR methodologies, but it can be customized with user data.

The econometric tools included in the DST are aimed to identify which technologies and methodologies will help for reaching water operator economic level of leakage and which is the most cost-effective combination and sequence of the four leakage management activities for the specific local conditions. The DST has 3 econometric tools. One tool for the assessment of the financial savings associated with leakage reduction through the installation of Pressure Reducing Valves (PRVs) with various methods of control (fixed-outled, time modulation, and flow modulation) for a selected pressure managed area. The analysis is relatively simple and does not require full pipe network analysis, and it is based on a power law relationship. The cost of the PRV installation and the reduction in water consumption is compared with the cost of the leaking water.

The other econometric tool calculates in a quick and practical way the economic intervention frequency for active leakage control based only on three key parameters: natural rate of rise of unreported leakage, marginal cost of water, and cost of intervention (Lambert and Fantozzi, 2005; Lambert y Lalonde, 2005). This tool is called "Express ELL Calculation" and considers three methods for an approximate assessment of natural rate of rise of unreported losses. Finally, the DST has a tool that determine the optimum combination and sequence of the four leakage management activities that will allow the economic level of Real Losses to be achieved that is based on the BABE (Bursts and Background Estimate) approach and the principles of FAVAD (Fixed Area and Variable Area Discharges). This tool is called "Full ELL Calculation".

To summarise, benchmarking and econometric tools are used to define best practise and targets under the utilities' specific conditions and should be used with support of the best practice database in DST. The DST also gives guidance on how to implement the cost-benefit analysis for evaluating options, thus helping to identify the appropriate Leakage Management Strategy.

EPM Water Audit

As previous mentioned, the other part of this research project tried to evaluate the current level of leakage at EPM water distribution systems, have a water audit, and bring them a more detailed insight of water losses composition to attack the leakage problem core.

In this case, the water audit had two components: system appraisal and water balance calculation. The purpose of the appraisal was to review the regional characteristics of the system; current practice and methodologies; level of technology; staff skill and capabilities; and the company's data and methodology for the water balance calculation. The appraisal included discussions with senior and operational staff on system features and practice, current management practice, perceptions, financial and political constrains and influences, and future planning. In this stage of study, it was also included the selection of a suitable test area for the field verification tests.

The water balance calculation for the total system adopted the IWA standardised water balance with 95% confidence limits for each component of water balance for 2005 year. The GIGAAU Research Group did not validate the system input volumes, nor the consumption volumes, and took all data from previous leakage calculations made by EPM personal. These calculations showed that water losses were 88.636.652 m³/year (31.8% system input volume). Of the total water losses, the real losses were estimated at 67% and apparent losses at 33%. Additionally, the low levels of variability of water losses (±2.8%), and real losses (±9.8%) for the 95% confidence limits are remarkable, so that made them very reliable.

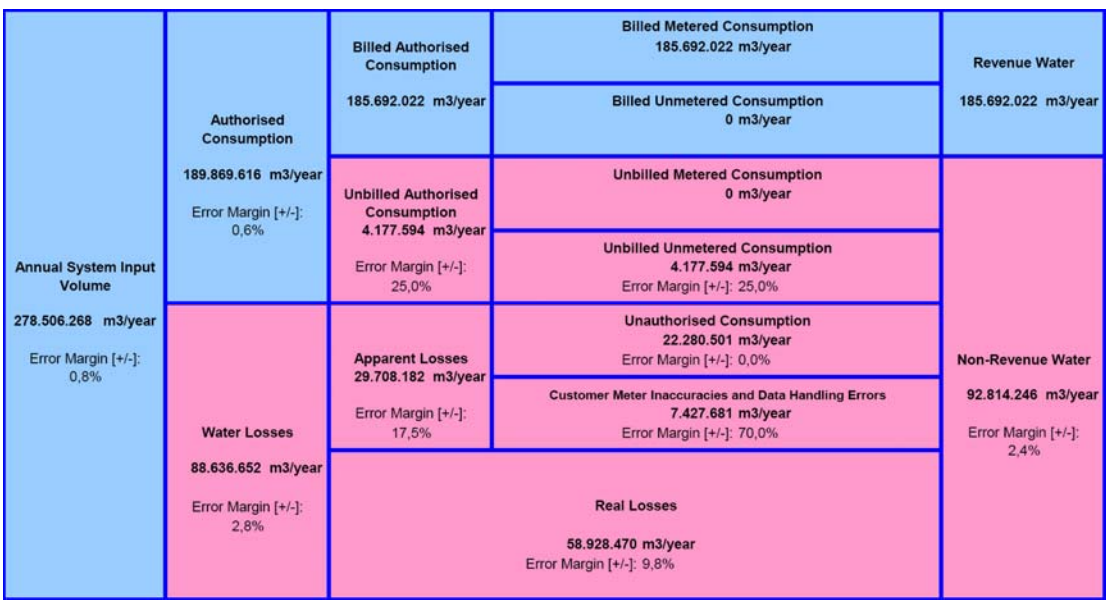

Figure 4. EPM Water Balance

During this research project Data Base Tool was developed to calculate the water balance and water loss performance indicators for each of the 85 DMAs that composed the system.

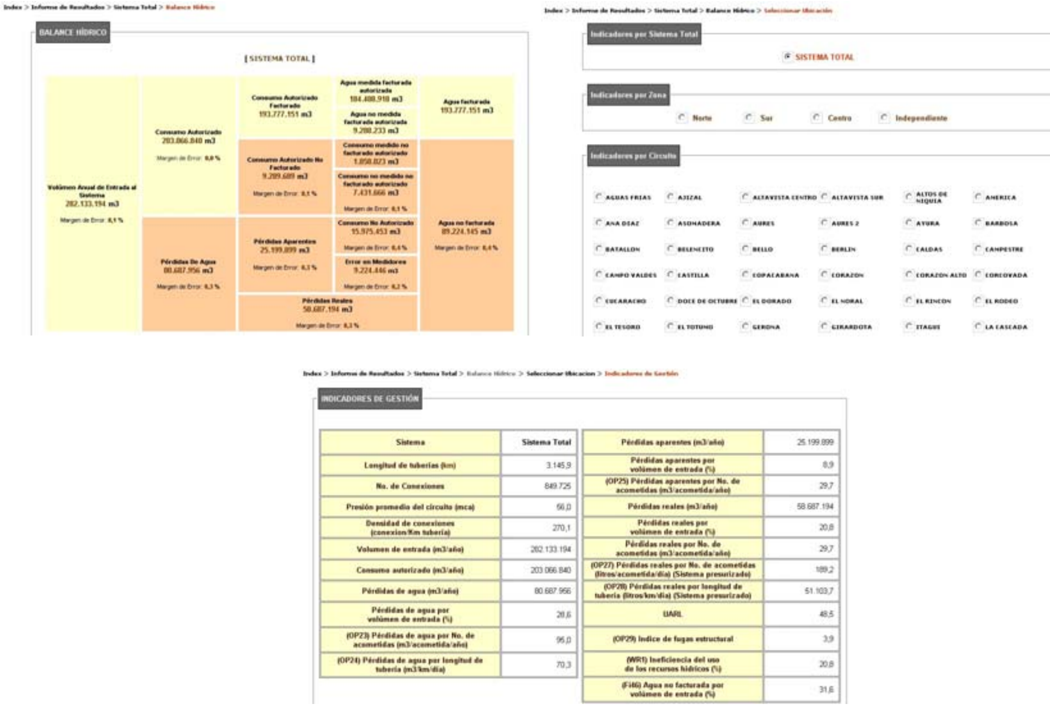

Figure 5. EPM Water Balance Data Base Tool

Component Analysis of Real Losses

Once the volume of real losses was known, it was necessary to break down into components. These components were derived using component analysis based on BABE and FAVAD concepts. As data from EPM repair records did not differentiate between reported and unreported burst, and it was not possible to obtain separate times for location and repair of burst and leakage; a first water real loss estimate was made using data from the number of breaks and burst on mains and service pipes repaired during the reporting period, assuming that 80% of damages were located at service pipes, and reported bursts were 60% higher that unreported (current rate at 0.67 breaks/km of mains/year). Additionally, average flow rate and leakage total run time were taken from BABE methodology for the different types of bursts. The N1 exponent was taken equal to 1.0 considering the pipe material composition of the system.

Then the total annual volume of leakage from mains and service pipes were calculated as follows: Number of (un)reported bursts x average leak flow rate x average leak duration. To obtain the background losses this figures were subtracted from the volume of real losses:

- Total volume of real losses: 58,928,470 m³/year (100%)
- Reported volume of losses: 3,212,698 m³/year (5.5%)
- Unreported volume of losses: 21,032,417 m³/year (35.7%)
- Background volume of losses: 34,683,355 m³/year (58.8%)

These figures clearly show that the major component is the background losses. This fact was verified later by ICF field test.

Water Loss Performance Indicators

The IWA's recommended performance indicator for water loss, the Infrastructure Leakage Index (ILI), for the total system was calculated at 4 (±1) that puts EPM in an impressive place on the international context, close to the best currently achieved technical standard of real losses management.

Economic Level of Leakage

The balance between installed capacity of the system and water demand shows a system with an oversized infrastructure (c. 48%) due to the big reduction in water consumption as the result of the great increase on water tariff in the last decade. Due to this fact, the marginal cost of water is limited only to variable operational costs that are very low (c. U$ 0.1). Thus, the economic frequencies of intervention of active leakage control calculated by any of the models including in DST showed periods of time double or bigger than those used today. In this case, the definition of leakage targets has to be determined not only on a financial basis, but on operational and environmental concerns as well.

Field Verification

In order to improve the understanding of the real loss components in the EPM distribution system, this project undertook two field tests: Infrastructure Condition Factor, and N1 pressure exponent at two different, but representative, test areas.

Infrastructure Condition Factor Test

The condition of the infrastructure is characterized by the Infrastructure Condition Factor (ICF). The ICF is the ratio between actual background leakage and the unavoidable amount of background leakage. This method requires all recoverable leakage to be removed from the pilot study area and a measurement made of the lowest achievable (background) leakage.

The area of pilot ICF test is a small zone with closed boundaries and a single feed point called Apollo district. This zone has a high connection density (295.6 conn/km). The pipes are made of ductile iron with a total length of 1.1 km, and their sizes vary from 75 mm to 100 mm of diameter. The average pressure at zone was 50 m head.

Figure 6. Apollo Pilot Zone – General View

Before the test, two systematic sounding surveys at night were carried out in the zone to find out unreported bursts, but the surveys did not detect leaks. To remove the water consumption during the test, it was decided to shut off all service connections before. The flow at entry point to the pilot zone was measured by means of a 19 mm class C multiple jet water meter installed in a 25 mm bypass.

Figure 7. Apollo Pilot Zone – Test Measurements

The results of the test showed figures of ICF from 2.3 to 4.7 with an average value of 3.5 that is very close to ILI of 4. This fact, confirms that it has been observed in many systems, the value of the ICF is found to be similar to the value of the ILI. Additionally, these results are in good agreement with the values obtained by the sensitivity analysis of the volume of real losses from 1 to 4.9 with an average value of 2.9.

N1 Pressure Step Test

This test also requires a small pressure zone with closed boundaries and a single feed point. During the test, the supply pressure was reduced by operating a PVR. The inflow to the zone and the pressure at the average pressure point in the zone are logged while the pressure at the inflow to the zone is reduced in a series of steps during the stable portion of the minimum night flow period when consumption is at a minimum.

The test was undertaken at a pressure zone with 4 396 connections by operating PVR during minimum night consumption with only residential consumption. The average value of N1 pressure exponent was 1.33. This value is clearly within the range (0.5-1.5) quoted by Lambert (2001) and may suggest that the system had relative low leakage associated with background losses. This accord with the field test exercised prior to the N1 derivation.

Further work

It is important to note, that the results of component analysis model is the basis for a sound strategy of leakage reduction. But as it was stated before, the estimated volume of real losses in the components analysis is sensible to ICF's value. In order to determine the weighted average ICF for the whole system it is necessary to undertake more field tests in a representative sample of DMAs across the EPM system.

Additionally, it is necessary that EPM obtains typical flow rates for different types of pipe failures in a representative sample, and will have to improve the work management system to differentiate reported and unreported leakage and burst, failure types, awareness time, location and repair times. With this information EPM will have a robust real losses model that will become the basis for economic analysis of the various intervention options.

Conclusions

The Research Project presented here focuses on supporting water operators in leakage management. The developed DST will provide users with a comprehensive view on the state-of-the-art in the water distribution sector. This will be of great help to users when they are looking for information on technologies and methods to solve their leakage related problems. The GIGAAU Research Group trust to make the DST a reference point for the Latin American water professionals interested in assessment and reduction of water losses.

The field tests undertook at EPM system showed that the major component of real water losses is the background losses that may be a direct result of the high average system pressure. It appears too that the high connection density plays an important role on the unavoidable leakage then the EPM would likely need to decide on either a pressure management optimization program taking in account the 410 PVRs installed at the system and or an infrastructure replacement program focused on service pipes that would offer better returns than the main replacement.

On the other hand, the reported volume of losses is not important, so the policy of damage attention has to be maintained (maximum 2 days). The unreported volume of losses has a marginal benefit on leakage reduction, but the intervention frequency has to be maintained at current level (whole system survey every 2 years).

Although, the EPM system shows an impressive performance of its leakage management, it is clear that there are new tools that could be implemented to reduce its current leakage level with no major capital expenditures.

Acknowledgements

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References

Cabrera, E., Almandoz, J., Arregui, F., and García–Serra, J. (1999) Auditoria de redes de distribución de agua. Ingeniería del Agua, 6(4),387–399.

Fernandez, D. (2004) REDI Informe final: Sector del Agua y Saneamiento. Consultant's report. The World Bank, Washintong D.C.

Lambert, A., Brown, T.G., Takizawa, M., Weimer, D. (1999) A Review of Performance Indicators for Real Losses from Water Supply Systems. Aqua 48(6)

Lambert, A. (2001) What Do We Know About Pressure: Leakage Relationship. Proc. of IWA International Conference on System Approach to Leakage Control and Water Distribution Systems Management. Brno, Czech Republic.

Lambert, A., and Fantozzi, M. (2005) Recent Advances in Calculation of Economic Intervention Frequency for Active Leakage Control, and Implications for Calculation of Economic Leakage Levels. Proc. of IWA International Conference on Water Economics, Statistics and Finance, Crete.

Lambert, A, and Lalonde, A. (2005) Using Practical Predictions of Economic Intervention Frequency to Calculate Short-run Economic Leakage Level, with or without Pressure Management. Proc. of IWA International Conference Leakage 2005, Halifax, Canada.

Liemberger, R. (2002) Do you know how misleading the use of wrong performance indicator can be? Proc. of IWA International Conference on Managing Leakage, Cyprus.

Cabrera, Andrews, J.F. (1993) Modeling and simulation of wastewater treatment processes. *Wat. Sci. Tech.* **28**(11/12), 141–150.

Billing, A.E. (1987) Modelling techniques for biological systems. M.Sc. thesis, Dept Chem. Eng., Univ. of Cape Town, Rondebosch 7700, South Africa.

Non-Revenue Water Reduction in Indonesia
- The Challenge and the Way Forward

Chris Ingram* and Ahmad Hayat**
***Water Supply Advisor, World Bank Institute, World Bank Office - Jakarta, Jakarta Stock Exchange Building, Tower 2, 13th floor, Jl. Jend. Sudirman Kav. 52-53, Jakarta 12190, INDONESIA** cpmingram@hotmail.com

****NRW Management Facilitator World Bank Institute, World Bank Office - Jakarta, Jakarta Stock Exchange Building, Tower 2, 13th floor, Jl. Jend. Sudirman Kav. 52-53, Jakarta 12190, INDONESIA** ahayat@worldbank.org

Keywords: NRW reduction; Indonesia; Challenge

1. Introduction

Indonesia comprises more than 15,000 islands set across 3 time Zones. It is the world's 4th most populous nation, with more than 215 million inhabitants. Developments in the water supply sector have not kept pace with population growth and currently less than 25% of Indonesia's households are served with a piped water supply, (compared to 99%+ in Malaysia just next door). The Nation's water supply is provided by some 320+ local public sector water supply companies who have been massively under-funded in recent years and consequently do not have the capacity to serve their customers.

Figure 1. Location of Indonesia

Recent economic growth has not been mirrored in increased water supply. There has been no significant investment in Water Supply Sector since the Economic Crisis of late 1990s.There have been some recent developments in providing new water production facilities and transmission mains by Multilateral and Bilateral Donors. But the more difficult and politically less prestigious downstream tasks of network extensions, rehabilitation and improvements to provide for and distribute the additional production capacity have not been carried out hand-in-hand with the upstream facilities and in most cases have been largely ignored.

Consequently there is a huge NRW problem, which in some cases has merely been exacerbated by the provision of extra production capacity, resulting in increased pressures on already flimsy distribution systems. In most cases the NRW Problem is misunderstood by the very people who should be in a position to assist in mitigation measures.

This paper describes in detail some of the challenges faced by the World Bank Institute in its Water Sector Capacity Building Program in Indonesia, in identifying these problems and bringing them to light and to the attention of the appropriate Authorities. Initial efforts towards NRW Reduction Capacity Building within the Indonesian Water Companies are also described, together with future targets for reducing NRW in some selected leading Utilities.

2. The Challenge

Many Local Water Companies (local Indonesian acronym is ***PDAMs***) do not have the human resource capacity to identify losses and have not been aware of NRW Reduction methodology which would be of assistance. Their plight is compounded by an almost national lack of adequate production and bulk metering, a lack of a Network Information System (NIS) or even basic mapping or “as-built” drawings or records of the pipework within their Network.

Add to this the factors of poor quality materials used and inferior construction practises, together with instances of corrupt practises, illegal connections, poor billing systems and in some PDAMs an inherited debt from Central Government for completed inferior Projects, then it becomes clear that there is a massive task ahead.

SEAWUN (South East Asia Water Utilities Network) has analyzed information from 14 PDAMs and the results were: Total volume of NRW: 127 million m3 /year Assuming a split between commercial and physical losses of 30/70:

- 38 M m^3 commercial losses
- 89 M m^3 physical losses

The weighted average tariff was calculated to be US$ 0.13 per m3 Assuming that both commercial and physical losses could be reduced by 50%: Reduction of commercial losses would generate annually US$ 2.2 million additional revenues (just for these 14 PDAMs)!!!

3. A Difficult Start

In April 2005 ***PERPAMSI,*** (National Association of Water Utilities), supported by the World Bank Institute had organized a three day Non-Revenue Water Reduction training course, where the new standardized methodology was presented to representatives from selected PDAMs.

A few interactive sessions during this first training course had shown that little had been understood and that the wealth of new information and methodologies was just too much to be digested in the limited time of the event – which was a more a series of classroom presentations rather than a workshop.

The need for additional, more practical and interactive training became obvious. It was decided to design such a tailored training course and hold it for the first time in Jambi in August 2005.

4. The Phase 1 Works

An interactive approach was therefore utilized in the Jambi Workshop, as follows:

Week 1: Team of trainers analyzed the NRW situation of the PDAM Jambi and developed a NRW reduction strategy.

Week 2: First two days findings were transferred into questions for the trainees.

Week 2: Second 2½ days; Trainees (working together in groups) had to gather data of the Jambi water supply system, determine the level of NRW and quantify its components, calculate performance indicators and develop a NRW reduction strategy.

The groups summarized their findings in PowerPoint presentations and present them to the other course participants. Quality of presentations was assessed by the team of trainers and groups were ranked accordingly.

Director of PDAM Jambi presented the NRW analysis and NRW reduction strategy that was developed jointly with the trainers during the first week of the program.

Course participants did not get a certificate but "homework": to carry out a similar analysis for their PDAMs and present the results in the next NRW training course that was held in Jakarta in December 2005.

Quality of the homework varied widely – fundamental mistakes were made. Errors were discussed and trainees were instructed how to correct data and prepare improved presentations for the final NRW workshop of this first phase – Bali, May 2006.

Each of the 11 PDAMs participating in the NRW course had to speak on one of the following topics:

- Calculating and using NRW performance indicators
- Limitations in data availability and quality
- Key elements of a successful NRW reduction program
- Main reasons why comprehensive NRW reduction is not done in Indonesia

The presentations, although of course different in quality, were a good mix of theoretical lessons learned during the course and data and experience from the respective PDAM. Presenters and their fellow colleagues performed well in discussions and the difference in knowledge between them and those that have not participated in the course was obvious.

5. Redesigning the Concept

Phase 1 proved to be successful, the feedback received from participants showed that they understood the concepts and learned how to use the tools through the homework assignments.

However, the training of individuals was not sufficient since turnover at PDAMs may result in losing staff with the precious knowledge. Furthermore, having individuals familiar with the key issues of Non-Revenue Water will not guarantee that NRW will be reduced. Hence the concept had to be re-designed.

Lessons learnt from Phase 1 have led to the development of the following course framework which is used in the second phase of the NRW training program. Retaining whatever worked during Phase 1 and adding new elements, WBI decided to use an approach that will serve multiple purposes for Phase 2:

- WBI provide Hands-On support for NRW Reduction with Active Leakage Control.
- WBI and PERPAMSI continue the training of PDAM staff in a series of NRW workshops.

The best performing PDAMs become ***Centers of Excellence*** in various regions of the country to eventually pass on their knowledge to PDAMs in their regions that could not benefit from the capacity building workshops organized by WBI and PERPAMSI.

The participants of the workshops established a network of practitioners to share information and ideas on NRW:

(http://groups.yahoo.com/group/Forumpeduliairtakberekening).

The knowledge acquired during the workshop is expected to be integrated into the general strategy of the participating PDAMs through action planning. To achieve the above, WBI and PERPAMSI is using a specific methodology developed by the United Nations Institute for Training and Research (UNITAR) together with British Petroleum (BP).

6. Redesigning the Concept – Sharing Knowledge for Fighting NRW

The objective is to identify sources of expertise within the PDAMs and make sure the expertise is transferred to the other PDAMs so that they can use it to reduce their own NRW. Whenever we find that there is no sufficient expertise among the PDAMs we turn to outside expertise such as WBI or PERPAMSI. The methodology is used:

- to provide a strategic planning tool to reduce NRW
- to facilitate the workshops in order to identify the champions among the PDAMs and to identify opportunities for learning
- to facilitate the exchanges between the workshops to help with the homework and with the measures PDAMs wish to implement to fight NRW.

The NRW Self Assessment Matrix – where do we stand? he principle is to recognize who is strong and who is weak in various aspects and allow the weak to visit the strong for Knowledge Sharing.

7. **Workshop 2/1: Makassar**, December 2006 – A vigorous Start to Phase 2

This 3-day workshop assembled 24 PDAMs from all over the country eager to learn about NRW. The agenda combined expert presentations, site visits, a role play, technical group exercises knowledge sharing exercises and a presentation from the host PDAM.

Based on the success of the Knowledge Sharing initiative, a Statement of Commitment to cooperate by forming a **"Learning Network"** was signed by the PDAMs at the conclusion of the Workshop.

8. Redesigning the Concept - Knowledge Sharing:

An Example of the Self-Assessment Matrix

Para-meter	1 Basic	2	3	4	5 High
Water Balance	**We do not establish a water balance**	**We have tried to establish a water balance but gave up since we don't know the split in physical and commercial Losses**	**We establish a water balance following our own format**	**We establish an annual water balance in accordance with the international form**	**We establish an annual water balance in accordance with the international form and also use 95% confidence limits to indicate accuracy bands.**

Table 1

As a result of the group discussion and the diagrams, the PDAMs identified the champions, for example:

- **Bogor and Jambi** for the water balance, Maps/GIS and leak repair records,
- **Medan and Surabaya** for system input metering,
- **Makassar** for system input metering and pressure monitoring and leak repair records,
- **Surabaya and Tangerang** for Maps/GIS,

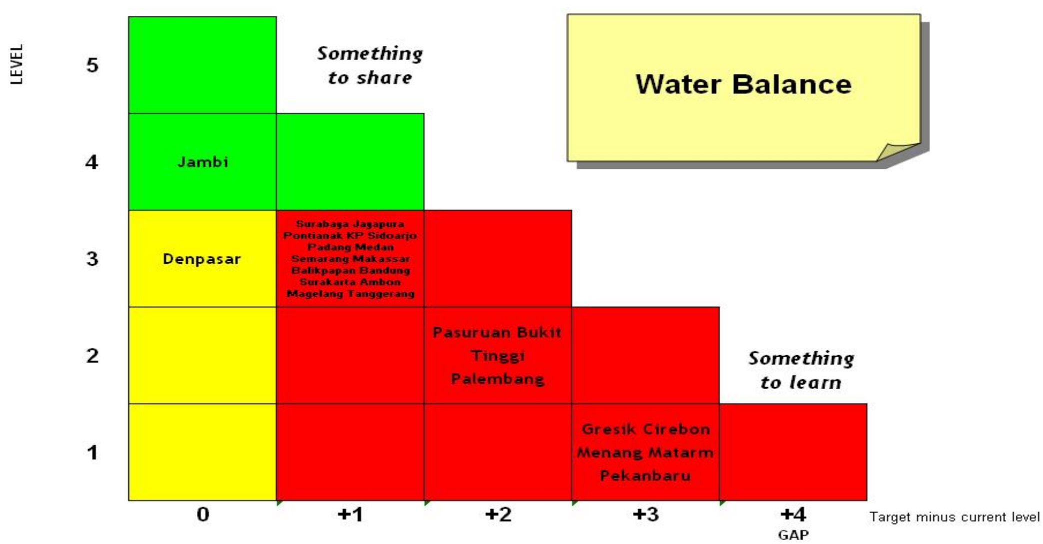


Figure 2 Knowledge Sharing – Water Balance

9. Workshop 2/2: Surabaya, - May 2007

This Workshop continued the sequence from the earlier Makassar Workshop 2/1. An RW Examination was held. The 2 Winners received a prize: *They were given tickets for "WATER LOSS 2007"!!!.*

Homework set after the Workshop concentrated on making a Water Balance for the 21 PDAMs who participated. This proved to be a major exercise and needed a great deal of pushing to extract the data from the 21 PDAMs

10. Problems Encountered

Some PDAM Managers did not understand the continuity element of the Phase 2 Workshops and wanted to send different Staff to each Workshop (It was Mr X's turn for Workshop 2/1, therefore it's Mr Y's turn for Workshop 2/2)!! ***WRONG!! We need to have continuity with the same delegates to the completion of Phase 2.***

Some very motivated staff at the Workshops returned to their PDAM to be told to *"Get on with your normal work!"* Staff did not have time to complete their homework and some have lost interest.

PDAMs tried to save money by cutting corners on DMA Set-Up; e.g. reducing size of Measurement Chamber. *This resulted in false meter readings as turbulent flow passed through the meter! (Insufficient straight pipe lengths upstream and downstream of the meter).* Furthermore – often no PRV was installed (normally for cost considerations).

Figure 3 A Sub-Standard DMA Measurement Chamber

11. Successes

Some immediate minor successes were achieved. For example – the setting up of the Quick Response Leakage “Team” in Jambi!

Figure 4 – The Quick Response Team - Jambi

However, following the Workshops 2/1 and 2/2, far greater success has now been achieved from the results of the homework submitted from the participating PDAMs, as shown in the following charts.

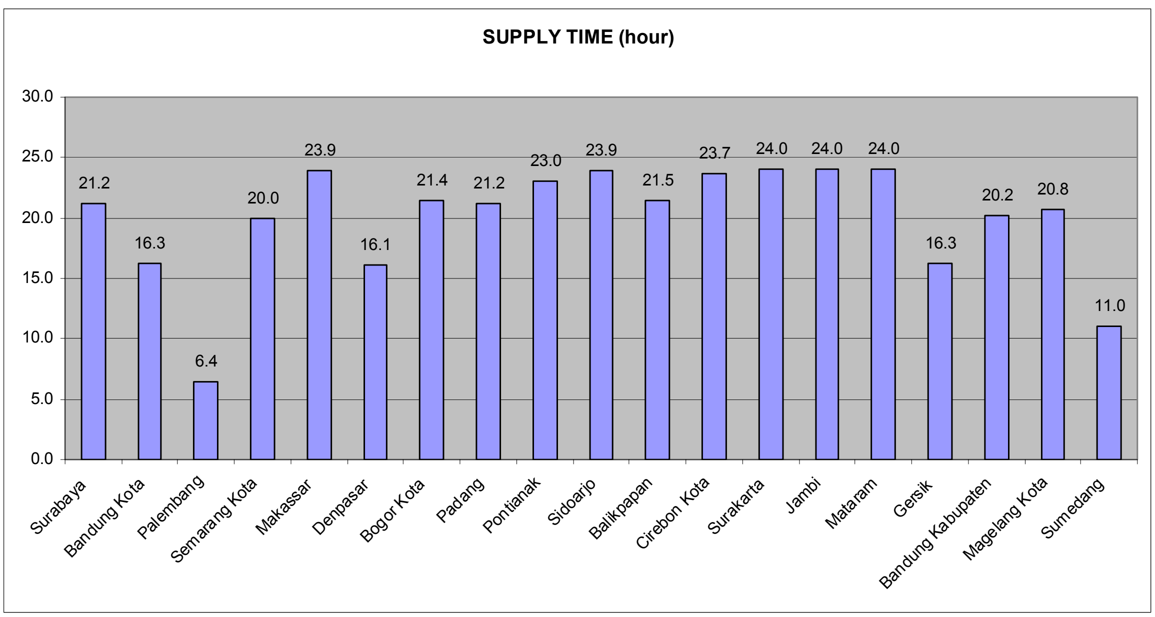


Figure 5 Supply Times of 19 PDAMs

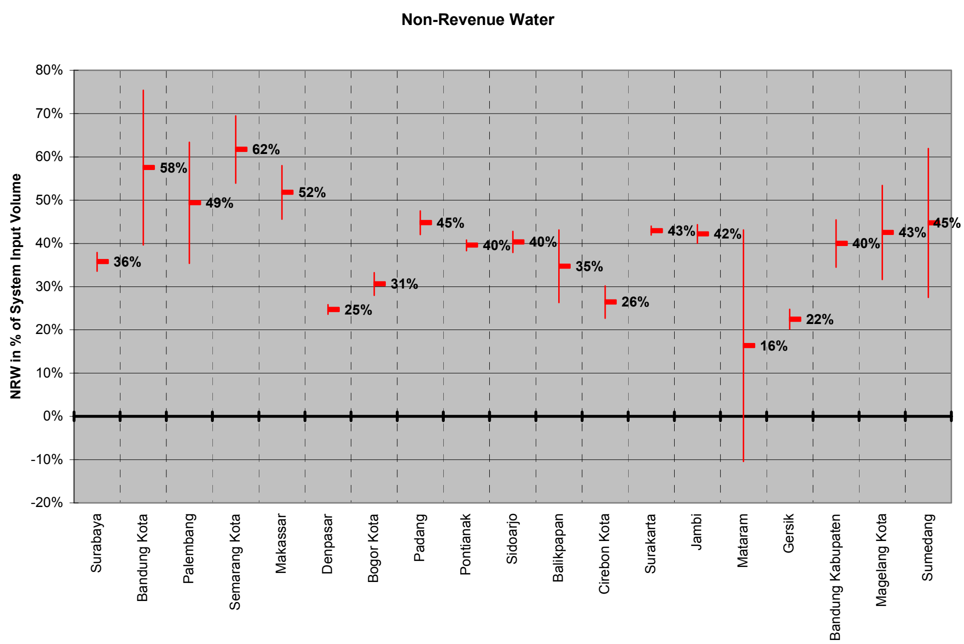


Figure 6 Non-Revenue Water Indicators from 19 PDAMs

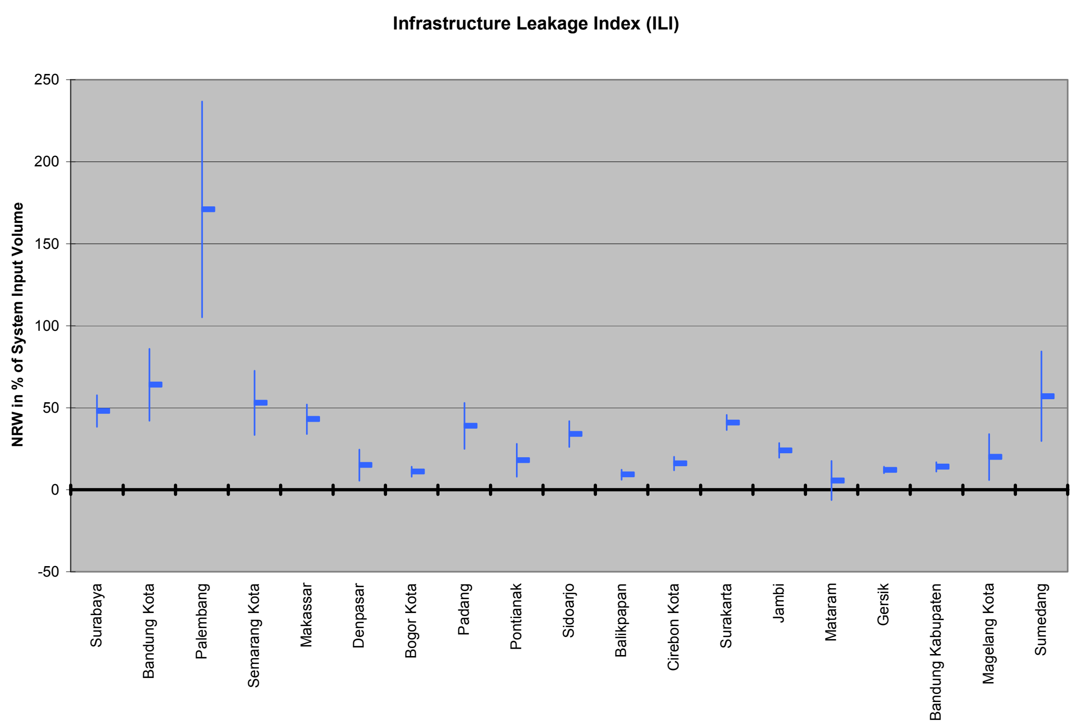


Figure 7 Infrastructure Leakage Index from 19 PDAMs

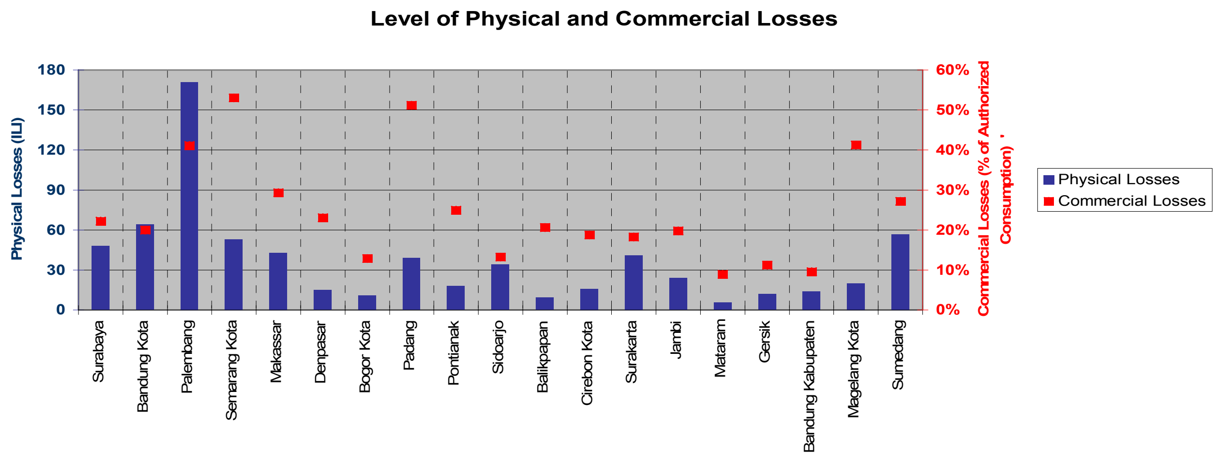


Figure 8 Comparison of Physical and Commercial Losses from 19 PDAMs

12. The Way Forward

The next Workshop (No 2/3) will continue the sequence from the earlier Workshops 2/1 and 2/2. This will probably be held in March/April 2008. Water Balance Homework will be reviewed and progress on establishment of DMAs to be reviewed. (This will be used as a basis for Expert's Field Missions)

It is also proposed to establish a ***DMA Rolling Fund*** whereby:

- Approx. 15 PDAMs each to be given **US$25,000** to construct their first DMA to prove its value to management.
- Technical Advice in the DMA selection and Set-up to be given by a WBI Expert
- Further advice and training in Leak Detection and Repair to be given by another WBI Expert
- Average savings per DMA calculated to be approx. 371m3/day
- DMA pays for itself in < 9 months
- Savings used to construct DMA No 2 et seq.
- US$25,000 repaid to the fund after 2 years for use by next 15 PDAMs - et seq.

The WASAP-"B" initiatives will continue, with emphasis on Asset Management in general and Distribution System operation and management, combined with NRW Reduction in particular.

13. Learning from Each Other – How WBI will Help.

WBI will set up a mechanism to assist PDAM Staff who would like to pay a visit to their colleagues and learn from them through observation and discussion. WBI will also coach Indonesian counterparts to familiarize them with the method of knowledge sharing, which in turn will make sure that the process is self-driven.

PERPAMSI will be there to continue and the important thing is that the Knowledge Sharing element will, by this time, have reached a level, whereby Indonesian "Champions" in each field can help their counterparts in other PDAMs.

14. Conclusions

There is still a massive task ahead in Indonesia, which can only be undertaken by a dedicated Team, supported by available financing, the political will and the enabling environment to move forward for the ultimate benefit of the health and prosperity for the population in general. The NRW Reduction element of this task is of enormous importance and forms a central aspect of the entire WASAP Program.

Audit of 29 Water Distribution Networks of Romania

J Valverde* , V Ciomos**

* La Alborada D7-A – Cerro Colorado, Arequipa, Peru, jlvalverde@esan.org.pe

** Splaiul Independentei, nr 202A, 6th district, Bucharest, vciomos@ara.ro

Keywords: Water Network Audit; Water Balance; Performance Indicators

Introduction

This paper seeks to give the first steps on these matters of Network Audit and Water Balance that the Water Companies in Romania may use in the next years to evaluate the advances of efficiency in operational management of the network.

As a result of the preliminary studies of water losses and network audit in the Project "Technical Assistance for Project Preparation in Wastewater Drinking Water Sector – Romania", (ISPA Measure 2003/RO/16/P/PA013-05 – EUROPE AID/119084/D/SV/RO), we have a good idea of the real actual state of water supply infrastructure, pipes, metering and operational management in five counties of Romania and we can be confident in recommend the intervention to renovation of pipes, metering and mapping in order to reduce water losses, get efficiency in the network management and thinking in get the required EU Standards.

It was a very good opportunity to use some tools that were proposed by IWA, and have the experience to know how useful could be work with Performance Indicators and the relativity of some considerations that may change a Bench Marking Study.

We prepared the Water Balance for twenty nine networks in which operators never thought before in a methodology like we used and were not prepared with data required. And, of course, final index were relatives, with low level of confidence but really useful in network evaluation.

In order to do this research about Water Balance, Network Audit and benchmarking to know the real state of the networks and water losses indicators, an enquiry was distributed to the operators of the 29 cities in five counties in Rumania. The information required and then used to compute the Performance Indicators and to carry out the Water Balance and benchmarking is displayed in the next lines.

- Volumes (abstracted, consumed, metered, billed)
- Customers (Residential, non residential)
- Networks features (length, material, diameter, age)
- Service connections (features, no.)
- Free delivered water volume
- Failures (number and type)
- Meters replacement
- Unauthorized Service Connections
- Pressure control (maximum pressures)

We used the IWA standard terminology [(Lambert and Hirner, 2000) and Best Practice manual (Alegre et al., 2000)]. We adapted different formats to be filled by the Water Supply Operators due the different terminology used by them. The elements asked by the enquiry refer at least to the years 2005 and 2006.

In some cases, to give a better support to the water balance, we have carried out mensuration of flows in strategic points of the networks with ultrasonic portable equipment to know the real volume of produced water and water consumptions.

Objective:

- Have a base evaluation for the network condition seen from the point of view of losses.
- Water Balance
- Water Losses Estimation.

Results:

The results obtained enable us to evaluate the water network in the 29 cities, estimate the Performance Indicators and present a model for Water Balance.

In spite of the effort done over this research and of the importance given to this matter by the water sector of Romania, some routines, such as the inappropriate operation and maintenance of the assets, the inadequate control and management of the networks pressure and the non-existence of mapping and of information systems, have to be changed to get better performance of the network in the next years. The Project "Technical Assistance for Project Preparation in Wastewater Drinking Water Sector – Romania" took in consideration the obtained results to formulate the adequate strategy to improve the actual situation.

In order to present the sequential work and results, we have chosen the Culj County (cities: Cluj Napoca, Huedin, Gherla, Dej) as model of the audit carried out. Finally we present a table with the results of the 29 cities.

Water Balance

For the evaluation of the water balance and technical condition of the water distribution networks in five counties of Romania, an analysis of the elements of the network, like water pipelines, pressure and data of the companies was conducted using the technical indicators proposed by the IWA methodology.

In some cases, to give a better support to the water balance, we have carried out mensuration of flows in strategic points of the network with ultrasonic portable equipment to know the real volume of produced water and water consumptions.

With respect to the scope and availability of the necessary supporting documents, were considered the following technical parameters of evaluation of the technical condition of the network: Age of pipes, Failure rate, Water losses, Pressure.

As the operating records kept by the Operator do not make it possible to determine the complete Water Balance, some punctual values were estimated in order to have an approximate idea of the water losses and it's components (apparent losses, unauthorized consumption, customer meter and data errors).

Q_B	Billed Authorized Consumption (m3/year)
Q_{NB}	Unbilled Authorized Consumption (m3/year)
Q_L	Volume of water losses (m3/year) $Q_{RL} + Q_{AL}$
Q_{RL}	Real losses (m3/year)
Q_{AL}	Apparent losses (m3/year)
Q_{SIV}	System Inflow Volume (m3/year)
Q_R	Registered Flow ($Q_B + Q_{NB}$) (m3/year)
Cn	Number of connections
Ln	Total length of the network (km)
Lc	Total length of the connections (km)
Pm	Average pressure in the network (w.c.m.)
Qs	Supplied Flow ($Q_R + Q_{AL}$) m3/year
T	Time of water service per day (houy/day)

Initial Data

Table 1-1 General Index

Symbol	Unit	Cluj Napoca	Huedin	Gherla	Dej
Q_B	*m3/year*	29,369,346	559,679	2,116,800	1,422,710
Q_{NB}	*m3/year*	0	0	0	0
Q_L	*m3/year*	24,029,465	856,375	1,055,050	1,935,290
Q_{RL}	*m3/year*	22,525,754	804,632	934,307	1,854,506
Q_{AL}	*m3/year*	1,503,710	51,743	120,744	80,784
Q_{SIV}	*m3/year*	53,398,810	1,416,054	3,171,850	3,358,000
Q_R	*m3/year*	29,369,346	559,679	2,116,800	1,422,710
Cn	*Nr.*	35718	2756	3539	5015
Ln	*km.*	639	35.8	65.2	139.6
Lc	*km.*	114.2976	9.76	14.96	25.45
Pm	*m.w.c.*	30.0	42.6	39.6	47.0
Qs	*m3/year*	30,873,056	611,422	2,237,544	1,503,494
T	*hour/day*	24	24	24	24

Index of efficiency of the water system

Table 1-2 Index of efficiency of the water system (in percentage) – Cluj County

	Cluj Napoca	Huedin	Gherla	Dej
n_s	*0.55*	*0.40*	*0.67*	*0.42*
n_n	*0.58*	*0.43*	*0.71*	*0.45*

Efficiency of the system $n_s = Q_R / Q_{SIV}$

Efficiency of the network $n_n = Qs / Q_{SIV}$

Current Annual Real Losses (CARL)

The basic indicator for expressing Real Losses is known as the Current Annual Real Losses, where Real Losses are expressed in units of liters/service connection/day (when the system is pressurized)

$$CARL = \frac{Q_{RL}}{Cn} \qquad [\text{ lt / service connection / day }] \qquad (1)$$

Table 1-3 Current Annual Real Losses (CARL) – Cluj County

	Cluj Napoca	Huedin	Gherla	Dej
m3/year/conn.	*630.7*	*292.0*	*264.0*	*369.8*
lt./day/conn	*1727.8*	*799.9*	*723.3*	*1013.1*

Unavoidable Annual Real Losses (UARL)

In order to get this value we estimated some parameters. UARL is considered to be the lowest technically achievable level of leakage that could be achieved if all of the latest techniques in leakage control were used.

$$UARL = \frac{(A * Ln + B * Cn + Lc * Cn)}{Cn} * Pm \qquad \text{[lt / service connection / day]}$$

(2)

A, B, C - Parameters are based on the results of an international survey containing data from 27 various water systems in 19 countries (Lambert, 2002).

In cities where actually water service is not 24 hours per day, we have corrected de UARL value according to the number of hours of service.

Table 1-4 Unavoidable Average Real Losses (UARL) – Cluj County

	Cluj Napoca	**Huedin**	**Gherla**	**Dej**
m^3/day	*1288*	*132*	*173*	*337*
liter/day/conn.	*36.1*	*47.8*	*49.0*	*67.2*

NRW - Non-Revenue Water (T1).

The volume NRW determined by the “balance method“ using the measured inflows is the basic input parameters for calculation of the selected water losses indicators. The total inflow was evaluated for each city on the basis of the data provided by the Operator and it was compared with the total consumption using the billing system.

The total volume of non-revenue water in each city is presented as a percentage of produced water (Q_{SIV}) delivered to each city.

$$NRW = \frac{NRWc}{Q_{ISV}} * 100 \qquad \text{[\%]} \qquad (3)$$

Where:

NRWc - Non-Revenue Water of the city [m^3/year]

Q_{SVI} - Water produced and delivered to the city [m^3/year]

Table 1-5 Evaluation of Non Revenue Water (NRW) Index – Cluj County

	Cluj Napoca	**Huedin**	**Gherla**	**Dej**
NRW	*45%*	*60%*	*33%*	*58%*

Leakage per km of Network (LKN) T2

The calculation of Leakage per km of network is defined as a ratio of a volume of real losses over a certain time period to the total length (Ln) of the evaluated system. The following formula was used for the LKN calculation:

$$LKN = \frac{Q_{RL}}{L_n} \qquad [\ m3\ /\ km\ /\ year\ ] \qquad (4)$$

The Leakage per km. of network is a more objective indicator of water losses from the viewpoint of the technical condition of the network. It's partial disadvantage is that it does not include the affect of pressure relations in the pressure zone.

Table 1-6 Leakage in m3 per km. of network per year (LKN) – Cluj County

LKN	Cluj Napoca	Huedin	Gherla	Dej
m3/km/yr	*35252*	*22476*	*14330*	*13284*
m3/km/day	*97*	*62*	*39*	*36*

Infrastructure Leakage Index – ILI (T3)

The ILI indicator is defined as a ratio of *Current Annual Real Losses* (CARL) to the Unavoidable (technical minimum) Annual Real Losses (UARL), Lambert et al, 1999. It is an indicator of water supply systems expressing the technical condition of the system from the point of view of water losses.

As the operating records kept by the Operators do not make it possible to determine the actual *Current Annual Real Losses* (CARL) for each city, the ILI calculation uses simplified and estimated taken from experience in other countries.

$$ILI = \frac{CARL}{UARL} \qquad [\quad] \qquad (5)$$

Where:

CARL - Current annual real losses [m^3/year]

UARL - Unavoidable annual real losses [m^3/year]

The average operating overpressure for each city was taken in field by data logger and it concerns an average hydrodynamic pressure in the city.

Table 1-7 Evaluation of Infrastructure Leakage Index (ILI) – Cluj County

	Cluj Napoca	Huedin	Gherla	Dej
ILI	*47.9*	*16.7*	*14.8*	*15.1*

Economical Leakage Index – ELI (T4)

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 *Economical Leakage Index* (ELI) values can be determined using the following simple relation.

$$ELI = EI \cdot LI \qquad (6)$$

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

As the cities in Cluj County provide the three possibilities, the economical index can reach the values of 0.5 to 1.5. The selection is based on three data. The first determines whether the evaluated city is supplied with water by gravity or by pumping stations, the second determines whether the water treatment method and the third determines whether the average hydrodynamic pressure in the city exceeds the limit of 50 m of water column.

LI – losses index is based on the following relation

$$LI = \frac{LKN}{3600} \qquad (7)$$

Where the LKN valued is calculated according to the relation (4). The LKN = 3600 [m^3/km/year] 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 ELI indicator, the following simple methodology was used.

If **ELI > 3,5** it is a network where the water losses cause significant economic operating losses and where it is desirable that the operator should focus intensively on their reduction.

2,5 = < ELI = < 3,5 it is a network where the present water losses do not cause any major economic operating costs

ELI < 2,5 it is a network 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.

Table 1-8 Evaluation of Economical Leak Index (ELI) – Cluj County

	Cluj Napoca	**Huedin**	**Gherla**	**Dej**
EI	1	1	1	1
LI	9.8	6.2	4.0	3.7
ELI	***9.79***	***6.24***	***3.98***	***3.69***

Network evaluation of the cities in Cluj County

Four Performance Indicators were selected for the evaluation of the technical condition according to indicator "TI" Water Losses: Non Revenue Water (NRW), Leakage per km. of network (LKN), Infrastructure Leak Index (ILI) and Economic Leak Index (ELI).

Based on the determined and reach values of the four Performance Indicators, the water network of the evaluated cities are classified into relevant categories. We have proposed a total of 5 basic categories of evaluation of the individual indicators for the need of the technical audit:

C1 (very good) **:** Optimum condition of the relevant indicator. It does not require any special measures leading to changes in this indicator;

C2 (good) **:** Low level of risk of the relevant indicator of the technical condition and no principal measures are needed;

C3 (average) **:** These are average values of the relevant indicator that do not require immediate solution;

C4 (critical) : Critical values of the relevant indicator. This means that potential planned measures addressing the situation should be implemented;

C5 (unacceptable) **:** Undesirable condition requiring an immediate solution according to the operator's possibilities resulting in improvement of the values of the relevant indicator. As regards the evaluated drinking water distribution network, each evaluated part (the whole water distribution network, pressure zone etc.) is audited by means of the selected indicators and it is classified in the appropriate evaluation category, which makes it possible to identify critical parts of the evaluated network and prioritize them in the reconstruction and repair planning.

The levels of evaluation categories were estimated individually for each sub-indicator and they are presented in Table 1-9.

Table 1-9 Table of Evaluation – Cluj County

Category	T1		T2		T3		T4	
	NRW (%)		LKN (m3/km/year)		ILI ( )		ELI ( )	
	from	to	from	to	from	to	from	to
C1	0	10	0	10000	0	10	0	1
C2	11	20	10001	20000	11	20	1	2.5
C3	21	30	20001	30000	21	30	2.5	3
C4	31	40	30001	40000	31	40	3	3.5
C5	41		40001		41		3.5	

The limits of the individual categories for the water losses sub-indicators T1 - T4 were determined for the purpose of this study on the basis of the experience and knowledge of other studies. In Romania, the water companies have different standards like other countries in European Union, then, calculated values of the individual sub-indicators of each city were evaluated according to the limits shown in Table 1 - 9. However, we can change the limits of the individual categories for the water losses sub-indicators T1 - T4 at our own discretion and the classification of the individual sub-indicators concerning the relevant network cities will change dynamically.

Technical Condition of the water network of the cities in Cluj County

Evaluation of the technical conditions of the individual networks seen from the point of view of pressure losses and the values of sub-indicators for each city zone are shown in Table 1-10.

The overall evaluation of the Cluj County from the point of view of the four Performance Indicators of water losses TI was based on a simple average of evaluations using sub-indicators T1 - T4. Categories C1 – C5 were allocated numerical values 1 – 5. This numerical value was converted back to the city network evaluation category.

Table 1-10 Evaluation of water network – Cluj County

City	T1 NRW		T2 LKN		T3 ILI		T4 ELI		T water losses
Cluj Napoca	45%	*C5*	35252	*C4*	47.91	*C5*	9.79	*C5*	***C5***
Huedin	60%	*C5*	22476	*C3*	16.74	*C2*	6.24	*C5*	***C4***
Gherla	33%	*C4*	14330	*C2*	14.76	*C2*	3.98	*C5*	***C3***
Dej	58%	*C5*	13284	*C2*	15.09	*C2*	3.69	*C5*	***C4***

Conclusions

In accordance with the results and the EU Standards the general situation in County of Cluj is:

City	*Network Condition*
Cluj Napoca	Unacceptable
Huedin	Critical
Gherla	Average
Dej	Critical

Situation of water network in five counties

As a general conclusion, water network in the cities of the five counties are in critical condition or worse.

It is necessary to renovate the network and prepare isolated sectors for a good control of losses.

It is also important to prepare the cadastre of the network for the efficient management of the system

Audit of 29 Water Distribution Networks of Romania

	City	T1 NRW		T2 LKN		T3 ILI		T4 ELI		T water losses
	CLUJ - TURDA									
1	**Cluj Napoca**	45%	*C5*	35252	*C4*	47.91	*C5*	9.79	*C5*	***C5***
2	**Huedin**	60%	*C5*	22476	*C3*	16.74	*C2*	6.24	*C5*	***C4***
3	**Gherla**	33%	*C4*	14330	*C2*	14.76	*C2*	3.98	*C5*	***C3***
4	**Dej**	58%	*C5*	13284	*C2*	15.09	*C2*	3.69	*C5*	***C4***
5	**Turda**	57%	*C5*	32514	*C4*	43.28	*C5*	9.03	*C5*	***C5***
6	**Campia Turzi**	42%	*C5*	27881	*C3*	29.30	*C3*	7.74	*C5*	***C4***
	GORJ									
7	**Targu Jiu**	36%	*C5*	33851	*C5*	47.86	*C5*	12.42	*C5*	***C5***
8	**Rovinari**	35%	*C5*	8762	*C5*	44.63	*C5*	3.89	*C5*	***C5***
9	**Motru**	31%	*C5*	6329	*C4*	42.44	*C5*	4.08	*C5*	***C5***
10	**Bumbesti Jiu**	24%	*C5*	5844	*C3*	2.91	*C2*	2.28	*C5*	***C4***
11	**Targu Carbonesti**	34%	*C5*	7538	*C4*	43.06	*C5*	16.57	*C5*	***C5***
12	**Novaci**	17%	*C4*	1188	*C1*	1.81	*C1*	0.46	*C1*	***C2***
13	**Ticleni**	35%	*C5*	8517	*C5*	10.88	*C5*	4.60	*C5*	***C5***
	OLT									
14	**Slatina**	23%	*C5*	9155	*C5*	12.73	*C5*	3.81	*C5*	***C5***
15	**Caracal**	39%	*C5*	13817	*C5*	23.05	*C5*	5.76	*C5*	***C5***
16	**Bals**	36%	*C5*	8730	*C5*	20.59	*C5*	2.42	*C5*	***C5***
17	**Corabia**	49%	*C5*	4513	*C4*	4.34	*C3*	1.25	*C4*	***C4***
18	**Scornicesti**	31%	*C5*	7729	*C4*	46.39	*C5*	5.15	*C5*	***C5***
19	**Draganesti**	20%	*C5*	4647	*C4*	4.83	*C3*	1.72	*C5*	***C4***
20	**Piatra**	32%	*C5*	659	*C1*	1.45	*C1*	0.18	*C1*	***C2***
21	**Potcoava**	50%	*C5*	21009	*C5*	52.76	*C5*	5.84	*C5*	***C5***
	SALAJ									
22	**Zalau**	41%	*C5*	32747	*C5*	63.84	*C5*	9.10	*C5*	***C5***
23	**Simleu Silvanei**	34%	*C4*	13875	*C3*	13.07	*C2*	3.85	*C5*	***C3***
24	**Cehu Silvanei**	36%	*C4*	8175	*C2*	32.01	*C3*	9.08	*C5*	***C3***
25	**Jibou**	51%	*C5*	50573	*C5*	57.70	*C4*	14.05	*C5*	***C5***
	SIBIU									
26	**Medias**	25%	*C5*	12822	*C5*	13.64	*C5*	3.55	*C5*	***C5***
27	**Agnita**	22%	*C5*	17418	*C5*	5.40	*C3*	4.22	*C5*	***C5***
28	**Dumbraveni**	12%	*C3*	713	*C1*	0.89	*C1*	0.29	*C1*	***C1***
29	**Copsa Mica**	25%	*C5*	6740	*C4*	11.44	*C5*	1.60	*C5*	***C5***

General Analysis of the Method

- The method has two flexible points to adjust the results according to the reality of the Water Company and region:

  - The Economical Index "EI" and

  - The Losses Index "LI"

- Water networks in the five studied counties are not in good conditions. The best network is in Rovinari (Gorj)
- The most important task for reducing losses is to renovate the net and to make sectors of the net for good operational control
- Working in the quality of the data for technical indicators in Rumania.

References

Alegre, H. Performance Indicators for Water Supply Systems, Task Force Performance Indicators (July 1999)

Lambert A. and Hirner W. (2000) "Losses from Water Supply Systems: Standard Terminology and Recommended Performance Measures"

Skarda, B.C. (1997) "The Swiss experience with Performance Indicators and special view points on water networks"

Tuhovcak, L., Svoboda M. Svitak Z. and Tothova K. (2005) The Technical Audit of Water Distribution Network Using Different Leakage Indicators. Leakage 2005

Tuhovcak, L. and Vrbkova, P. (2002) – Infrastructure Leakage Index and Other indicators as Leakage Assessment, Proceedings of the IWA specialised conference Leakage Management – A Practical Approach, Limassol

The Dimension and Significance of Water Losses in Turkey

M. Çakmakcı*, V. Uyak, İ. Öztürk***, A. F. Aydın***, E. Soyer***, L. Akça*****

* Zonguldak Karaelmas University, Environmental Engineering Department, 67100 Incivez Zonguldak-Turkey. cakmakci@itu.edu.tr

** Pamukkale University, Environmental Engineering Department, Denizli-Turkey. uyakv@itu.edu.tr

*** Istanbul Technical University, Environmental Engineering Department, Maslak 34469, Istanbul-Turkey. afaydin@ins.itu.edu.tr, esoyer@ins.itu.edu.tr, iozturk@ins.itu.edu.tr, lakca@ins.itu.edu.tr

Keywords: Water loss; water distribution network; unaccounted for water; active and passive leakage control

Abstract

Water loss in water distribution systems can be grouped as either physical (technical) losses and apparent losses (non-revenue water (NRW) or commercial loss (UfW)). Current Turkish water statistics shows that approximately 50% of the treated potable water in city centers is lost and unaccounted in Turkey. It was observed that 40% of the water losses have been recognized as commercial loss (UfW) and 60% is technical loss. It is estimated that in some cities, more than 40% of the water losses is commercial loss. Existing statistical data on water losses shows that the relationship between water loss and distribution system age does not show significant correlation. This may be concluded as the water losses are more dependent on construction and material quality of the distribution system rather than the network age. Water losses increase significantly when the pipe connections, especially the house connections, are not done properly. This paper evaluates the water losses in 81 provincial centers with special interest on metropolitan cities. Within this scope, the success story of Istanbul having reduced the amount of lost water down to less than 25 %.

Introduction

Water loss occurs in all distribution systems, only the volume of loss varies. This depends on the characteristics of the pipe network, the water provider's operational practice, and the level of technology and expertise applied to controlling it and other local factors. The volume of the lost varies widely from country to country, and between different regions within a country. One of the keystones of a water loss strategy is therefore to understand the relative significance of each of the components, ensuring that each is measured or estimated as accurately as possible, so that priorities can be set via a series of action plans.

The expressions of *water loss* and *non-revenue water* are now internationally accepted, and have replaced expressions such as *unaccounted for water* (UfW) which are less consistent and make inter-country comparisons more difficult (Farley and Throw, 2003).

If the transmitted water in distribution network is called Q and the billed water is called Q_i, $Q-Q_i$ gives the water loss. Water losses are separated in two parts: real and apparent losses. Real losses are caused by technical reasons. Technical reasons are pipe breakdown or burst, reservoir overflows, leakage from valves and seals. Illegal usage of consumers or theft, meter inaccuracy, the amount which is not measured by consumer's water meter is named as apparent loss.

Real losses may be determined by leakage control. Leakage control can be done by active and/or passive ways. Active leakage control is done to determine leakage by measuring flow rate and pressure in an isolated zone. By this method, leakage can also be determined on pipe-to-pipe connections and pipe-to-valve connections by voice sensitive devices. Passive leakage control method is done by monitoring instantaneous pressure and flow rate changes in distribution network, and reservoir water level. Pipe breakdown or burst can be easily identified by passive leakage control method. Water loss caused by pipe breakdown or burst can be minimized by this method. If optimum pressure of distribution network is determined by active leakage control, this value can be adjusted for distribution network by passive leakage control method.

Water Loss and Leaks

Water is lost in the distribution system depending on technical and commercial factors. It is practically impossible to avoid them. Technical losses are leaking water through cracks which are formed in time on pipes, building and pipe connections of the distribution system. Commercial loss originates from illicit and illegal use of water without pricing. There are sufficient and dependable data in the international literature for the percentage of technical losses. Technical losses are predicted based on national statistics as they differ considerably for one country to another.

Results obtained by United Nations Environmental Program on distribution system technical losses in some European countries are given in Figure 1 (UNEP, 2006). According to them, technical losses are below 15% in developed rich countries like Germany, Denmark, Finland and higher in Mediterranean countries (Spain and Italy) and around 50% in Hungary, Slovenia and Bulgaria. As a gross approximation, Turkey is included in the category of countries with high losses disregarding some exceptions.

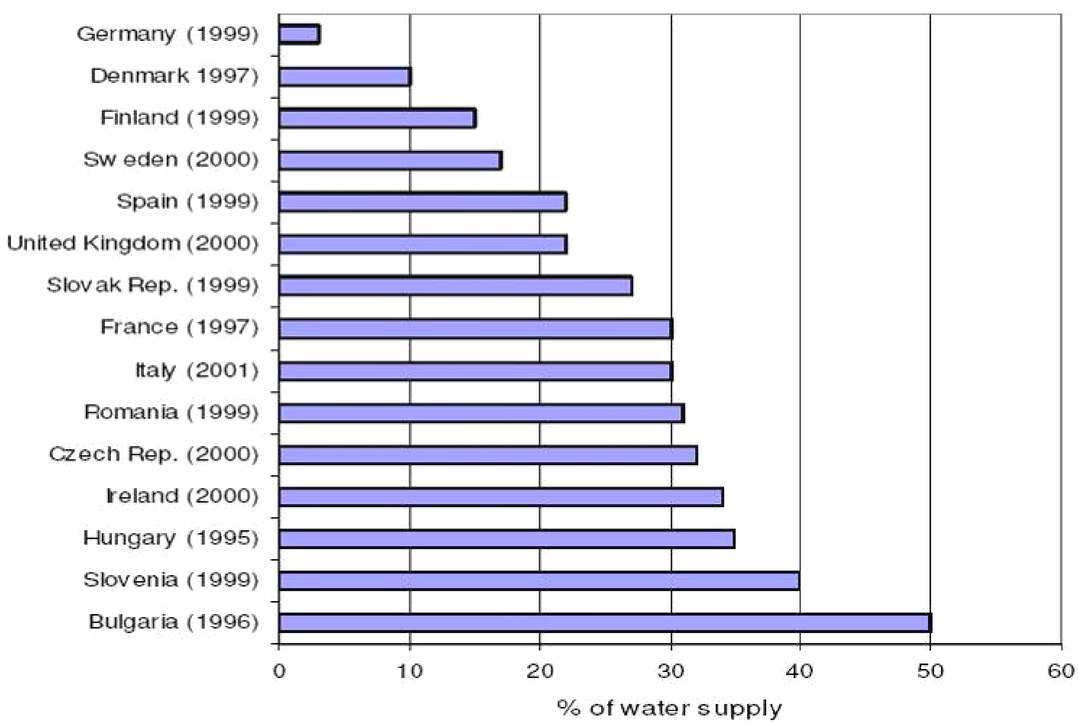


Figure 1. Water losses data in different countries (UNEP, 2006)

According to Twort et al. (1985) technical losses in water distribution systems where efficient standard controlling is being pursued constitutes 22-25% of the total amount of water supplied to the system and expecting a loss below 20% is highly optimistic. Similarly, Muslu (1996) stated that water transmission and distribution system losses can be lowered to below 12 % at optimum conditions in newly built systems and to around 20% in old systems.

There are number of studies which focused on decreasing water loss all over the world. Las Vegas Valley Water District, which used Acoustic Leakage Monitoring in a period of 12 months to minimize water loss, has found 540 leakage points on fire hydrants, water gauges, valves and pipeline networks (Morgan, 2006). The cost of the water loss is 2.250.000 USD ($) with treatment and transporting cost. Thornton (2003) denotes that decreasing pressure by 10% brings on 15% decrease on water loss for non-metal pipes. The pressure has been presented by Jowitt and Xu (1990),Vitkovsky et al. (2000), Alonso et al. (2000) and Ulanicka et al. (2001) as a conditional parameter of leak indicator in water networks.

High and increasing water losses are an indicator of ineffective planning and construction, and low operational and maintenance activities. In Turkish cities, the average yearly water loss is as high as approximately 50% of the water volume produced based on Turkish Statistical Institute data of year 2003 (TSI 2003).

This study primarily focuses on the water losses in the water distribution networks of 81 provinces of Turkey with special interest on metropolitan cities presenting the major causes of the problem. An effective and economically sustainable water loss management approach has been proposed starting with the provincial centers under the light of the experience from successful local practices.

Water Loss in Distribution Networks in Turkey

Population and Delineation

Turkey is a country with approximately 75 million people. There are 16 metropolitan municipalities with populations larger than 500,000, more than 3,200 municipalities with populations smaller than 500,000, and more than 37,000 villages with populations smaller than 2,000. The economy and other conditions for the agglomerations are different. Therefore, Turkey has been delineated into three regions (west, central and east), and a further delineation into groups of agglomerations depending of size of population. The delineation into regions is shown in Table 1 and size of agglomerations is shown in Table 2 below (ENVEST, 2005).

Table 1. Delineation of Turkey into regions for analytical purposes

Region	Turkey’s Geographical Regions
1 (West)	Marmara and Aegean Regions
2 (Central)	Mediterranean, Black Sea and Central Anatolian Regions
3 (East)	Eastern Anatolian and South-Eastern Anatolian Regions

Source: ENVEST, 2005

The share of population living in Greater Municipalities is largest in the western region, less in the central region and, lowest in the eastern region.

The population of villages is largest in Region 2 and lowest in Region 1. In Figure 2 illustrates the population in each agglomeration group of each region.

Table 2. Delineation of Turkey into regions and agglomerations

	Region 1 (west)	Region 2 (central)	Region 3 (east)
Greater municipalities		*Cities*	
	Izmir	Ankara	Diyarbakir
	Bursa	Adana	Gaziantep
	Sakarya	Eskişehir	Erzurum
	Istanbul (10 districts)	Kayseri	-
	Kocaeli	Konya	-
	-	Antalya	-
	-	İçel	-
	-	Samsun	-
Group of agglomerations		*Number of agglomerations in each group*	
150,000 to 500,000 inhabitants	4	8	6
50,000 to 150,000 inhabitants	26	40	27
10,000 to 50,000 inhabitants	116	181	77
2,000 to 10,000 inhabitants	735	1,254	580
Agglomerations with < 2,000	7,862	16,974	10,278

Source: ENVEST, 2005

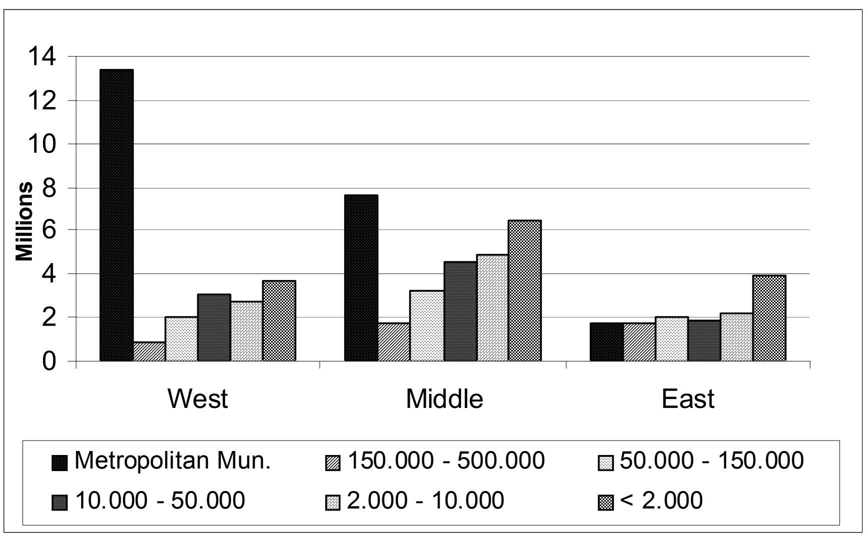


Figure 2. Distribution of population by region and size of agglomeration (TSI, 2000)

Drinking water Production and Consumption

The water demand for different population groups and regions in Turkey is outlined in Table 3. The consumption and losses are shown as liters per capita per day (lcd).

The figures for overall consumption and household consumption illustrate that compared to West-European countries are high and (billed) household consumption is low. The low values for household consumption mainly reflect that water prices are quite high (typically in the 0.50-1.00 EUR/m^3 range) while incomes are low. The economic explanation is also consistent with the finding that household consumption is less in smaller agglomerations as incomes here are typically less. In addition, there is some unbilled household consumption. The table includes this as "industry & other (institutional, commercial, etc)". The precise volume hereof is not known.

Table 3. Drinking water consumption and loss for different population groups

Agglomeration	Total production	Technical loss	Total Consumption	Household	Industry & other
Turkey	*188*	*57*	*131*	*71*	*60*
Region 1 (west)	*181*	*47*	*133*	*77*	*56*
Greater municipalities	218	52	166	95	71
150,000-500,000	268	91	177	85	93
50,000- 150,000	183	55	128	64	64
10,000-50,000	138	41	96	57	39
2,000- 10,000	110	33	*77*	51	26
< 2,000	92	27	64	44	20
Region 2 (central)	*198*	*65*	*133*	*67*	*66*
Greater municipalities	*330*	*117*	*212*	*92*	*121*
150,000-500,000	305	102	203	80	124
50,000- 150,000	182	55	127	64	64
10,000-50,000	137	41	96	57	39
2,000- 10,000	110	33	*77*	51	26
< 2,000	103	31	72	50	22
Region 3 (east)	*178*	*57*	*121*	*63*	*58*
Greater municipalities	*224*	*66*	*158*	*68*	*90*
150,000-500,000	293	114	179	75	105
50,000- 150,000	183	55	128	64	64
10,000-50,000	137	41	96	57	39
2,000- 10,000	110	33	*77*	50	26
< 2,000	138	41	97	67	30

Source: ENVEST, 2005

From Figure 3 it appears that the household consumption is larger in the west and the technical losses seem to be lowest in the Western region. This is consistent with an observation that the Western region is generally richer than the Central and Eastern regions. However, it should be noted that the differences between regions is much less than the differences between large and small cities.

Figure 4 illustrates how water produced is consumed in Turkey and the three regions. It appears that approximately 50% of all water produced in Turkey is unaccounted for (UfW). On average, 30% of the total water production is lost due to leakage and spillage in pipelines, reservoirs, etc. 20% is not billed for (illegal connection, provided free of charge and water providers' own use, etc). 38% is used in households and only 12% is used in industry, institutions, etc.

As mentioned previously the losses are high compared with most Western European countries. However, compared with the new EU countries, the losses experienced in Turkey seem to be at the same level. Improvement of the water supply networks will reduce the leakages, improve the water quality and reduce the demand for water production.

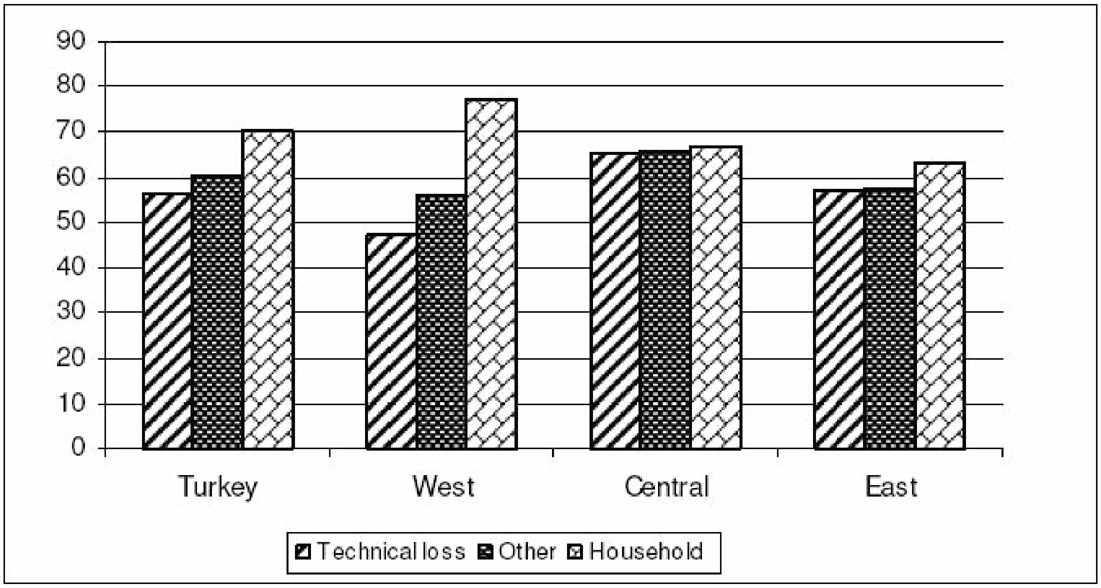


Figure 3. Water use in three delineation regions of Turkey (lcd)

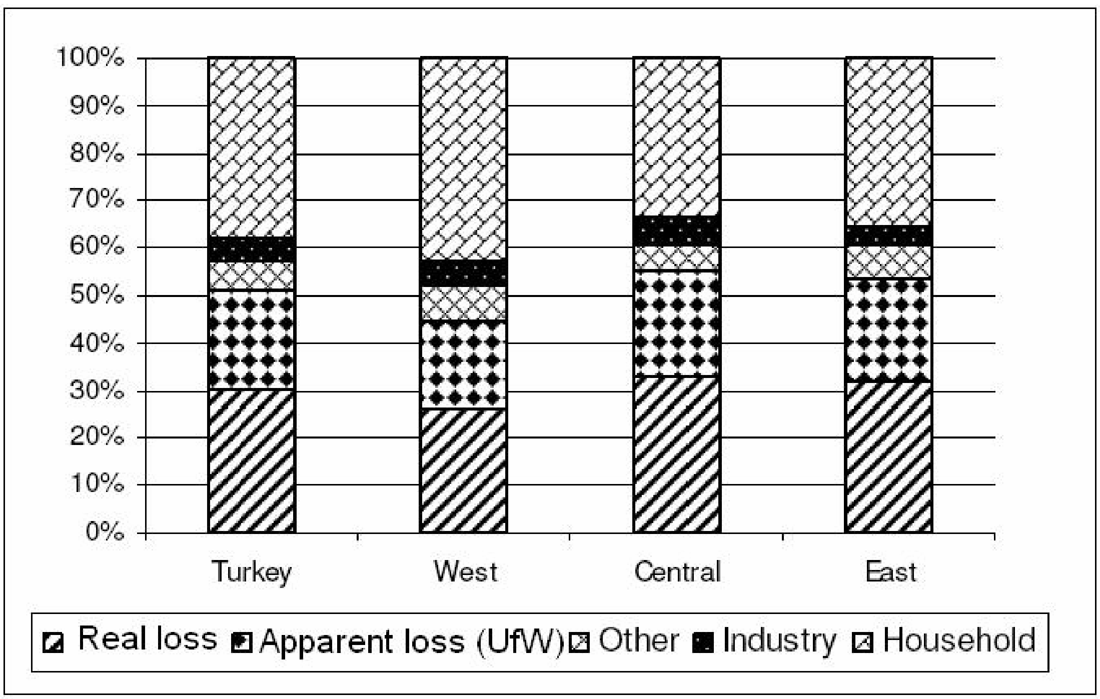


Figure 4. Distribution of loss and consumption in all water produced in Turkey (% of total water use)

Connection Rate

The rate of people provided with drinking water networks was in 2002 on average 88% for the whole of Turkey (ENVEST, 2005). The average consumption rates for the three regions and population groups are shown in Figure 5.

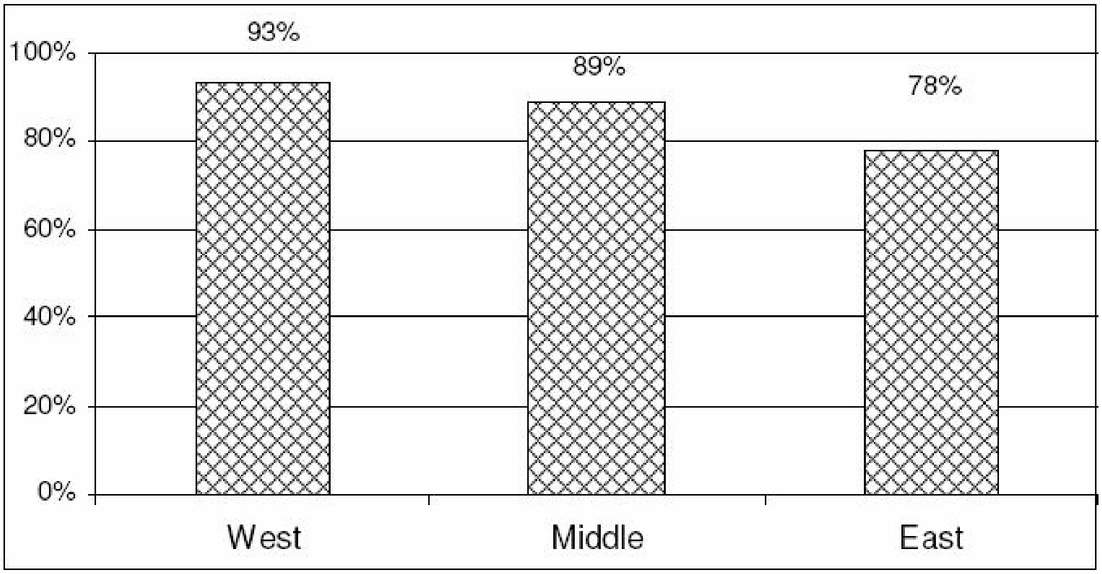


Figure 5. Average connection rates in the three regions

The connection rate to piped water is highest in the largest cities and towns. Connection rates are more than 95% in greater municipalities, generally more than 80% even in small cities and villages, except for the rural areas in the eastern part of Turkey, where connection to piped water is only slightly higher than 50%.

Pipeline Network

In Turkey, establishment of centralized water supply and distribution systems has a long history that goes back to ancient Byzantine times in Istanbul. Intensive construction of water distribution networks was initiated in 1960 by Iller Bank.

Based on information from Iller Bank and ISKI, the mostly used pipe material is PVC in the cities and towns provided with water supply network through Iller Bank, and ductile iron in larger cities. An overall rough distribution of material used in Turkey is: PVC 43%, ductile iron 41%. Asbestos cement 12%, steel 3%. The percentage of pipe length with a certain age is indicated in Figure 6 as function of the size of the town (ENVEST, 2005).

Figure 6 illustrates that 60%of the pipes in larger cities (150,000 to 500,000) were laid 25 to 30 years ago, and that the same investment took place in cities with 50,000 to 150,000 inhabitants just 10 years later (15 to 25 years ago). Pipelines in smaller cities are even younger. This indicates that with an average pipe lifetime of 30 years for asbestos cement pipes and approximately 50 years for plastic and ductile iron pipes less than 20% of the pipelines in the larger cities are beyond their expected life, and may need general replacement. However, the water quality data indicate that some network rehabilitation may be warranted.

Level of Water Loss in Metropolitan Cities

This study aims to provide guidance for water utility operators and their consultants on the processes involved in establishing and implementing effective water loss management in 16 metropolitan cities of Turkey. The 2000 census showed that 33.5% of total population (or about 50% of city population) of Turkey has been living in these 16 metropolitan cities. Figure 7 gives the amount of water losses of these metropolitan cities in 2003.

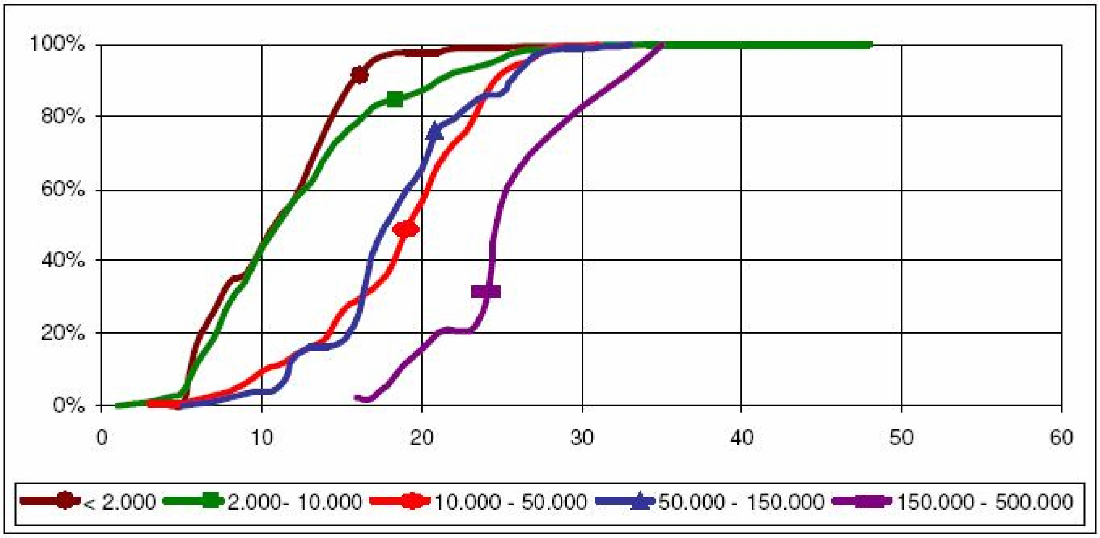


Figure 6. Pipeline age (% of cumulative network length) (ENVEST, 2005)

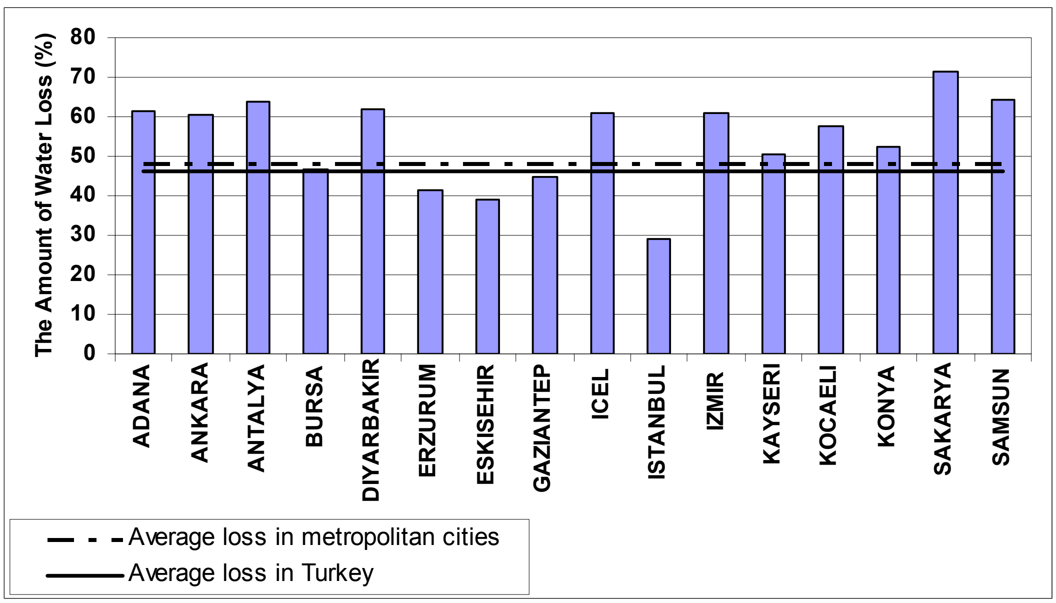


Figure 7. The amount of water loss for 16 metropolitan cities of Turkey

As can be seen from the figure, among the 16 metropolitan cities only Istanbul has a network loss <30% and the average water loss ratio of the cities in general is ~46%. The network loss ratio of more than 60% in half of the metropolises is a clear indicator of the problem's economical aspect. The causes of water loss in water distribution networks in Turkey, especially the metropolitan cities, could be summarized as follows:

- Network pipes are very old (more than % 50 of the network is 30 years old or older)
- Effective pressure management is not applies (water losses resulting from excessive pressures)
- Poor construction and maintenance of networks
- Water scheduling
- Costumer side leakage
- Illegal connections

The most important factor among those of listed is the fact that the water distribution network is not separated into appropriate pressure zones. This results in a steep rise of the technical losses due to the increase in water pressure in the lower parts of the city especially at nights. Since SCADA-based pressure management is not applied even in the metropolitan cities, except for Istanbul, the technical losses still account for more than 40% in some cities regardless of network pipe renewal.

Water Loss Management Practice of Istanbul Metropolitan Municipality

Istanbul Water and Sewerage Administration (ISKI) has conducted a water loss management practice in the period of 1995-2005 including the activities of water distribution network renewal, inputting the data on water supply, distribution and sewerage into the GIS database, and SCADA-aided effective pressure management applications. The practice resulted in a decline of the network losses from the level of 65% in 1994 to a current value of 25%. Approximately ~8-10% of the 25% of water loss corresponds to non-revenue water and the remaining 15-17% is due to technical losses. A total decrease in losses of 40% has been realized in the network itself up to a degree of 35%, and through the maintenance, repair or closure of the old water storage tanks found in most of the buildings resulting in a change of ~5%. The SCADA-based effective pressure management technique proves to be the fastest approach in water loss reduction especially at nights.

Conclusion and Recommendations

Average water loss is 50% in water distribution network of Turkey. Compensating the loss of water distribution network is especially critical in drought years. Economical benefit of decreasing of the water loss to a 20% level in city centers is approximately ~500.000.000 EURO (Ozturk et al, 2007). It’s possible to come across tragicomic situations where the province or district municipalities are looking for a new water source while their water loss reaches up to 50% or more. The prompt and fundamental solution to this critically important problem could be preventing the site allocation and financial supports associated with using new water sources especially for municipalities with more than 30% of water loss. Management approach for decreasing the water loss in water distribution networks at city centers are given below:

- Establishment of preferably GIS-based piping plan of the existing water supply and distribution network (network construction and hydraulic plan, valve locations, information on type, material, diameter and length of pipes)
- Construction of a mathematical simulation model for water distribution system
- Field monitoring of pressure of flow at sufficient points (in general around 50 points)
- Calibration of the model to an accuracy of a permanent ±1.5-2.0 meters for three snap-shot periods
- Design and implementation of a permanent leakage and pressure control system

Here the water distribution network hydraulic model and SCADA-supported pressure management (separation of the network into pressure zones and pressure minimization especially at nights) should be given the priority. This is simply because the water losses have a linear correlation with pressure in general. For example, a decrease of 10% in the network pressure results in a decrease of 10-15% in water losses. Following the application of an effective pressure management, old pipes carrying high leakage risk should be renewed and water storage tanks should have periodic maintenance and repair. Current practices in Istanbul reveal that with the use of the SCADA-based effective pressure management only, technical losses could be reduced to levels of 35-40%.

Acknowledgements

We express our gratitude to ENVEST Planners Consortium led by COWI A/S, TR Ministry of Environment of Forest, and ISKI for kindly letting us share their latest information.

References

Alonso, J. M., Fernando, A., Guerrero, D., Hern´andez, V., Ruiz, P. A., Vidal, A. M., Martinez, F., Vercher, J., and Ulanicki, B. (2000) Parallel computing in water network analysis and leakage minimization. *Journal of Water Resources Planning and Management, ASCE*, July/August, 251–260.

ENVEST Planners Consortium (2005). Technical Assistance for Environmental Heavy-Cost Investment Planning, Turkey. Quality of Water Intended for Human Consumption - Drinking Water Directive. TR Ministry of Environment and Forest.

Farley, M. & Trow, S. (2003). Losses in Water Distribution Networks. International Water Association (IWA) Publishing. London.

Jowitt, P. W. and Xu, C. (1990) Optimal valve control in water distribution networks. *Journal of Water Resources Planning and Management, ASCE*, July/August. 455–472.

Morgan, W. (2006) Managing water loss. *Journal of American Water Works Association*, 98(2), 33-35

Muslu, Y. (1996). Wastewater Treatment Volume I, II. ITU Publishing. Istanbul. (in Turkish)

Ozturk, İ, Uyak, V., Çakmakcı, M., Akça, L. (2007) Dimension of water loss through distribution system and reduction methods in Turkey. *International Congress River Basin Management Volume 1*, 22-24 March Antalya, Turkey, pp. 245-255.

Thornton, J. (2003) Managing leakage by managing pressure: a practical approach. *Water21* October, 43-44

TSI. (2000). Turkish Statistical Institute. 2000 Population Census. (in Turkish)

TSI. (2003). Turkish Statistical Institute. Water Statistics. (in Turkish)

Twort, A. C., Law, F. M. & Crowley, F. W. (1985). Water Supply 3rd Edition. Edward Arnold Publishing. London.

UNEP (2006) United Nations Environment Program official website http://www.grid.unep.ch/product/publication/freshwater_europe/consumption.php.

Vıtkovsky, J. P., Simpson, A. R., and Lambert, M. F. (2000) Leak detection and calibration using transients and genetic algorithms. *Water Resources Planning and Management, ASCE*, July/August, 258–262.

Influence of Measurement Inaccuracies at a Storage Tank on Water Losses

G. Gangl*, J. Kölbl*, G. Haas*, E. Hassler, D. Fuchs-Hanusch*, P. Kauch***

* Graz, University of Technology, Institute of Urban Water Management and Water Landscape Engineering, Stremayrgasse 10, A-8010 Graz, Austria, gangl@sww.tugraz.at

** Waterworks of Villach, Klagenfurter Straße 66, A- 9500 Villach, Austria erwin.hassler@villach.at

Keywords: Measurement Inaccuracies, Water balance, Water loss

Abstract

Water losses can be calculated by comparing the measured system input into a water supply network and the measured consumption by customers. The measured difference can lead to relatively expensive investments in the supply net. Member states of the European Union can prescribe the use of measuring instruments for the levying of taxes and duties. These customer meters have permissible inaccuracies defined in a European parliament and council directive. On the other hand, the measurement instruments metering the system input also have permissible inaccuracies.

In the Austrian city of Villach, installed measurement instruments were checked as a basis for calibration of a hydraulic modelling of the supply net. In this paper, possible variations of two measuring instruments measuring the same system input are discussed.

Introduction

When describing the actual status of a water supply network, several indicators should be taken into consideration. Some examples are the distribution of the annual failure rate, the average net age or the variation of water loss. Water loss should be as low as possible, for hygienic, technical and ecological reasons. To quantifying the amount of water loss by leakage, the International Water Association provides a standard template for calculating the water balance in the blue pages (2000).

National Situation

According to the OVGW W 63 Austrian Association for Gas and Water guideline (1993), water loss should be as low as possible regarding the reasons described above, but also for legal reasons. On the one hand, a low leakage rate is a competent indicator for a network in good condition and results in reduced expenditure for the ongoing network maintenance. On the other hand, it is impossible that a water supply network has no leakage. Allowed tolerances in laying and bedding, tolerances for connections, external influences or the aging process of the used materials cause a smaller or major leakage rate. In order to quantifying these water losses and to determine methods for reducing these losses, a reference level or a limit level is necessary.

National and international associations (IWA, DVGW, OVGW) have published performance indicators and reference levels, whose calculation is influenced by several different input factors (Gangl et al., 2006). The results should support and inform the water supply company about the actual condition of the supply network and make it possible to find methods for reducing water losses. These methods can not be compared to financial consideration to the saved water volume in short term periods. By not investing in the supply network for reducing water loss over a longer period, a shortage in supply and hygienic problems can lead to the possible total collapse of the water supply.

According to §5 of the Austrian Drinking Water Regulation (TVO, 2006), a water utility has to rehabilitate its supply net to avoid a negative influence on drinking water. The European standard (ONORM EN 805, 2000) states that a water utility should try to minimise interruptions in the supply net, according to chapter 14.1. The Austrian Standard ONORM B 2539 (2005) states that the system input in the supply network has to be measured at least monthly. The maintenance of measurement instruments has to be done according to the manufacturer requirements or by suspicion of abnormal measurement inaccuracies. Which type of instrument shall be used (mechanic or electronic) is not specified.

Water balance

A simple way for quantifying the volume of water losses is to calculate a water balance. The system input is compared to the authorised consumption. The difference is the amount of water losses, which can be split into apparent and real losses. The IWA (International Water Association) has published a template (Table 1) to calculate a water balance. In reality water supply utilities don’t have the same quality of data for each of the parameters for the water balance. Some of the input parameters are estimated based on experience; others are calculated by using reference levels of guidelines (DVGW W 392, ÖVGW W 63) as a percentage of the system input or of the measured consumption (e.g., the apparent loss).

Table 1: IWA Water balance (2000)

<table>
<tr><td rowspan="9">system input volume [m³/year]</td><td rowspan="4">authorised consumption [m³/year]</td><td rowspan="2">billed authorised consumtion [m³/year]</td><td>billed metered consumption (including water exported)</td><td rowspan="2">revenue water [m³/year]</td></tr>
<tr><td>billed unmetered consumption</td></tr>
<tr><td rowspan="2">unbilled authorised consumtion [m³/year]</td><td>unbilled metered consumption</td><td rowspan="7">non revenue water [m³/year]</td></tr>
<tr><td>unbilled unmetered consumption</td></tr>
<tr><td rowspan="5">water losses [m³/year]</td><td rowspan="2">apparent losses [m³/year]</td><td>unauthorised consumption</td></tr>
<tr><td>metering inaccuracies</td></tr>
<tr><td rowspan="3">real losses [m³/year]</td><td>leakage on transmission and/or distribution mains</td></tr>
<tr><td>leakage and overflows at utility´s storage tank</td></tr>
<tr><td>leakage on service connections up to point of customer metering</td></tr>
</table>

As a result of calculating a water balance, a quantifying of the amount of water loss is possible. On this basis, several methods for changing the actual situation can be taken into consideration. These methods can be very expensive and should be discussed in detail before their realisation.

There are several state of the art possibilities for reducing water losses in a supply network. For more detailed information, see the appropriate publications (e.g., Farley & Trow, 2003).

Measurements of water loss

The majority of the Austrian water supply utilities use state of the art process control systems. In these systems the whole measured data of pumping stations, wells, storage tanks and flow meters in the supply network are saved and sent to a control centre. Small daily and weekly fluctuations of the system input are caused by seasonally customer demand and can be allocated by the storage capacity of the storage tanks. Abnormal variations or a large increase in system input can be an indicator of pipe failures.

The leakage rate caused by a pipe failure depends upon the system pressure, the orifice area and the type of the crack (Lambert, 2001). With the Toricelli formula (Formula 1), the leakage rate can be estimated by assuming a circular crack, depending on the system pressure:

Formula 1: Toriccelli

$$v = \varphi * \sqrt{2 * g * h} \;\; and \;\; Q = v * a$$

With a circular crack with a diameter of 8 mm and a system pressure of 5.5 bar, the leakage rate is nearly 1.0 l/s. A fluctuation in this size can be identified only in small district meter areas where the minimum night flow during the night is similar to the leakage rate. An example is pictured in Figure 1, where the increase of the system input during the night minimum is caused by a leakage until repair on the 3rd of June 2004.

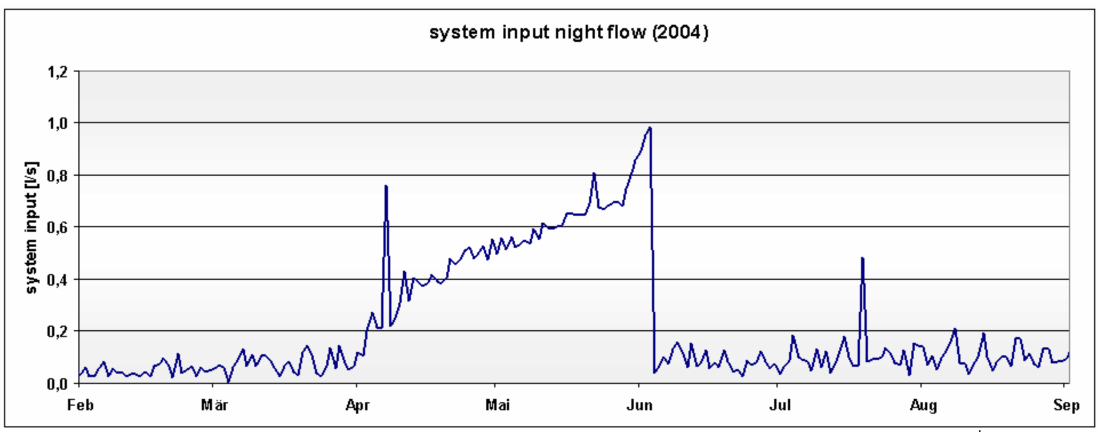


Figure 1: Graph of the night minimum system input in a small meter area (repair of failure on 3rd June)

Measurements of the system input on storage tanks

To calculate a water balance, the system input which can be measured on a storage tank is compared to the authorised consumption. The difference is the water loss.

According to (Farley & Trow, 2003) leakage monitoring is the inflow monitoring into zones or districts to measure leakage and to prioritise leak detection activities.

Measurement inaccuracies as part of the apparent losses are, according to manufactures, in a range of 0.5 % of the measured flow-velocity. For quantifying the total volume of apparent losses, the German DVGW W 392 (2003) suggest to calculate

1.5 to 2 % of the system input, if no plausible measured data are available. In this paper, a possible fluctuation of the system input is discussed.

Within the Waterpool Competence Network, the scientific project PiReM – pipe rehabilitation management – was carried out together with several Austrian water supply utilities. One part of the project was a hydraulic modelling of the distribution network of the city of Villach (Kölbl et al., 2007). For the calibration of the network, a check of the installed flow meter was also necessary. The consequence of differences in the water balance caused by measurement inaccuracies of the system input is presented with the example of a district meter area.

The supply network of the district meter area (DMA) of Möltschach has a total mains length of 15, 500 m; the average system pressure is 5.5 bar and currently 481 service connections are installed. The system input into the supply network is made from one storage tank. This storage tank is filled by a pumping pipe when the water level in the tank is below a defined level. In the storage tank, a water level sensor (pressure transmitter) is installed for measuring the water level and, in addition, the outflow is measured by an electromagnetic flow meter (Figure 2).

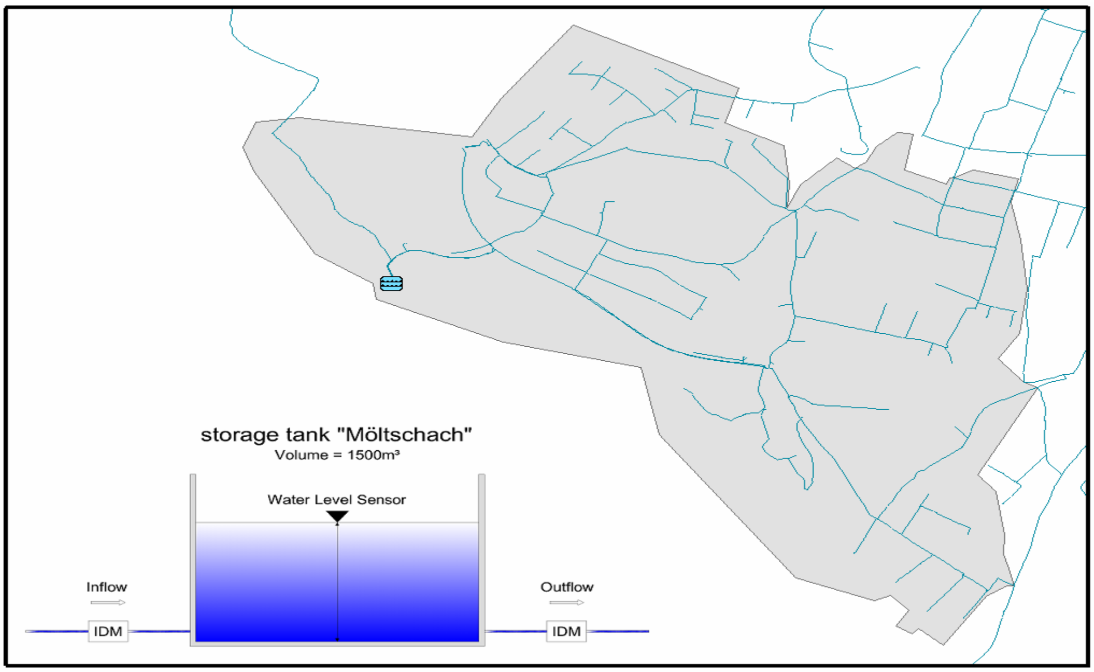


Figure 2: Map of Möltschach DMA with storage tank

The system input can be calculated, on the one hand, with the water level sensor if the dimension of the water surface and the change of the water level as a function of time are known, or, on the other hand, directly with the electromagnetic flow meter. Both measuring instruments should measure the same system input within a determined range of accuracy (flow meter ±0.5 % of flow-velocity, water level sensor ±0.25 % of measured range).

Measuring instruments used

Electromagnetic flow meter

The principle of electromagnetic measurement instruments is based on the Faraday's law of magnetic induction. A moved conductor induces voltage in a magnetic field. This voltage is proportional to the average velocity of the moved conductor. In a water pipeline, the water represents this conductor. The average velocity v is measured between two opposite electrodes (Figure 3). According to the VSA Swiss Water Pollution Control Association (1999-2003), measurement inaccuracies increase proportionally with a decreasing flow velocity under 0.5 m/s starting from a constant 0.5 % to more than 4 % of the flow velocity (Figure 4).

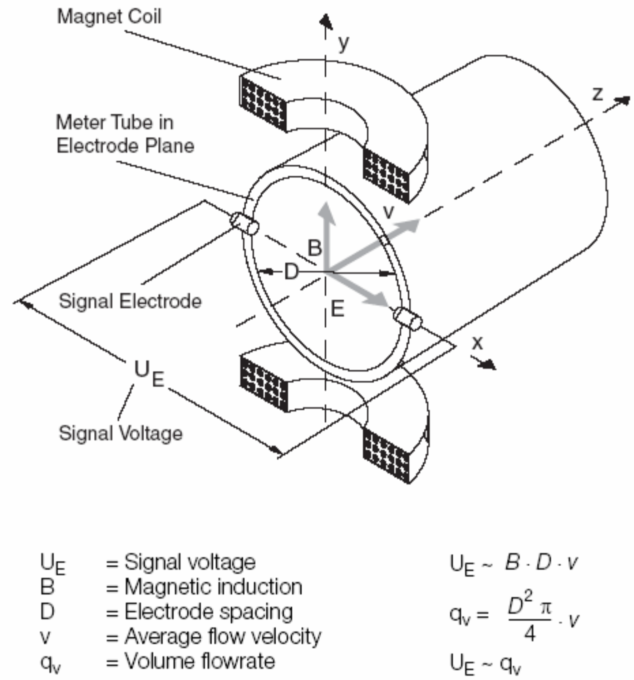


Figure 3: Diagram of installed electromagnetic flow meter (ABB FXM2000)

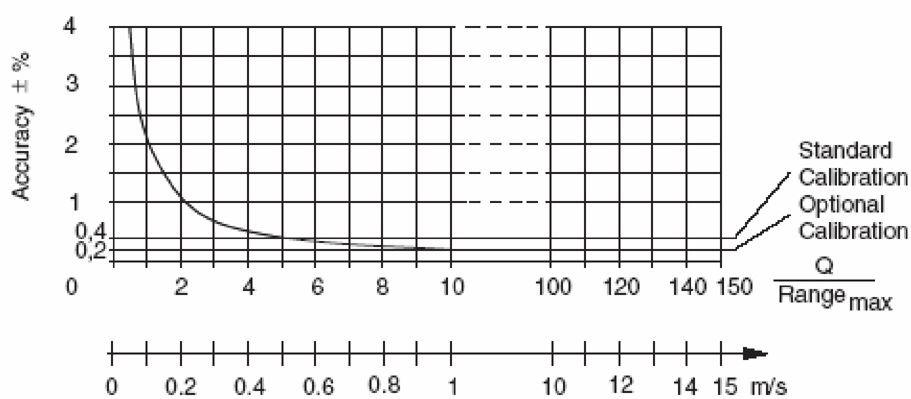


Figure 4: Accuracies depending on flow velocity

The advantage of the flow meter is that there are no flexible components or components stressed by the flow. An electromagnetic flow meter from ABB - Fischer & Porter is installed in the storage tank. According to the manufacturer, possible measurement inaccuracies are in a range of 0.2 % of the flow rate at a velocity higher than 1 m/s. Below this velocity, the inaccuracies increase up to more than 4 % of the flow rate.

Water level sensor with pressure transmitter

An important point for these measurement instruments is the measured span, on which the accuracy depends. According to the manufacturer, accuracy depends on the measurement span. The measure principle of these instruments is based upon the hydrostatic pressure on the floor. Hence, the floor pressure corresponds to the water column up to the water surface.

According to manufacturer, pressure is transmitted to a silicon pressure sensor and its measuring diaphragm via the diaphragm and its liquid filling. The resistance of four doped piezo-resistors in a bridge circuit in the measuring diaphragm changes. This change in resistance generates an output voltage in the bridge circuit that is proportional to the measured pressure. This voltage is converted via a measuring amplifier and a 4 to 20 mA current driver into a direct current of 4 to 20 mA that is proportional to the pressure (Figure 5).

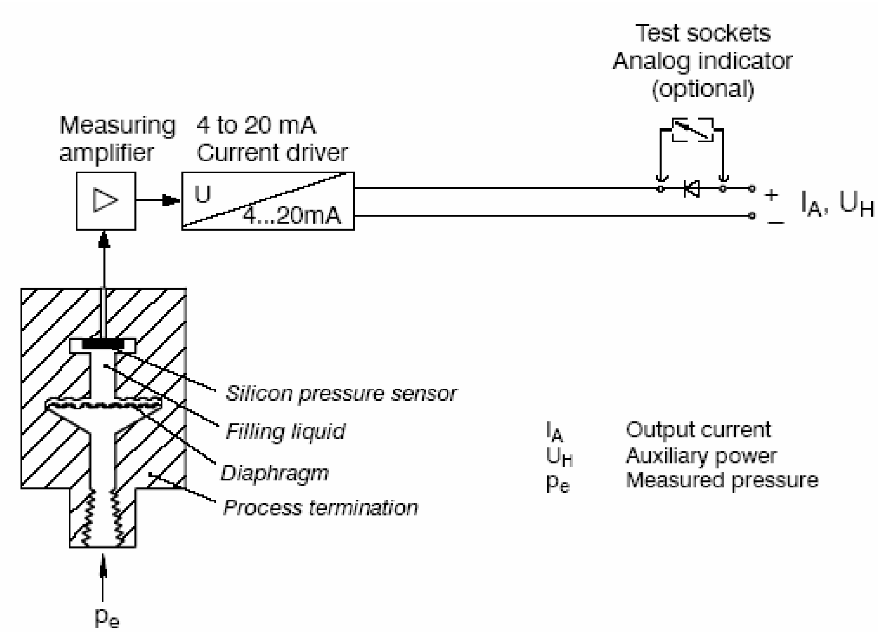


Figure 5: Diagram of pressure transmitter (Siemens SITRANS P, MK II)

According to the VSA Swiss Water Pollution Control Association (1999-2003), measurement accuracies are in a range of ± 0.2 %, and an additional annual drift of 0.1 % of the measured span has to be taken into consideration. The manufacturer defines accuracy in a range of ≤ 0.25 % and an annual drift of ≤ 0.2 % with maximal span.

Measurement drift

In Figure 6, the corrected annual drift of both meters at the storage tank is shown. The corrected values represent only the meter reading of the periods where the storage tank was not filled. Thus, a direct comparison of both meter readings was possible, because the change of the water level is only caused by the outflow of the tank into the supply net. In these periods, the change of the water level in time caused by system input was measured with the pressure transmitter and the water surface with an area of 364.4 m² was converted into a flow. Downstream, the same system input was measured with an inductive flow meter, situated at the water main.

By also considering the periods of filling the storage tank, possible inaccuracies can be higher over the time. Therefore it is not possible to directly compare the measured change in water level (with the pressure transmitter) and the measured system input (with the electromagnetic flow meter).

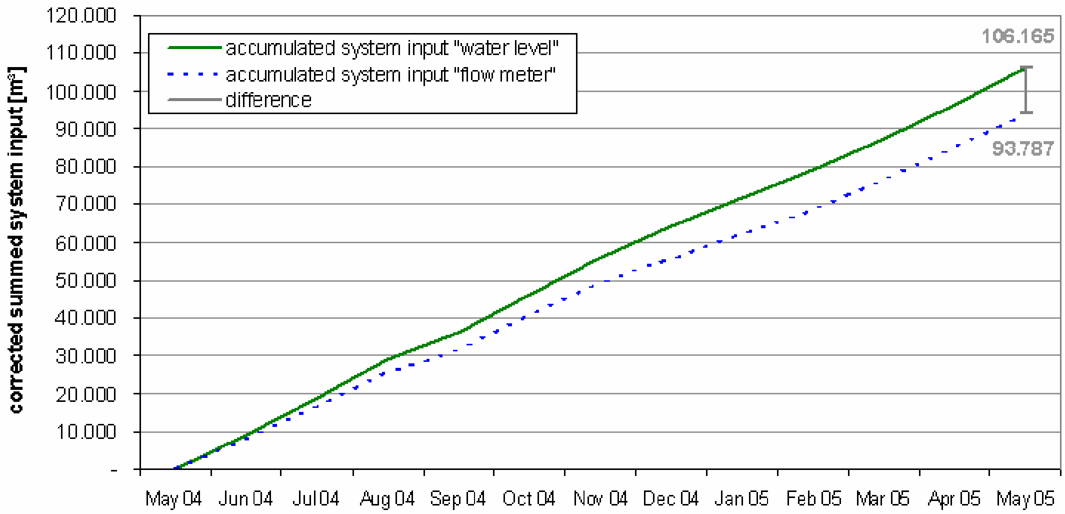


Figure 6: Corrected accumulated meter reading

The flow meter indicates the corrected system input, which is equivalent to the output of the storage tank without filling at the same time, a water volume of 93,787 m³. The corrected annual system input according to the water level sensor would be at a level of 106,165 m³. Hence, depending on which meter is used, the system input parameter in the water balance varies with a volume of 12,378 m³.

For the period 2000-2005, the system input, the authorised consumption (billed and unbilled metered consumption) and the increasing number of service connections was analysed (Figure 7). As the customers' meter reading is once a year at end of May, the annual period of the billed consumption and the system input is from June to May. For a comparison of the three performance indicators, the data series were standardised to the mean value over the dataset of 6 years (Figure 8). As a result, on the one hand the increase in authorised consumption is higher than the increase in the service connections. The system input, on the other hand, is decreasing.

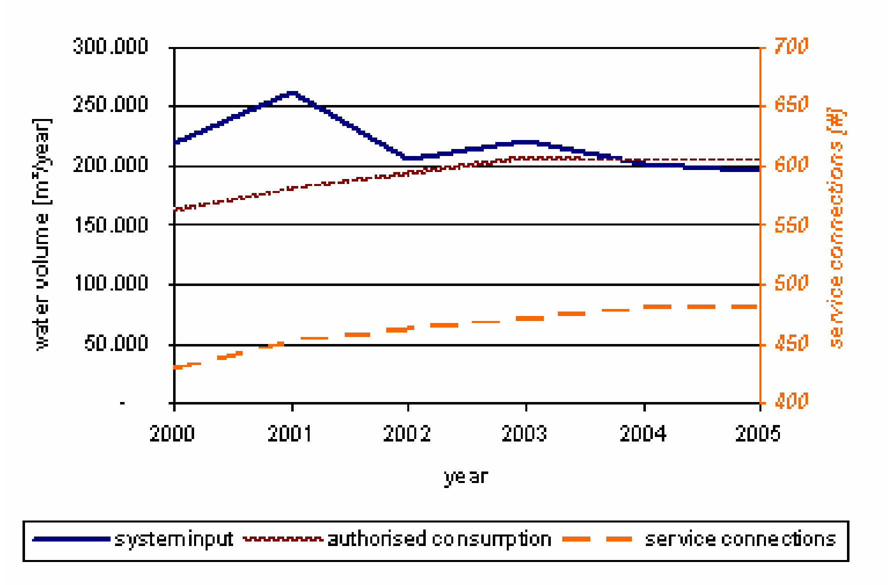


Figure 7: Original distribution of service connections, system input, and authorised consumption

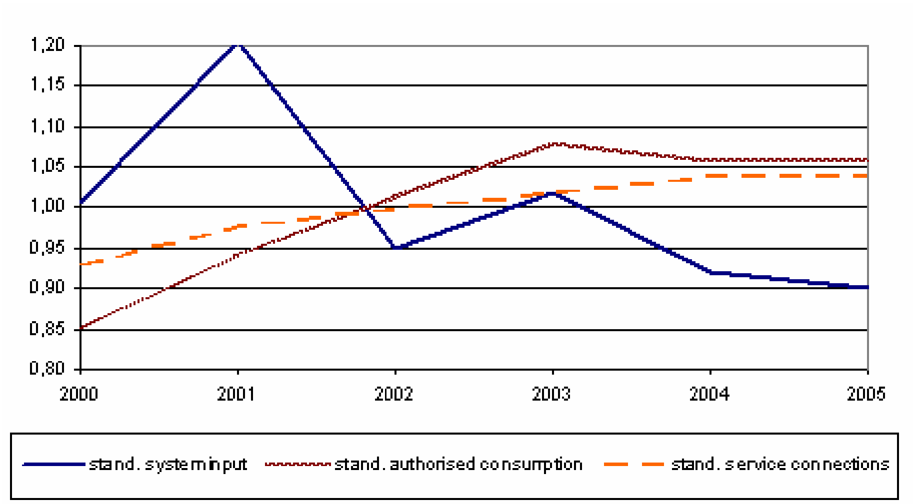


Figure 8: Standardised original distribution of service connections, system input and, authorised consumption

For 2005, an annual billed consumption of 204,044 m³ was measured using mechanical water meters at customer site for the district observed. Other authorised consumptions like consumption at hydrants, water posts or for street cleaning did not take place. The compared total system input of the storage tank Möltschach for this period is only 194,670 m³. As a result the water balance would calculate a negative system input of 14,000 m³, which is not possible, and can only be explained by measurement inaccuracies.

Detailed analyses

When taking into account the possible inaccuracies of the pressure transmitter with a maximum 0.45 % of the measured value, the measured value is in a range of 105,690 m³ to 106,640 m³. Electromagnetic flow meter inaccuracies, which depend on a maximum flow velocity of 0.5 % difference for velocities over 0.4 m/s, result in a range of 93,780 m³ to 93,790 m³. Hence, the difference volume is in a range of 11,900 m³ to 12,860 m³, which is 12.7 % to 13.7 % of the system input measured with the flow meter.

When adding this difference as a percentage of the input water level to the total system input of 194,670 m³ per year measured with the flow meter, the result is a water volume of 221,360 m³ to 222,750 m³ per year.

Compared to the measured authorised consumption of 204,040 m³, the water loss for this district is calculated in a range of 17,320 m³ to 18,710 m³. According to Directive 2004/22/EC of the European Parliament and the Council on measuring instruments, the maximum permissible errors, positive or negative, on volumes delivered at flow rates (2004) between the transitional flow rate (included) and the overload flow rate is 2%. The maximum permissible errors, positive or negative, on volumes delivered at flow rates between the minimum flow rate and the transitional flow rate (excluded) is 5 % for water having any temperature. Hence, when apparent losses are approximately 10,200 m³, real losses can be calculated therefore to be nearly 7,700 m³.

Performance Indicators on water losses

According to the DVGW W 392 German standard (2003), a specific water loss can be calculated with a net length of 15.5 km to q_{vr} =0.06 m³/(km*h). For an urban area, the value is at the intersection between medium and middle loss.

For an international comparison, the ILI – Infrastructure Leakage Index - of the IWA was also calculated by using the WB-Easy Calc software from, Liemberger & Partners (2006). For this district, the ILI of 0.4 with a possible inaccuracy of 15% is, in comparison to the Austrian ILI-values (Gangl et al., 2006), a very low value. It is important to note that the boundary condition of 3,000 service connections is not fulfilled for the calculation of the ILI.

When considering the average net age of the Möltschach district meter area, (Figure 9) together with the failure rate in three year steps (Figure 10), the calculated performance indicators for water losses seems to be plausible. The analyses were made for the used materials cast iron CI, ductile iron DI, steel ST, polyethylene PE, polyvinylchloride PVC, and for the total net. The distribution of the failure rate has been decreasing in the last years few and the average net age of 27.4 years, dominated by the materials cast iron CI and steel ST, is also low. According to the ÖVGW W 100 Austrian guideline (2007), an annual failure rate below 7 failures per 100km represents a net in a good condition,

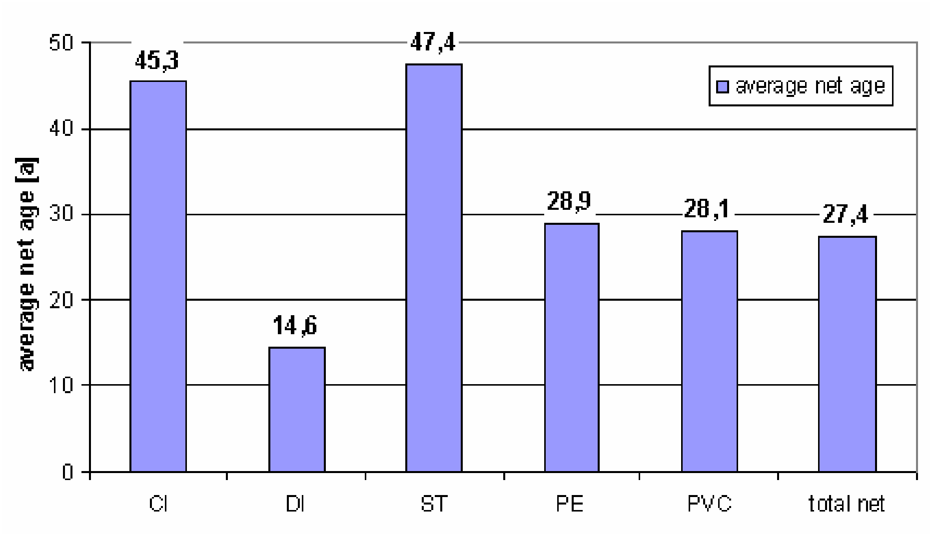


Figure 9: Average net age of Möltschach DMA

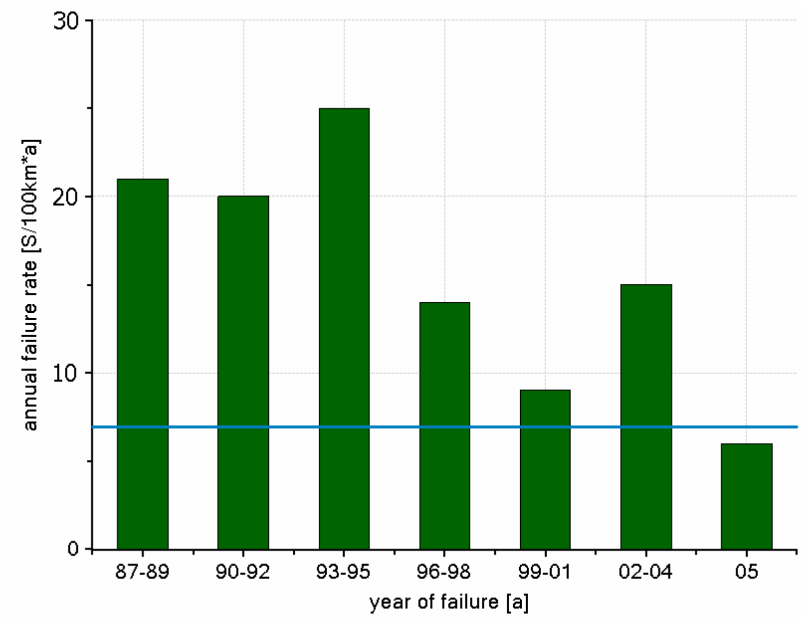


Figure 10: failure rate in 3-year steps of the Möltschach DMA

Considering the fact that these calculations are only possible when taking a difference of approximately 13% as a result of the comparison of the two measuring instruments, it is clear that in this district area the leakage rate could also be higher.

Conclusion

One of the most important indicators for describing the actual status of a water supply network is, next to the annual failure rate, the volume of water losses. Depending on the lost volume, several countermeasures are possible, which have normally a huge influence on the financial budget. Austria is in the lucky situation that water losses are, on the one hand, quite low caused by good network conditions as a result of the rehabilitation strategies of the water supply utilities. On the other hand, Austria is rich in water. Water which has to be pumped to storage tanks like those in Möltschach causes costs, so under financial considerations, water losses should be reduced.

A simple way for calculating the volume of water loss is to use the IWA water balance template. The output result can only be as good as the input parameters, so a former check of the present measuring instruments seems to be necessary. In this paper, possible variations of measurement inaccuracies in a small district meter area were discussed. Wrong conclusions out of these inaccuracies can lead to cost intensive investments, which can easily be avoided by a simple calibration of the installed measuring instruments.

References

Austrian Drinking Water Regulation (2006); BGBl. II Nr. 254/2006, www.ris.bka.gv.at

DVGW W 392 (2003); Rohrnetzinspektion und Wasserverluste – Maßnahmen, Verfahren und Bewertungen, www.dvgw.de

Farley, M., Trow, S. (2003); Losses in Water Distribution Networks; ISBN 1-900222-11-6

Gangl, G., Theuretzbacher-Fritz, H., Kölbl, J., Kainz, H., Tieber, M. (2006); Erfahrungen mit der Wasserverlustberechnung im ÖVGW Benchmarking-Projekt; ÖVGW Symposium 2006, 85-96

IWA blue pages (2000); Losses from Water Supply Systems: Standard Terminology and Recommended Performance Measures

Kölbl, J., Haas, G., Gangl, G. (2007); Hydraulische Rohrnetzberechnung – Wasserwerk Villach. – Final report of part project of Competence Network Waterpool, Graz, Austria.

Lambert, A. (2000); What do we know about pressure:leakage relationships in distribution systems?, IWA Conference “System approach to leakage control and water distribution system management”, ISBN 80-7204-197-5

WB Easy Calc – the free water balance software (2006); Liemberger & Partner; www.liemberger.cc

ON EN 805 (2000); Water supply - Requirements for systems and components outside buildings, www.oenorm.at

ON B 2539 (2005); Technical surveillance of drinking water facilities – Technical rules of OVGW, www.ovgw.at

OVGW W 63 (1993); Wasserverluste in Versorgungsleitungen, Anschlussleitungen und Verbrauchsleitungen, www.ovgw.at

OVGW W 100, blueprint (2007); Water Supply Pipes – Operation and Service; www.ovgw.at

Directive 2004/22/EC of the European Parliament and of the Council on measuring instruments (2004)

Torricelli, E. (1644); Opera geometrica

VSA - Swiss Water Pollution Control Association (1999-2003); Messtechnik in der Siedlungsentwässerung

The reality of undertaking a large leakage control project

Ing. Dewi Rogers, (1)

Ing. Corrado Rossi (2)

(1) Managing Director DEWI S.r.l., Perugia, Italy , email: dewiltd@tin.it

(2) Technical Director ATO 2 Marsicano, Avezzano, Italy, email: corrado.rossi@ato2marsicano.com

Key words: Leakage control, mathematical models, pressure control, mains survey, GIS, leakage location

Abstract

Water networks the world over loose around a half of the available water mainly through leakage. As a result, intermittent supply has become the norm rather than the exception with all the risks that this entails, particularly to the quality of the water and the durability of the network. The solution is to create a permanent leakage and pressure control system which at its core requires a detailed knowledge of the network and its operation which is usually lacking. This paper describes the approach, difficulties and solutions of undertaking such a project in one of the leakiest networks in Italy. This project, which covered over 1200 km and 35 municipalities, represents probably one of the largest commercial leakage projects in Europe.

Introduction

Many water networks all over the world are in such a poor condition that it is no longer possible to guarantee a 24 hour supply. Consequently, the closure at night of the reservoir outlets has become normal practice, despite the enormous risks this poses to the quality of the water and to the structural durability of the network.

Intermittent supply is usually caused by the high leakage. International experience has shown that the best way to reduce and subsequently maintain a low level of leakage in a water network is to divide it into a number of sectors called District Meter Areas (DMAs), each supplied preferably by a single supply pipe on which is installed a flow meter. In this way, it is possible to permanently control the level of leakage in each district and identify immediately the presence of a new leak. The approach is illustrated in detail in the Water Loss Task Forces' DMA guidance notes.

To create DMAs requires a thorough knowledge of the network and its operation, the lack of which is probably the main reason why leakage is such a problem in the first place. The mains records are at best out of date and often non-existent. In addition, if customer meters are installed, they are usually inaccurate and not regularly read.

Such a situation is also common in the central and southern part of Italy. In an attempt to improve the situation, a law was passed called the Galli Law which aimed to reorganise the water industry by moving the management of the networks away from the individual municipality onto a larger and more cost effective basis by amalgamating networks into catchment areas called Ambito Territoriale Ottimale. ATO 2 Marsicano is one such utility in central Italy. It is composed of 35 Municipalities and according to official figures, represents the leakiest part of Italy, with over two thirds of the production being lost through leakage. So bad is the situation that the main city, Avezzano, has water supply for only 7 hours of the day.

In order to drastically improve matters, a project was awarded to a group of companies comprising RPA S.r.l., Severn Trent Italia S.p.A., DEWI S.r.l. and Ingea S.r.l. with the ambitious aim of not only reacquiring the lost knowledge, but to significantly lower the existing leakage level – all in less than 3 years. As such, it represents probably one of the largest commercial projects ever undertaken in Europe. This paper outlines the work undertaken and the difficulties which had to be overcome.

Technical approach

The key elements for undertaking a leakage control projects are outlined below in Figure 1.

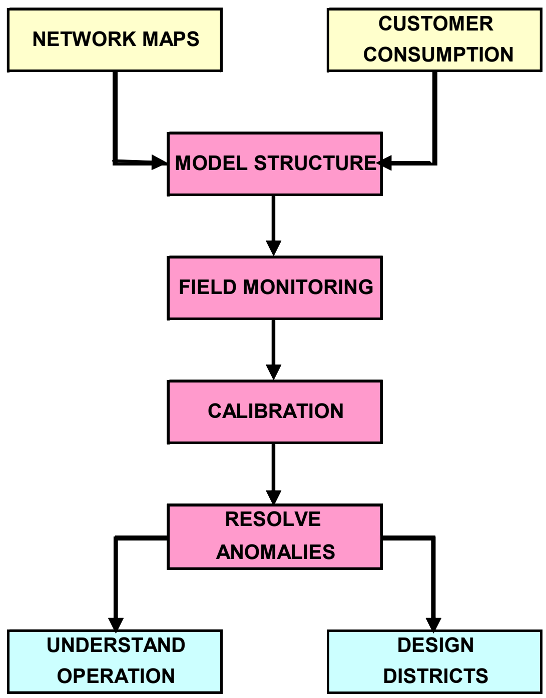


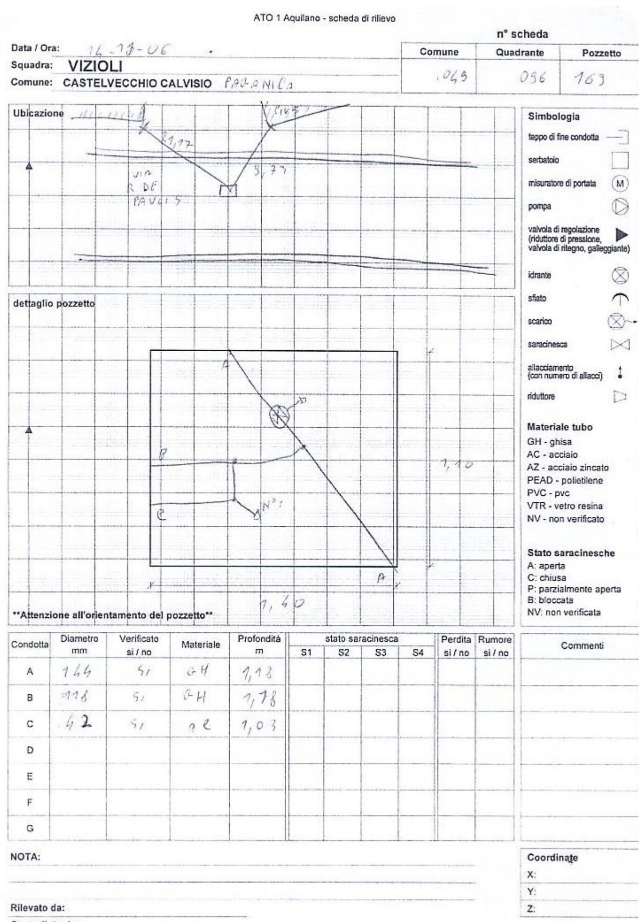
Figure 1: Key elements of a leakage control project

It shows how by combining the knowledge of the network structure, the consumption of the customers and the existing flows and pressures in a mathematical model, it is possible to acquire the necessary understanding of the existing operation of the network to design the optimum configuration of the DMAs. This over the years has become fairly standard procedure. The problem is to apply this methodology in networks where there is little or no existing knowledge. The approach adopted in the Avezzano and the problems encountered and how they were overcome are described in the following paragraphs.

Mains records

The standard of the mains records was very poor. Only about one third of the pipes were mapped and what was available was of very limited accuracy. It was necessary therefore to undertake a whole scale survey involving the inspection of every manhole connected to the water network. Considering the 1250km of network to be checked, the organisation of such a task was enormous.

Superficially it might seem a relatively straightforward task to undertake a mains survey – simply open all of the manholes, copy what's inside onto a manhole sheet and plot it all on the base map back in the office. The reality is seldom so easy. First of all it is necessary to find the manhole cover which can sometimes be a major task in itself as often it has been covered by asphalt or hidden in the undergrowth. Once it has been uncovered it is then necessary to open it, which can be a long and arduous process. Only then can the work of understanding the static network really begin. It is of course essential that the information is collected in a disciplined and well-ordered way, as inverting the survey sheet compared to the manhole for example, would significantly complicate the restitution. When it is considered that the surveying is undertaken in all weather and often in the middle of busy roads, the chances of error are significant unless a rigorous procedure is in place. It helps to have well trained staff and rigours controls in place.


ATO 1 Aquilano - scheda di rilievo

Data / Ora: 14-11-06
Squadra: VIZIOLI
Comune: CASTELVECCHIO CALVISIO PAGANICA

n° scheda		
Comune	Quadrante	Pozzetto
049	096	169

Ubicazione

dettaglio pozzetto

Attenzione all'orientamento del pozzetto

Simbologia
tappo di fine condotta
serbatoio
misuratore di portata
pompa
valvola di regolazione (riduttore di pressione, valvola di ritegno, galleggiante)
idrante
sfiato
scarico
saracinesca
allacciamento (con numero di allacci)
riduttore

Materiale tubo
GH - ghisa
AC - acciaio
AZ - acciaio zincato
PEAD - polietilene
PVC - pvc
VTR - vetro resina
NV - non verificato

Stato saracinesche
A: aperta
C: chiusa
P: parzialmente aperta
B: bloccata
NV: non verificata

Condotta	Diametro mm	Verificato si / no	Materiale	Profondità m	stato saracinesca S1	S2	S3	S4	Perdita si / no	Rumore si / no	Commenti
A	144	si	GH	1,18							
B	118	si	GH	1,78							
C	62	si	AZ	1,03							
D											
E											
F											
G											

NOTA:

Rilevato da:
Controllato da:

Coordinate
X:
Y:
Z:

Figure 2: Survey sheet

The restitution of the information is probably the single most important activity in the mapping process as it represents a check of all the information collected in the field and allows the many anomalies to be highlighted. These can include the identification of a pipe in only one manhole. It is necessary therefore to undertake a pipe tracing exercise with a pipe locator. Such an approach is not foolproof though: it is possible that the signal is transferred to other services in the vicinity, that the signal is lost in the rubber joints or worse is lost in repairs using a different type of material. Great skill is needed therefore to interpret the information correctly.

In ATO 2 Marsicano the maps were first digitised and then transformed automatically into the GIS structure as shown in Figure 3. The information, including the survey sheet and photographs, is accessed simply by clicking on each object. The final GIS allows a graphical representation of a number of databases and as such represents a very powerful tool for the management of a water network in general and in particular the control of leakage.

The co-ordinates of all of the points were measured by the surveyor and added to each node of the GIS.

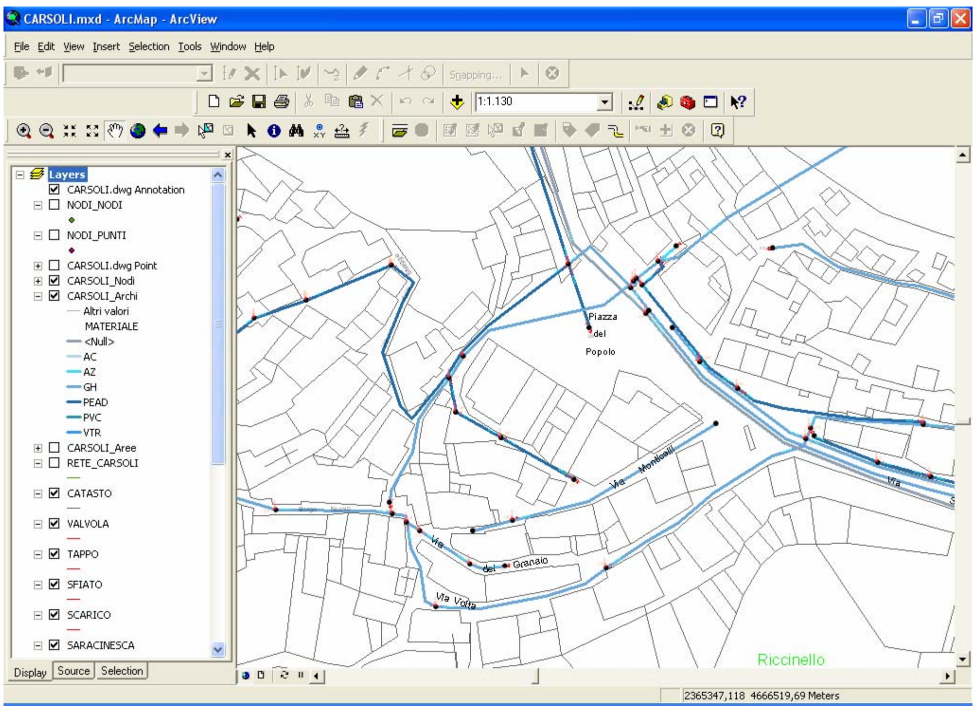


Figure 3: GIS maps

Customer consumption

A very important element in quantifying water loss is customer consumption. Only around half of the properties in the ATO 2 Marsicano area have a meter and even if they have one installed, very few are regularly read and maintained. It was necessary therefore to quantify two components:

- the accuracy of the meters when installed;
- the consumption of the properties without a meter.

This was achieved by installing a very high accuracy test meter connected to a data logger on a sample of properties, either directly on the customer connection upstream of the tank, or in series with the existing meter where present. The results showed an under-registration of the existing meters of 9% and an average customer consumption of just over 100 l/person/day.

By recording with the data logger, it was also possible to derive the typical demand profile and evaluate the effect of air getting into the system on the measurement of the meters.

Mathematical model

A well built and calibrated mathematical model simulates accurately the hydraulic operation of the real network. As such it enables the impact of creating the permanent DMA boundary to be assessed even before the valves are closed in the field. However, the importance of the model to verify the accuracy of the data used to construct it is often overlooked. When the initial knowledge of the network is very limited, as was the case in ATO 2 Marsicano, and the work to recover this deficiency is so inherently complicated despite all the latest location technology, the ability to verify the end result is essential to ensure the successful outcome of the project. This was certainly the case in the ATO 2 Marsicano project as in other smaller projects undertaken in the south of Italy.

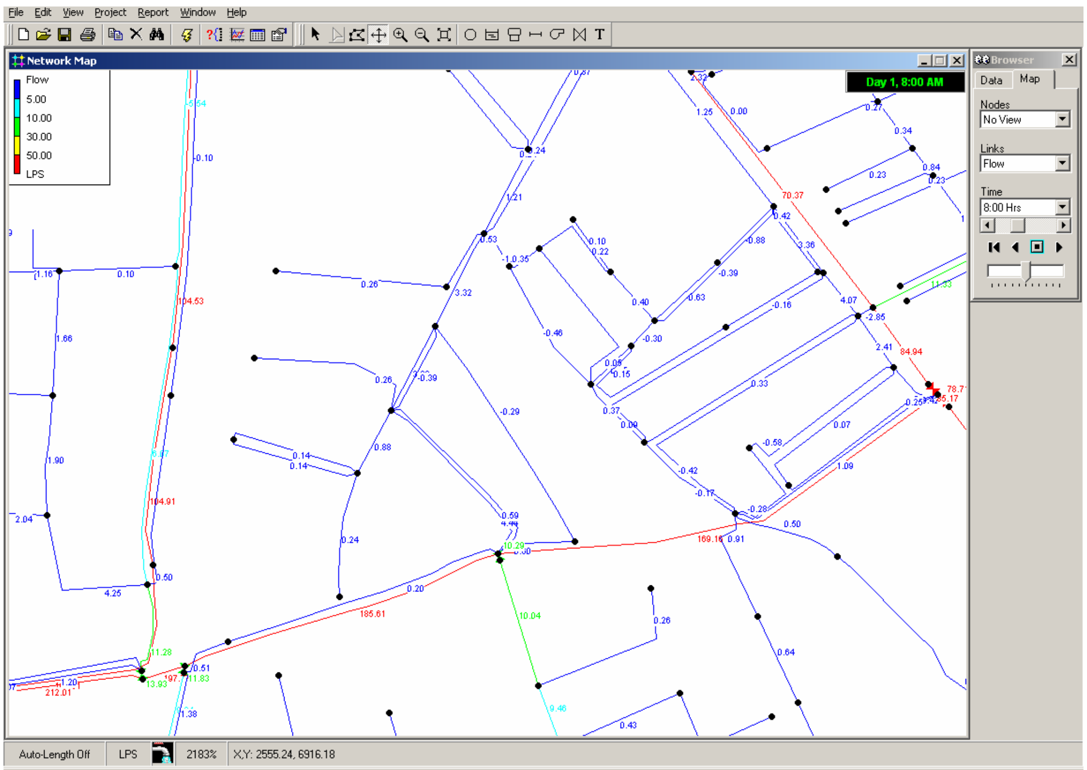


Figure 4: Mathematical model of Avezzano

The activity of calibrating a mathematical model involves comparing the calculated pressures and flows with those measured in the field. Any difference is indicative of an error in the model. With skill and experience it is possible by using the model to identify the likely cause of a such differences. It is important to realise the significant difference between simply monitoring the pressures in the network and analysing them with the aid of a mathematical model. This much is clear from one of many examples of the anomalies identified during the project.

The data recorded in the field in a network near Avezzano is shown in Figure 5.

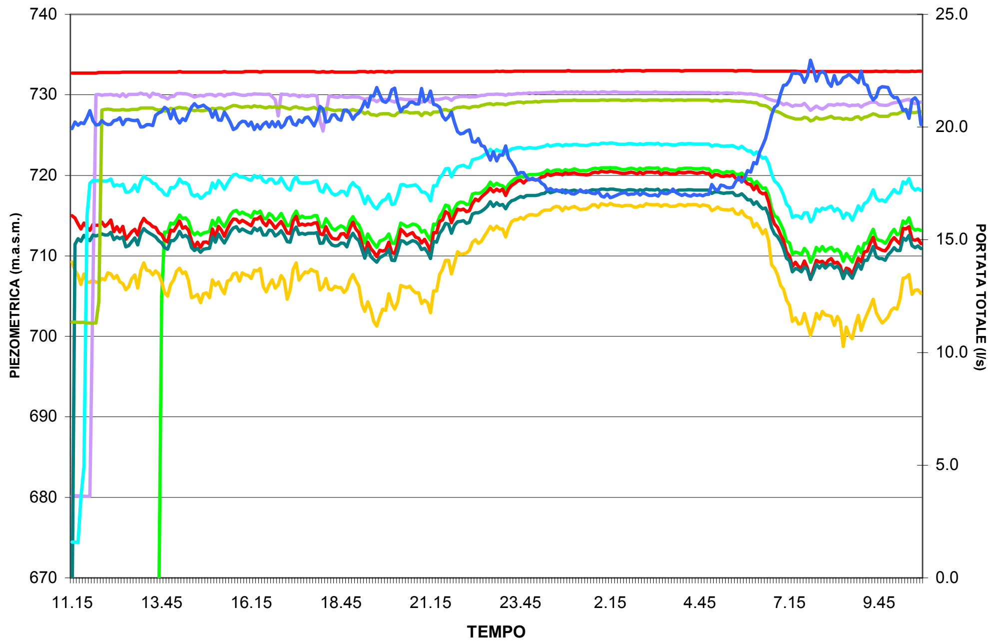


Figure 5: Head recorded in the field

The pressure in the network is more than adequate. However what cannot be appreciated from the data, but which was very evident with the model, is that there was an unknown closed valve on the main 150 mm supply pipe to the lower part of the network. This explains the significant variation in head in the lower part of the network (as exemplified by the lower curve) which was not initially replicated in the model. By opening this valve in the network, it was possible to not only improve the operation of the network and optimise the configuration of the leakage districts, but very importantly allow the creation of a permanent pressure control system to lower the existing leakage level and reduce the formation of new leaks.

Leakage location

The acoustic technique, which is at the heart of such instruments as the correlator, noise logger, ground microphone and listening stick, has been perfected to such an extent over the years that when the characteristics of the pipe are known perfectly, it is possible to locate an invisible leak with an accuracy of better than +/- 0.5 m. However, all of these instruments depend on one critical factor: pressure in the pipes to generate a leak noise. In Avezzano for instance, as for many of the other 35 Municipalities covered in the project, water is supplied for little more than 4 hours in the morning and 3 hours in the evening making the application of acoustic instruments a very complicated and organising the leakage location teams a nightmare. This was overcome in the ATO 2 Marsicano project by using programmable noise loggers. Over 150 were deployed on a rota basis. This ensured that even when the water was being rationed, the work of installation could continue. The moment the network was pressurised, the loggers would then all record the noise. The following day the teams collected and interrogated the loggers and identified the likelihood of a leak by checking the flashing lights. Each team would then use the correlator to pinpoint the precise location of the leak during the hours of water supply and transmit the information to the contractor to execute the repair.

It was found that not all noise loggers on the market were suitable for such application. Some are pre-programmed to record just at night in the belief that the highest pressure and hence the highest noise occurs at night. Obviously this is not the case with intermittent supply. Furthermore, it was found that the hours of supply varied significantly from network to network making the easy programming of the recording window essential.

Figure 6: Location of leaks

Organisation and results

In addition to the technical challenges that such a large project entailed, planning and managing the work was also a significant task. Four teams composed of one engineer and one technician were created to undertake the survey work, each having a vehicle and all necessary safety and surveying equipment. It was estimated that each team would survey 2 km each day and this proved to be close to the mark particularly when the time necessary to resolve anomalies was taken into account. Each team was also responsible for the initial restitution of the network as well as preparing the final survey sheets and photographs for subsequent insertion into the GIS. Two topographic surveyors then surveyed every manhole with a high resolution GPS instrument to measure accurately the coordinates. Two AutoCAD experts transformed the initial restitution in a GIS-compatible structure whereby each pipe had a start and end node and all the databases were compiled. Great attention was given to defining the optimum structure of the GIS which contained all the necessary information without creating an excessively heavy structure which would be difficult for the end user to apply. For this reason, open valves for instance, which are normally considered nodes, but which effectively act as an open pipes, were considered attributes to the pipes. An expert in ESRI's ArcGIS then transformed the AutoCAD file into the finished project using special software created for the project. Training was given to the client's staff in the use of the system.

A total of 675 flow and pressure points were monitored. Over 50 new flow meters were installed. On pipes larger than 75 mm, pressure tapings for insertion meters were created. Where possible, the teams used for the survey work were deployed for the monitoring to exploit the local knowledge that had been acquired.

Once all the data had been collected it was combined into the mathematical simulation model. Using a special routine created by DEWI S.r.l., it was possible to transfer directly from the GIS into the modelling software. Great care was taken with the calibration of the models.

Three teams were used for undertaking the leakage location exercise, which involved installing noise loggers at intervals of around 50 m to identify the noisiest pipes. Correlators and ground microphone were than used to locate the exact position of the leak which according to the contract was deemed to be precise only if situated within an 1m x 1.5 m excavation - a very tight tolerance indeed. The participation of the client was essential in this stage to deal with uncertain leaks. This raises an important question about how best to apply penalties to this kind of work, particularly to avoid the risk of some large leaks not being notified for fear of incurring penalties.

The project was undertaken successfully within the three year time period stipulated by the contract, during which time 1250 km (15% more than originally estimated) were surveyed and checked for leaks. A mathematical model was constructed for all the largest networks, which amounted to well over half of the whole length of mains, and DMAs were designed. Pressure control was implemented as part of a very successful trial in 9 DMAs in Avezzano which together with the repair of the leaks contributed significantly to increasing the hours of supply.

Conclusions

In many networks all over the world, there is a serious leakage problem. Numerous systems loose well over half of the water produced and water is often rationed for many hours of the day. One such network is that of ATO 2 Marsicano in central Italy. With over 1200km of network divided into 35 municipalities, it is considered one of the leakiest water networks in Italy, with over two thirds of the water being lost through leakage.

It is likely that the main reason for such a dramatic situation is the lack of understanding of the network and how it operates hydraulically. On the other hand, without this understanding, it's impossible to create a permanent leakage control system which experience has shown is the only realistic solution to the problem. It was therefore necessary to reacquire the knowledge by surveying every manhole in the network, create a GIS system and monitor the pressures and flows to enable the construction and calibration of a mathematical simulation model. In this way it was possible to verify the accuracy of the survey work and identify and resolve the anomalies. Once the model had been verified, it was applied to define the optimum configuration of the permanent leakage and pressure control system.

The intermittent supply, whilst harmful for water quality and the durability of the network, also presented serious organisation problems for the leakage location activity. This was resolved by deploying over 150 programmable noise loggers at a time to identify the leakiest pipes which were then checked using leak noise correlators and ground microphones. Well over 2000 leaks were located and repaired yielding a saving of almost 10 million m^3/ year. The project was undertaken in less than 3 years which was within the contractual time period.

The ATO 2 Marsicano project shows that it is possible not only to recover the knowledge which is so lacking worldwide in the management of water networks, but to do so in a commercially viable way. The success of the project owes a lot to the technical solutions which were applied, the organisational skills of the project team and most importantly the direct assistance and collaboration of the technical staff in the client's office.

Sustainable reduction of water loss in urban water distribution systems

Dipl.-Ing. Erwin Kober, EnBW Regional AG

Key words: water loss; damage rate; monitoring of inflow

Water loss - rehabilitation

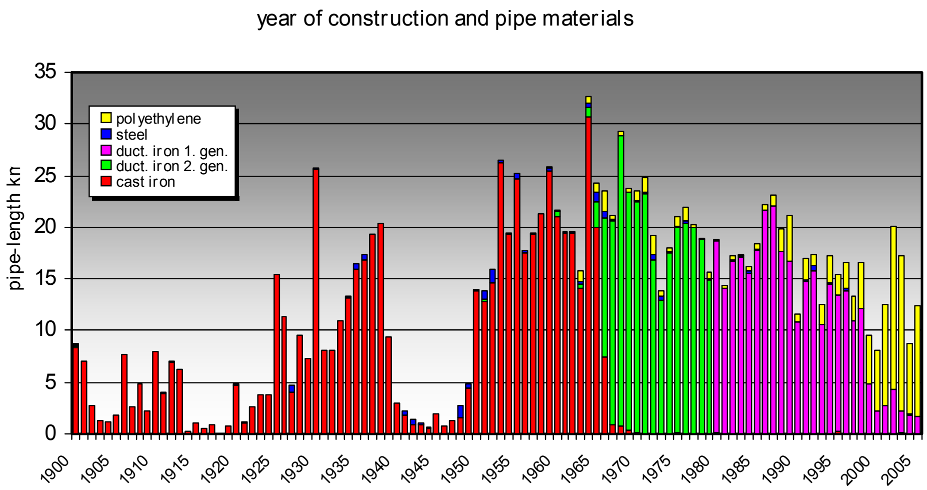
Introduction

Under technical, economic and ecological aspects the fight against water loss becomes more and more important for water supply companies. In Germany, most of the water distribution systems in the cities were constructed between the middle and the end of the last century. With an average pipe age of 45 years, the average annual rehabilitation rate of water distribution systems is about 1%. For this reason, water pipes must have a durability of at least 100 years. In highly developed industrial countries, the pipe systems have become much older and vulnerable to damage. This results in an increase of the water loss in this case, if no efficient constructional and operational measurements are undertaken.

With the available technologies such as noise measurement and the correlation method, the detection of leakages is unproblematic. The actual problem is to identify developing leakages very early and to detect them geographically. In this context, EnBW developed a system for monitoring water distribution systems.

Damage rates and tolerable water loss

Even though the technical durability of soil-covered pipes could last many decades, these parts of the water supply system will become more and more susceptible to damage. The damage rate in distribution systems increases with age. Aggressive soils, soil movement dependent on frost and traffic, construction activity and last but not least dynamic pressures caused by water consumption lead to a strain for the pipe systems. Depending on pipe materials and fittings used this leads to an increase of leakages during the decades which will affect the operation of the system.



polyethylene	102.4 km
steel	15.6 km
duct. iron 2. Gen	312.9 km
duct. iron 1. Gen	277.0 km
cast iron	637.4 km

Figure 1: rehabilitation / material and age-structure of the water distribution system of Stuttgart (2006)

The water distribution system of EnBW in Stuttgart contains 50 % cast iron pipes which are laid predominantly in clay soil. Because of these soil conditions, the damage rate in Stuttgart increases during frost and in dry seasons. The damage rate of cast iron pipes is - under normal conditions - 3 damages / (km x month). In dry seasons and seasons with frost, these will increase up to 10 damages / (km x month). During the last 10 years the damage rate increased from 0.19 to 0.24 damages / (km * p.a.) for cast iron pipes and from 0.05 to 0.07 damages / (km * p.a.) for ductile iron pipes.

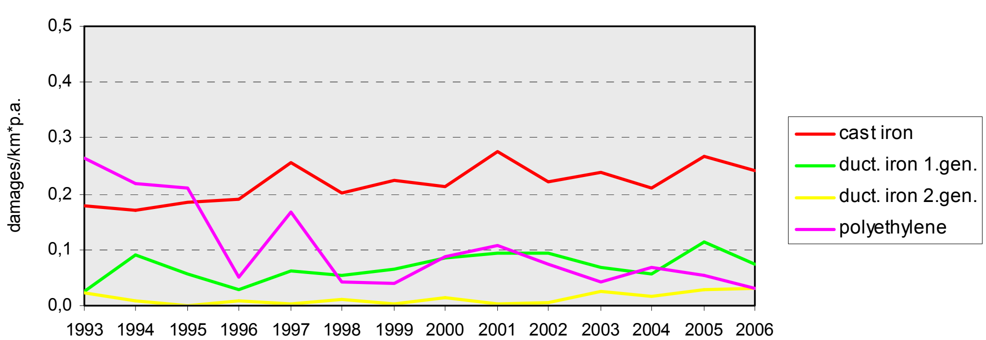


Figure 2: rehabilitation / development of damage rates (pipes)

Table 1: benchmarks for damage rates of pipes in water distribution systems (DVGW W400-3)

definition of damage rates	damage rates	
	principal and local mains (damages per km and year)	service pipes (damages per km and year)
low	≤ 0.1	≤ 5
average	> 0.1 to ≤ 0.5	> 5 to 10
high	> 0.5	> 10

The water loss of a water supply company is caused primarily by leakages in the pipe system. Other influences such as loose fittings and joints and water meters cause permanent loss. In Stuttgart, all these influences have a extension of about 2 - 3 l / (min x km).

By singular or periodical inspections of the pipe systems water loss can be decreased only for a short time. Because of the constant development of damages or leakages in a pipe system, a long term reduction of water loss can only be achieved by permanent monitoring measures. In this context, the monitoring of inflow(s) has to be proved as the most efficient and economic method.

During the last years, the total water loss in the distribution system of EnBW in Stuttgart, with a system length of 1,534 km, was about 4 Mio. m³ /p.a. After the reduction of this amount on the low loss from loose fittings and joints and the influence of water meters, the amount of real water loss in the distribution system itself will be approx. 2 Mio. m³ / p.a. (8 %) and the specific water loss will be at 0.15 m³ / (h x km) respectively.

Table 2: characteristic benchmarks for specific real water losses for distribution systems in m³ / (km x h) (DVGW W392)

range of water loss	intervals of inspection	structure		
		large city	urban	rural
low	max. 6 years	< 0.10	< 0.07	< 0.05
average	3 years	0.10 - 0.20	0.07 - 0.15	0.05 - 0.10
high	1 year	> 0.20	> 0.15	> 0.10

In the year 2005 about 850 leakages were recorded in the Stuttgart distribution system. On the basis that the average loss of a leakage will be approximately 1 m³/h, the detection of an average leakage will take at least 0.27 years or approx. 100 days.

Even if this is only a statistical consideration, these calculations show that water loss can be reduced efficiently if the duration of leakages last could be shortened.

Monitoring methods for pipe systems

Using the available technologies, leakages can be identified from the following characteristic physical properties:

- leakage noise arising at the leakage and
- continuous outflow at the leakage which will interfere with water consumption.

Due to the fact that the measurable leakage noises dependent on the pipe material only occur in the direct surroundings of the leakage, the available technologies are only applicable for the detection of the leakage itself or to contain the leakage area (noise loggers) but not for the early detection and localization in bigger networks or network districts.

This aspect is especially important for systems constructed with polyethylene pipes, because this pipe material is highly noise-absorbing.

The continuous water outflow at the leakage will cause an increasing water inflow in the pipe system. A monitoring of the inflow (flow rate) enables an evaluation, if new additional leakages occur - depending on the size of the pipe-network or network district.

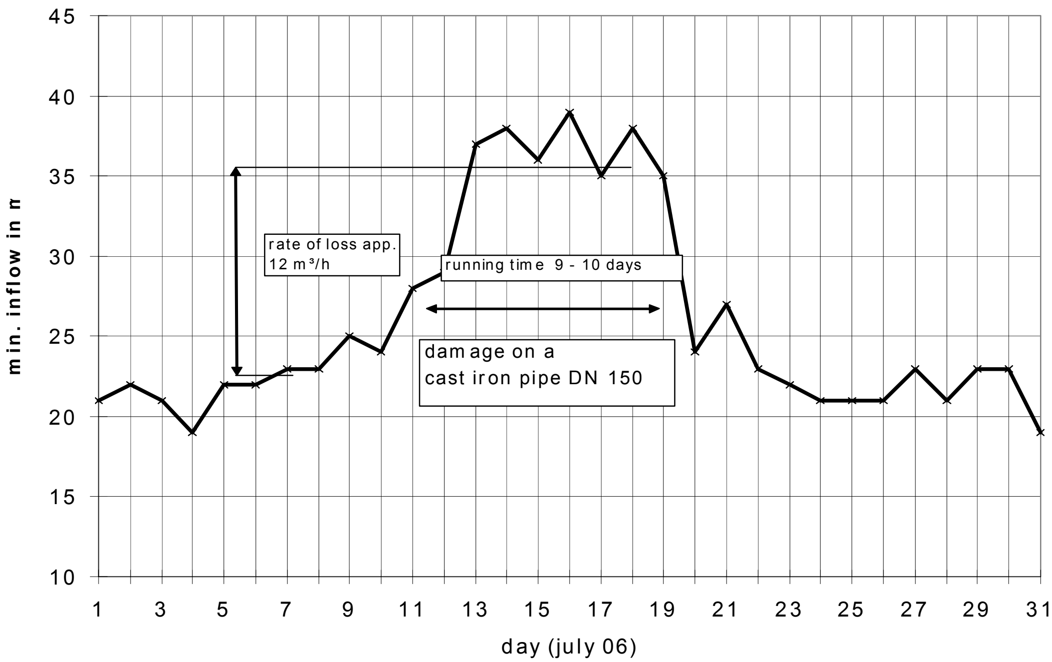


Figure 3: measurement of water loss / identification of a leakage by measurement of minimum night inflow (9,700 inhabitants, 38 km network length)

Dependent on the malfunction messages of a monitoring system, advanced measurements to isolate and to detect the leakages could be carried out using the approved acoustical technologies. The first active element in a chain of monitoring of a pipe network is the permanent measurement of the zone inflow(s).

Installation of measuring facilities for a pipe network monitoring

The outlets of each water reservoirs or source have to be equipped with applicable measuring facilities for the flow rate. Therefore usually inductive flow meters will be used; in case of bigger pipe diameters ultrasonic flow meters can also be installed. Each metered hour values will be transmitted to and recorded on the scada system using the company's telecontrol network. If a telecontrol network is not available, the measurement data can be recorded on a local installed data logger. If required, the data can be transmitted using the telephone network or by radio communication. Using these techniques, it is possible to monitor the water consumption (inflow) continuously.

In small zones (networks) this kind of leakage monitoring works without any problems, because the effort for the detection of a leakage is based on a manageable network district.

If a leak should occur in a bigger zone, with a pipe length of 170 km for example, these single leakages will not be identified on the basis of a central inflow measurement because of considerable fluctuations of night consumption. Furthermore the effort for the location and detection of the leakage in such a big zone is exceedingly high.

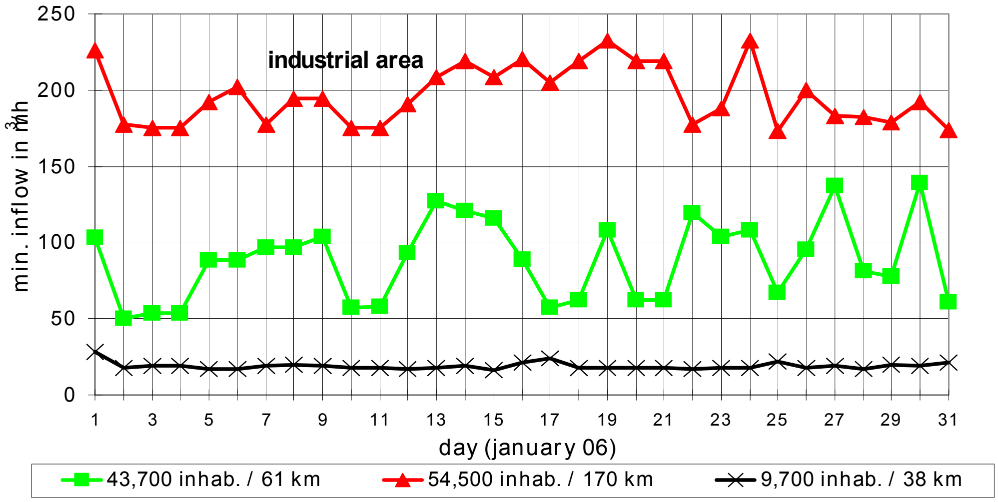


Figure 4: water loss / minimum night inflow in water supply systems of different sizes

For the practical operation of zone monitoring it is necessary to install the measuring facilities for smaller network districts. In this context, all outlets of water reservoirs and pumping stations in Stuttgart have been equipped with flow meters.

Furthermore, in all bigger zones, manholes with flow meters have been constructed in appropriate hydraulic positions in order to realize smaller districts.

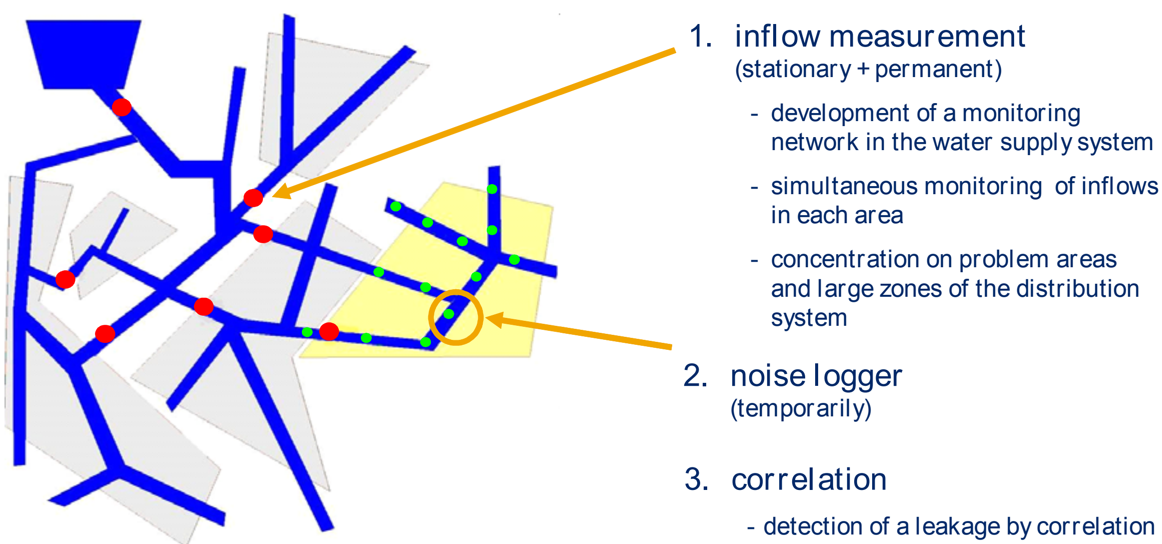


Figure 5: water loss / philosophy of district metering

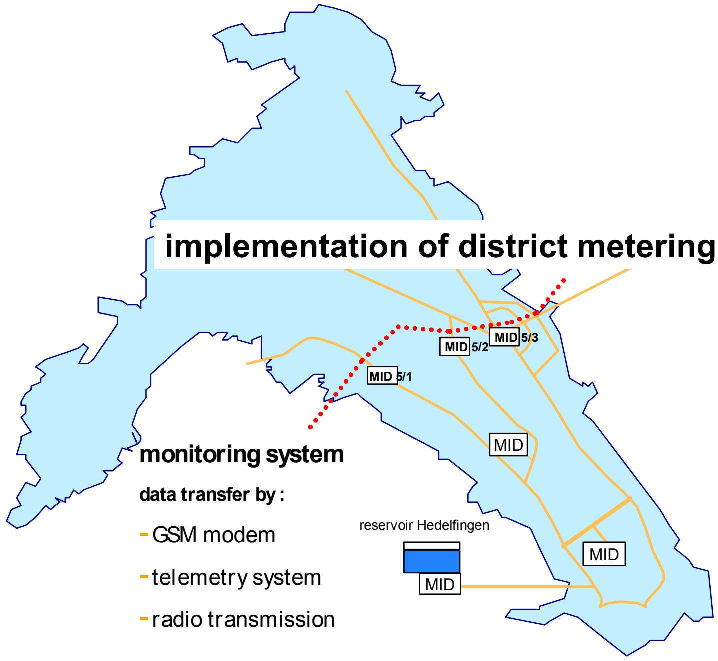


Figure 6: water loss / example for implementation of district metering

Since 2005, EnBW has used an integrated system based on a clamp-on ultrasonic flow meter. This system can be installed directly on the pipes without the necessity of a manhole - the data are transmitted by GSM. This system has to be proved as the most efficient and economic method of measuring flow rates.

Figure 7: water loss / EnBW-system 'Leak Control'

Strategically rehabilitation of water supply systems

The application of an appropriate strategically rehabilitation programme is essential for a safe and largely faultless operation of a pipe network with tolerable damage and water loss rates. In this context, the statistical analysis of damages and the application of the HERZ-method, which is based on the pipe material and age structure of the pipe network, are approved.

Using the HERZ-method, the life-expectancy of each pipe material has to be estimated as shown in figure 8.

pipe material	40	60	80	100	120	140	life ex.	100%	50%	10%
								life expectancy		
cast iron							60-120	60	90	114
duct. iron 1.gen.							40-100	40	70	94
duct. iron 2.gen.							100-140	100	120	136
steel							60-100	60	80	96
polyethylene							40-80	40	60	76

Figure 8: rehabilitation / acceptance of physical life relating to pipe material

The determination of the rehabilitation volume (in km p.a.) is based on calibrated expected service life of pipe materials.

Figure 9 shows the determination of rehabilitation volume of EnBW's water supply system in Stuttgart. The actual rehabilitation rate is 12.5 km p.a. (0.81 %) and will rise to 15.3 km p.a. (1.0 %) in 2017.

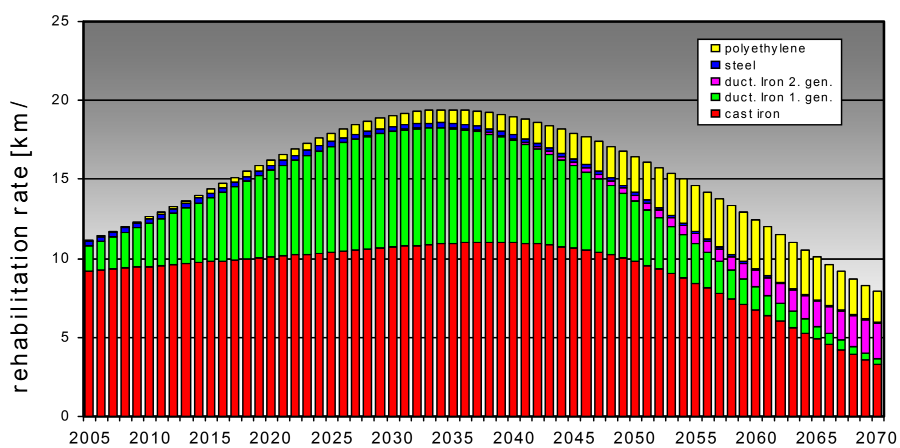


Figure 9: rehabilitation / determination of rehabilitation rate

The following step will be the identification of single measurements and the assignment of priorities. In this context the pipe material - / pipe section - specific damage rates have to be calculated. After a plausibility check and consideration of external influences (e.g. sewers, gas pipes etc.) the process leads to a ranking of projects.

Through concerted replacement of defective pipes or pipe sections a decrease of expensive damages and disturbances is to be expected. In the medium period (5 -7 years) a lowering of repair cost of approximately 30 % is expected.

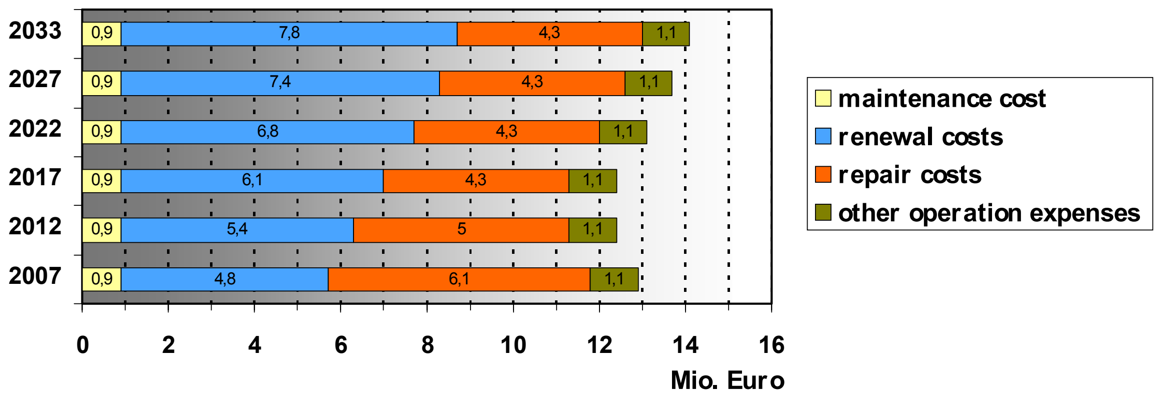


Figure 10: rehabilitation / expected compensation effect

Summary

The continuous measurement of inflow to water supply zones or to zone districts respectively allows identification of leakages. As a precondition, zones or zone districts, which have to be monitored, have to be selected in such a way that they are not too large - to keep the variations in night consumption in a tolerable range. The limit of an appropriate size would be at approx. 5,000 inhabitants or a pipe length of 15 km.

Because of the early detection and location of leakages and the strategically rehabilitation of vulnerable pipes and network districts liable to damage, the specific water loss rates in Stuttgart could be decreased permanently to an amount of approx. 0.15 m³ / (h x km). The experience and the know-how developed at EnBW could be passed on to other water supply companies.

Contact:

EnBW Regional AG
Erwin Kober
Lautenschlagerstr. 21
70173 Stuttgart
Tel.: +4971128946165
e.kober@enbw.com

Combating Non-Revenue Water in a large multi-functional company; A case study of EPAL; Portugal's largest water supplier

A Donnelly

EPAL Empresa Portuguesa das Águas Livres, SA. Avenida de Liberdade, 24, Lisboa 1250-144, Portugal.

E-mail: adonnelly@epal.pt

Keywords: Monitoring; Losses; Management

Introduction

As the oldest water company in Portugal, EPAL has developed an enviable reputation for reliability and service quality over the past 140 years. The company manages an extensive production and transport system supplying other distribution entities and direct large users as well as a distribution network. The challenges of age and scale are considerable and whilst financially sound, levels of Non-Revenue Water (NRW) are higher than should be associated with such a reference company.

However, other influencing factors have been recognised as being of significant importance by the management board. These include reduced demand from bulk, industrial and domestic consumers since 2005, a trend expected to continue and which is linked with increasing awareness from government, regulators and consumers as regards water usage emanating from the droughts suffered over recent years. It is also expected that a significant increase in the role and influence of the domestic regulator as regards reporting and financial controls will occur in the coming years. All of these points indicate that a more stringent and structured approach is required within the company in order to optimise service, reduce NRW whilst increasing network efficiency and reliability.

Over recent years, EPAL has embarked on a major programme of network and infrastructure renewals, the benefits of which have born positive results in terms of efficiency and service quality. However, several projects to increase monitoring of trunk and distribution networks have been less successful than required, resulting in an incomplete toolset being available for efficient network management, leakage assessment and future rehabilitation projects. To this end, the Monitoring and Control Group (GMC) was launched in 2006 in order to integrate existing projects associated with network monitoring with the project aimed at reducing water losses, both real and apparent. This paper and associated presentation aims to outline the background situation as regards NRW within EPAL, the challenges, solutions and difficulties encountered and addressed by the GMC since the project was initiated.

Company Overview

EPAL is the largest water supply company in Portugal, supplying directly or indirectly around one-third of the entire population. The company traces its origins back to 1868 although now part of the national Águas de Portugal holding group and is responsible for significant assets of national strategic and historical importance. The core business activity as an inter-municipal water supply company is divided into two principal divisions.

The Production and Transport division (APT) delivers bulk treated water to 26 municipal councils who supply 2.6 million people and 34 large users in the central region of the country, up to 150km north of Lisbon along the axis of the River Tagus. The principal water source is Castelo de Bode reservoir, supported by smaller scale extraction from the River Tagus, groundwater sources and the historic Olhos D'Agua spring system, dating from the late nineteenth century. The division manages two treatment stations and a mains network of 750km, the basis of which are five large diameter trunk mains from the sources and treatment stations to Lisbon and surrounding municipalities. The principal APT client is the EPAL Lisbon Distribution division, which also supplies water to councils neighbouring the city, resulting in considerable volumes of water traversing the distribution system.

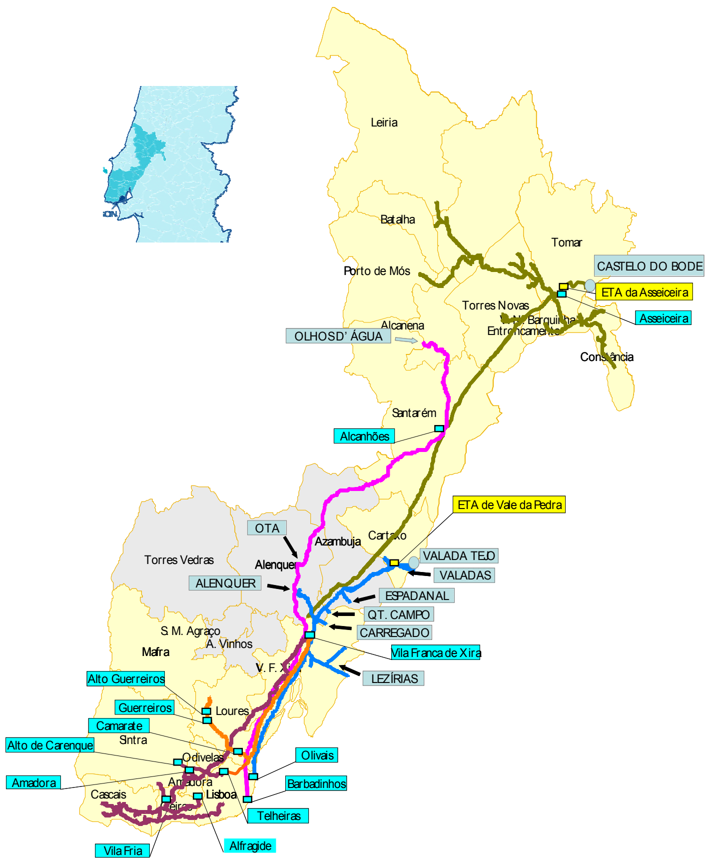


Figure 1 EPAL Production & Transport system

The Distribution arm of EPAL (ADS) is responsible for water supply in Lisbon, serving 345,000 clients with an average daily demand of between 170,000 and 270,000 m^3. As with cities of a similar antiquity, the network has expanded in a haphazard manner in line with urban development over many decades. Given the challenging topography of Lisbon, famous for its seven hills, a system of pressure zones has been implemented since the inception of the system in the 19th century. Originally water entered the city at one of the highest points or by the River Tagus, from where it was pumped to higher areas. This required pressure management to reduce excess pressure or to maintain sufficient pressure in the pumped areas. Currently four pressure bands are maintained at intervals of 30 metres, each with separate pressure management through fourteen reservoirs and nine pumping stations. All 22 transfer points between the two company divisions are metered along with the pressure zones, providing five large scale metered zones.

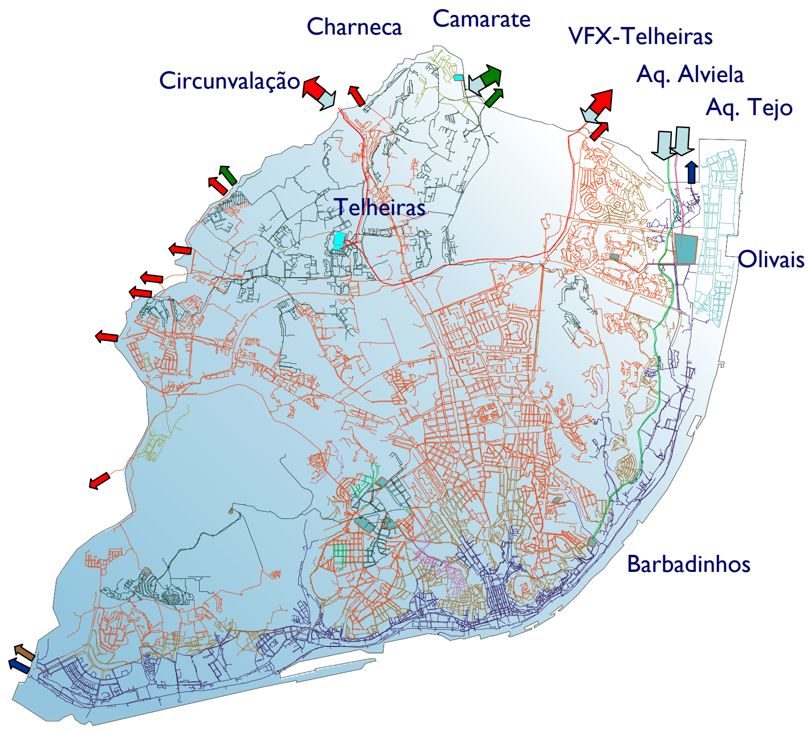


Figure 2 EPAL City of Lisbon Distribution system

NRW Situation and History

Levels of non-revenue water (NRW) have been decreasing in both divisions of the company in recent years, principally due to upgrading of key trunk mains within the production and transport division and a major project to renew and renovate the distribution network within Lisbon since 2001. The distribution network had deteriorated over recent decades due to under investment resulting in a significant backlog of renovation and replacement work being required. In both divisions, more rigorous monitoring of system inputs have been deployed, although still lacking in several key areas. Various projects and initiatives regarding leakage and NRW reduction have been undertaken over the last 15 years, none of which have been applied globally within the company or with lasting impact.

The principal scheme regarding leakage has been the enhanced network renewal and rehabilitation program, a costly, intrusive and disruptive technique for any company to undertake, especially in a city as complex as Lisbon. Over a quarter of the distribution network, 315 kilometres, has been renewed, bringing significant gains in terms of burst frequency (figure 3) leakage reduction and service reliability. Additional benefits have included the location of un-metered and illegal consumption points thus improving apparent losses, correction and validation of the GIS database and refurbishment of customer service connections. However, with each renovation project undertaken, it becomes increasing necessary to target future interventions more specifically with greater attention given to network performance as opposed to more simple indicators such as mains age or material.

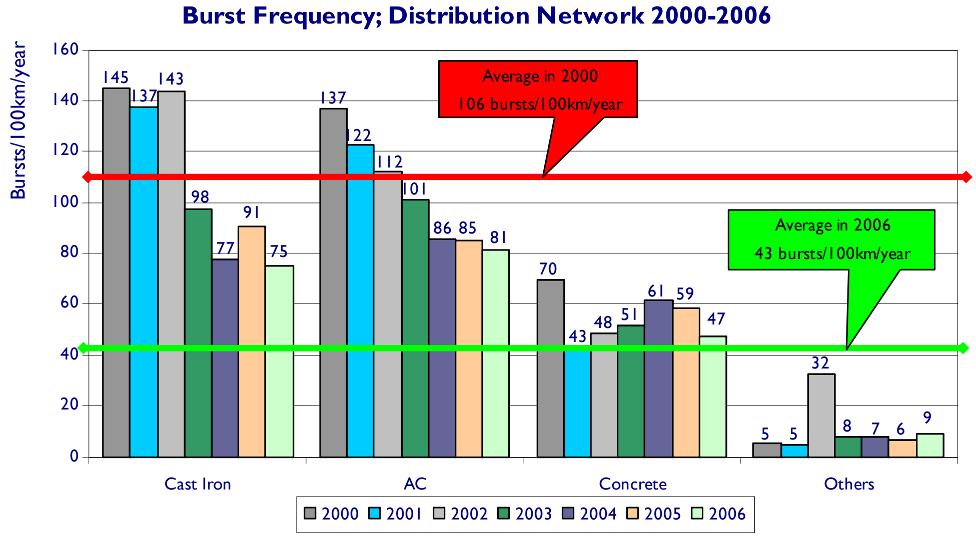


Figure 3 Reduction of Burst Frequency in EPAL Distribution Network

Despite these initiatives, NRW levels are considered to be above the socio-economic, environmental and technical acceptable limit. In 2006, losses in the production and transport system were 10million m^3 from an input of 163 million m^3, whilst the distribution network returned NRW values of 23.4million m^3 from an input of 116.1 million m^3 during the same year, losses having been reduced from 39.8 million m^3 during the previous six years. The company is a practitioner of IWA methodologies using the water balance, ILI and performance indicators; hence the ILI for the distribution system has been calculated on an annual basis over recent years. For 2006, this was 7.8, although the quality of this value may be questioned given the lack of suitable data to verify the division of real and apparent losses.

The trend of reducing water losses has to be considered alongside the fact that customer demand dropped in 2005 for the first time in the 137 years. The reduction occurred across all customer categories with municipal clients increasingly relying on their own sources, whilst industrial and domestic demand has diminished because of several factors. These include greater awareness of environmental issues following severe droughts in 2003 and 2005, a continuing reduction in the resident population of Lisbon, poor performance by the national economy affecting industrial users with all consumers wishing to reduce water bill expenditure. Whilst EPAL itself continues to maintain a strong financial position, the trend of reducing demand has been sustained into 2007 and is expected to continue. Whilst regulatory pressure to reduce water losses has yet to impact significantly, the situation is expected to change over coming years. IRAR, the Portuguese governmental regulator, is implementing an extraction tax on all water sources along with more demanding reporting and performance target setting. Thus, reducing NRW was identified as a key target by the Board as part of maintaining the short-term financial stability of the company as well as longer-term investment and renewal programmes.

Monitoring & Control Group; GMC

Against this background, the Monitoring and Control Group (GMC) was initiated in autumn 2005, aimed at improving network monitoring, control and reduction of water losses and integrate existing monitoring projects. As NRW has been reduced, it has become harder to target individual areas and specific reasons for water losses; hence the need to evolve existing practices. A four-year action plan was presented to the Board in January 2006 with overall objectives to improve monitoring and control systems, increase effectiveness of existing initiatives and introduce more responsive and accurate evaluation of network performance as regards real losses and apparent losses quantification. The target is to reduce NRW to best practice levels by the end of 2009. For the Production and Transport system, the objective is to reduce NRW by half from 11 million m^3 whilst the target within the Distribution network is 15 million m^3 from 26.6 million m^3. A project is underway to define the Economic Level of Leakage (ELL) for both systems and the overall company, which may result in these objects being revised.

The philosophy of the project is to implement the basic four principles of leakage reduction as outlined by the IWA, through a combination of enhanced pro-active leakage control, improved monitoring, reaction and repair times, more precise asset management and network rehabilitation, exploiting pressure management opportunities. In addition to the factors outlined in Figure 4 below, characterisation and quantification of apparent losses is an imperative target in order to address metering losses, illegal and unmetered consumption.

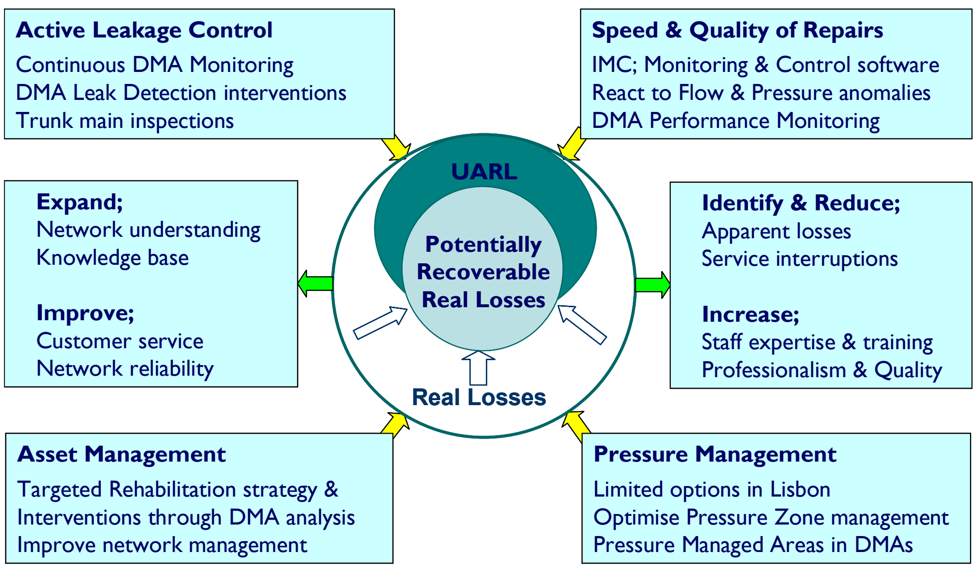


Figure 4 Applying the 4 IWA Leakage Principles at EPAL; Anticipated Inputs & Gains

Network Monitoring

Trunk Mains; Production & Transport

The principal goal within the production and transport system is to improve monitoring of flows within principal trunk main systems and company installations as at present it is not possible to statistically isolate the five principal trunk mains which supply Lisbon. This precludes an accurate water balance to be calculated for each system as the logic of the existing SCADA control system is directed towards managing reserves and meeting demand. As a result of data analysis of current metering points, the vast majority of losses are attributed to the oldest trunk main system, Alviela, dating from the late nineteenth century. This is suspected to be largely correct based on site investigations but given the significant costs associated with renewing this trunk main, it is regarded as essential to confirm this prior to intervention work. Hence, the goal is to install additional flow monitoring points covering all input, export and inter-connection points along the systems which are currently without metering. Several additional large diameter valves are also to be installed at otherwise open inter-connection points, thus permitting regular calculation of the water balance for each trunk main system as well as treatment works and pumping depots. In addition, a pilot study involving the sub-division of the Alviela trunk main into smaller segments will also be undertaken to permit accurate assessment of each section of around 15-20kms.

A parallel initiative regarding smaller scale metering is also underway, in which the direct customer supplies from the trunk main systems will be upgraded. At present, around one-third of the 120 metering points, including all principal exports to adjacent councils and distribution systems with significant flow volumes are included in the SCADA system with electro-magnetic meters. The remaining points are monitored using mechanical meters without any remote data logging as consumption volumes in what are largely rural locations do not warrant the significant investment required if the SCADA system was extended. As a result, a programme to install passive telemetry on existing meters to characterise the flow profile at these locations is underway, after which an upgrade to electromagnetic meters is scheduled for 2007/08, being expected to bring benefits in terms of more accurate metering and network performance. As a result of the 30 telemetry systems installed to date, it has been possible to improve response times in cases of meter problem or supply anomalies.

Included in the project is the installation of additional metering at company sites, 80% of which are not at present monitored and various locations at which the company is obliged to provide free public water supplies under historic agreements. Where metering is not present at these locations, it is being installed along with passive telemetry, if volumes are deemed sufficient. These projects are expected to bring two advantages, namely, whilst consumption cannot be billed, it may be accounted for and eliminated from real loss analysis. In addition, greater accountability will be required from those responsible for company sites as regards water use and efficiency whilst initiatives have already been implemented to reduce usage at the public water supply points by installing pressure reduction equipment.

DMA Implementation

Within Lisbon the primary activity is the creation of permanent DMA monitoring and associated telemetry systems in order to improve network understanding, evaluation and control. Whilst DMAs have existed within the city for several years, these have been implemented for temporary leakage detection campaigns, with the only permanent zonal monitoring being the five pressures zones, one of which encompasses almost half the distribution network. With such large zones, there are simply too many factors influencing network performance with normal fluctuations masking anomalies and their causes, thus it has not possible to characterise NRW into real and apparent losses.

During initial analysis, DMA implementation objectives were defined as having pressure and flow monitored at 15 minute intervals at each entrance or exit point with data available on the desktop of key users daily, with the integrity of the locked-in DMA verified using a pressure zero test. Furthermore, data from large user and automatic meter reading telemetry systems integrated along with data from the SCADA system with the DMA entity fully included in GIS and client databases. The optimal DMA size was defined as between 1,500 and 3,000 clients with 5,000 the maximum permitted, given that compulsory client metering exists in Portugal, with a network length of between 5 and 10 kilometers.

Given the distribution network complexity, it has been decided to phase-in creation of DMAs, with ‘naturally closed’ zones being the first to be implemented and serving as prototypes for implementation and maintenance work procedures as well as IT systems and data management. An initial group of 22 natural DMAs were identified, these being distinct zones with a single entrance point and either no boundary valves or existing closed pressure zone boundary valves. The objective for selecting these DMAs was to define documentation and procedures for DMA implementation, install and test monitoring, metering and telemetry equipment, train staff on new equipment and procedures permitting the identification of process or equipment deficiencies as well as planning of ALC interventions. A further group of 21 DMAs with a maximum of four boundary valves to be closed were also selected in the initial project, from which the objective was to achieve 35 DMAs in 2006. By using simpler zones as pilot projects, the risk and impact on network operations was minimised, whilst permitting suitable analysis and planning tools to be developed prior to expanding DMA implementation into more complex areas of the network.

Evolution of temporary ‘campaign DMA’ designs included a review of existing designs using Epanet to validate DMA layout and hydraulic performance, installation of more district meters where required and permanent flow and pressure monitoring via telemetry. A parallel GIS system upgrade and database review has provided a further tool for planning and evaluating DMA implementation. During this period, DMA Implementation Projects were developed including analysis and review of existing boundaries and equipment; collation and analyse of DMA network and client data and documentation preparation for approval by Network Operations. This was followed by DMA *lock-in* with real-time monitoring at critical points, post-implementation analysis and subsequent active leakage control interventions. As existing metering points were to be utilised wherever possible, the installation of pressure management was not included in initial phases. In addition, the majority of the distribution system is pumped and the existing pressure boundaries provide a significant pressure management tool with little potential for expansion. Indeed, only three DMAs with pressure reducing valves (PRVs) at the entrance points exist, hence the optimisation of these installations was included in the process. Analysis of dividing DMAs in pressure managed sub-zones being deferred for the post-implementation phase of DMA analysis.

This process continued into 2007 with more complex areas of the network being selected for segmentation using DMAs thus expanding DMA coverage to over 60% of the network, with a target of 75 DMAs from the anticipated total of around 125 required. Included in the target areas were DMA requiring works such as meter chamber construction or small network interventions to permit DMA implementation. The continuing integration of DMAs in existing management systems was aligned with the start of using DMA performance ranking to plan interventions as regards network rehabilitation, ALC and apparent losses.

DMA Analysis

Following successful implementation, a second level of DMA characterisation and analysis is being undertaken resulting in DMA Reference Manuals, the objective being to provide dynamic documentation of DMA status. The first section of the document is aimed at providing an easy reference, principally for network operations and maintenance staff in which the DMA entity is identified and defined including key elements such as meters, boundary valves, pressure management, mains materials and clients. An in-depth analysis of consumption and pressure profiles is undertaken with monitoring of pressure at maximum, minimum and average points. Secondly, an analysis of DMA performance and ranking is undertaken during which key performance indicators (KPIs) are identified including quantification and characterisation of leakage performance, the IWA Water Balance, UARL, ILI and Nightline analysis. This latter section is thus aimed at providing a ‘flash’ of network performance during the analysis period, leading to recommendations for future actions such as ALC interventions, apparent loss audits including client database verification and metering analysis, pressure management options, network rehabilitation or other intervention works.

Initial Reference Manuals have been used to develop and refine the documentation itself as well as the production process, relating to availability and quality of data from the GIS and client database systems as well on-site field monitoring and data collection procedures. Future steps will include simplifying and automating the analysis process as much as possible to reduce the workload, whilst continuing to refine data standards, interpretation of indicators and expanding the remit into water quality and additional pressure management.

The other key tool developed by the company is the DMA data management software program known as iMC; Integration, Monitoring & Control. The basic aim is to integrate network monitoring data into a single, easily utilizable system and accessible via the company intranet. The data is sourced from the SCADA system as well as DMA, large user and pilot automatic meter reading telemetry networks. This is seen as an essential tool for more network management and Active Leakage Control with daily updates and alarms presented on a simple desktop interface with basic statistics and graphics including Net and Gross DMA daily total and nightline, pressure variations, Minimum Hour Running Mean calculation (based on 15 minute interval data), 'Leakiness' indicator (% minimum hour/average hour), 28 day Running Mean analysis for daily total and nightline consumption as well as alarms for flow and pressure anomalies. The longer-term aim of the iMC software is to evolve the system into a true decision support tool (DST) from which the need and priority for any type of network intervention can be identified. To date, the requirement to develop the system itself has been a priority along with integrating use of the analytical tools available in existing network operations, maintenance and leak detection teams including staff training and alteration of procedures where necessary.

NRW and Leak Detection

Trunk Mains Leak Detection

Given the longer time-scale scale of the Production & Transport macro-metering project (3 years to 2008) and a similar lack of concise metering within Distribution network trunk mains, a pilot project was undertaken using the Sahara leak detection system. A selection of 23 kilometres of mains of 600mm and larger were selected, based on age, material, burst history, strategic importance, known current condition and potential requirement for rehabilitation. As the project was seen as a trial and no similar inspections of the mains had ever been undertaken, the use and adaptation of existing access points where possible was a major consideration as regards site selection to minimise overall expenditure. Site analysis commenced during September 2006 with access point works completed at 28 locations by February 2007, allowing the planned inspections during March 2007.

The results of the inspections were very encouraging, with a total of 25 leaks of varying sizes detected, several being categorised as large and mostly being unreported bursts at locations at which surface water was not present. Repairs were undertaken at all sites irrespective of leak size category on a rolling programme following the project over three months, with some sites being restricted due to access issues. The repair period coincided with the seasonal rise in temperatures and thus, network consumption, hence accurate quantification of gains has not been possible, however, both overall non-revenue water during subsequent months and analysis of predicted versus actual daily pressure zone consumption, indicate gains of around 5,000 m^3 per day. Based on this project, a similar exercise is planned for 2008 with the aim of inspecting trunk mains which are not expected to be included in the rehabilitation program but on which leaks are known or suspected.

Distribution Network Leak Detection

To date, the project has concentrated on implementing continuous monitoring through the introduction of DMAs; however this has been accompanied by acquisition of new leak detection equipment, staff training and changes to working practices. Productivity of the leak detection team is required to rise and be strengthened as they are able to dedicate more time to active leakage detection as opposed to setting up of temporary DMAs as was previously employed. However, this process has required a review of staff training and intervention methodologies to make best use of new analytical tools available, principally iMC software.

The strategy being applied is one of *Localise-Locate-Pinpoint* in which the targeting of leaks is undertaken in three distinct steps. Using DMA data, a systematic analysis and characterisation of each area is undertaken to *localise* priority areas, the objective being to identify levels of losses within each zone, from which the ranking and requirement for a leakage sweep is defined. This is followed by a L*ift & Shift* operation using correlating acoustics loggers, which are deployed in the target area for a period of 48-hours, or step testing in addition to more traditional valve tapping. Based on this analysis, individual leaks are *located* using a traditional mid-range correlator, after which the leak position is *pinpointed* using a ground microphone and reported to the maintenance section to undertake repairs. This is repeated if necessary based on the size of the DMA to ensure that the entire zone is covered. Once all reported leaks from the initial analysis have been repaired in the first cycle of *Find & Fix*, the process of deploying the acoustic loggers is repeated a second time to verify the repairs and identify further leaks which may have been hidden in the initial sweep. Following any further repairs, a final sweep with the acoustic loggers is undertaken to verify the area if the intervention exit nightline values have been met.

Apparent Losses

With greater accuracy as regards DMA monitoring, a renewed force against apparent losses is being undertaken with quantification of real versus apparent losses on a DMA level being the first stage. Based on this analysis, priority areas for apparent loss intervention campaigns are being defined, the requirement being to audit a DMA to ensure all consumption points are included in the GIS and client database system, eliminating illegal connections and substituting inaccurate or damaged meters. In parallel, a project to review the GIS database including customer connections and meters is underway to reduce the number of fraudulent connections, unbilled consumption points and improve GIS data quality. Aligned with this initiative is a project to quantify internal company consumption as 80% of company premises do not have metered supplies. There are various gains associated with this project, such as reducing the impact of unbilled water on water balance calculations, identifying leaks within company sites and creating pressure on site managers to reduce water usage. Within the distribution network, a priority list of large users has been identified and a project to install telemetry in up to 650 users is underway, this being aligned with DMA implementation as several instances of large users having a major impact on DMA analysis have been identified, thus precluding rigorous analysis of DMA performance.

Successes and Challenges

The project has undoubtedly brought a range of benefits to EPAL, although much remains to be resolved. Important gains are the 'Buy-in' to the concept of network management and assessment using DMAs, definition of key procedures and documentation, improvements in staff training and awareness, a revised network rehabilitation strategy based on DMAs as well as other factors. The new monitoring equipment and iMC software is detecting new bursts, contributing to a reduction of monthly distribution losses of 400,000m3 less than 2006. These gains being due to the cumulative effect of all projects relating to network performance, but now EPAL is able to quantify and maintain gains obtained from the rehabilitation program.

The challenges presented in the EPAL network are extensive, but the methods and technology required to combat main issues have been proven globally and the task facing the GMC is to continue to interpret existing research and practical experiences from elsewhere and apply them systematically, reliably and credibly. The project has to be viewed as a long-term policy decision by the management board, based on the rigorous application of network monitoring and assessment from which control and reduction of NRW will result. Whilst the approaches being adopted and implemented may not be at the global cutting edge of innovation and development, the objective of this case study is to highlight the key strategic plan, the technical and analytical systems being deployed and the practical difficulties and constraints encountered by the project to date. Not all of these relate to technical problems, with structural organisation, delegation of tasks as well as staff attitudes and philosophy notable as key issues currently being addressed as the project evolves.

The next stages are to improve DMA analysis, reinforce Active Leak Control resources, techniques and equipment provision including the trunk main metering scheme along with a review of data used in DMA Reference Manuals including ILI calculations and apparent losses estimates. A re-alignment of meter reading circuits with DMA boundaries is required along with definition of a DMA Apparent losses audit process and linking of GIS, client billing systems and monitoring systems. In general, EPAL needs to maintain the rhythm of expanding monitoring systems whilst setting and achieving targets for NRW reduction per DMA and trunk mains. Quantification of real and apparent 'gains' is required to justify further investments along with calculation of the ELL to define future targets and acceptable standards. It is important for the company to propagate a culture of greater awareness and attention to leakage and whilst the proposals are not rocket science, they have been proven globally and EPAL is no different in that respect. The goal of EPAL is to become an international best-practice example for a large multi-facet company, able to provide experienced consultancy on a national and global level, building on the already excellent reputation which the company enjoys.

References

FARLEY, M. (2001) Leakage management and control – A Best Practice Training Manual. World Health Organization, Geneva, Switzerland

LAMBERT, A. and HIRNER, W. (2000) The Blue Pages – the IWA information source on drinking water issues. IWA – International Water Association.

IWA Water Loss Task Force (2004) Water 21 series – Practical Approaches to Water Loss Reduction
IWA - International Water Association.

FARLEY, M. and TROW, S. (2000) Losses in Water Distribution Networks: A Practitioners' Guide to Assessment, Monitoring and Control. IWA – International Water Association

Pressure management extends infrastructure life and reduces unnecessary energy costs

J. Thornton*, Thornton International Ltd, Rua Arueira 370, Cond. Sausalito, Mairipora, SP 07600-000, Brazil, thornton@water-audit.com

A.O. Lambert, ILMSS Ltd, 3 Hillview Close, Llanrhos, Llandudno, North Wales, LL30 1SL, UK; allan.lambert@leakssuite.com**

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Abstract

Pressure management encompasses several approaches and has a number of important benefits; it has been referred to as *"the preventative method par excellence"* of water loss management. Whilst changes in leak flow rates and some components of consumption are now reasonably predictable (Thornton and Lambert, 2005), there has been little published data as to how improved management of excess pressures and surges can influence new break frequency of mains and services.

This paper summarises pressure: break frequency data, provided by members of the Pressure Management Team of the IWA Water Loss Task Force (WLTF), from over 100 international examples. Reductions in new break frequency are shown to be significant, typically ranging from around 25% to 90%, and averaging around 50%. The latest WLTF conceptual approach to understanding and predicting why and how such large reductions are achievable is also outlined. Several case studies are presented from Utilities where the results of pressure management implementation have been tracked and compared with the latest method of prediction. Implications for infrastructure management and energy management will be considered more fully in other future papers.

Progress since Leakage 2005

Review of Leakage 2005 papers on this topic

At the Leakage 2005 Conference two papers (Thornton & Lambert, 2005; Pearson et al, 2005) presented data on new break frequencies, on mains and/or services, *'before'* and *'after'* the introduction of pressure management. The results presented generated considerable interest, as they generally showed significant and immediate reductions in break frequency following pressure management.

In both papers, the authors – all Water Loss Task Force members - had previously agreed that the data would be analysed and presented using the provisional hypothesis that break frequency BF varies with pressure P to the power N2, i.e.

$$\text{BF varies with } P^{N2}, \text{ or } \quad BF_1/BF_0 = (P_1/P_0)^{N2}$$

as this form of equation had previously been successful in representing FAVAD relationships between pressure and leak flow rates (using an exponent N1), and pressure and consumption (using an exponent N3).

The results showed N2 exponents varying between 0.2 and 12. However, it was evident from the analyses (notably Fig 9 of Pearson et al) that the high N2 values were strongly associated with small % reductions in pressure, and low N2 values with larger reductions in pressure. This showed that the 'N2' approach for analysis and prediction of pressure: break relationships was clearly inappropriate.

Progress since Leakage 2005

Principal authors of the two papers exchanged views during early 2006, and agreed:

- that the N2 approach to analysis should be abandoned as inappropriate
- that additional *'before'* and *'after'* break data should be collected and published
- that an alternative conceptual approach, based on failures being due to a combination of factors, needed to be developed
- to advise Water Loss Task Force members, and other followers of WLTF approaches, of the change in emphasis since the Leakage 2005 conference
- that the further work should be co-ordinated and published by the pressure management team of the WLTF

The alternative conceptual approach, described in more detail in this paper, was circulated as a Power Point presentation to Water Loss Task Force members in September 2006. Additional data were collected from 110 systems in 10 countries, and in a short article in Water 21 (Thornton & Lambert, 2006) the additional data were shown in the form of Table 1, together with the message that the N2 approach had been abandoned, and an alternative conceptual approach that was being evaluated.

Since the December 2006 Water 21 article, some encouraging (but limited) further work has been done (using data from Australia, Canada, Cyprus) to see if general qualitative predictions of reductions in break frequency can be made by comparing the *'pre-pressure management'* break frequency (on mains, per 100 km/year; on services, per 1000 services per year) with the assumed frequencies for infrastructure in good condition, used in the Unavoidable Annual Real Losses (UARL) formula.

A topic of obvious interest, for Utility managers in developing countries with poor infrastructure, and high break frequencies at comparatively low pressures, is whether pressure management can be effective in reducing new break frequencies in such circumstances. Data from large loss reduction projects in Malaysia and Brazil in this paper confirm this to be the case.. Additional data from a performance based NRW reduction project in Bahamas are shown in Fanner (2007)

The suppression of surges (pressure transients) is a key issue in controlling new break frequencies, and some initial results from Philadelphia Water Department (PWD) are presented, of the effect of a PRV on suppressing surges in a pumped distribution system by the use of DMA and PRV. This effect will be studied further by the WLTF PM team and updates will be provided as further data becomes available

The Extended Data Set

An extended data set of 112 systems from 10 countries is summarised in Table 1. The following can be noted:

- *'before'* pressure (metres) ranges from 23 to 199, median is 57 and average 71
- % pressure reduction ranges from 10% to 75%, median 33%, average 37%
- % reduction in breaks ranges from 23% to 94%, median 50% , average 53%
- the data shows no significant difference between average % break reductions on mains and service connections

The data from Table 1 are also shown in Figure 1 as a plot of % reduction in pressure vs. % reduction in new break frequency, for mains and services together.

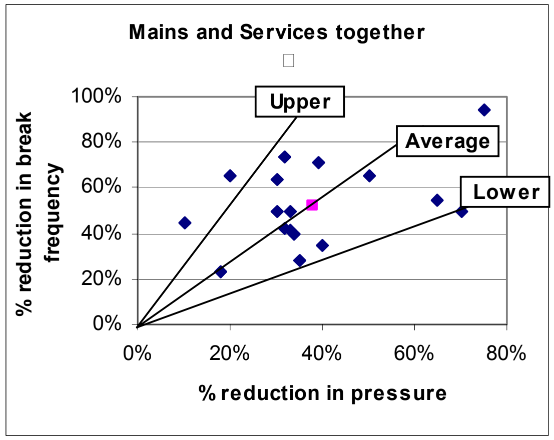
Table 1 The influence of Pressure Management on new break frequency from 112 systems in 10 countries

Country	Water Utility or System	Number of Pressure Managed Sectors in study	Assessed initial maximum pressure (metres)	Average % reduction in maximum pressure	Average % reduction in new breaks	Mains (M) or Services (S)
Australia	Brisbane	1	100	35%	28%	M,S
	Gold Coast	10	60-90	50%	60%	M
					70%	S
	Yarra Valley	4	100	30%	28%	M
Bahamas	New Providence	7	39	34%	40%	M,S
Bosnia Herzegovin	Gracanica	3	50	20%	59%	M
					72%	S
Brazil	Caesb	2	70	33%	58%	M
					24%	S
	Sabesp ROP	1	40	30%	38%	M
	Sabesp MO	1	58	65%	80%	M
					29%	S
	Sabesp MS	1	23	30%	64%	M
					64%	S
	SANASA	1	50	70%	50%	M
					50%	S
	Sanepar	7	45	30%	30%	M
					70%	S
Canada	Halifax	1	56	18%	23%	M
					23%	S
Colombia	Armenia	25	100	33%	50%	M
					50%	S
	Palmira	5	80	75%	94%	M,S
	Bogotá	2	55	30%	31%	S
Cyprus	Lemesos	7	52.5	32%	45%	M
					40%	S
England	Bristol Water	21	62	39%	25%	M
					45%	S
	United Utilities	10	47.6	32%	72%	M
					75%	S
Italy	Torino	1	69	10%	45%	M,S
	Umbra	1	130	39%	71%	M,S
USA	American Water	1	199	36%	50%	M
Total number of systems		112				
		Maximum	199	75%	94%	All data
		Minimum	23	10%	23%	All data
		Median	57	33.0%	50.0%	All data
		Average	71	38.0%	52.5%	M&S together
		Average		36.5%	48.8%	Mains only
		Average		37.1%	49.5%	Services only

A simple interpretation, likely to give generally conservative predictions, is to assume that the % reduction in new breaks = BFF x % reduction in maximum pressure, where BFF is a Break Frequency Factor, this can be checked against the data in Figure 1.

- The average value of BFF for Mains and Services together from Table 1 is 52.5%/38% = **1.4**, so a line drawn through the data in Figure 1 with a slope of 1.4 gives an 'average' prediction

Figure 1 Simple basis for predicting % reduction in breaks from % reduction in pressure



- An 'Upper' line, with a BFF of 2.8 (twice the average) encompasses all but two of the data points which give larger reduction in new break frequencies
- A 'Lower' line, with a BFF of 0.7 (half the average) encompasses all the data points which give smaller reductions in new break frequencies

The Latest Conceptual Approach

Explaining the concept

The latest conceptual approach currently being used by the Pressure Management Team of the WLTF, in attempting to develop an improved practical understanding of pressure/break frequency relationships, is shown in the following series of figures.

In Figure 2.1, the X-axis represents system pressure and the Y-axis represents failure rates. When a new system is created, mains and services are normally designed to withstand maximum pressures far greater than the range of daily and seasonal operating pressures for a system supplied by gravity. The system operates with a substantial factor of safety, and failure rates are low. Even if there are pressure transients in the system (Figure 2.2), the maximum pressures do not exceed the pressure at which increased failure rates would occur.

Figure 2.1 New system supplied by gravity operates well within design maximum pressure

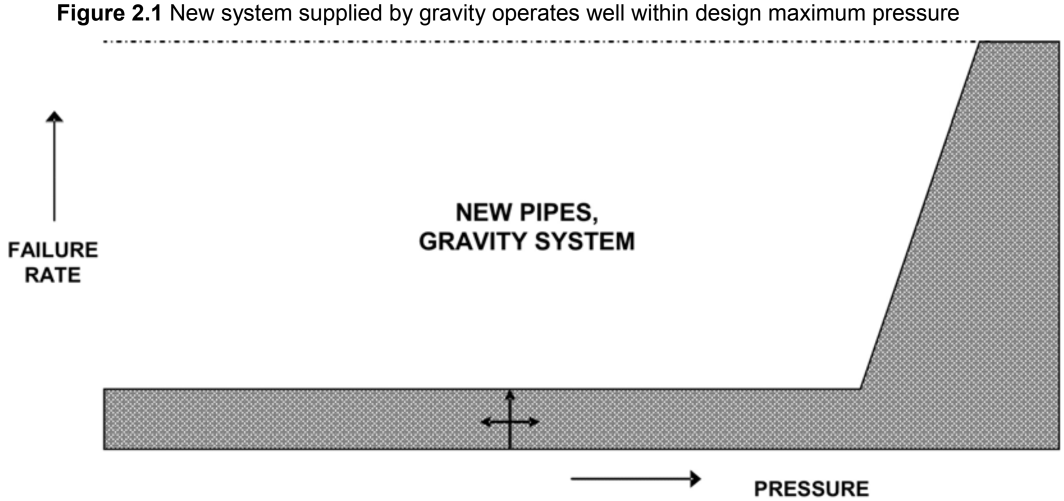
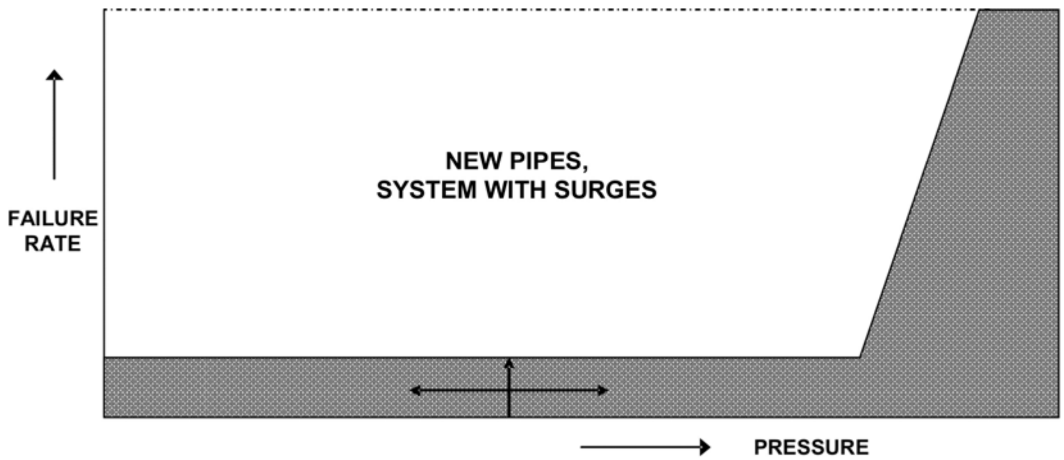
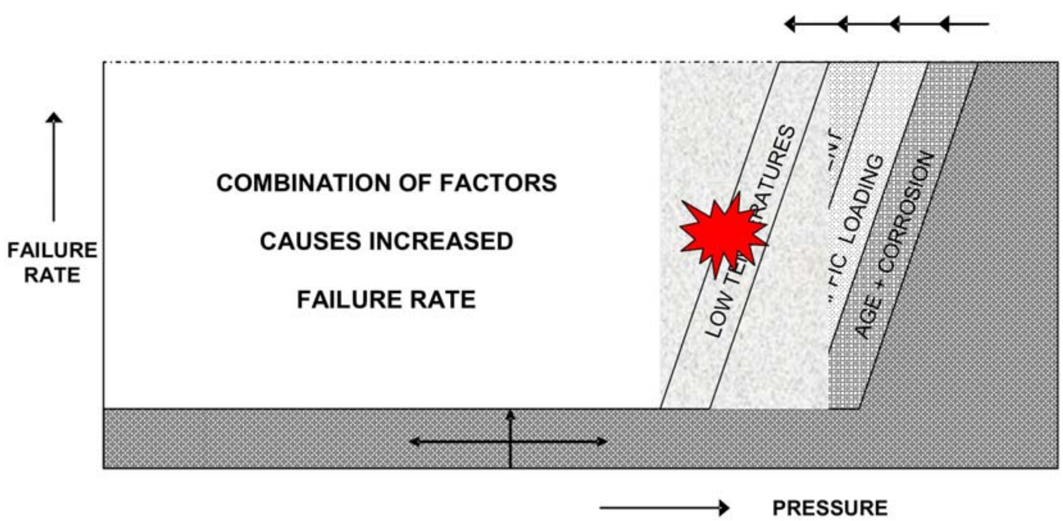


Figure 2.2 New system with surges also operates well within design maximum pressure



As the years pass, adverse factors based on age (including corrosion) gradually reduce the pressure at which the pipes will fail (Figure 2.3). Then, depending upon local factors such as traffic loading, ground movement and low temperatures (which will vary from country to country, and from system to system), at some point in time the maximum operating pressure in the pipes will interact with the adverse factors, and break frequencies will start to increase. This effect can be expected to occur earlier in systems with pressure transients or re pumping, than in systems supplied by gravity.

Figure 2.3 Combination of adverse factors (including surges) cause increased failure rates

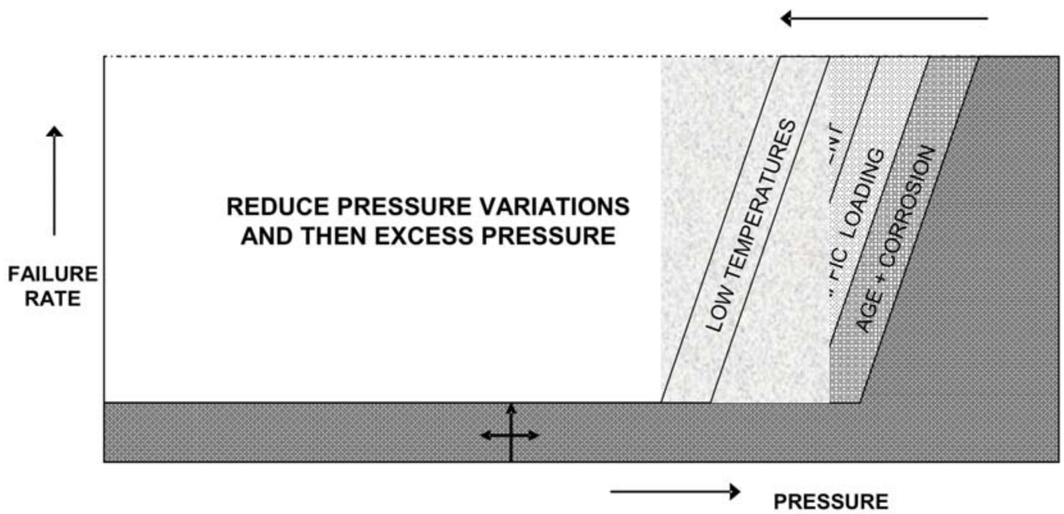


If the system is subject to surges or large variations in pressure due to changing head loss conditions, then introduction of surge control or flow or remote node pressure modulation may be expected to show a rapid significant reduction in the new break frequency. The average pressure in the system is unchanged, but the reduction of surges and large variations means that maximum pressures do not interact to the same extent with the adverse factors.

If there is excess pressure in the system at the critical point, over and above the minimum standard of service for customers, then permanent reduction of the pressure by installation of pressure management (PRV, sub-division of large Zones, etc) will move the range of operating pressures even further away from the pressure at which combinations of adverse factors would cause increased frequency of failure.

Figure 2.4) shows the effect of reducing surges and variations in pressure and then reducing excess pressure.

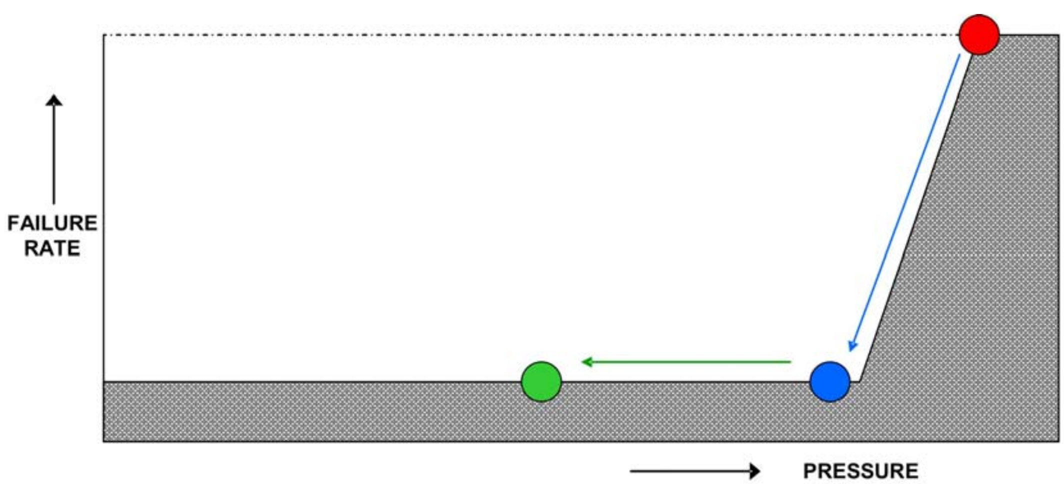
Figure 2.4 Reduction of surges and variations and reducing excess pressure limits interaction with adverse factors and increases factor of safety



A hypothesis as to why mains and/or service connections in some systems show large % reductions in new break frequency with pressure management, but in others the % reduction is only small, can be proposed using this concept.

- If, before pressure management, there is already a relatively high break frequency (Red Point in Figure 2.5), then a relatively small % reduction in pressure may cause a large % reduction in new break frequency (towards Blue Point).
- But if there is already a relatively low break frequency before pressure management (Blue Point in Figure 2.5), then any % reduction in pressure (from Blue Point to Green Point) should have little effect on new break frequency, but will create a greater factor of safety and extend the working life of the infrastructure.

Figure 2.5 % reductions in break frequency influenced by initial break frequency



The Straw that breaks the Camel's back

Some international experiences

Although some Utilities ascribe their high seasonal break frequencies to one particular cause (low temperatures, ground movement, traffic loading, corrosion etc), further investigation often seems to show that it is the occurrence of a higher pressure (added to the other adverse effects) that triggers many of the individual failures.

Most Utility engineers will have experienced situations of sudden increases in breaks when parts of their distribution system are subjected to excess pressure, due to events such as by-passing of a service reservoir, unauthorised opening of a boundary valve or PRV bypass, or a PRV failing in open mode. That pipe failures can be caused by surges from pumping or sudden valve closures is also well known, and failure rates in systems with intermittent supply have been identified as many times higher than would be expected from an equivalent system with continuous supply. There are also examples from Melbourne and in South Africa, where individual mains breaks in gravity systems have been identified as being due to operation of customers' equipment.

The interest of one of the authors in this topic was stimulated, some 10 years ago, by the casual observation of a Swiss Utility engineer to the effect that it was easy to predict when most of the breaks in his distribution system with metal pipes would occur – in the winter, overnight, when distribution pressures reached their maximum.

In Melbourne (Australia), the high seasonal peak in break frequency occurs at the time of maximum demand (in summer, around January), and has been locally attributed to ground movement, rather than any other reason. However, further investigation by a local Task Force member identified that most of the breaks actually occurred in the early hours of the morning, when system pressure was at its highest.

From the above examples, it is not surprising that identification and reduction of pressure transients and large variations, and of excess pressures, can be expected to reduce high break frequencies. So, in the case of pipe failures, to quote the famous proverb, high pressure – however brief - can often be *'the straw that breaks the camel's back'.* By identifying, reducing and avoiding surges, pressure variations and excess pressure in our distribution systems, we can influence the frequency of new breaks on mains and services. But is this general approach also effective in developing countries with high break frequency situations and relatively low pressures?

Brazil, Malaysia and Bahamas

In a recent presentation (Paracampos 2007) Francisco Paracampos reported that in the central business unit of SABESP (the water utility of Sao Paulo, Brazil) he had observed that in the 180 Zones with PRV, break frequencies on mains and services were around 10 per km/year. However, in areas not covered by PRV, break frequencies were almost double at around 19 per km/year.

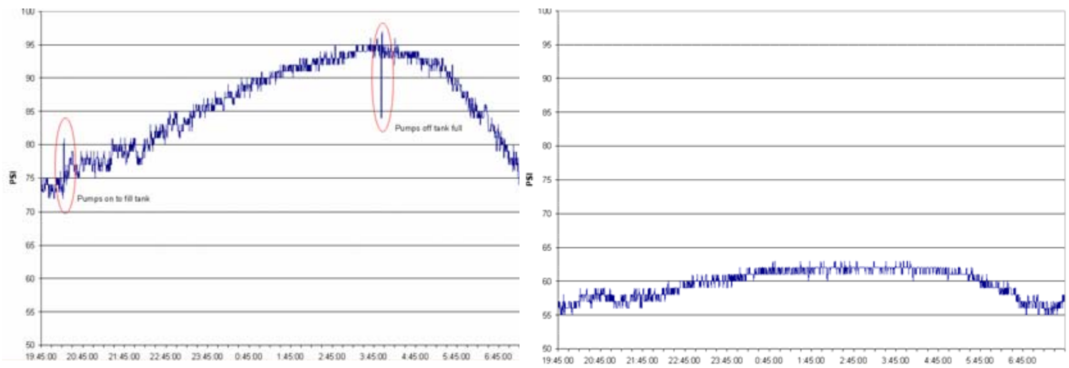
In Malaysia, in a system with high break frequencies throughout the year, SYABAS (the water utility for Selangor State) is setting up numerous pressure managed zones (PMZ). SYABAS has identified that most breaks occur at maximum pressures at night, and has recently evolved a policy of using fixed outlet pressure management to reduce new break frequency. In a sample of 34 PMZ with 224 km of mains, new mains break frequency has fallen from more than 300 per 100 km/year to 18 per 100 km/year. Although some of this data is of quite limited duration, and a longer period of comparison is needed to confirm these statistics, these results are nevertheless dramatic.

Data on changes in break frequency following pressure management, for a relatively low-pressure and high break frequency pumped system in the Bahamas, are discussed in Fanner (2007)

Influence of PRV on surges

As part of a National AWWARF research program to identify suitable methods for North American utilities to employ for sustainable water loss reduction, Philadelphia Water Department (PWD) installed a pressure managed DMA. In addition to impressive reductions in real loss volumes PWD noted that the DMA and PRV helped to damp out distribution transients caused by pumping changes (Figure 3) when a nearby water storage facility reached maximum and minimum water levels.

Figure 3 before and after control in DMA 5 shows distribution transients removed by PRV control



What are the priorities now?

Encouraging Implementation

Present knowledge of pressure/break relationships has similarities to the situation in the UK and Japan in the 1980's, when it had been clearly identified by field tests that leak flow rates in distribution systems were more sensitive to pressure than predicted by the *'square root'* relationship (flow varies with the square root of pressure). The reasons for the greater sensitivity to pressure were not understood, and research into this topic took another 15 years to reach a satisfactory practical conclusion (the FAVAD concept). However, inability to reliably predict results did not stop progressive Utilities from introducing successful pressure management schemes from 1980 onwards, with demonstrable reductions in leak flows particularly at night.

It appears to the authors that, while an increasing number of Utilities and national organisations are showing interest in the latest results of the WLTF pressure/break frequency studies, there is a reluctance to include any predictions of the financial benefits in calculations of payback period for pressure management schemes, until a reliable prediction method has evolved. This is surprising, because for most systems the short-term financial benefits of even a modest reduction in break frequency and repair costs will far exceed the financial benefit calculated only on the basis of the predicted reduction in leak flow rates, and significantly reduce the calculated pay-back periods. Also, calculations of economic leakage levels surely must now take account of the influence of pressure management (Fantozzi and Lambert, 2007)

The authors recognise that it may take years of applied research to achieve predictions of pressure/break frequency for individual systems to the same degree of accuracy that FAVAD has achieved for pressure/leak flow rates and pressure/consumption relationships. The immediate priorities are therefore:

- to provide Utilities with a quick overview calculation of the probable range of outcomes of basic pressure management for individual systems, in terms of changes in leak flow rates, break frequencies and consumption
- to attempt separate predictions of changes in break frequency of mains and services, as average costs for repairs differ significantly.

Quick Overview Calculations

The free 'CheckCalcs' software (2007) uses a simple 3-step approach (Figure 4). By entering proposed change in average pressure (increase +ve, decrease -ve), together with '% of consumption outside property', and 'Yes' or 'No' for presence of private storage tanks, the software predicts the Lower, Average and Upper % changes in leak flow rates, new break frequencies and consumption, using FAVAD concepts and Figure 1. More detailed predictions can then be made, if required, using the 'PressCalcs' software.

Figure 4 'PMOpportunities' Worksheet from free CheckCalcs software

The simple screening process shown below helps to quickly identify the probability of pressure management opportunities.	
Step 1:	**Check for presence of surges by recording sample pressures in system at 1-second intervals.**
Step 2:	**Assess probability of Pressure Management opportunities based on type of supply (gravity or pumped) and average pressure. In <u>Developed Countries</u> the assessment assumes a minimum standard of service for pressure of around 20 metres at all times. In <u>Developing Countries</u>, a lower standard of service for pressure is assumed to apply, with greater opportunities for pressure management at lower pressures.**

Enter Licensee's name when issuing software			Type of System	Average Pressure	Probability
Watertown			Gravity supply	Less than 30 metres	LOW
Average System Pressure Pav is	**50.0**	metres		30 to 39.9 metres	MODERATE
System is supplied principally by gravity with	**Continuous supply**			40 to 60 metres	MEDIUM
Using this information, and the assessment method shown in Cells G15 to M21, the probability of pressure management opportunities for this system can be provisionally categorised as	**MEDIUM**			More than 60 metres	HIGH
			Direct pumping	All	HIGH
			Intermittent Supply	All	HIGH

Step 3: Predict possible changes in leak flow rates, frequency of new bursts and repair costs, and residential consumption, for change in pressure						
Assumed change in average system pressure	-5.00	metres	**Probable range of predicted changes:**	**Lower**	**Average**	**Upper**
Assumed % change in Pav	**-10.0%**		% change in current leak flow rates	**-5%**	**-10%**	**-15%**
% of annual residential consumption outside property	**30%**		% change in new burst numbers and annual repair costs	**-7%**	**-14%**	**-28%**
Do customers have private storage tanks? (Yes/No)	**No**		% change in residential consumption	**-0.4%**	**-1.0%**	**-1.6%**

Separate Predictions of Changes in Break Frequency for Mains and Services

The authors have started to test the simple predictive approach shown in Figure 2.5, which uses the break frequencies on mains and services *'before'* pressure management to indicate whether the % reductions in break frequency are likely to be relatively low or high. The break frequencies used in the Unavoidable Annual Real Losses (UARL formula) are used as an existing WLTF *'low'* standard for comparison, these are as follows:

- for mains and private pipes, 13 breaks/100 km/year
- for services, main to property line or curb-stop, 3 breaks/1000 service cons/year

Wide Bay Water, Australia: this distribution system (19,000 services, 690 km mains) is being progressively sectorised with flow modulated pressure managed zones. Surges have been identified and suppressed. Average pressure has been reduced by 16%, from 63 to 53 metres. Previous mains break frequency was close to UARL frequency, so no significant change occurred (Points B to C on Fig 2.5). However, previous service pipe break frequency was 12 times the UARL frequency, and a substantial reduction would be expected (Points A to B on Fig 2.5), and was observed. See figures 5.1 and 5.2

Figures 5.1 and 5.2 Wide Bay Water: changes in break frequency following pressure management

Figure 5.1: Mains

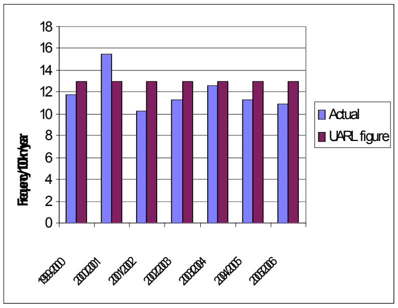
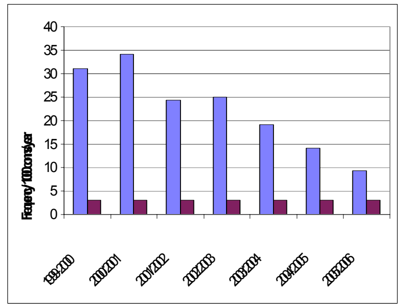


Figure 5.2: Service connections



Halifax Regional Water Commission (Canada), In the Dartmouth pressure managed zone (3158 services, 59 km of mains), fixed outlet pressure management was replaced by flow modulated pressure management. Maximum pressure (at night) was reduced by 20% from 78.9 to 64.4 metres. Mains break frequency, initially 3 times the UARL frequency, would be expected to reduce, and did, to 1.5 times the UARL frequency. In contrast, service pipe break frequencies prior to flow modulation were very low (below the UARL frequency), and showed no observable reduction in frequency as predicted.

Lemesos (Cyprus), Changes in break frequency data following establishment of smaller zones (Charalambous, 2005) were re-analysed. Initial mains break frequency was 2.7 times, and initial service break frequency 11 times, the UARL frequencies. Significant reductions in both types of breaks would be expected (and occurred) when average zone night pressure reduced by 32% from 52.5 to 38.5 metres. The actual reductions (45% and 40% respectively) were close to the average values (32% x 1.4) predicted from Fig.1.

Conclusions

Table 1 clearly demonstrates that reductions in new break frequencies following pressure management can be so substantial that they demand attention from progressive Utilities.

The conceptual approach outlined in Figures 2.1 to 2.5 appears to be broadly consistent with general international experience.

Separate predictions of changes in break frequency for mains and services, based on comparison with break frequencies used in the UARL formula, appear to be a promising approach.

It is hoped that Utilities will be encouraged by this work to implement pressure management where appropriate and report the results.

The WLTF Pressure Management team will continue to analyze data as it becomes available and publish results periodically.

Longer term implications and benefits for infrastructure management and energy management will also be future important topics for the Pressure Management Team

Acknowledgements

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References

Thornton J. and Lambert A. (2005): *"Progress in Practical Prediction of Pressure/Leakage, Pressure/Burst Frequency and Pressure/Consumption Relationships"*. Proceedings of IWA Special Conference *'Leakage 2005'* , Halifax, Canada, September 2005

Pearson D. et al (2005): *"Searching for N2: How does Pressure Reduction reduce Burst Frequency?"* Proceedings of IWA Special Conference 'Leakage 2005' , Halifax, Canada, September 2005

Thornton J. and Lambert A. (2006) *"Managing pressures to reduce new breaks"* Water 21 IWAP December 2006

Fanner P. (2007): *"Pressure management works…and doesn't!"* Proceedings of IWA Special Conference *'Water Loss 2007'*, Bucharest, Romania, September 2007

Fantozzi M. and Lambert A. (2007): *"Including the effects of Pressure Management in calculations of Economic Leakage Level"*. Proceedings of IWA Special Conference *'Water Loss 2007'*, Bucharest, Romania, September 2007

Paracampos F. (2007): *"Curbing demand in Sao Paulo through a successful water efficiency initiative"* Proceedings of Global Water Leakage Summit, London UK 2007

CheckCalcs free software: contact www.leaksuite.com or www.studiofantozzi.it 2007

Charalambous B. (2005): *"Experiences in DMA redesign at the Water Board of Lemesos"* Proceedings of IWA Special Conference *'Leakage 2005'* , Halifax, Canada, September 2005

RESEARCH ON PRESSURE-LEAKAGE RELATIONSHIP IN WATER NETWORKS OF HOUSING ESTATES

Dr Eng. Wojciech KORAL*, **

* Water and Sewage Utility, Rybnicka 47, 44-100 Gliwice, Poland, wojciech.koral@pwik.gliwice.pl

** Institute of Water and Wastewater, Silesian Technical University, Konarskiego 18, 44-100 Gliwice, Poland

wojciech.koral@polsl.pl

keywords: pressure-leakage relationship, pressure-failure relationship

Introduction

International research shows that water losses (measured as night flows) depend on pressure:

$$\frac{L_1}{L_2} = \left(\frac{P_1}{P_2}\right)^{N1}$$

where N1 = 0.5-2.5 and it depends on the type of leaks and the type of materials which system are made (Lambert at al., 2000). This formula was created for DMAs where pressure was regulated by PRV. Is it also valid for pumping stations with different ways of controlling night pressure?

Research done in Gliwice, Poland from 1994 to 2007 in six different housing estates (DMAs), supplied by local pumping stations, shows that relationship described above is weak in water network where main component of measured night flows are leaks in water supply systems inside buildings. Additionally, increasing pressure does not cause immediate increase of leakage but it leads to higher level of failure frequency of water network.

Description of the objects under research

Research was done at six housing estates (DMAs) supplied by local pumping stations:

- three of them were controlled by frequency converter (i.e. pumping station ‘W’)
- one (‘J’) was controlled by frequency converter with additional PRV to reduce and to stabilize night pressure
- one was controlled by pressure switch (to stabilize the minimal pressure)
- the last one was a classic hydrophore supplied from a tank with free surface of water.

Flow chart of pumping stations (‘W’, ‘J’) was shown at **Figure 1**.

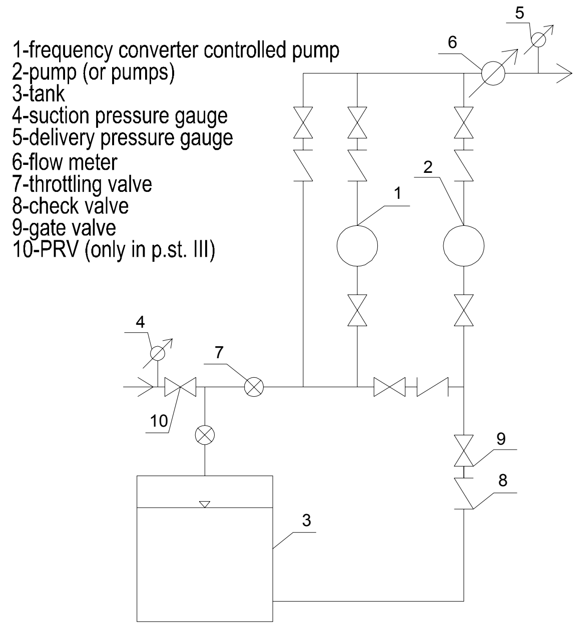

Figure 1. Configuration of pumping stations

Supplied housing estates consisted of a different buildings (from three to twelve storeys). The system of preparing warm water was diversified:

- in two housing estates warm water was prepared by local gas heaters (LCWU),
- in other housing estates warm water was prepared by central stations, supplied by pumping stations (CCWU).

Water network ‘W’ was made of steel, other networks were diversified (steel, PVC, PE80, PE100).

Paper shows results of research done in pumping stations ‘W’, ‘J’ and ‘B’. The details of the research were described in doctoral thesis of the author (Koral, 2005).

Methodology

There were three criteria of selecting the housing estates for research:

- at housing estate ‘W’ there was the high value of night flows
- at housing estates ‘J’ night pressure was high (up to 6.0 bar) and unstable
- at housing estates ‘B’ pressure changed in cycle from 3.8 to 6.0 bar (hydrophore)

Pressure and flows were measured every two minutes only at working days between 2:00 and 4:00 a.m. since 1998 (pumping stations ‘W’ and ‘J’). At pumping station ‘B’ pressure and flows were measured every second during two months (2003). Flows were measured by electromagnetic flow meters.

Time series, descriptive statistics (average, standard deviation and correlation) were made for night flows and pressure. Additionally, unitary usage per day, per a supplied flat and meter of water pressure was calculated.

Research on pressure-leakage relationship in water networks of housing estates (2000-2007)

Water balance in selected DMAs

As the first step (according to IWA best practice) a balance of water usage was done at selected areas. Additionally, in the balance, water looses were compared with average night flows to find out how much of them are real losses and leakage inside the buildings.

That division helps to make economical decision about looking for failures.

Table 2 shows sample water balance for DMA 'W'.

Table 2. Water balance for DMA 'W'.

Year	Water input [m^3/d]	Water sold [m^3/d]	Losses – real leaks [m^3/h]	Night flows [m^3/h]	Leaks in buildings [m^3/h]
1998	944	706	9,94	13,23	3,29
1999	873	648	9,40	13,71	4,31
2000	833	599	9,77	13,92	4,15
2001	737	568	7,03	11,09	4,06
2002	530	537		4,07	4,07
2003	475	477		3,84	3,84
2004	481	455	1,08	3,72	2,64
2005	497	424	3,04	5,30	2,26
2006	524	403	5,04	7,03	1,99
2007	507	392	4,79	6,69	1,90

The water balance shows that main component of night flows during years 2002-2004 was leakage inside buildings (usually leaks from toilet tanks). During other years real losses was connected with failure of water network.

Descriptive statistics for selected DMAs

The next step after preparing the balance was a calculation of basic descriptive statistics of night: pressure and flows. Coefficients were calculated for all DMAs and years of measurement. Sample coefficient for DMA 'W' shows Table 3.

Table 3. Statistic coefficient for DMA 'W'.

Year	Night pressure [bar]		Night flows [m^3/h]		Correlation
	average	st. dev.	average	st. dev.	
2000	3,49	0,10	13,92	1,43	0,57
2001	3,74	0,29	11,09	4,62	-0,01
2002	3,91	0,25	4,07	0,85	0,03
2003	3,63	0,31	3,84	1,76	0,22
2004	3,54	0,26	3,72	0,46	0,32
2005	3,43	0,17	5,30	0,88	-0,43
2006	3,41	0,21	7,03	0,97	0,22
2007	3,41	0,20	6,69	0,84	0,03

Results of research show that if the basic component of water losses are failures, correlation coefficient is statistically significant. During other years, relation of pressure-leakage was weak, because leaks from toilet tanks are not pressure sensitive.

Frequency polygons of night: pressure and flows

The third step of analysis was preparing a frequency polygons of night: pressure and flows for every two minutes measurement. Sample polygons for DMA 'W' are shown at Figure 2 and Figure 3.

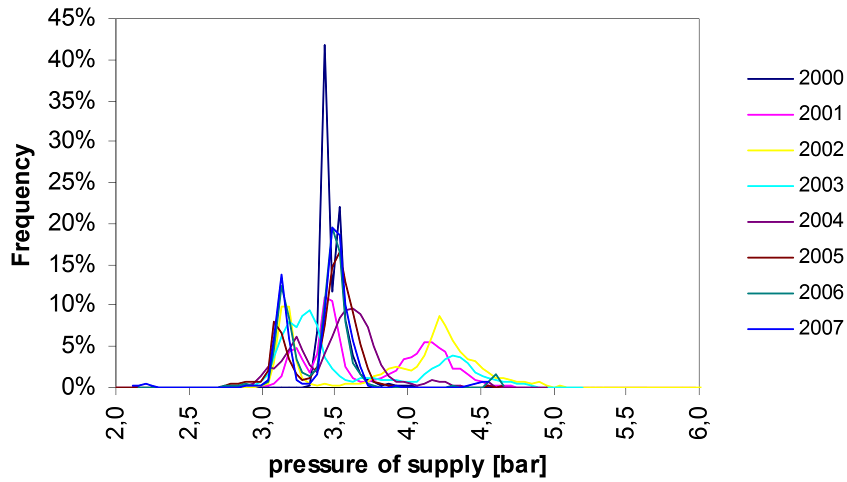

Figure 2. Density curve of pressure for pumping station 'W' (2000-2007)

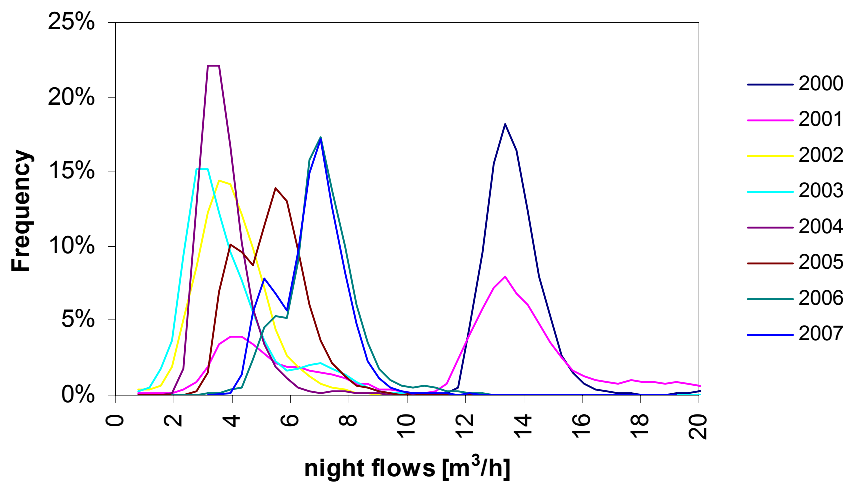

Figure 3. Density curve of night flows for pumping station 'W' (2000-2007)

Results show that if pumps do not work at night, frequency polygons are irregular and multimode. Density curves of night flows are multimode for DMAs where water network was repaired or with new failure.

Additionally, mode value of night flows decreases every year but this phenomenon is not a result of change of pressure. Ten years of research leads us to the conclusion that decrease in leakage results from increasing number of individual water meters installed inside multifamiliar buildings, which is connected with growing price of water (descending value of leaks in water supply system, Table 3).

Time series analysis of night: pressure and flows

Analysis of descriptive statistics and frequency polygons shows that stability of night pressure and flows was diversified (different values of standard deviation, Table 3). To show that variability time series of night pressure and flows were drawn (Figure 4, colours are connected with years of measurement, upper line – pressure, down – flows).

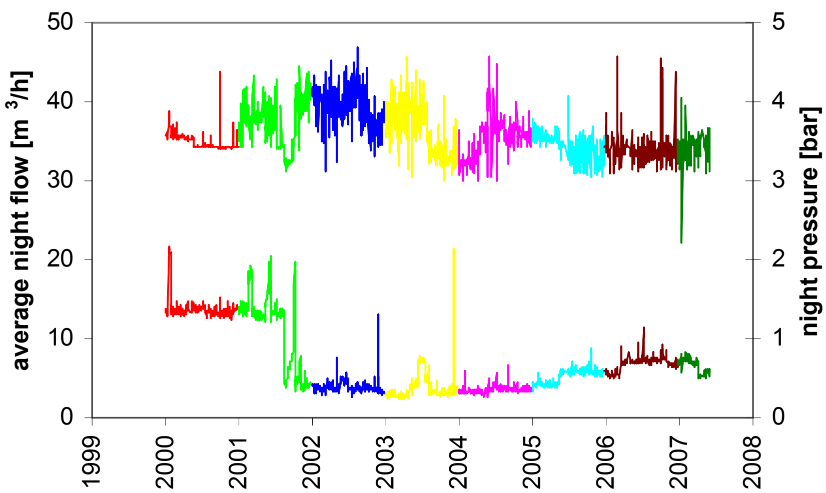

Figure 4. Time series of average pressure and night flows for DMA 'W'

Time series confirm conclusion about weak pressure-leakage relationship, especially for years 2002-2004 – change of 0.5-1.0 bar does not influence value of night flows.

Analysis of unitary leakage (2000-2007)

Analysis of time series and structure of night flows leads us to the conclusion that comparing different DMAs is ineffective. Using ILI or unitary coefficient (dm^3/conn*d) is useful if the main component of leakage is real losses, not leaks inside buildings. Because of that the author uses another unitary coefficient of leakage – dm^3/*d *flat and per m H_2O of pressure supplying DMAs.

Moreover, that unitary coefficient is very useful for identifying buildings with potential leaks in water supply system and it helps estimate possible apparent losses.

Sample of time series of unitary leakage shows Figure 5.

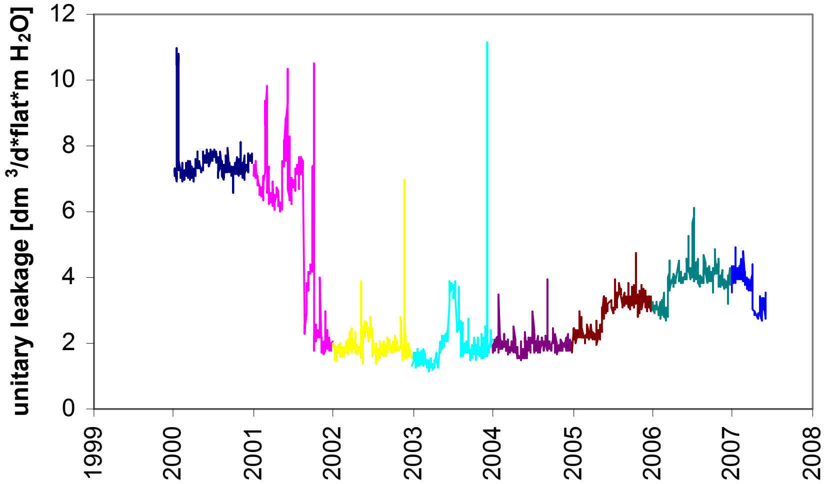

Figure 5. Unitary water losses - DMA ‘W’ (2000-2007)

Coefficient of unitary leakage helps to isolate atypical situation: flushing of network (November 2002), a break of main (December 2003) or connections (2005 and 2006). Additionally, its variability shows type of failure – break (2004) or corrosion (September 2001).

Research on influence of reduction and stabilisation of night pressure (by using PRV) on value of leakage

Values of night pressure (measured since 1998 to 2000 in DMA ‘J’) were high - up 4.9 bar and unstable - variation up to 1.0 bar. It lets check pressure-leakage relationship (IWA ‘blue pages’, 2000) for DMA where the basic component of night flows was leaks in water supply system inside buildings. The research was done from May to December 2001.

Results show that reduction and stabilisation of pressure (done by PRV) had weak influence on night flows and their stability – before and after PRV installation variation of flows was up to 2.0 m^3/h and pressure-leakage relationship was weak (Figure 6).

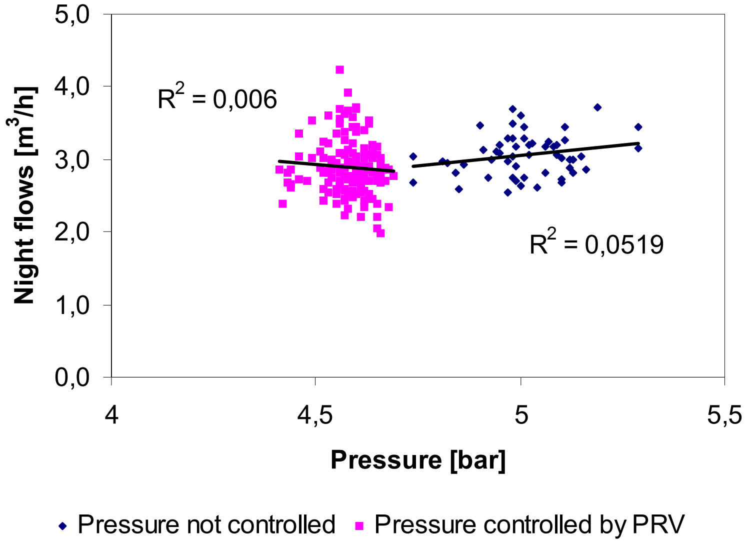

Figure 6. Pressure - night flows relationship for pumping station "J" (May- December 2001)

Unfortunately a small reduction of night flows caused increase of apparent losses – values of leakage in water supply systems decreased under starting flow of some water meters.

Research on local hydrophore

Results of time series of pressure supplying DMAs (with no pressure control) show their instability. For this reason supplementary research of DMAs supplied by hydrophore was done. Pressure value changed in cycles from 3.8 to 6.0 bar. Pumps were supplied from tank with free surface.

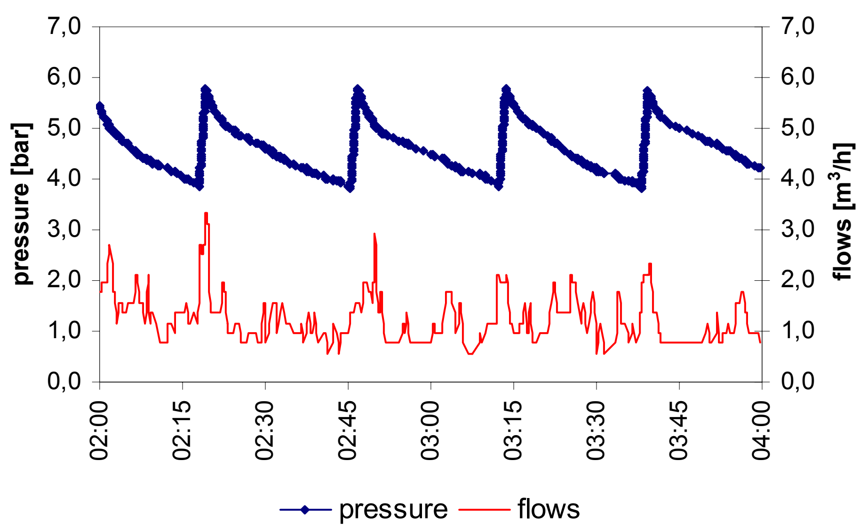

Figure 7. Time series of pressure and night flows for DMA ‘B’

Frequency curve of night flows has negative skewness which indicates value of leakage about 0.8-1.0 m^3/h, connected with leaks inside buildings. Time series of night pressure and flows suggest that value of pressure has influence on leakage (Figure 7) but this relationship is weak statistically (Figure 8).

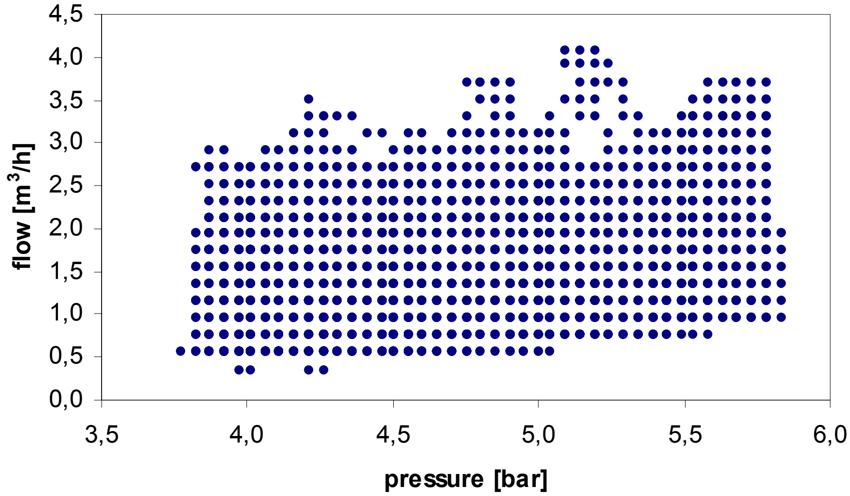

Figure 8. Pressure - night flows relationship for pumping station "B"

Research on changes of pressure profile on value of leaks

Configuration of pumping stations let us ask: what happens if we change the profile of pressure from controlled by flows to constant. Sample of that change shows Figure 9.

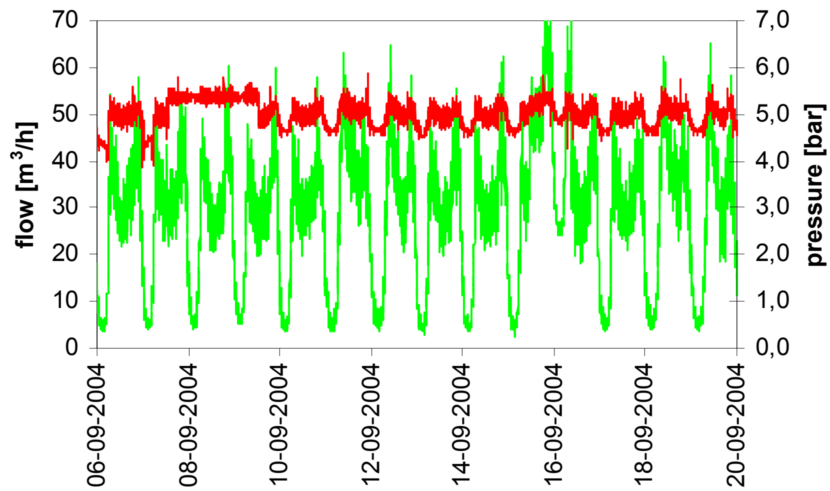

Figure 9. Change of pressure profile – long time failure (DMA 'G')

In each case after change of pressure profile a new failure took place after three to ten days, usually in warm water network. Because of failures those trials were stopped after the third time.

It was different after failure of PRV - after four hours six new failures appeared at supplied DMA 'S' (minimal flows increased from 25 to 70 m^3/h), in spite of relatively small growth of pressure (from 4.2 to 5.0 bar). Results show Figure 10.

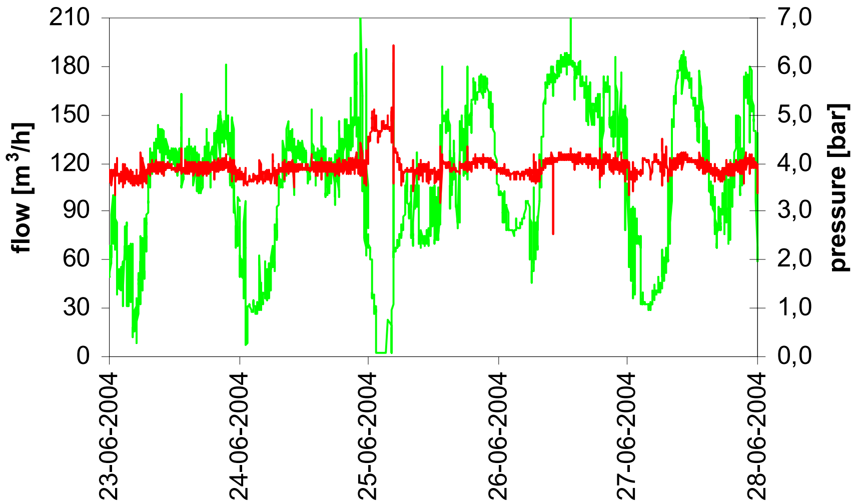

Figure 10. Change of pressure profile – short time of appearing of new failures

For this reason pressure is controlled by flows (to compensate hydraulic losses) in every local pumping station supplying housing estates in Water and Wastewater Utility in Gliwice.

Summary

Results of research show that in DMAs where the main component of night flows is leakage in water supply systems (input and sold water is balanced) the pressure-leakage relationship is weak and changes of pressure do not increase flows but they usually cause new failures.

Bibliography

Bragalli Ch., Sacchi S (2002).: Burst frequency and leakage related to pressure control in water distribution network, 'Leakage management – practical approach', Cyprus 2002

Koral W. (2005): Influence of methods of controlling pressure on leakage in water networks, doctoral thesis, Gliwice (in Polish)

Lambert A. O.,Hirner W. (2000): Losses from water supply systems. Standard terminology and recommended performance measures. IWA Blue Pages, www.iwahq.org

Lambert A., Brown T.G., Takizawa M., Weimer D. (1999): A review of Performance Indicators for real losses from water supply systems Journal of Water Supply: Research & Technology - AQUA, December 1999.

Lambert A. (2001): What do we know about pressure-leakage relationships in distribution systems?, IWA conference 'System approach to leakage control and water distribution system management', Brno 2001

McKenzie R. (2002): Leakage reduction through pressure management in the Great Johannesburg area, IWA conference 'Leakage management – practical approach', Cyprus 2002

Pearson D., Fantozzi M., Soares D., Waldron T. (2005): Searching for N2: How does pressure reduction reduce burst frequency? 'Leakage 2005', Halifax 2005

Thornton J., Lambert A. (2005): Progress in practical prediction of pressure-leakage, pressure-burst frequency and pressure-consumption relationships, 'Leakage 2005', Halifax 2005

A closer look at measured night flows in sectorised networks

R P Warren*

*Tynemarch Systems Engineering Ltd, Crossways House, 54-60 South Street, Dorking, Surrey, RH4 2HQ, UK, www.tynemarch.co.uk

rwarren@tynemarch.co.uk

Keywords: night leakage; customer use; UK

Introduction

In many countries various forms of network sectorisation are established and can deliver significant benefits in saving leakage and many other benefits such as understanding network demands and providing opportunities for pressure management. Sectors may be of any size but the most common implementation is the District Metered Area (DMA), typically a few hundred to a few thousand properties.

This paper looks at some of the benefits and issues associated with sectorisation, in particular the limitations of the approach as the sector sizes become smaller and leakage levels are reduced. Some new approaches to separating customer night consumption from the measured night flows are also considered.

This paper is partly based on recent research on separation of leakage from night flows that was funded by UK Water Industry Research Ltd (UKWIR).

UKWIR study

The UKWIR study was part of an ongoing programme of research across all areas of the water industry. The main study objective was to identify the limitations of current methodologies for separating leakage from night flows and to assess the opportunities for improving the approach (UKWIR, in publication).

Why use sectorisation?

Where a DMA or any sectorisation is established, it is possible to obtain flow profiles in the night when customer demand is least and leakage is dominant and to use these to determine leakage levels.

The overriding purpose of the leakage estimate may be:

1. To identify a relative change in the sector that may prompt active leakage control (ALC) effort
2. To compare several sectors for changes to identify the sector that is the most likely to benefit from ALC intervention
3. To determine an unbiased estimate of leakage that can be used for reporting overall leakage levels

These purposes represent increasingly more exacting requirements. For purpose 1 it is only necessary to examine the differences in night flows provided the assumption of similar customer night consumption holds, however further analysis is required if night consumption is variable. For purpose 2 it will be necessary to make some estimate of customer night consumption to determine leakage levels, and for purpose 3 it will be necessary to ensure that the allowances for customer consumption are unbiased. For larger sectors or sectors at a higher level than the DMA only limited benefits can be obtained from purposes 1 and 2.

In countries such as the UK, there is increasing reliance on sector information to maintain the network at low levels of leakage and for many companies DMA sizes have become progressively smaller to achieve this aim. Smaller DMAs provide more detailed data but are also more difficult to analyse and require a higher metering specification.

Customer night flow characteristics

Domestic or household customers are usually significant in number within a DMA and have daily or night demands that are within a relatively narrow range. They are thus amenable to modelling statistically.

Whilst some household customers use large amounts of water occasionally or seasonally for outdoor use, the range of flow rates remains relatively small compared to commercial or non-household customer demands. In addition, non-households may be few in number within a DMA and statistical approaches may have more limited success. The focus of this paper is on DMAs which supply largely household properties.

An important feature of household night consumption is the intermittent nature of the flows. This arises from the occurrence of use events (e.g. toilet flushing, washing machine use) with gaps between events. The graph below illustrates the intermittent nature of flows at night on a small DMA.

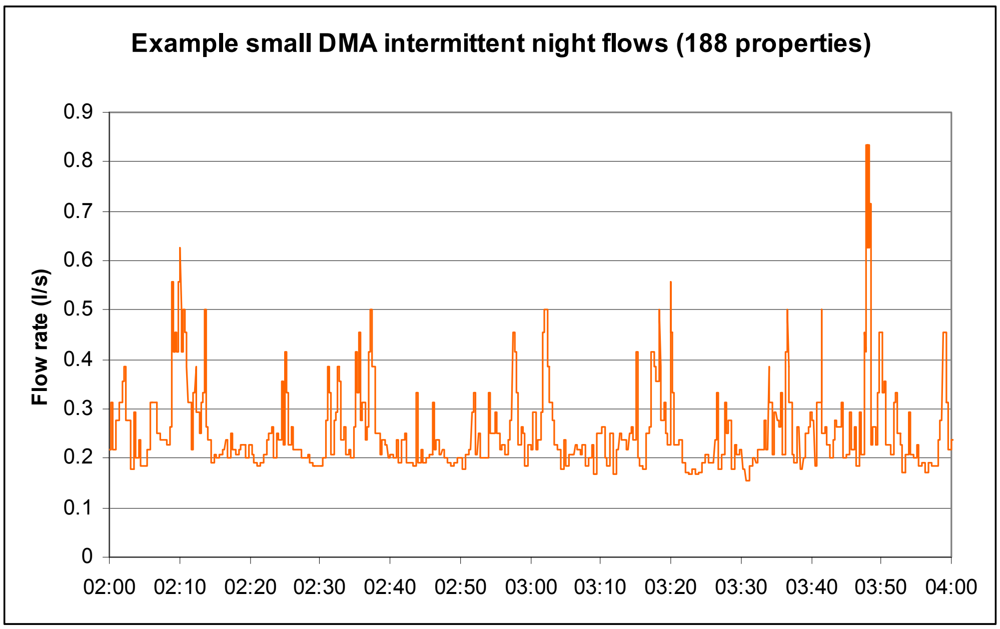

Figure 1 Detailed night flow pattern in a small UK DMA

This feature suggests that there may be benefit from using a smaller interval to analyse night flows and this is discussed later in the paper.

DMA design

DMA design may be constrained in some countries by regulations for fire flows and emergency use and designs must account for water quality issues that may arise when limiting the flow routes through the network. These are fundamental issues that are fully considered in the IWA DMA Guidance Notes (IWA/Water Loss Task Force, 2007) and are not considered further in this paper.

The DMA design must also ensure that adequate metering is in place to record the flows, particularly the low flows at night. This is generally achieved at design, but experience in the UK shows that DMA flows reduce through:

- leakage reduction
- non-household demand reductions (e.g. factory closure)
- DMA resizing

It is evident that a periodic review is necessary to confirm the fitness for purpose of the metering installation as the initial design assumptions change. Inappropriate meters will under-register and provide misleading leakage data.

Checking DMA design

A simple approach to checking the installation without recourse to zonal flow data is to express the minimum design flow, Q_{min}, of the meter in litres/property/hour and compare it to the zonal flows. For example,

- a DMA of N = 1000 properties,
- supplied by a single meter with a design Q_{min} of 0.278 l/s (1000 l/h),
- will have a Q_{min}/N of 1 l/prop/h.

This figure indicates the lowest leakage level that can be tolerated before the meter under-registers and can be compared directly to the leakage levels experienced. Thresholds can be set to indicate whether under-registration is not a problem, is definitely a problem or is indeterminate and will depend on current leakage levels. For multiply-metered zones some proportioning of the night flows will be necessary. More sophisticated tests can be applied using the actual night flows.

Whilst flows below Q_{min} indicate definite failure, flows above Q_{min} are not necessarily satisfactory. For a 15-minute recording interval, the intermittent nature of night flows means that there are periods when the instantaneous flow rate is below the average level. The graph below uses short-interval flow recording to indicate the actual under-registration against nominal meter characteristics. The average flows above Q_{min} under-register more than expected because of periods at flow rates lower than Q_{min}, while the flows below Q_{min} under-register less than expected because of those periods where the flow peaks register more fully.

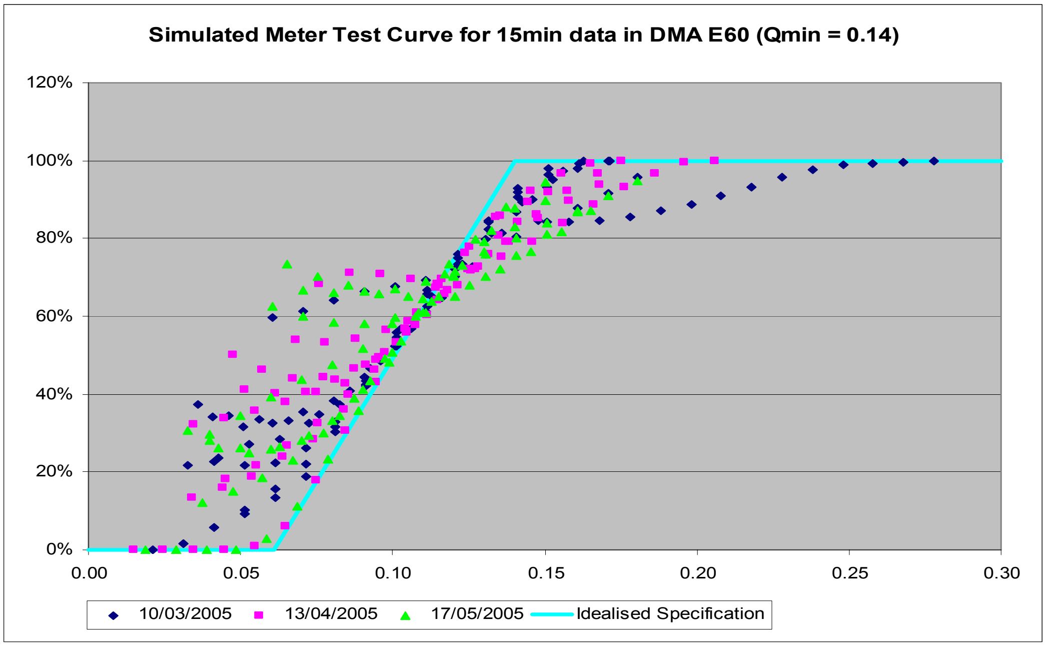

Figure 2 Simulated recorded v actual intermittent flows at low level in a mechanical meter

Pulse size limitations

Most DMA meters provide a pulse output to the logger when a volume of flow has been recorded. The pulse size becomes important if smaller intervals are to be used for the analysis. Inappropriate pulse sizes will lead to coarse discrimination of the night flows. The pulse size can be compared to the expected night consumption as follows:

- Calculate the DMA average night consumption volume expected in the interval of recording.
- (e.g. 1000 properties at 2 l/prop/h during a 15 minute interval is 500 litres)
- Compare this to the pulse size (e.g. 100 litres)
- If the ratio of pulse size to consumption volume is high (e.g. over > 25%) there may be problems in discrimination and increased uncertainty of the result.

When the interval is reduced this effect becomes more obviously apparent. Pulse size constraints can be a limitation on the use of shorter intervals. The graphs below indicate the effects of pulse size discrimination.

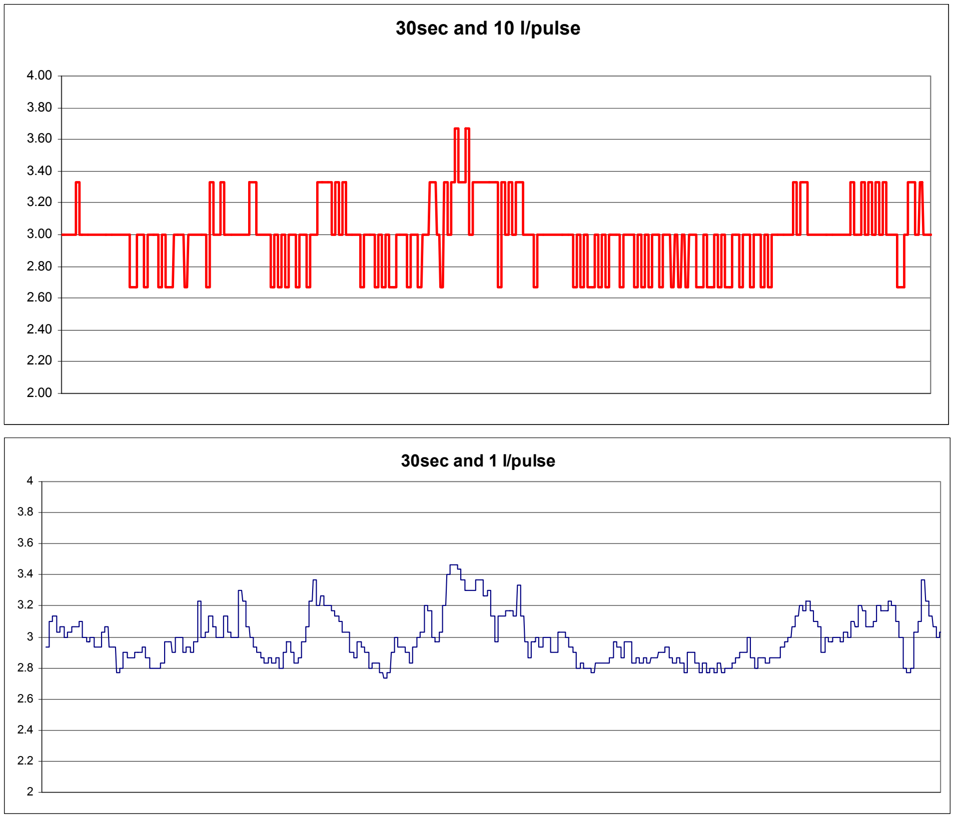

Figure 3 Effects of discrimination with different pulse sizes at short intervals

Reduced interval analysis – intermittent use

Logged data has conventionally been recorded at 15-minute intervals. This is a compromise between the need for more detail and the overhead of storing more data from shorter intervals. Current and anticipated improvements in data recording technology offer an opportunity to use shorter intervals if there is advantage in doing so.

If reduced intervals are used in smaller areas, there is an opportunity to observe lower minimum flow levels as gaps between use events occur. For larger areas such gaps may not be evident as the frequency of use events causes them to overlap.

The night leakage approach seeks to observe flows when the consumption is at a minimum. The use of reduced intervals follows this principle by observing the period when the consumption is at a minimum. Clearly if this approach is used the corresponding consumption allowances will also need to be reduced. By determining night flows that are closer to the actual leakage levels the measurement and allowance uncertainties in the estimate may also reduce.

An intermittent use allowance (IUA) is required to allow for the consumption events that overlap as the DMA size increases. This has been estimated from simulation on a set of DMAs for which valid data at a 1–second interval has been obtained. Each of the DMAs used had periods without intermittent use allowing a base flow to be determined. The simulation randomly combined the DMAs to develop the allowance. An equation of the following form was developed.

$$IUA_t = c_t + a_t N^{b_t}$$

In this equation *a, b* and *c* are coefficients for a given interval *t.* N is the number of properties and the resultant IUA is in l/h for the DMA. The family of curves for varying intervals is shown in the following graph.

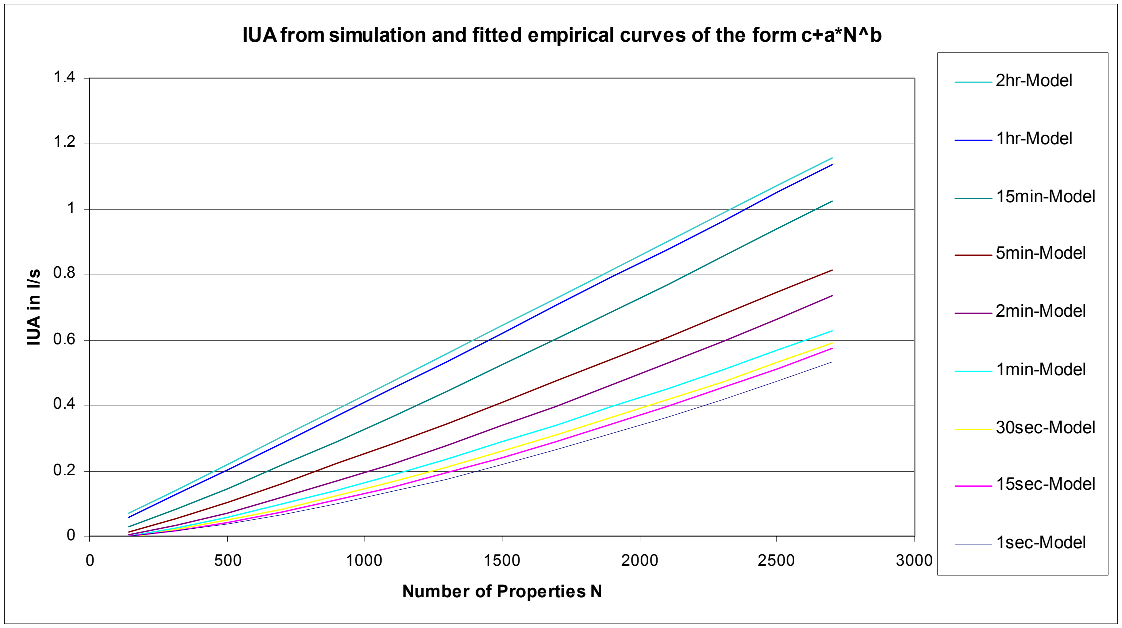

Figure 4 Intermittent user allowance (IUA) from simulation on a UK DMA set

The line becomes approximately linear as the interval increases and *b* tends to 1, but at shorter intervals and for smaller DMAs a non-linear profile can be observed.

The parameter values will vary internationally depending on the demand patterns of the households observed. In the UK much of the flow arises from devices such toilet flushes and washing machine use. In countries with fewer or different devices in use the intermittent pattern will lead to different allowances.

Reduced interval analysis – continuous use

The IUA analysis does not account for the presence of consumption that runs continuously through the night and a further continuous use allowance (CUA) is necessary. For this analysis it is necessary to review the behaviour of individual logged properties and their night-to-night changes. The IUA statistic is dependent on the recording interval within the night; the analogous “interval” for the CUA is the number of nights.

Analysis of the persistence of continuous use was carried out. The frequency of the continuous users is shown in the following graph developed from a logged survey of individual households.

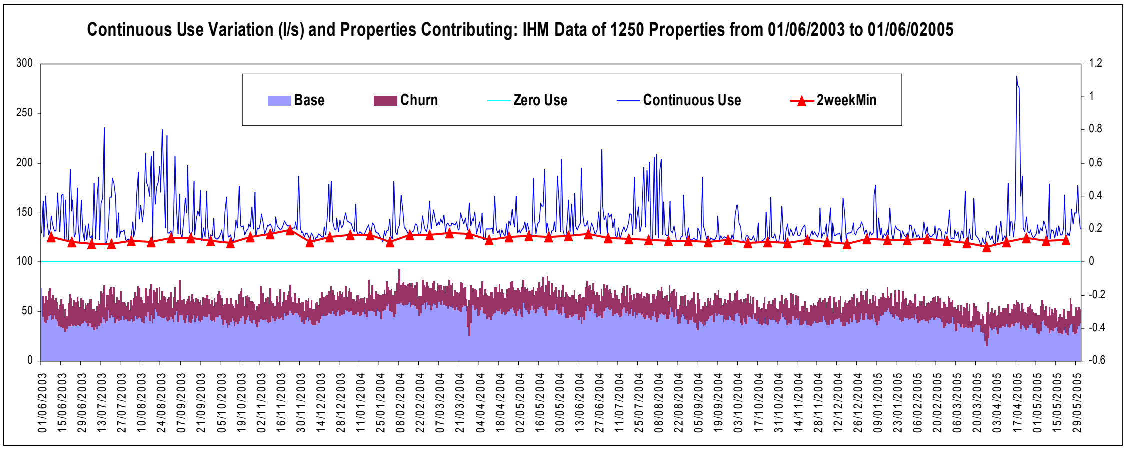

Figure 5 Persistence of households showing continuous night flows by count and flow rate

The graph shows the statistics of the small subset of households that are using water continuously through any single night. Different households will contribute on different nights, but some households show persistent continuous flows. In the bottom section of the graph the count of these households is shown as small (about 50 out of 1250) and not varying significantly. The count is split into two parts: the upper (dark shaded) part shows those households where the continuous flow has persisted less than 14 days and the lower (lighter shaded) part those households where the continuous flow has persisted 14 days or over. This "churn" or turnover of households shows that the short-term flows, particularly those with high flow rate, appear in changing and different locations which allow them to be viewed statistically.

In the top section of the graph, the total flow from these households is shown. This shows that there is a base flow of households using a low continuous flow rate with a larger peaking flow from some households on some days. Two summer seasons can be identified where peaks occur. The minimum flow in a 14-day window is also shown and it can be seen to remove all of the peaks providing a stable base level of continuous flow. By seeking an allowance statistic of this kind the estimate of leakage can be more stable as it is unaffected by seasonal variations in continuous night use.

The 14-day period appears appropriate for the UK because of the intermittent nature of the summer weather. For countries with more persistent warm dry summers than the UK the period will require local review.

By considering a fixed period of 14 days a single equation for the CUA could be derived from simulations using the individual property logged data set. The form of the equation was made similar to the IUA, although in fact the intercept parameter, *c*, passes through the origin.

$$CUA = c + aN^{b}$$

In this equation *a, b* and *c* are coefficients for any interval, but relate to a minimum over 14-days. N is the number of properties and the resultant CUA is in l/h for the DMA. The curve is shown in the following graph.

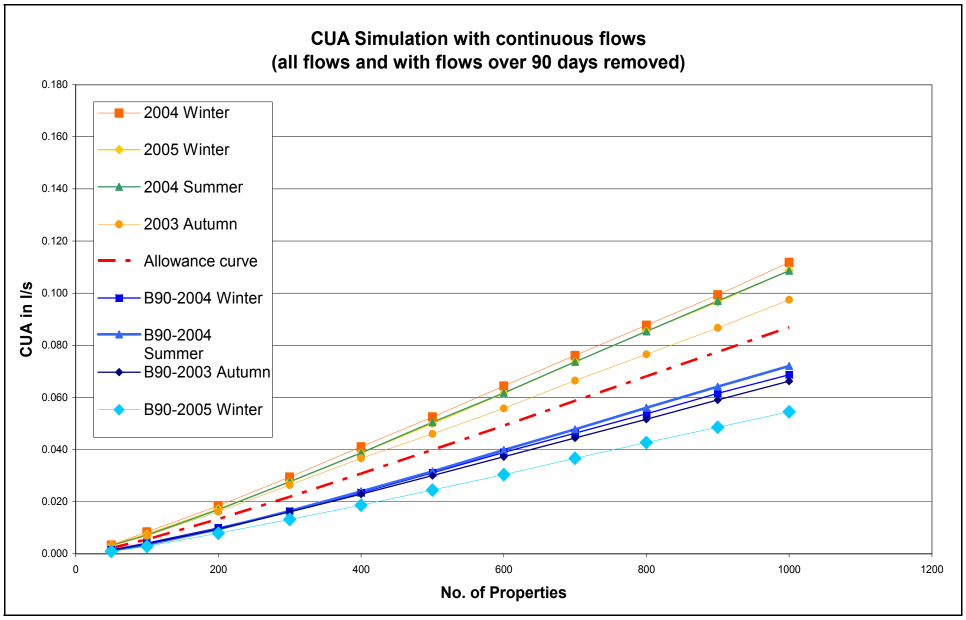

Figure 6 Continuous use allowance estimate from simulations

The single allowance curve (red, dashed line) was estimated from simulations which attempted to account for the possible effects of summer and winter and the inclusion or exclusion of potential service pipe leakage as the monitor was external. No significant difference was found between the seasons. The points above the allowance curve included continuous flows persisting greater than 90 days which may have been very small service pipe leaks (the identified leaks had already been excluded). The points below the allowance curve excluded the 90-day persistent flows and will also have excluded some consumption. The allowance curve is a best view from the current data for the CUA.

Related night flow statistics

It is important that the allowances relate directly to the night flow statistic that is used. Experience suggests that a variety of flow statistics are used (e.g. 7-day 50th percentile of the minimum rolling hour etc.) often without reference to the allowances that are compatible. In the simplest case a fixed 2-hour minimum night flow averaged across nights can be used with an average night consumption allowance for the same period. This has the advantage of robustness and simplicity, but is susceptible to customer consumption variations if used for operation leakage estimates (e.g. purposes 1 or 2 above). Other statistics are better at handling consumption variations, but require more complex consideration of the impact on the consumption allowances made.

For the IUA/CUA method, the compatible night flow statistic that should be used with the allowances is:

- within each night find the minimum valid value at the selected interval
- across 14 nights obtain the minimum valid value from the contributing nights

This estimate will provide consistent allowances that account for the size of the DMA and the interval of recording, achieving purposes 1-3 as identified above.

Benefits

The study demonstrates the potential of alternative approaches to night leakage estimation that account for:

- The characteristics of the components of night flows, both within the night and between nights.
- The composition of the DMA.
- The actual measurements made and the meter/logger combination used.

These considerations allow more consistent leakage estimates between DMAs and minimise uncertainty.

Limitations and further research

The methodology may be implemented in practice with only minor changes to data loggers and receiving systems. However it is recognised that this may be difficult for some organisations (e.g. where the software can only receive and process 15-minute data).

The method may be limited in effect for some DMAs where it is not possible to alter the meter or logger set-up. However it does provide information on the fitness for purpose of the current measurements and indicates where changes are needed to improve the leakage estimates.

The methodology is appropriate for DMAs with primarily household consumption. It is possible to accommodate non-household consumption within the DMA provided this is not excessive. Where non-households contribute the majority of night consumption the analysis will always be difficult unless customer logging is used. Further research into the characteristics of non-household night consumption is needed to allow for the inclusion of non-household properties.

The data sets used for the study were substantial and reasonably representative of UK conditions. However further data would allow a more definitive set of parameter values to be established for UK use. Studies on data sets from other countries would also be of interest to develop the method, particularly those countries with different consumption patterns and device use.

Conclusions

The project has demonstrated that there are opportunities to improve the estimation of DMA night leakage through the methodology presented.

The assumption that the DMA configuration and metering is fit for purpose is challenged and some checks on DMA suitability are provided.

The constraints imposed by the use of the standard 15-minute data recording interval are challenged and opportunities to use shorter intervals are proposed.

There is an expectation that the data from DMAs will meet the increasing requirements placed upon it. The work describes processes to ensure that all aspects of leakage analysis from meter specification through to analysis are able to meet these expectations. Further work is necessary to develop the method and ensure that the expectations can continue to be met.

Acknowledgements

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The author is grateful for kind permission of UKWIR to publish this paper. The opinions expressed in this paper are those of the author and do not necessarily represent those of UKWIR.

References

IWA/Water Loss Task Force, District metered Areas Guidance Notes, Version 1 February 2007 (Available from www.iwaom.org/wltf)

UKWIR (in publication) Separation of leakage and night use in district meter areas

minimum night flow was considered to be significantly higher than it should be, providing the opportunity to demonstrate and measure a reduction in real losses through pressure management, and additionally, through advanced pressure management.

To be considered successful, reductions in real losses through advanced pressure management had to be achieved without degrading minimum system requirements. Adequate minimum residual pressures had to be maintained during peak hourly flow or maximum day demand plus fire flows. Water quality was also a concern, with possible rapid changes in velocity, flow reversal between supply points or excessive water age. Other concerns included customer complaints from low supply pressure, and a loss of metered sales offsetting the savings gained from reductions in real losses.

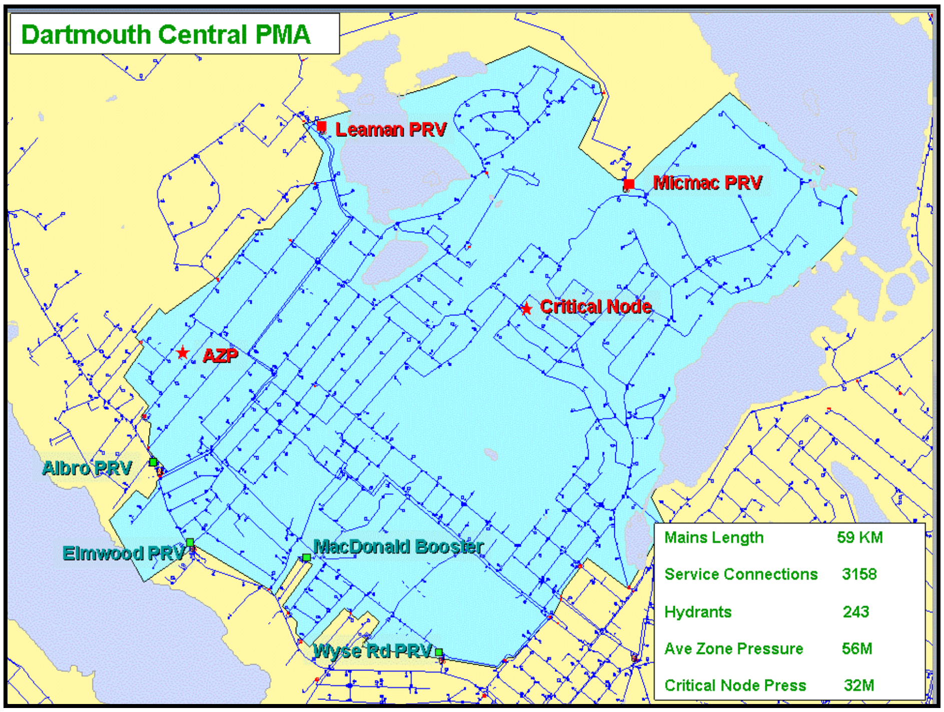


Figure 1 Dartmouth Central PMA

DMA to PMA

The Dartmouth Central DMA, in its present configuration, was created following the construction of the Micmac pressure reducing and metering chamber in May 2002. Fixed outlet pressure control was required to prevent excessive pressures in the lower elevations of the DMA. However, the HRWC had not considered this a Pressure Managed Area, whereas the use of fixed outlet pressure control in the HRWC is very common and likely pre-dates the term Pressure Managed Area. To satisfy the intent of AwwaRF 2928, equipment was added to modulate the system pressure in response to changes in demand at which point, the HRWC had a true Pressure Managed Area with advanced pressure control. This type of control is achieved by controlling outlet pressure in relation to demand. The outlet pressure is increased when demand increases and reduced when demand decreases.

Operation

Equipment Description and Set-Up

To modulate system pressure as demands changed, battery powered PRV controllers were installed in the Micmac and Leaman supply chambers with pipe configuration as displayed in Figure 2. The controllers, as indicated in Figure 3, were supplied with bias chambers that were adapted to the bottom of the pressure reducing valve control pilots. To lower the system pressure, the controller applies air pressure to the bias chamber, which in turn applies a closing force to the pilot valve, thus causing the main valve to close, lowering the system pressure. This type of controller uses the subtraction method, reducing the pilot setting through the bias chamber. Should the unit fail, the pilot, which is set slightly above the target pressure for peak demand, resumes full control. Process connections to the inlet and outlet of the PRV, along with input from the magnetic flow meter, provide the controller the necessary information to continuously adjust system pressures as demands changed. The PRV controllers were programmed to increase the outlet pressure during peak periods and reduce the outlet pressure during off-peak periods, while preventing the system pressure from dropping to the point where the larger fire flow PRVs would respond.

Figure 2 Standard HRWC supply chamber configuration

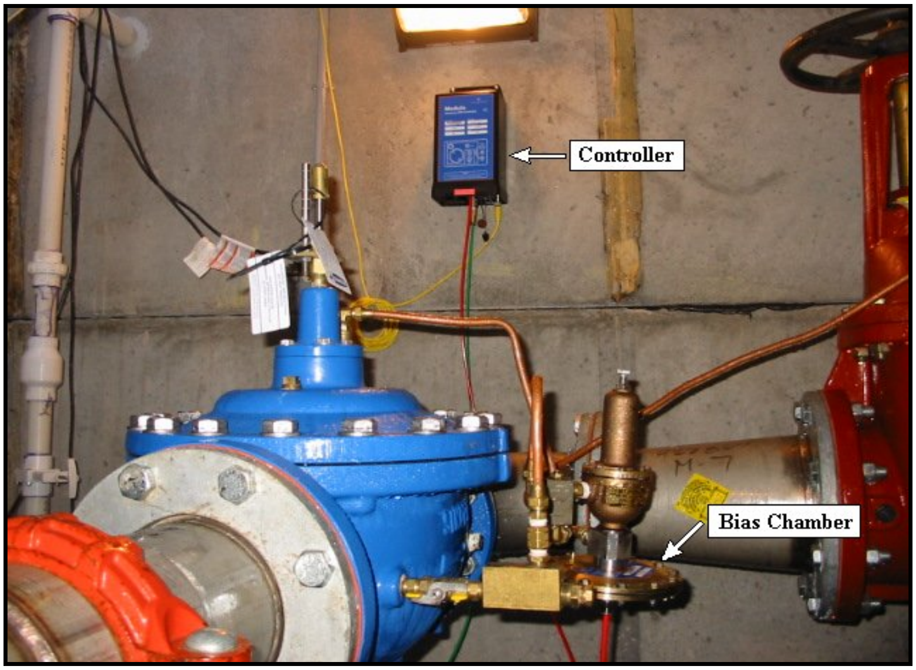


Figure 3 PRV controller with bias chamber fitted to pilot

To monitor system performance, pressure loggers were installed at the critical node and AZP [average zone pressure] point. The critical node was selected as the hydrant at the highest elevation within the PMA. The AZP point was determined using HRWC records of annual static pressure readings from each hydrant within the PMA. A suitable hydrant representing the weighted average pressure was selected. Pressure and flow from each supply chamber and each outlet of the PMA were monitored by the HRWC SCADA system and stored in HRWC's data historian for future analysis.

The AwwaRF 2928 project objectives required 24 hour diurnal curves representing no pressure control, fixed outlet pressure control, and flow modulated pressure control over three consecutive days with results displayed in Figure 4. Where PRVs were already in service, obtaining data reflecting no pressure control required adjusting the outlet pressure of the PRVs upward for a 24 hour period. For this 24 hour period, the outlet pressure at Leaman was increased by 9 meters head [mH] while Micmac was increased by 7mH. With these increases, the outlet pressures at Leaman and Micmac were within 4mH of their respective inlet pressures.

To obtain data for the 24 hour fixed control period, the outlet pressures at Leaman and Micmac were returned to their normal settings of 39mH and 51mH respectively. For this 24 hour period, the PRVs were controlled by their pilot valves.

Attempting to operate both Leaman and Micmac in flow modulation mode for the first time, it became apparent it would be best to place Micmac in a standby mode and supply the PMA through Leaman for the 24 hour flow modulated control test period. Although this was not the original intent, this would simplify the process and improve accuracy as flow and pressure data would be from a single source. The controller at Leaman was programmed to regulate the pressure between 31mH at 100 m3/hr, through 41mH at 300 m3/h, and 24 hours of flow modulated data was collected.

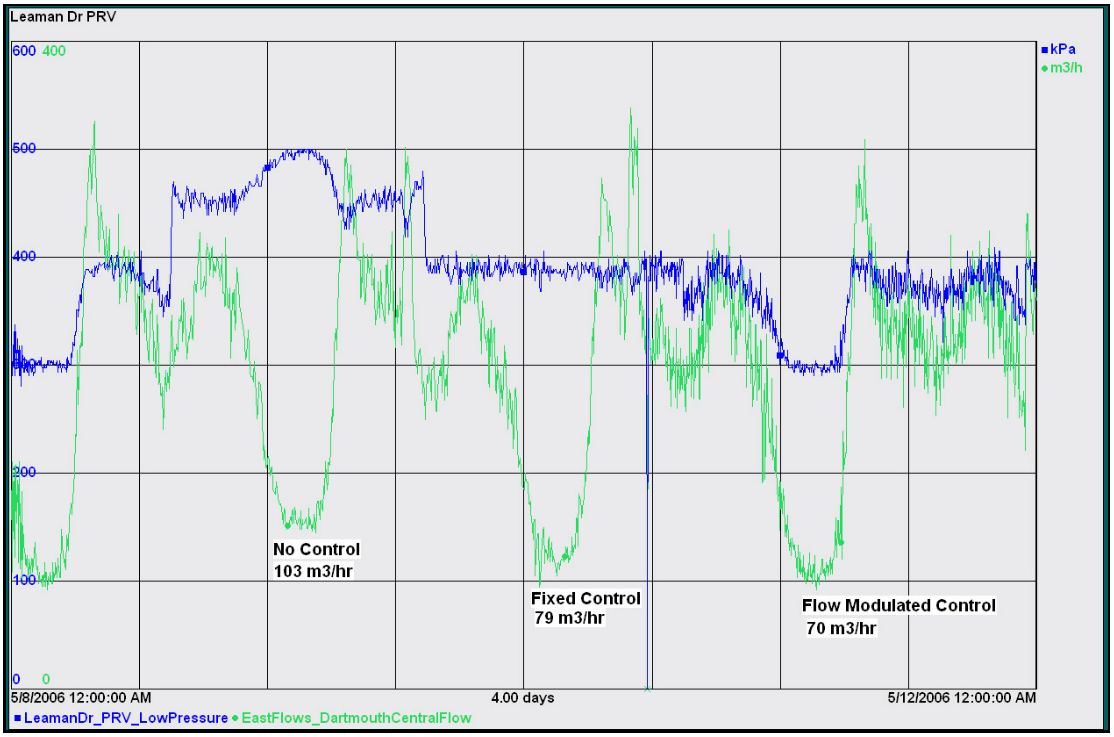


Figure 4 Minimum night flows during three 24 hour trial periods

Operational Observations

Over the twelve month trial period, repeated attempts to operate the Leaman and Micmac supply chambers simultaneously in flow modulation mode were unsuccessful. Typically, in response to an increase in demand, one of the supply chambers would respond by increasing the system pressure as the flow through that chamber increased. This increase in system pressure is sensed at the second supply chamber where a corresponding reduction in flow occurs, which is interpreted by the PRV controller as a reduction in demand. The second supply chamber responds to this perceived reduction in demand by reducing the system pressure, thus creating a cycle that eventually results in the complete closure of the second or lag supply chamber. Various control settings were tested, however, over time, one supply chamber would eventually override the other. Programming the PRV controller at the Micmac supply chamber to function in time-based modulation with Leaman in flow modulation was also tried with limited success. Therefore, for the majority of the 12 month trial period, the PMA functioned with Leaman in flow modulation mode and Micmac in standby.

Apart from the aforementioned flow balancing problems, there were few operational issues. During the first weeks in flow modulation mode, low pressure complaints were received from customers living in proximity to the critical node. Investigations into these complaints concluded that the system pressure was reaching the minimum target pressure during the late evening while customers were still awake. To resolve this issue, the controller settings were altered to prevent reaching the minimum target pressure prior to midnight. Although there were no water quality complaints from customers, a sample station near the Micmac supply chamber experienced a gradual decline in chlorine residual due to the lack of flow through this facility. To resolve this issue, HRWC staff established a constant flow rate, at a fraction of the minimum night flow requirement for the PMA, through the Micmac supply chamber. There were a variety of hardware problems, including controller failures which required their replacement on three occasions. There were also problems with the bias chamber, which was identified by the manufacturer as "stiction", where friction within the bias chamber caused sticking within the chamber, resulting in extreme and rapid pressure variations. Replacement of the bias chambers resolved this serious problem.

Results

From the installation of flow modulation within the Dartmouth DMA, further inroads in leakage reduction were realized and a fifty percent reduction in the total number of breaks was achieved. Another benefit that can be seen is the fact that the AZP is relatively stable over the entire day. Pressure fluctuations due to high or low demands have been reduced.

For the three years prior to advanced pressure management, the Dartmouth Central DMA averaged 23 breaks per year. In the 2005/06 fiscal year, the annual breaks were reduced to 12. At HRWC, where a typical DMA requires two inflow chambers, the payback period for these chambers, complete with advanced pressure management, was approximately 13 years. The breakdown in savings between fixed outlet control and flow modulated control is indicated in Table 1. Considering that the DMA chambers which represent the majority of the cost have a minimum life cycle of 50 years, the economics are very encouraging. This cost benefit analysis only considers the direct savings from the reduction in real losses and does not include the reduction in break frequency. With the Dartmouth DMA, the reduction in break frequency from an average of 23 to 12 breaks per year represents a savings of $44,000. Notwithstanding this decrease, there were 22 breaks for the 2007/08 fiscal year. This increase is believed to be attributed to an extremely cold winter [10 consecutive weeks of -10 degree Celsius weather] and the fact that the controllers were off line for an extended period due to malfunction.

Table 1 Payback periods for fixed and flow modulated control

Savings	Fixed	Flow Mod	Total
m3/yr	195,350	34,311	229,661
$ Marg /yr	$13,869	$2436	$16,305
Payback Marg	14.4 yrs	3.3 yrs	12.8 yrs

Total Construction Costs = $200,000

As part of AwwaRF 2928, consumption profiles were developed for each of the three control days. The profiles are very similar with no significant difference between the control days, suggesting the reduction in system pressure had little or no affect on customer consumption and furthermore, demonstrated the three control days were suitable to be compared with each other. It is therefore felt there is no significant loss of revenue to offset the benefit in the reduction of real losses.

Independent fire flow tests were conducted to ensure the supply chambers in flow modulation mode could provide adequate fire flows. Hydrants near the critical node were selected and several tests were conducted during late evening and post midnight periods when the system pressure was at its minimum target pressure. Results indicated flow rates slightly lower than Insurance Advisory Organisation residential requirements. Field observations and a review of all data confirmed the supply chambers responded to the fire flow tests and increased the system pressure to meet the demand. It was determined that the lower than expected flow rates were a result of hydraulic losses through the small diameter, tuberculated mains in the area of the flow test.

Future Direction

With the initial success in leakage reduction within the Dartmouth PMA, HRWC staff is planning to install flow modulation in two other DMAs which exhibit high night time flows and significant background noise. These areas include the Halifax peninsula low DMA [Figure 5] and the Dartmouth Burnside DMA. The Halifax peninsula low shows particular promise as the minimum night flow is in the order of 500 m^3/hr, with an average zone pressure around 65mH, and pipe with an average age nearing 75 years old. This DMA is adjacent to Halifax Harbour with leaks rarely surfacing but flowing direct to the ocean via large underground trenches which often house old combined sewer infrastructure with significant infiltration potential. Leak detection surveys are hampered in this area where background noise often masks active leakage. It is likely that two chambers housing flow modulated pressure control devices will be installed in 2008. HRWC may install a combination pressure control/flow metering device in these chambers for efficiency and effectiveness.

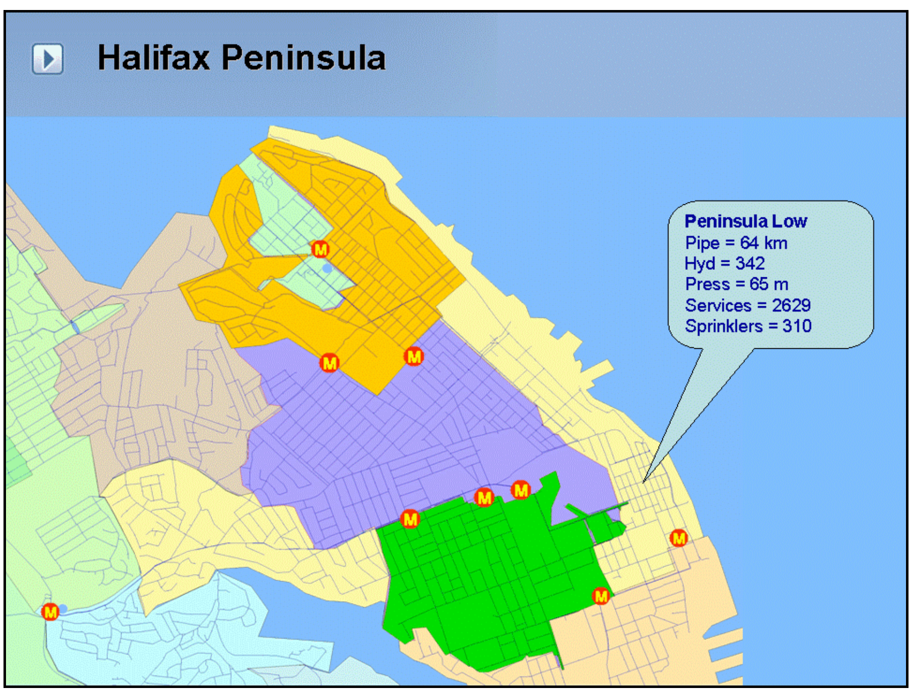


Figure 5 Halifax Peninsula Low DMA

It is also likely that HRWC staff will install spread spectrum communications within future control chambers to serve as a communication link between controllers. A concept of future control improvements is illustrated in Figure 6. In this manner, it is hoped that the controllers will not be jostling for position, as the case with the Dartmouth Central DMA, where one of the chambers was dominant as a zone feed. Through programmable logic controller [PLC] configuration or basic remote terminal unit [RTU] programming, it is expected that the chambers will balance flows with less iterations to obtain steady state flows.

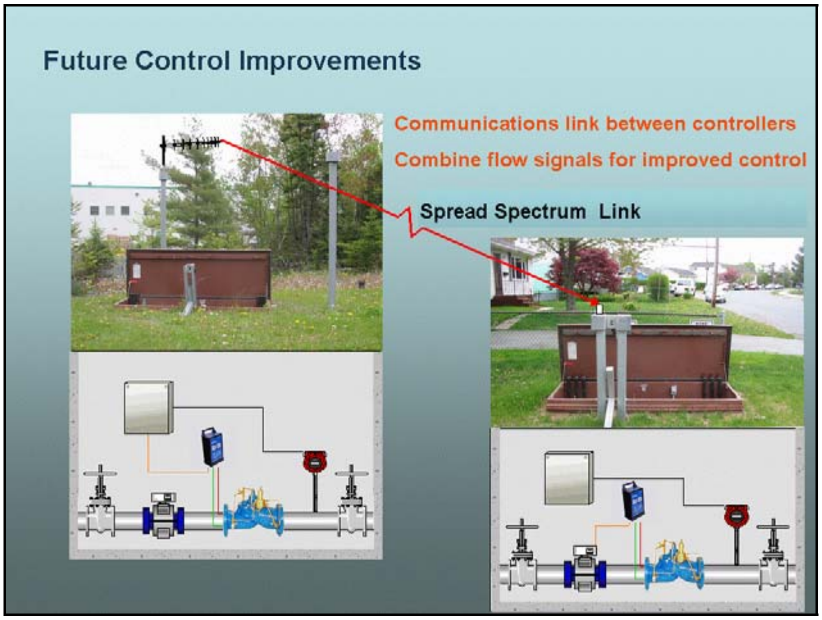


Figure 6 Concept of Future Control Improvements

Based on the research conducted as part of the AwwaRF 2928 project, it is clear that flow modulated pressure control is an economical and effective method to make further inroads in leakage reduction with minimal impact on customer service. Further research on controller communication can only add to this technology to provide enhanced operational functionality.

References

American Water Works Association AwwaRF Project 2928, Leakage Management Technologies (to be published soon)

Thornton, J. Managing Leakage by Managing Pressure. Water 21, October 2006

Thornton, J. and Lambert, A. Progress in practical predictions of pressure leakage, pressure: burst frequency and pressure: consumption. IWA Conference Proceedings, Leakage 2005, Halifax, Nova Scotia September 2005

Pressure-management in mature networks using batch-processed pressure-dependent hydraulic modeling

S Tooms*, N Tansley, A Green+**

*Hyder Consulting, 50 Rocky Lane, Aston, Birmingham, B6 5RQ

**Severn Trent Water, 2297 Coventry Road, Birmingham, B26 3PU

+Advantica, Ashby Road, Loughborough, Leicestershire LE11 3GR

Keywords: Pressure, reduction, model,

Summary

Pressure management design is normally carried out for individual schemes working either directly from pressure measurements or using individual hydraulic models. This can lead to ad-hoc pressure management design rather than identifying the most cost-effective schemes at the outset.

However, many water companies now have hydraulic models of the whole of their network, and this provides a way to identify the potential for further pressure management within the network, even for a large water company including several million customers.

Severn Trent Water is a large water company, providing water and sewage services to a population of eight million people in central England. The network is fairly mature, with a growth rate of approximately 1% per annum, and more than 98% of the population connected to the network. Over the last twenty years the company has invested heavily in pressure management and now has over 3000 pressure reduction valves in the network, through which over 40% of this population is served. The company realised that there would be opportunities for further pressure management within the network, which may well deliver cost-effective savings. However identifying and prioritising those potential schemes by hand was seen as an expensive and staff-intensive process at a time when skilled staff are at a premium.

Therefore Severn Trent Water worked with leakage and network-model specialists from Hyder and Advantica to develop a batch processing system that would run the models, identify all the potential district-level schemes within the network, identify the optimum control mode for each scheme and carry out a cost-benefit analysis for each scheme. This would lead on to detailed design and construction of the cost-effective schemes. 130 individual models, covering 2000 existing metered districts were analysed in this way.

Pressure Management Strategy

Severn Trent Water has hydraulic network models covering almost all of their supply network, kept in an online library which can be accessed throughout the company. These were used in a four stage process to assess the need, identify areas for investigation and then design and construct new pressure management schemes.

Assessing the need

The first part of the project was to assess the current range of pressures throughout the network. All of the average-day models in the Severn Trent Water model database were extracted. The model nodes were matched to the DMAs used for leakage control and average pressures in each of the DMAs were calculated, for all 2000 DMAs, comprising 750,000 demand nodes. The results (in Figure 11 below) showed that there is a large range of average pressures across the DMAs in the network.

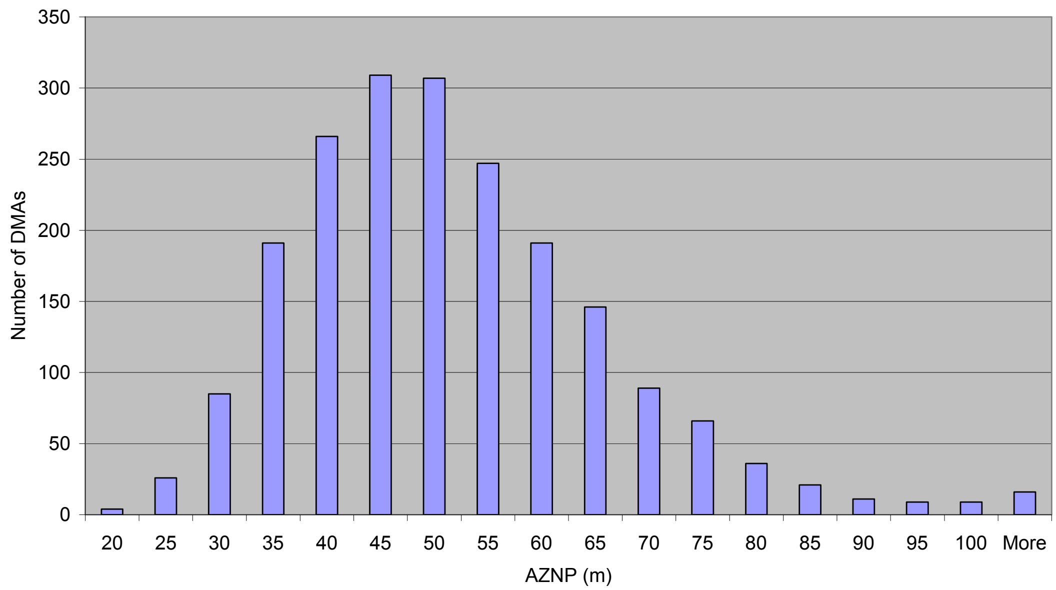


Figure 11: histogram of the distribution of average zone night pressures

According to this model analysis, more than 15% of DMAs (corresponding to 10% of properties) experienced average zone night pressures greater than 60 metres head.

Identify areas for investigation

The next stage in the project was to identify the parts of the network where maximum pressures are high enough to justify pressure management, and also the minimum pressures in that part of the network are high enough to provide the required pressure to customers after pressure management schemes had been put in place.

In each of the 2000 DMAs, the models were used again to identify:

- the critical node (the node with the lowest pressure at some time during the day)
- the inlet to the DMA (where it is a single feed) and
- the average pressure in the DMA at each one hour time step.

Actual night-flow losses were used to assess current leakage, and as a starting point for predicted leakage saving.

For each DMA where the minimum critical point pressure was greater than 25 metres, the critical point and average point pressures were recalculated to take into account the effect of a new PRV at the inlet. This recalculation included the headloss from the new PRV installation, the effect of alternative controllers and also the reduced head losses within the DMA resulting from reduced leakage. This is illustrated in Figure 12 below. In the figure, the second estimate of the total head takes into account the reduction in head loss caused by the reduction in demand. The new leakage (after pressure reduction) is related to the Average Zone Night Pressure (AZNP)

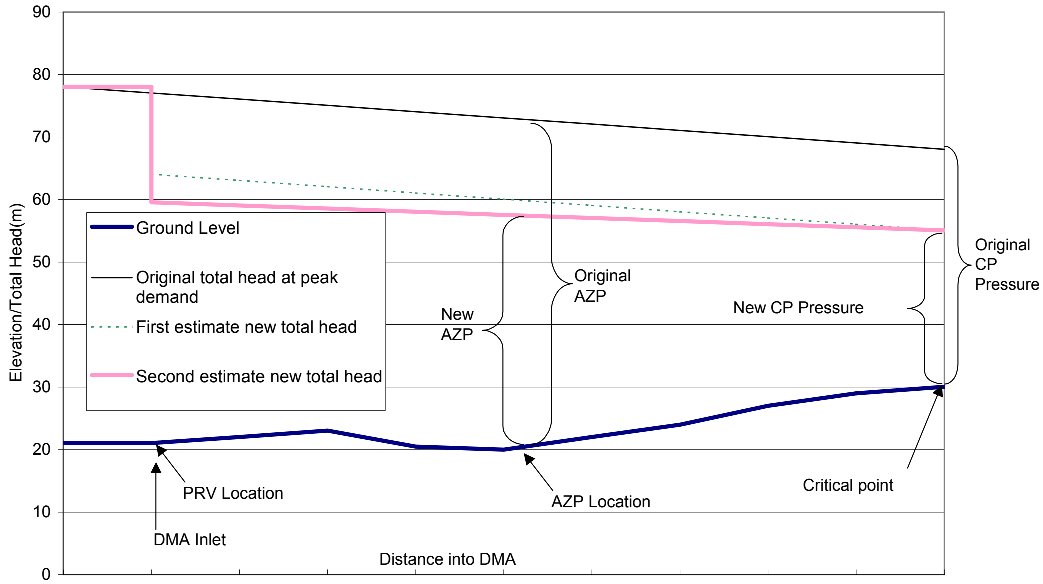


Figure 12: Assessment of the effects of pressure management

This process identified over 400 DMAs where further pressure management was feasible according to the models. Of these, 308 DMAs-level schemes were assessed to be cost effective even considering only flow reductions. Reductions in numbers of repairs make almost all of the schemes coist-effective. Figure 13 below shows the forecast costs and savings.

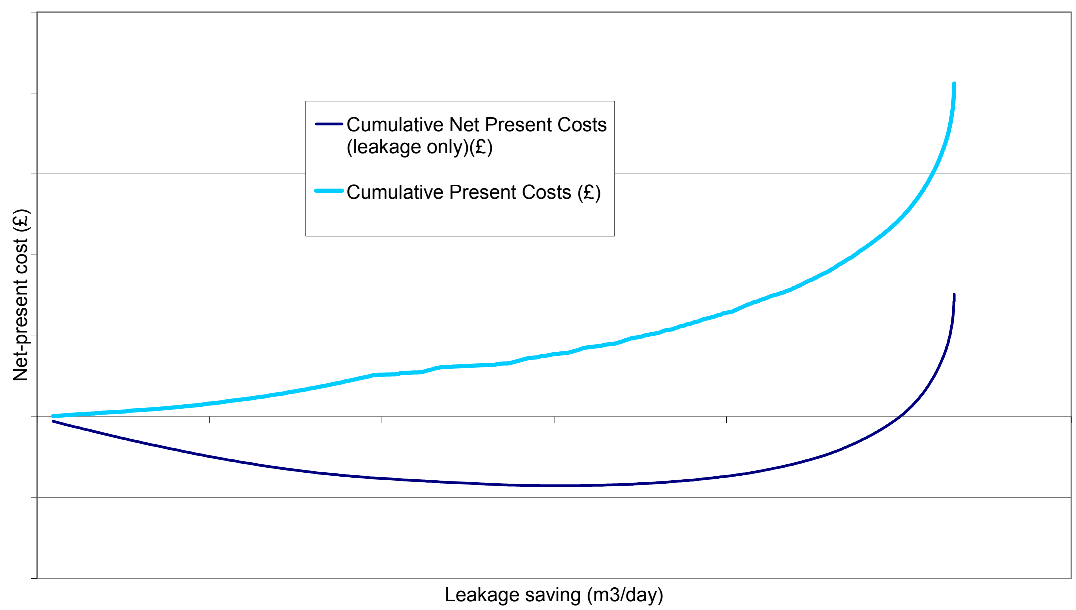
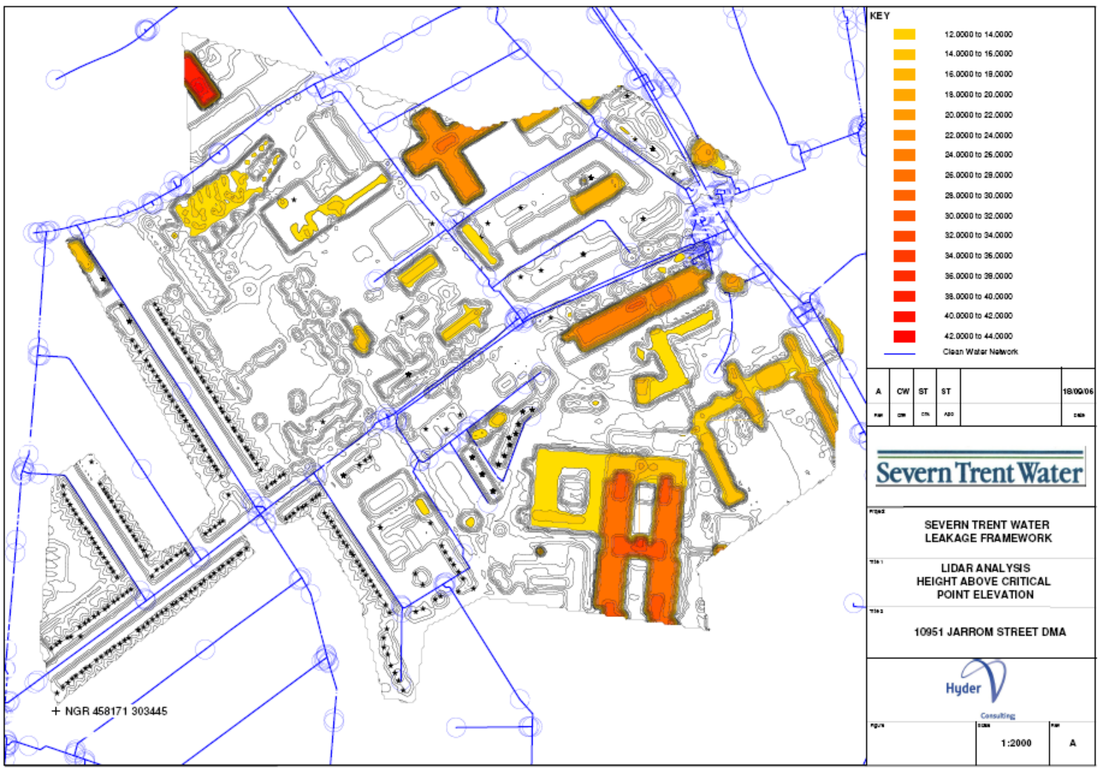


Figure 13: Net financial savings predicted

Design of New Schemes

From this set of 308 apparently cost-effective schemes, 81 of the most cost effective were selected for further investigation. The actual current inlet, critical-point and average pressures were measured. These measurements, over a one-week period, were used to produce a refined design, including sizing of PRVs and selecting the optimum controller.

In the urban areas of the Severn Trent Water Region, high rise buildings have historically limited pressure management. This is because some buildings relied on mains pressure to get water to the top floors, rather than using a pump. Two methods were used to identify these buildings in each scheme. For some DMAs the elevations of houses were mapped in detail from LiDAR survey data. LiDAR surveys gather surface elevation data at small intervals (typically 2 metre grid) with high vertical resolution (typically 20 cm). The results of one of these surveys is shown in Figure 14 below. This shows properties above the critical point elevation as shaded areas.



Note: colours indicate the height of buildings above the critical point in the mains.

Figure 14: Property elevations above critical points from LiDAR data

For other areas, aerial photos were used to estimate building heights, and these results were combined with a digital terrain model to identify buildings above the critical-point elevation.

Results

At the time of writing 45 new schemes have been designed in detail, and the first of these have already been implemented. Early results indicate that the savings originally estimated have been achieved.

Conclusions

This project is important in a number of ways:

- It identified further pressure management schemes in a region which had already been subjected to an intensive pressure management programme, indicating that further schemes can be available even in areas with established pressure management

- The project identified schemes that would not have otherwise been identified, including ones where critical point pressures were below the required level of service but could actually be raised by careful choice of pressure management and still deliver leakage savings
- It illustrated how batch processing of network models can efficiently deliver the results of a complex analysis for practical implementation in even the largest water companies

Next steps

Following this initial success, the approach is now being improved to incorporate automated outline design of sub-DMA level schemes. The cost-effective schemes will be investigated. The project is also being extended to take advantage of new pressure monitoring and telemetry within the network. All of this is helping to achieve rapid and cost-effective pressure management in a mature and well-managed network without overloading the skilled design staff. .

QUANTIFICATION OF METER ERRORS OF DOMESTIC USERS: A CASE STUDY

Arregui F.J.[1]; Pardo M.A.; Parra J.C.; Soriano J.*

farregui@ita.upv.es. Institute for water technology. Universidad Politecnica de Valencia.Valencia (Spain)

Keywords: Water meter performance; water meter accuracy; apparent losses

Introduction

Most residential water meters can be classified into two types: velocity meters (single jet and multiple jet) and positive displacement meters (oscillating piston and nutating disc). Positive displacement meters are insensitive to many of the influence factors that affect velocity meters. However water quality and suspended particles greatly degrade the water meter error curve and in some cases produce a definitive blockage of the meter.

In contrast, velocity meters are affected by many different factors like flow distortions, environmental and working conditions or changes in the internal dimensions of the measuring chamber or the inlet nozzle (for example those caused by calcium depositions) that may interfere with the flow velocity passing through the meter. The errors of velocity meters, especially for low flows, are sensitive to any increment of the drag torque on the sensor element. Consequently, many are the variables that can affect the accuracy of these meters. The combined action of these variables can have unpredictable consequences depending on the meter construction and materials. This circumstance makes it very difficult to predict in advance, for a given water supply, the behaviour of a specific type of velocity meter.

In Spain, the most used and less expensive metering technology for domestic users is single jet. Different manufacturers compete in this market offering models within a wide range of prices and metrological performances. The construction characteristics and quality diversity of available meters are considerable. Quite often, different models even from the same manufacturer are used simultaneously in the same water supply.

This scenario makes it more complex to analyse the real performance of the meters unless a long term strategy has been prepared for such a task. As said before, since many interrelated variables can simultaneously affect meters performance, a considerable sample has to be draw from the field. Therefore, only a long term study can provide with enough information to clearly identify and quantify the parameters with most influence on the error curve for each meter type.

This paper describes some of the problems that may arise when carrying out a research on this subject and illustrates it with examples of a real case study.

Methodology

The error of a water meter is not constant and independent of the circulating flow rate. Usually for low flows the errors are larger and more sensitive to external variables and at medium and high flows remain relatively stable through out the working life of the instrument. For that reason, the amount of water that a meter registers compared to the actual volume consumed is a function of two parameters: a) the water consumption patterns of the users which define their consumption flow rates and consequently the operation point of the meter and b) the characteristic error curves of the each meter type. Combining appropriately these two parameters a weighted error (which is a measure of the metering efficiency of a water meter for a specific user) for a given type of meter and user can be obtained.

For domestic users, and because of the large number of meters that are installed in a utility to measure residential water consumption, this evaluation has to be carried out by statistical sampling of users consumption patterns and meters performances. The immediate consequence of this statistical approach is the uncertainty associated to each value obtained for both, the average consumption pattern of each type of user and the average error curve of each brand of meter. When combining these two uncertain parameters, the weighted errors that are calculated are only estimates of the real values which will remain unknown. Obviously, the quality of this latest estimate depends on the uncertainty associated to the previous parameters.

Uncertainties related to the water consumption patterns

The uncertainty associated to the estimation of the consumption patterns are caused by different factors like:

- *Erroneous stratification of the population*. As a first stage, and previous to the sampling step, a stratification of the population in several classes has to be carried out. The intention is to group the users in different classes of similar consumption characteristics, so the consumption flow rates in the group are as similar as possible.

  If this stratification is not properly done, a heterogeneous group, in which users may have very different characteristics, will be created. This will increase the variability of the consumption flow rates and therefore, for the same sample size, the uncertainty associated to the characteristic water consumption pattern of the class.

- *Incorrect selection of the sample.* In other cases, the criteria used to stratify the population can be correct. However, it is possible that some of the users selected for the sample may not really belong to the expected stratum. This is often caused by an improperly updated commercial database where some of the information stored about the users is inaccurate. In some other cases the user may have change its characteristics without the knowledge of the company (for example, it can have installed a different irrigation system or there may be more or less people living in the household).

- *Variability in the water consumption.* Water consumption in a household is different every day not only in quantity (Figure 1) but also in intensity (flow rate). For this reason, when determining the water consumption of a household, a minimum number of days should be considered so that the consumption registered is representative of the real water consumption. A minimum of a week or two of data-logging is advisable to reduce the uncertainty associated to this parameter.

- *Distortions caused by the measuring and data-logging equipment.* The information stored in the data logger about data consumption, does not exactly match to the actual values of the user water consumption. In first place, the meter is not capable of registering any consumption, whatever is its flow rate, and the error of the meter is not constant in all the measuring range. Furthermore, the pulse emitter resolution and the procedure used to store the information in the data-logger will also transform the flow signal that is finally processed (Arregui F. J., 1999).

When all data has been collected and processed a water consumption pattern - which gives information about how much water is consumed in each flow rate range - with its associated uncertainties is obtained. The problem when dealing with these uncertainties, in order to calculate the weighted accuracy of a meter, is to decide whether the volumes used in different flow rate ranges are independent of the volumes used in other ranges. For example, is frequent that the volumes used in the lower ranges are independent of the volumes used at higher flow rates because they only depend on the amount of leaks in the households and not on the intentional water used.

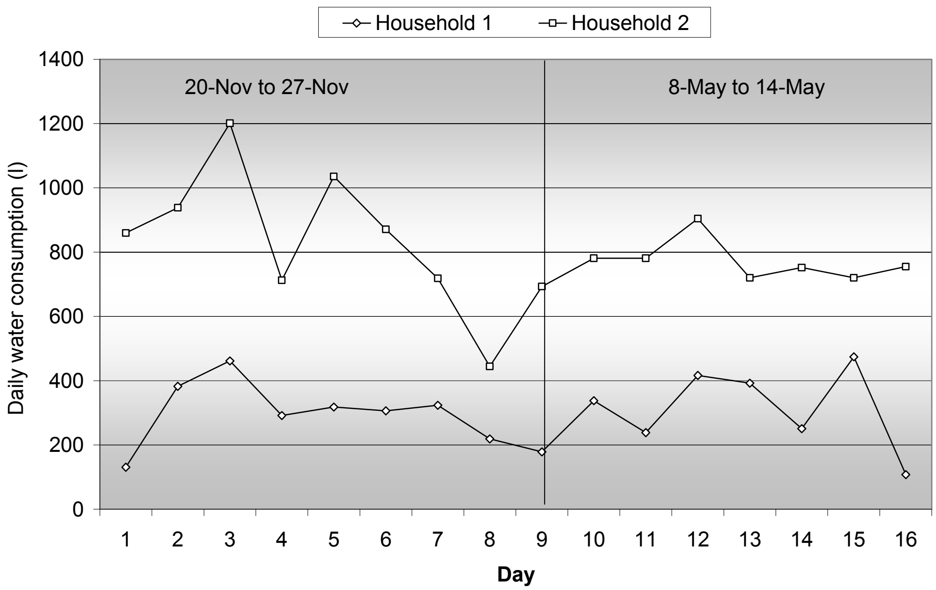


Figure 1. Total daily water consumption of two households for 16 days

Uncertainties related to the water meters error curve

To analyze the actual water meters performance several problems have to be faced. In first place, quite often water utilities simultaneously use a great variety of meters models, brands and technologies for measuring domestic consumption. This diversity leads to great difficulties when designing a proper approach to determine the amount of water not registered or registered in excess by the meters in the utility. The number of categories that have to be considered is too large and, consequently, the total sample to be drawn from installed meters to reduce the uncertainty of the results to an acceptable level is also too large to be economically feasible.

Furthermore, the tendency for most companies is to take a single snapshot of the meters errors, often during a single specific research project carried out in a relatively short period of time. An additional problem arises because usually a meter model is not produced for more than 2 or 3 years, or even less, without introducing significant changes in the design. Most of these modifications, although not externally perceptible, can alter the performance of the meter and the way its measuring error evolves with time. As a result it is almost impossible to predict how a meter model error will change with time, because there is not a well defined tendency. Different versions of the model will perform and degrade in dissimilar manners, even when they are under the same working conditions, and should be studied separately.

For this reason, a better approach for utilities to calculate in the medium-long term meters performance would be to make a continuous assessment of the error curve of installed meters. This way an appropriate quantity of meters of all ages (possibly versions) will be tested every year. With such approach a database of each version’s performance will be accessible and a significant amount of data will be available for the analysis.

In any case, it is important to keep in mind, once more, that the results obtained come from a statistical sampling of installed water meters and these results are uncertain. Knowing how to evaluate and reduce this uncertainty it is important to understand the results that will arise from the laboratory tests. Some of the uncertainties that can come up when estimating the error curve of the water meters are the following:

- *Erroneous stratification of the population.* The stratification of the meters is relatively easy if only variables like meter technology, brand, model and age are considered. However, the stratification is much more complex when trying to find other influence factors associated to the users or system characteristics. Examples of these parameters that may be of interest are the users facilities characteristics, the water consumption patterns of the users, the water quality, the number of pipe repairs in the network, weather conditions, etcetera. In such cases, the number of classes that should be created and sampled is so large that the study becomes unfeasible in the short term. Furthermore, as mentioned before, for a water meter model there may be changes through out the years in the manufacturing procedures and materials that can modify the influence of these variables on the metrological performance of the meter.
- *Incorrect testing procedure.* In first place the testing procedure can be wrongly defined. The selected flow rates, reference volumes, order in which the tests at different flow rates have to be carried out, or even the calibration of the test bench can have an important influence on the final results of the accuracy tests. In second place the tests can performed in an improper manner: faulty readings, meters that are left to dry for too long before they are tested, air remaining inside the system while the tests are done, etcetera. All these factors and circumstances can lead to confusing results which do not represent the real behaviour of the meters.
- *Unknown influence factors.* Some of the parameters may seem to have a random effect on the water meter accuracy and how it degrades with time. Since there are so many variables that affect the errors at the same time, the determination of the influence of a single variable may become a very difficult task. Besides, each user may have associated some specific variable (not identified) that can have a significant effect on the meter error curve. Examples are: a water softener upstream the meter, a particular pipe material, a leak, seasonal water consumption, etcetera.

The final result of this part of the work is an average error curve for each water meter stratum. In this case, the variables (errors of a given meter stratum for different flow rates) are not independent and the uncertainty of these variables has to be treated in a specific manner.

Calculating the weighted error

The weighted error is an indicator of the measuring efficiency of the water meters. It is calculated for each type of user and meter from the information of the water consumption pattern of the user and the error curve of the meter. It provides information about how much water it is not registered or registered in excess for a given meter and user type.

When analysing the results for the weighted error of a meter, the methodology used to “weight” both parameters is an important factor to be considered. Depending on the procedure followed to combine the water consumption patterns and the accuracy curve of the meters the weighted error will lead to different figures (Arregui et al. 2006).

Moreover, the interpretation of the weighted error should take into account the uncertainties related to the parameters used to calculate it. This way a final result of an estimated weighted error with an associated uncertainty can be given. It is always important to keep in mind that the weighted error of a meter is not a single figure (because of the way it is obtained) but an error interval in which, with a certain probability, the real error is expected to lay. This uncertainty has to be considered when planning future replacement scenarios to calculate the risks associated to the decisions taken.

It has been said before that this type of study has to be performed in a long-term basis. Therefore it is highly recommendable to have available a specific software package that can store and process both, water consumption patterns and water meter errors. This is the only way to guarantee that the calculations are always done in the same manner and are correct.

Case study

Following some results from a real case study will be analysed. During this work 200 households and more than 600 meters of different models and ages were tested.

Determination of the water consumption patterns

The water supply in which the study was carried out is a typical Spanish city, with most of its population living in apartment buildings. In order to determine the water consumption patterns (as the water meter perceives it) of domestic users four categories, depending on the type of hydraulic supply to the household and the water meter installation place, were defined:

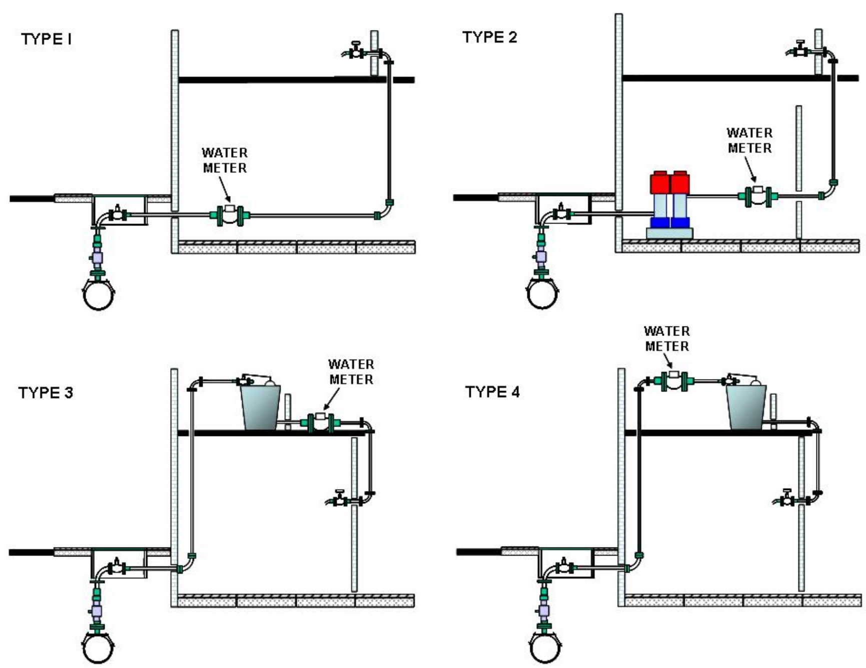


Figure 2. Categories of users considered during the study

1. Type 1. Direct connection to the water supply network. The water flows through the meter correspond exactly to the water demand inside the house. The consumption flow rates also depend on the network pressure.
2. Type 2. Water supply through a pump. The water flows through the meter correspond exactly to the water demand inside the house. The consumption flow rates are almost independent of the network pressure.
3. Type 3. Water supply through a reservoir with the water meter installed downstream this element. The water flows through the meter correspond exactly to the water demand inside the house. The consumption flow rates are independent of the network pressure.
4. Type 4. Water supply through a reservoir with the water meter installed upstream this element. The water flows through the meter depend on the inlet proportional valve and reservoir dimensions. The consumption flow rates depend on the network pressure.

Additionally, the influence that the amount of water that is consumed in a residence could have in the water consumption patterns was also examined. For that purpose, users with different monthly consumption volumes were chosen from each category.

Since the objective of this project was to obtain an initial approach to quantify domestic meters under registration no other variables that could influence water consumption patterns were examined at this stage.

A total of 200 users were monitored for at least a week to obtain the water consumption pattern. Class C oscillating piston water meters equipped with pulse emitters with a resolution of 0.1 litres were used. The users sampled for each category was calculated as a function of number of users in the water supply system. However, a minimum of 25 households for each category were monitored.

Difficulties found during the field work

Some users with the type 3 of configuration had installed pumps downstream the water meter to increase the pressure at the consumption points. In such cases the flow rates through the meter are conditioned by the pump operating point and do not correspond to the consumption flow rates of the user.

A number of the valves installed to control the refilling of the reservoirs were not proportional valves but shut-off valves. Therefore the filling of the reservoir was always produced at the same flow rate and the circulating flows through the meter for some type 4 households were not as expected.

Other users have a by-pass connection parallel to the reservoir. This way, when pressure in the network is sufficiently high, water is taken directly from the network. On the contrary, when pressure in the network is low the water is taken from the reservoir.

Conclusions

Users with configurations 1, 2 and 3 had similar consumption patterns. After a statistical analysis it was concluded that it could not be rejected the assumption that these consumption patterns belonged to the same group. The average consumption pattern of all households of this type (174 in total) with the associated confidence intervals for each flow rate range is shown in figure 3. The amplitude of the confidence intervals in the lower range is quite narrow. This means that the number of household monitored of these configurations is enough to have a good representation of their water used.

For users with configuration 4, for which the water meter is installed upstream the reservoir, the amount of water that is used in the lower ranges (less than 45 l/h) is significantly larger than for others configurations. The flow through the meter for this type of facility is in most cases restricted by the proportional valve that controls the refilling of the reservoir. Very often the highest flow detected is less than 500 l/h. The average consumption pattern for these households, including the associated confidence intervals for each flow rate range, is shown in figure 4. In this case, since the number of houses sampled is relatively small (26), the amplitude of the confidence intervals is much larger. This indicates that the number of houses that need to be monitored to obtain a reliable figure of the consumption pattern for this configuration, is considerable larger than 26.

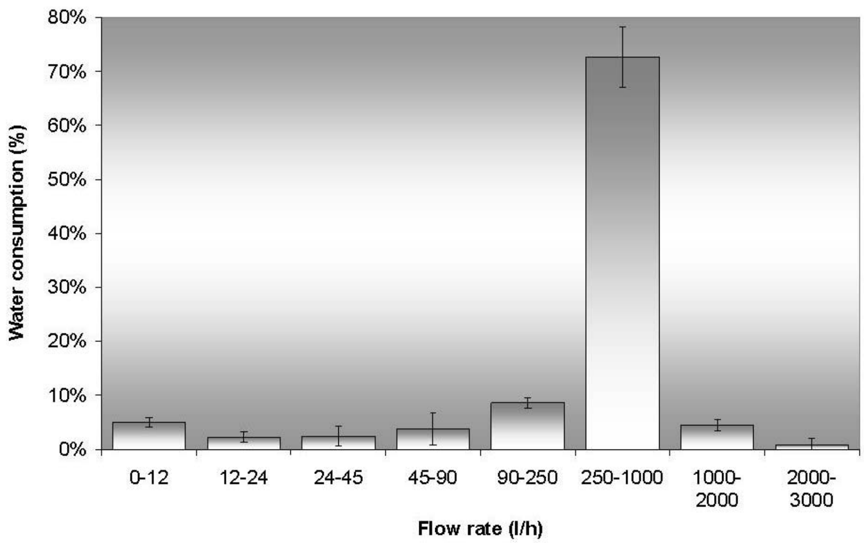


Figure 3. Water consumption pattern for meters which serve water directly to the user

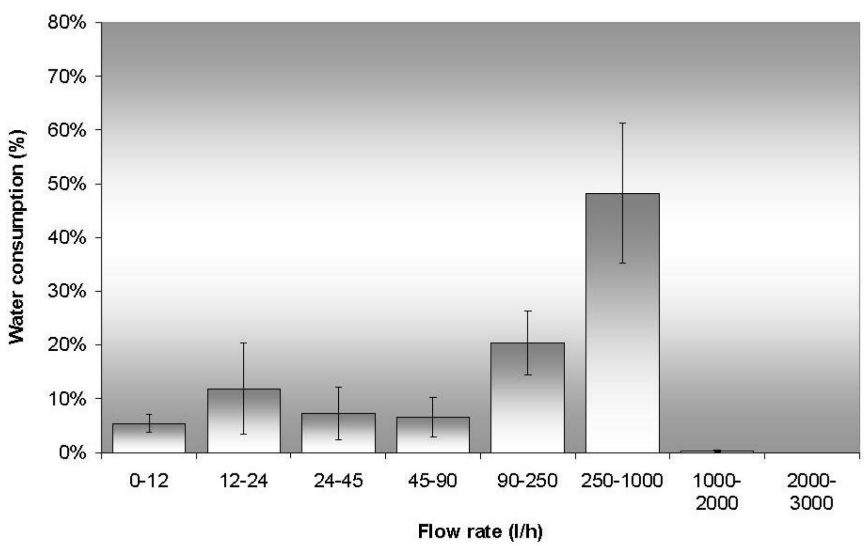


Figure 4. Water consumption pattern for meters which are installed upstream a reservoir

Finally when it was compared the average water consumption patterns of users with different monthly water demands it was found that there were not significant discrepancies as long as the water demand was not excessive.

Determination of the water meter accuracy curves

Approximately 75% of the meters installed in the water supply system under study belonged to two different models. Therefore the research project mainly focused in the analysis of these two models. A total of 160 meters of model 1 and 127 of model 2 were tested in the laboratory.

Meters of each model were also stratified into different age groups. The initial intention was to obtain a degradation rate for each model so the optimal replacement period could be calculated. However, due to the effect of unidentified variables a clear degradation rate could not be obtained, as shown in figures 5 and 6.

Prior to the laboratory work, the test procedure was carefully defined. Testing flow rates were selected so that the error curve could be reconstructed as accurately as possible from the resulting information from the tests. For this purpose meters were tested at six flow rates: 15 l/h, 30 l/h, 60 l/h, 120 l/h, 750 l/h and 1500 l/h.

Conclusions

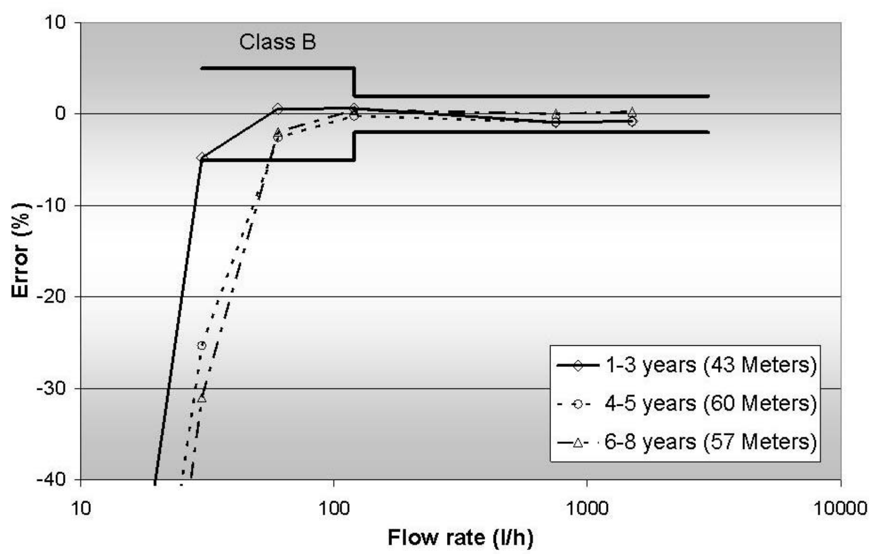


Figure 5. Accuracy tests results for two domestic Class B meters (Model 1)

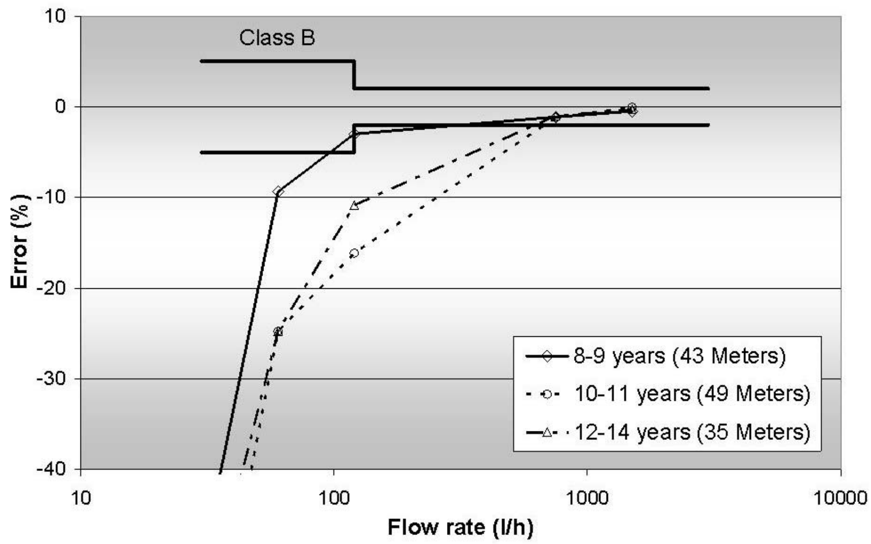


Figure 6. Accuracy tests results for two domestic Class B meters (Model 2)

As it can be seen, for model 1 (Figure 5), the average results of the error for meters 4-5 years old are quite similar to those obtained for meters 6-8 years old. The degradation of the meters seems to stop or at least slow down for the upper age ranges. A similar effect is detected for model 2 (Figure 6). The newer 10-11 years old meters show a similar accuracy curve compared to 12-14 years old meters.

For both meters the average error at 750 l/h and 1500 l/h remained inside the 2% error band. However, the behaviour at lower flows presented a much objectionable performance. Only 1-3 years old meters of model 1 were capable of maintaining its accuracy curve below the maximum permissible errors specify for a domestic Class B meter.

One of the factors that was identified as having great influence on the meters errors was the water quality. Calcium depositions inside the meter body, the turbine bearings and the entrance and exit nozzles caused severe damaged to the instruments, especially at low flows were the increase of drag has a significant effect on the error. However it could not be identified which variables (water quality parameters, brass composition, consumption flow rates, etc.) made the instruments more vulnerable from suffering calcium depositions.

In fact, model 1 presented two different degradation tendencies depending on how calcium depositions grew. During this study it was not possible to isolate the parameters that made depositions grow one way or the other.

Other common causes of meter failure were turbine breakage, uncoupling of the totalizer and the turbine at high flows, manufacturing defects that lead to inadequate low flow performance of new meters and a deficient repair of old water meters.

Another important result that should be mentioned is the high variability found for the error at low flows. In particular, only 5 meters of model 2 (from a total of 127) could measure water consumption at a flow of 15 l/h. The average error for these 5 meters was closer to -40% (Figure 7). At a flow of 30 l/h approximately 50% of the meters of model 2 were not able to register the flow. Even at 60 l/h there were 15% of the meters that could not measure any water consumption.

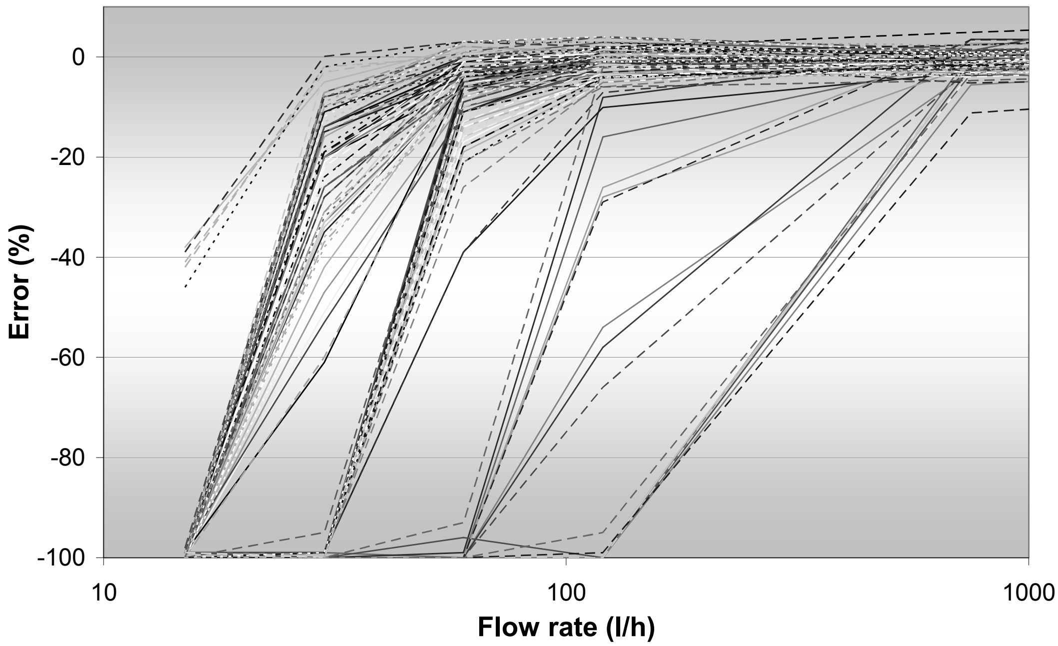


Figure 7. Accuracy tests variability of model 2 (160 meters)

Weighted error calculation

With the accuracy curve of the two models tested and the water consumption patterns of domestic users it is possible to calculate the weighted accuracy of the meters. For such purpose a specific software package was designed. This software is capable of storing all the information coming form the accuracy tests carried out at the laboratory and to manage all files containing the recorded water consumption of the users. In this manner it is possible to continue and update in the future the data collected during this project regarding the accuracy of the meters and the consumption flows of the users.

Furthermore, the availability of this software package, which incorporates a special modulus to calculate the weighted accuracy of the meters, makes it much easier, faster and reliable for managers the calculation of the metrological performance of meters which can be a quite complex task, especially when lots of data are collected.

Another important issue that should be mentioned when calculating the weighted accuracy is the importance of defining procedures. These procedures should be strictly followed when testing the meters and taking measurements of water consumption. If work is done following established procedures, collected data will have sufficient homogeneity to facilitate the analysis and to obtain more reliable results. Otherwise, the analysis of the data gathered during the study will be unfeasible.
The results obtained for weighted error of the two types of meters under study are shown in the following tables.
Model 1

Age	Meters which serve water directly to the user	Meters installed upstream a storage tank
1-3 years	-7%	-12%
4-5 years	-8%	-16%
6-8 years	-7%	-17%

Model 2

Age	Meters which serve water directly to the user	Meters installed upstream a storage tank
8-9 years	-11%	-23%
10-11 years	-13%	-28%
12-14 years	-12%	-26%

As it can be seen the final result for the weighted accuracy depends on many factors, each acting in a different direction, which lead to ambiguous results. Before the project started it was expected to find a degradation rate for the weighted accuracy of each meter model. Instead the value of the weighted accuracy found for different age groups of each model were quite similar.

For example, for model 2 the minor improvement of the error at medium flows (750 l/h) compensate the lost of accuracy at low flows in the 6-8 years old age group. This explains why meters 6-8 years old have a better weighted accuracy than meters 4-5 years old.

In both cases, the estimated errors of this single jet Class B meters when installed in a facility in which the flows through the meter are controlled by a proportional ball valve are very high. It is clear that under no circumstances these types of meters should be used in such facilities. Instead Class C single jet meters, oscillating piston meters or meters with a lower nominal flow rate (for example 0.6 m^3/h) should be installed.

Conclusions

Although serious field and laboratory work was carried out during this project at the end of the study it was clear that additional work was still needed in order to improve results reliability and to quantify the influence on the meters accuracy of different parameters. The complexity of this quantification comes from the fact that many variables are interrelated and affect meters accuracy simultaneously. Therefore, the amount of data required to identify the real influence of these variables is much larger than the information gathered during this project. For this reason, it was obvious that for this specific purpose, the study had to be extended on time.

However, to do so, well define procedures need to be implemented. Only with this approach it will be possible to store enough data in an adequately structured data-base and to analyse it in a simple and reliable manner. A common pitfall of many water utilities that initiate this type of studies has to do with the storage of the data collected, which is not saved in properly design data-bases that can support the insertion of new tests results and measurements of water consumption. For this reason it becomes very difficult to include in the original data set the additional work that can be done. Much information about how things are done or the procedures that were originally followed is usually lost.

In this sense, one of the most important conclusions that can be drawn from the project is the need of a specific software package that could manage and analyse all the information that can be collected in a long-term period. Such a tool assures that things are always done in the same manner and important information is kept saved and understandable.

Independently of the fact that the quantification of the influence of several parameters could not be obtained in this initial study, a reliable estimation of meters accuracy, and therefore commercial losses caused by meters inaccuracies, was calculated.

Additionally to meters accuracy, very interesting conclusions about meters performance and degradation were reached. In first place it was identify that water quality was an important factor in meters accuracy degradation. However, it was proved that this parameter does not affect all meters in the same manner since it interacts with other unidentified factors to produce dissimilar results. A prove of this was that even a specific water meter model, depending on where it was installed in the water distribution system, presented various degradation states. Water composition did not seem to be the cause for this result since some of the meters were installed in locations close to each other.

Another parameter that plays a major role in the accuracy rate of decay is the mechanical robustness of meters and its moving parts. It was found that a significant number of meters failures and meter under-registration were caused by the breakage of the turbine and the wear of the turbine bearings and the gears inside the totalizer.

References

Arregui F., Cabrera E Jr., Cobacho R. (2006). Integrated water meter management. IWA Publishing.

Arregui F.J. (1999). Propuesta de una metodología para el analisis y gestión del parque de contadores en un abastecimiento. PhD Thesis. Universidad Politecnica de Valencia. Spain.

Bowen P.T., Harp J.F., Hendricks J.E. and Shoeleh M. (1991). Evaluating residential meter performance. American Water Works Association Research Foundation . *Denver, CO*. USA.

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SOME EXPERIENCES IN REDUCTION OF LOSSES IN BELGRADE WATER SUPPLY SYSTEM

Stevo Savić, B.Sc.C.E.

Belgrade Waterworks

stevo.savic@bvk.co.yu

SELECTION AND INSTALLATION OF WATER METERS

INTRODUCTION

Water meter is the main element demonstrating all the values of a water supply system and fully determines its actual mobility.

The water meters are the last link in the system, faulty operation of which can render the entire activity absurd and compromise the operation of all segments of the a water supply system. This is where all the assumptions of the system values reduced to actual scopes end, and all the errors and deficiencies of the systems, visible and invisible, are sublimated from the entire system, from the production, the distribution up to the final link i.e. the water meter cubicle - the water meter.

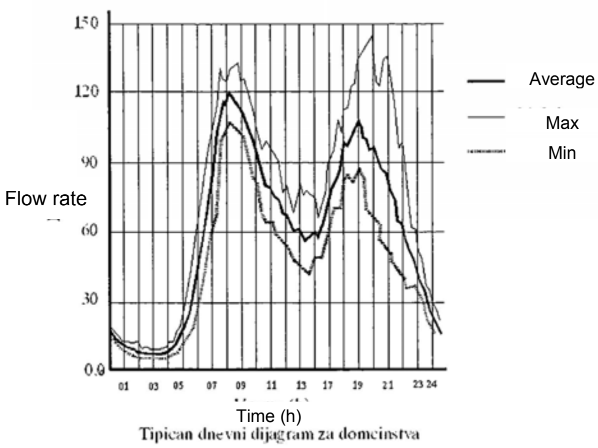
Hence, the logical question: "What would be the main motivation to select the water meter size in a more comprehensive manner?“ Namely, it is well known that all water meter producers provide, along with the accompanying material, in the form of various prospectuses, the information on the quantity of water required to pass through the water meter in order for it to set in motion and register the consumption. Subject to the size of the water meter, the water quantity required to set the mechanism in motion ranges from 15 l/h for the smallest water meters (13 mm) to 175 l/h for water meters with 50 mm diameter, in view of the fact that the increase of these values provided in l/h increases from one to the other water meter size by 50-100%. The scope of the losses produced this way can only be assumed. If, for example, we take a single family house with the standard connection (1") and ¾" water meter, namely Ø 20 mm, we have the following situation. Namely, it can be expected that the water meter in such a facility will have a significantly longer period of standstill at night time and at certain periods of the day. These water meter "standstills" range from 4-8 h a day. In case of a breakdown on the installations, namely, the tap points (leakage of WC tanks and taps), this water meter will measure the consumption, namely, the quantity of water required to set the mechanism in motion. In this case, this ranges between 15-45 l/h, according to the information of water meter producers, although in practice it is twice as much, according to the users' experience. For the subject facility (and the standard number of users) this represents a loss from 6-9 m^3/monthly i.e. over 30% of the usual consumption. If we know that the majority of the about 150.000 installed water meters in the Belgrade Waterworks System has this diameter, the enormity of the loss for the company is quite clear. This percentage is lower for the facilities with several apartments, due to the shorter period of standstill of water meters and makes up to 10% of the consumption. Hence, the continuous need to warn the consumers such defects should be eliminated in order to protect from the unnecessary loss of water. On the other hand, this can be prevented, of course, not completely, but sufficiently to provide all reasons for implementation. It is a question of a proper selection of water meter in order to reduce such and similar losses to an acceptable level. The losses produced by the wrong choice of a water meter will be discussed later and they are, unfortunately, greater and more destructive to the company than the above stated.

Due to such importance and in view of the resulting consequences, the choice and installation of water meters cannot be relinquished to offhand assessment, or assessment expressed only on the basis of hydraulic calculation of connection, which implies all types of possible consumption and regularly assumes the installation of unnecessarily large water meter, which then entails all negative consequences of the oversized water meter.

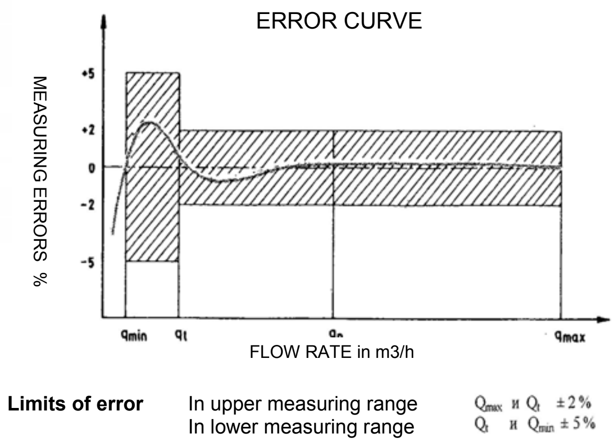
Further considerations on this subject will focus not just on the selection of the size of the water meter for the measurement of household consumption but also on all necessary assumptions i.e. parameters that have the greatest impact on this selection.

PEAK CONSUMPTION

In the desire to utilize the highest quality parts of the measurement range, compare the daily consumption diagrams and the water meter operation error diagrams, it was concluded that the peak consumption ("peaks") measured in the upper range of water meter operation (Qmax) is crucial for the selection of adequate water meter size.



Characteristic daily diagram
for households



Thus, the experts attempted in their research, applying elements of mathematical statistics to find a ratio, namely, a link between the selected time ("time base") and respective peak consumption.

In further research of the use of flushers and WC tanks, it was concluded that as with the largest tap points within the housing units the peak consumption (Qmax) for a short time base is greater in case of flushers (Figure 3). For a longer time base the results almost coincide in order for the flusher line with a time base of 1 hour to be lower than the one from the WC tank (Figure 4).

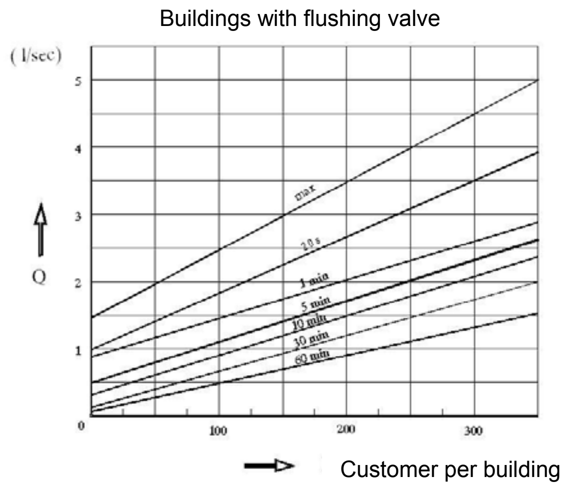


Figure 3

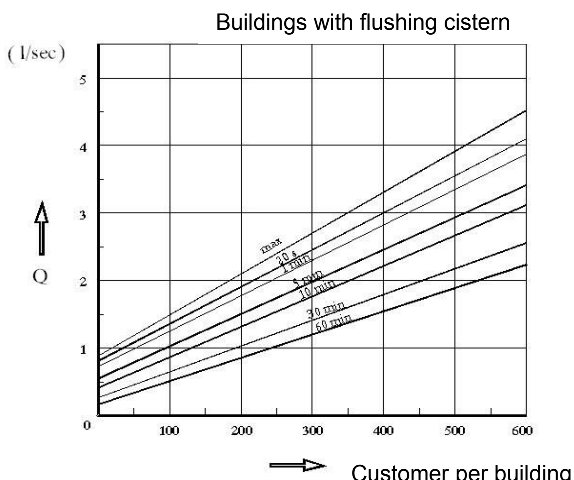


Figure 4

It is a general conclusion, based on this research, that the flushers have greater peak requirements than the WC tanks, but consume lesser quantities of water, measured in volume, due to possible time control of their use.

Finally, on the basis of all these analyses a method for calculation of installations from Diagram provided in Figure 4 was adopted, which demonstrates the ration of the number of users and peak consumption based on different time bases (facilities with WC tanks), where a 5-minute line was adopted for maximum flow, which actually represents a mean line (envelope) of measured points (Figure 5). They show precisely the inclination of the line in the positive direction with a certain standard deviation where this envelope includes 97.5% of the measurement points. Using the data from Figure 5 it is easy to calculate the Qmax, and accordingly determine the actual required size of the water meter.

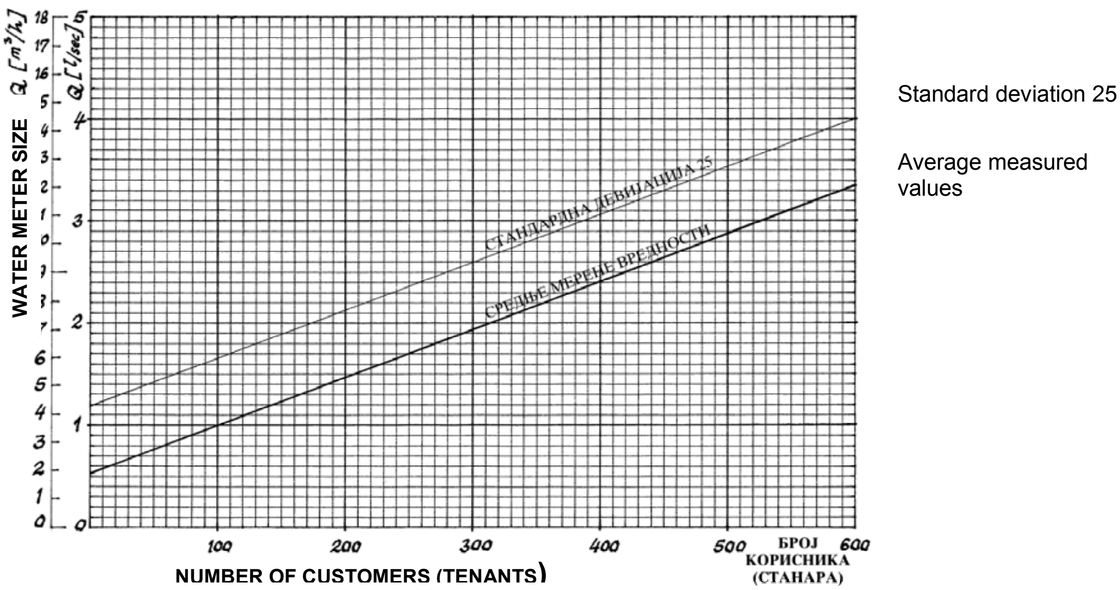


Figure 5

All previous researches based on various input parameters yielded a clear and explicit answer that a standard hydraulic calculation always gives oversized water meters which implies all negative consequences of such choice.

SELECTION OF WATER METER

In the attempt to find a unique way to determine the size of the water meter, subject to the number of housing units, calculated maximum flow and number of installed tap points of greatest size, the researchers found a solution in the form of a table, which makes it possible to come up with the optimum size of the water meter. When the maximum flow is calculated or found using the graph, the size of the water meter is determined very simply subject to the loss of the pressure in the water meter not exceeding 0.5 bar. This implies that the water meter has a load of 70% of the nominal (maximum) flow. The remaining 30% is retained as a possible reserve in case of extreme flows (peak consumption) in a short time interval (not longer than 5 minutes throughout the entire day). This is, of course, a sort of compromise between avoiding major pressure losses in the water meter and possible unfavorable choice of water meter which is larger than required.

The use of graphs and tables for determination of water meters shall be explained in a practical example which will show the results in case of determination of Qmax using the standard hydraulic calculation based on load units, as well as determination of Qmax according to number of tenants (apartments) from the enclosed graphs.

In an apartment building with 35 apartments, a calculation of building installations was made on the basis of unit load per each tap point. A simple addition of load units of all tap points yields a total load on the connecting part of the house installations and is relevant for proportioning the size of the water meter. Given example shows that the sum of units of load of all tap points in an apartment is 10 (unit load) (this includes the flusher, washbasin with tap, faucet, cold water tap…). The total load for the entire facility is 350 u.l. The respective flow of Q [l/sec] is obtained from the well-known formula $Q_{max} = 0,25 \sqrt{\Sigma \text{ u.l.}}$ Qmax = 4,68 l/sec.

According to the calculation the water meter adopted here would have the size of 30 m^3/h, (D = 50 mm).

Table 1

Water meter size in m^3/h	Water meter diameter in mm	Water meter load resistance per load unit in MWC*	Flow rate in l/sec at pressure loss in water meter of MWC* : (number of load units)									
			1	2	3	4	5	6	7	8	9	10
3	15	0.90000	0.264 (1,1)	0.373 (2,2)	0.456 (3,3)	0.527 (4,4)	0.589 (5,6)	0.646 (6,7)	0.696 (7,8)	0.745 (8,9)	0.791 (10,0)	0.833 (11,1)
5	20	0.32400	0.439 (3,1)	0.621 (6,2)	0.761 (9,3)	0.878 (12,3)	0.982 (15,4)	1.076 (18,5)	1.162 (21,6)	1.242 (24,7)	1.318 (27,8)	1.389 (30,9)
7	25	0.16530	0.615 (6,0)	0.868 (12,1)	1.065 (18,1)	1.230 (24,2)	1.375 (30,3)	1.506 (36,3)	1.627 (42,3)	1.739 (48,4)	1.845 (54,4)	1.944 (60,5)
10	30	0.08100	0.878 (12,3)	1.242 (24,7)	1.521 (37,0)	1.757 (49,4)	1.964 (61,7)	2.152 (74,1)	2.324 (86,4)	2.485 (98,8)	2.635 (111,1)	2.778 (123,5)
20	40	0.02025	1.757 (49,4)	2.484 (98,8)	3.043 (148,1)	3.514 (197,5)	3.928 (246,9)	4.303 (296,3)	4.648 (345,7)	4.969 (395,1)	5.270 (444,4)	5.556 (493,8)
30	50	0.01013	2.636 (98.8)	3.727 (197.6)	4.505 (296.2)	5.271 (395.0)	5.892 (493.8)	6.454 (592.6)	6.971 (691.4)	7.452 (790.2)	7.903 (888.8)	8.332 (987.6)

- Finally, applying the data on the number of tenants which were used by the researchers (2.6 per apartment), the same building with 35 apartments (which means 91 tenants in the building) in case of installed WC tanks, from graph in Figure 5, clearly shows that the anticipated maximum load is ~ 0,96 l/sec. The data is taken from the line of mean measured values (envelope) of all measured points for the time base as a 5-minute line. Table 1 shows a respective water meter size of 5 m^3/h (D=20 mm) with a pressure loss in the water meter between 4 – 5 m VS.

It is obvious that the use of a standard calculation would provide an oversized water meter and thereby all other problems related to major losses in small flows and, accordingly, more costly maintenance.

It is suggested to use this method of sizing the water meter based on researchers' several year experience in which the designers would have to have a reply to only two questions:

1. Number of tenants (apartments) in a building that is planned for connection?
2. Level of highest tap point in the building?

The reply to the first question determines the size of the water meter and the response to the second determines the need of a possible installation of the unit for pressure increase, if there is no existing pressure reserve in the distribution network.

INSTALLATION OF WATER METERS

Former practice in the installation of water meters was highly one-sided and deficient because, simply put, the water meters were installed in the water meter chamber directly between two stop valves. Such a layout of fittings does not observe even the most basic hydraulic requirements of providing a sufficient distance between the stop valves and the water meters for the disturbed flow, most frequently from the insufficiently closed stop valve, to return to the peaceful flow through the full section with a developed section rate, which would result in more reliable measurement data and longer period of water meter quality operation.

The experts dealing extensively with this issue, based on comprehensive research and looking for the most favorable terms of operation of the water meter, provided certain recommendations, namely, rules for installation of water meters and all pertaining (necessary!) fittings.

No.	Street name	House No	Replacem. of WM (same diameter)	Average daily consumption (ADC) in m3 for period		Replacem. of WM (smaller diameter)	Average daily consumption (ADC) in m3 for period	
				Winter	**Summer**		**Winter**	Summer
1	2	3	4	5	6	7	8	9
1.	Јурија Гагарина	277	Ø80		44,53	Ø50	45,63	
2.	Јурија Гагарина	255	Ø80		66,20	Ø50	63,68	
3.	Јурија Гагарина	235	Ø80		60,47	Ø50	60,18	
4.	Јурија Гагарина	241	Ø80		54,89	Ø50	61,29	
5.	Јурија Гагарина	243	Ø80		30,75	Ø50	34,78	
6.	Јурија Гагарина	237	Ø80		53,62	Ø50	57,13	
7.	Јурија Гагарина	169	Ø80		44,90	Ø50	48,27	
8.	Јурија Гагарина	247	Ø80		47,28	Ø50	47,00	
9.	Јурија Гагарина	251	Ø80		44,09	Ø50	37,62	
10.	Јурија Гагарина	271	Ø80		53,48	Ø50	76,31	
11.	Јурија Гагарина	275	Ø80		53,73	Ø50	56,86	
12.	Јурија Гагарина	261	Ø80		34,03	Ø50	37,73	
13.	Јурија Гагарина	197	Ø80		59,00	Ø50	59,63	
14.	Јурија Гагарина	263	Ø50		23,52	Ø30	21,98	
15.	Јурија Гагарина	253	Ø50		20,59	Ø30	22,75	
16.	Јурија Гагарина	267	Ø50		20,20	Ø30	21,06	
17	Др. Ивана Рибара	195	Ø50		8,80	Ø30	11,43	
18	Др. Ивана Рибара	199	Ø50		10,23	Ø30	12,84	
19	Јурија Гагарина	173	Ø80		60,51	Ø50	56,75	
20	Јурија Гагарина	239	Ø80		27,12	Ø50	34,30	
21	Јурија Гагарина	257	Ø80		31,64	Ø50	30,75	
22	Јурија Гагарина	167	Ø80		56,23	Ø50	57,00	
23	Јурија Гагарина	183	Ø80		51,81	Ø50	53,25	
24	Јурија Гагарина	187	Ø80		33,40	Ø50	40,00	
25	Јурија Гагарина	195	Ø80		15,61	Ø50	39,80	
26	Јурија Гагарина	249	Ø50		15,76	Ø30	31,75	
27	Нехруова	236	Ø50		8,27	Ø30	13,36	
28	Др. Ивана Рибара	187	Ø50		12,94	Ø30	14,56	
29	Др. Ивана Рибара	175	Ø50		11,65	Ø30	12,10	
30	Др. Ивана Рибара	171	Ø50		8,03	Ø30	12,90	
31	Др. Ивана Рибара	151	Ø50		11,51	Ø30	11,70	
32	Др. Ивана Рибара	147	Ø50		12,82	Ø30	22,00	
33	Др. Ивана Рибара	119	Ø50		10,94	Ø30	15,10	
34	Др. Ивана Рибара	103	Ø50		8,96	Ø30	25,04	
35	Нехруова	148	Ø50		14,81	Ø30	16,31	
36	Нехруова	152	Ø50		12,31	Ø30	14,31	
37	Јурија Гагарина	171	Ø80		29,62	Ø50	27,57	
38	Јурија Гагарина	189	Ø50		26,60	Ø30	28,72	
39	Јурија Гагарина	177	Ø80		11,67	Ø50	17,37	
40	Јурија Гагарина	211	Ø80		52,73	Ø50	48,89	
41	Др. Ивана Рибара	145	Ø50		17,93	Ø30	29,10	
42	Др. Ивана Рибара	167	Ø50		20,44	Ø30	18,29	
43	Др. Ивана Рибара	183	Ø50		16,12	Ø30	20,10	
44	Др. Ивана Рибара	179	Ø50		10,31	Ø30	17,56	
45	Др. Ивана Рибара	203	Ø50		5,11	Ø30	29,52	
46	Др. Ивана Рибара	207	Ø50		4,61	Ø30	7,35	
47	Др. Ивана Рибара	211	Ø50		7,84	Ø30	7,20	
				TOTAL:	**1356,99**		**1514,10**	

- The pipeline must be such that the water meter is always full of water.
- Elbows and T-pieces must be at least 10 D upstream and 5 D downstream from the water meter.
- The seals on the flanges (in larger water meters) must be placed precisely in order not to protrude into the pipes and disturb the flow.
- The non-return valves or pressure control units must be placed after the water meter at a distance of at least 5D.
- Valves (ball, stop, butterfly,...) must be installed at least 6-10 D upstream and 3 D downstream from the water meter.
- In order to preserve the water meter from undesirable material that might be found in the water it is necessary to install a strainer at 4-6 D upstream from the water meter.
- If the service is such that the creation of turbulence in the upstream pipeline is inevitable, a unit for settling the flow is used, namely, securing of developed section rate (bundle of pipes and system of radial wanes).
- If the settling unit is not used (in the situation of turbulent flow) it is recommended to use a distance of 10D upstream from the place of disturbed flow to the water meter.
- Before start up the water meter must be filled with water and handling of valves must be easy in order to avoid undesired effects of input air, as well as the water hammer which could damage the measurement unit.

The strainer (Figure 6) plays the most important role in mounting of all these fittings, the layout and the distance. It can certainly play a significant role in preserving the water meter, namely, its quality measurement, for the legal period of 5 years until its replacement.

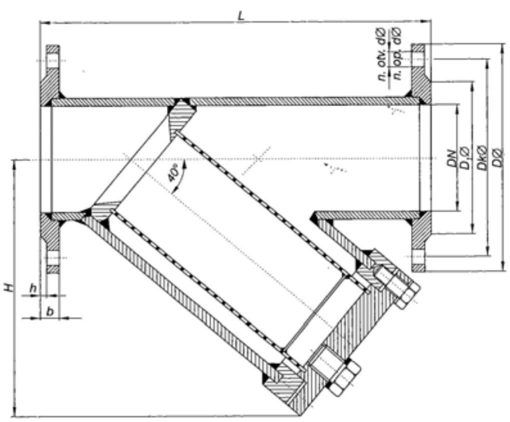
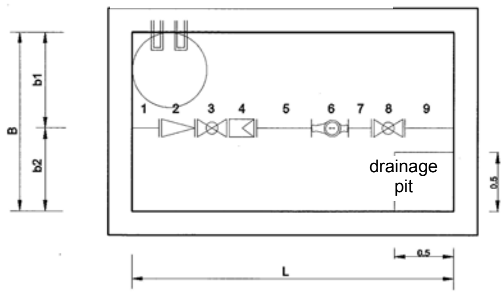


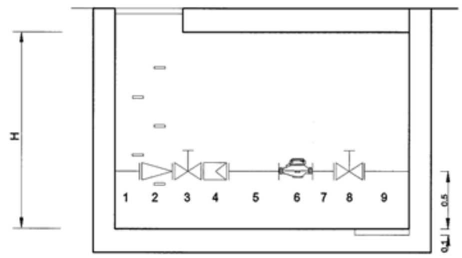
Figure 6

Diagram of a water meter chamber with fittings

CHAMBER LAYOUT (BASE)



CHAMBER LAYOUT (LONGITUDINAL CUT)



PILOT ZONE BLOCK 45 - NEW BELGRADE

In order to show the justifiability of the previous research the experts from the Public Utility Company of the Belgrade Waterworks determined a characteristic urban area (Pilot Zone), which has structures of various sizes (number of tenants) built within approximately same period. Of course, from the aspect of the choice of the water meter size, this zone is the most unfavorable group of consumers because the "standstill" period (most often during the night) is exceptionally short. It is during this period that greatest losses occur on small flows (leakage at tap points, network after the water meter and other fittings) which the water meter does not register. In individual houses (individual family houses, weekend houses, duplex apartments etc....) where the water meter "standstill" period is significantly longer, from 4-8 hours a day, the losses are significantly higher. A replacement of previously installed water meters was performed in the Pilot Zone by new water meters of smaller diameter and the water meter chambers were reconstructed as well as installed all necessary fittings as stated above. The results exceeded the anticipations, so that for the period winter-spring 2007 we have better measurement results (larger consumption) by ~12% with respect to the period of summer of 2006. The research is continued with another step of reduction of the size of the water meter (80 → 50 → 40) namely (50 – 30 – 25) which should raise these results even further.

No.	Street name	House No	Replacem. of WM (same diameter)	Average daily consumption (ADC) in m3 for period		Replacem. of WM (smaller diameter)	Average daily consumption (ADC) in m3 for period	
				Winter	**Summer**		**Winter**	Summer
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1.	Јурија Гагарина	277	Ø80		44,53	Ø50	45,63	
2.	Јурија Гагарина	255	Ø80		66,20	Ø50	63,68	
3.	Јурија Гагарина	235	Ø80		60,47	Ø50	60,18	
4.	Јурија Гагарина	241	Ø80		54,89	Ø50	61,29	
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6.	Јурија Гагарина	237	Ø80		53,62	Ø50	57,13	
7.	Јурија Гагарина	169	Ø80		44,90	Ø50	48,27	
8.	Јурија Гагарина	247	Ø80		47,28	Ø50	47,00	
9.	Јурија Гагарина	251	Ø80		44,09	Ø50	37,62	
10.	Јурија Гагарина	271	Ø80		53,48	Ø50	76,31	
11.	Јурија Гагарина	275	Ø80		53,73	Ø50	56,86	
12.	Јурија Гагарина	261	Ø80		34,03	Ø50	37,73	
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34	Др. Ивана Рибара	103	Ø50		8,96	Ø30	25,04	
35	Нехруова	148	Ø50		14,81	Ø30	16,31	
36	Нехруова	152	Ø50		12,31	Ø30	14,31	
37	Јурија Гагарина	171	Ø80		29,62	Ø50	27,57	
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42	Др. Ивана Рибара	167	Ø50		20,44	Ø30	18,29	
43	Др. Ивана Рибара	183	Ø50		16,12	Ø30	20,10	
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46	Др. Ивана Рибара	207	Ø50		4,61	Ø30	7,35	
47	Др. Ивана Рибара	211	Ø50		7,84	Ø30	7,20	
				TOTAL:	**1356,99**		**1514,10**	

The type and size of the range of optimum measurement with the loss of pressure in the water meter from 1-5 m VS, namely from 0.1-0.5 bar and is presented in Table 2 which shows that according to actual consumption measurement results in the Pilot Zone in the period of highest consumption, the installed water meters with diameter Ø80 mm, could be replaced completely with diameters of Ø25 mm.

Table 2

Water Meter diameter (**mm**)	Flow rate **l/s** with pressure loss in water meter of **1 MWC***	Flow rate **m3/ day** with pressure loss in water meter of **1 MWC**	Flow rate **l/s** with pressure loss in water meter of **5 MWC**	Flow rate **m3/ day** with pressure loss in water meter of **5 MWC**
Ø 15	0,264	23	0,589	50
Ø 20	0,439	38	0,982	84
Ø 25	0,615	53	1,375	118
Ø 30	0,878	76	1,964	168
Ø 40	1,757	152	3,928	336
Ø 50	2,634	228	5,888	508

The savings and the gain the Company could realize is perfectly obvious if one knows that a Ø25 mm water meter yields significantly better measurement results than the water meter Ø80 mm, is less expensive for maintenance, easier to install, requires a smaller water meter chamber, etc.

CONCLUSION

The conclusion is well known, and is agreed with by almost all researchers, that the highest losses are experienced on the connections. Besides the well known weak points on the connection (connection to service pipe, fitting connections in the chamber and other possible connections to the house installations), other large group of weak points are household services i.e. tapping points. The small flows at these points, due to incorrectly selected water meters, are not registered, and they regularly produce major losses, which is particularly characteristic for the night flows. It is a certain fact that the properly selected water meter could prevent such losses, including as well the obligation of installation which would provide quality measurement for the period until the legal replacement period.

REFERENCES:

Ingnar Bergquist, Helsingborg - Choise of type and size watermeters

DVGW – Standards

L. Ljujić, Beograd - Određivanje veličine vodomera za merenje kod potrošača

Mutschmman - Stimmelmayr - Snabdevanje vodom D. Obradović, Beograd - Savremeni vodovodi – informatika i operativno upravljanje

W.C. Wijntjes, Groningem - Peak demand and watermeters

When Customers Don't Pay: The Problem of Unpaid Bills

R H Jones, RM Consulting Associates, 14 Pilley Road, Tupsley, Hereford HR1 1NA, UK
roger.jones@rm-consult.com

Keywords: provision for bad debts; collections; non-revenue water

Synopsis

A water utility with a low collections ratio must not only tackle the causes of poor collections, but also address the rising investment in accounts receivable (customer debtors) on the balance sheet that results from low collections. Standard financial accounting practices and tax rules do not always permit an adequate provision to be made for what may be inevitable losses whatever their cause. This paper proposes a pragmatic approach to highlighting the measurement of collections along with making an adequate provision against the real threat of having to write-off customer balances some time in the future. There are implications for non-revenue water analysis.

The Setting: Challenges and Helping Hands

The issues highlighted in this paper are particularly relevant for water utilities operating in developing regions as well as those undergoing transition in a drive to achieve some degree of sustainability in the longer term. However, utilities in other circumstances may find some useful pointers towards addressing performance monitoring.

What does any water utility HAVE to do?

Essentially, **the following basic activities** (consistent with quality, affordable cost and other obligations):

- Abstract, treat and distribute potable water to its customers
- Collect, treat and dispose of wastewater
- Maintain, upgrade and expand (when necessary) the physical infrastructure
- Train and develop its workforce
- Measure and bill (invoice) consumption accurately and on time
- Obtain payment from customers for services supplied.

Developing countries need and receive assistance from a number of quarters:

- Funding and donor agencies, such as the World Bank, KfW or GTZ
- NGOs, like WaterAid
- Private sector organisations
- Public – Private Partnerships

International bodies such as the IWA have played a role in developing industry-wide tools to help the utility meet the various challenges. **NRW has become an established tool and backed by an ever-increasing application and expertise base, yet the problem of NRW continues to plague many utilities.** A recent paper highlights this situation and proposes a performance contract approach (Kingdom et al, 2007).

The Symptom: A Low Collections Ratio

The label – collections - is applied to the value of receipts from payments by customers for water (and sewer) services consumed by them and billed to them. The process chain for a water utility sets collections in context. The process chain for a water utility is **transformed from operations/water to commercial/cash** at the point of consumption as shown in figure 1 below.

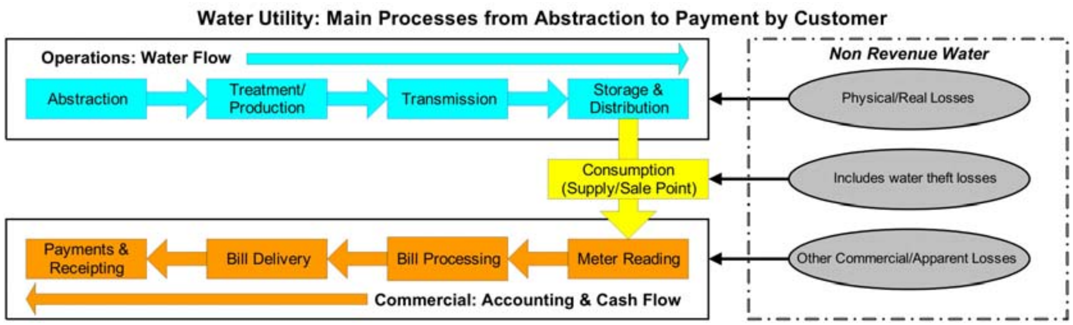

Figure 1

In Figure 2 the **key accounting entries** are shown in the "T" accounts in the boxes added to the previous diagram.

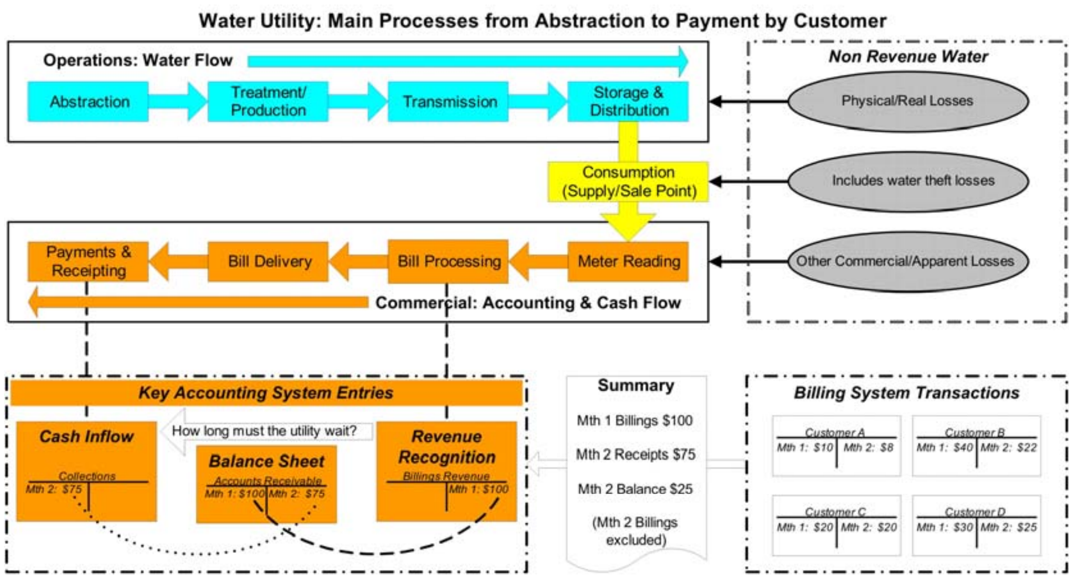

Figure 2

In efficient water utilities there is usually a tight linkage between the billing system and the accounting system to the extent that the two systems form a key part of the wider integrated information and control system. Unfortunately, many utilities' systems have a disintegrated relationship or one that is not what it should be and could be.

Conceptually, collections can be shown as an "equation" which incorporates the many factors, financial and non-financial, which have a bearing on the amount of collections. This "equation" is shown in figure 3.

The efficiency of the collections process, and also a proxy indicator of total service quality perception and the influence of all the other factors in the "equation", is measured in its most simple form by the following formula, **the collections ratio**:

Collections (payments by customers for bills)/Billings Revenue (value billed) x 100

This formula can and should be adjusted to allow for the lag between billings and the standard credit period allowed as well as any billing processing time:

Collections in month [M]/Billings Revenue in month [M – 3](value billed) x 100

A sustainable level of collections of at least 95% can be a problem for some water utilities, especially in many developing countries. It is unfortunate, but by no means unusual, for collections ratios to be well below 95%; 40% or even lower in some cases. Despite the sometimes vigorous efforts which the water utility management team may make, collections often remain below par.

Why is the collections ratio so often below an acceptable level?

The reasons for a poor collections ratio can be **many, varied, and often inter-related**:

- **Poor service which reduces the willingness to pay**; this can lead to a **vortex of failure** in which low collections lead to cost cutting, which results in lower service and this results in even lower collections and so on
- **A culture of non-payment**, perhaps aggravated by political factors
- **Affordability** issues for the poorer sections in the community
- **A non-existent or weak regulator** and poor legal framework for debt recovery
- **Meter inaccuracy, errors in meter reading and/or billing**
- **Low customer data quality** and record maintenance
- **Fraud and collusion** between utility staff and customers or illegal consumers

These and other factors can be summed up in the "collections equation" in figure 3 below. This makes it clear that all utility personnel, and many of the stakeholders, have a role and a responsibility.

The Collections "Equation"

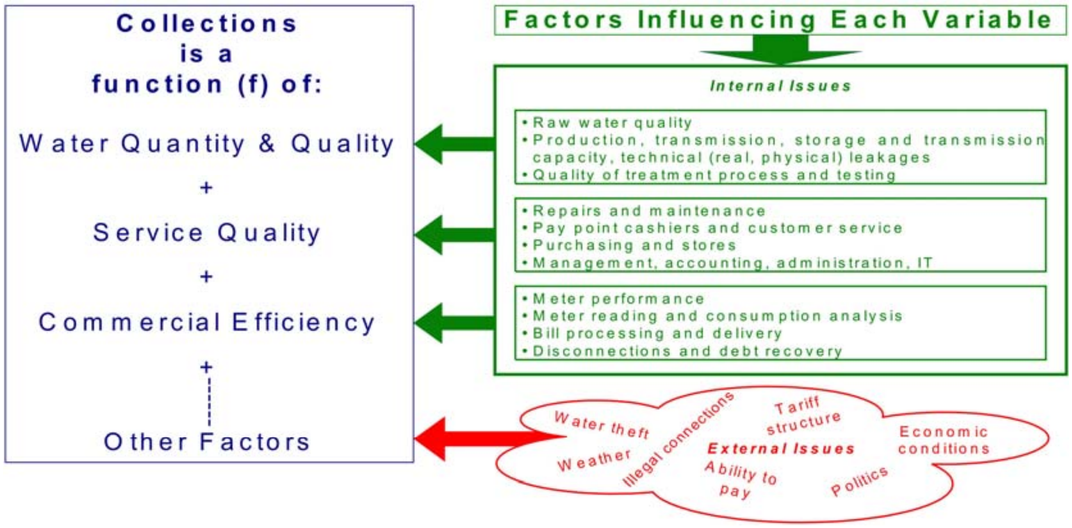

Figure 3

The situation is a double-edged sword: both billings revenue and accounts receivable are often overstated and the prospect of payment in full, even in the longer term, remains a distant hope increasingly incapable of ever being achieved.

The Problem: Overstated Billings and Accounts Receivable

If collections are consistently tracking below 100%, then the balance in accounts receivable (and in the billing system) MUST increase. **Over time this can lead to a significant rise in the investment in the accounts receivable figure in the balance sheet.**

For example, a 75% collections ratio results in the investment in accounts receivable doubling in less than six months. The schedule in Table 1 and the chart in Figure 4 below illustrate this.

Table 1

Accounts Receivable Balance with constant Billing and 75% Collections per month												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Monthly Billings	100	100	100	100	100	100	100	100	100	100	100	100
Monthly Collections	0	75	75	75	75	75	75	75	75	75	75	75
Accounts Receivable Balance	100	125	150	175	200	225	250	275	300	325	350	375

Quick rule of thumb: any collection rate trend < 92% = a doubling in accounts receivable < 12 months!

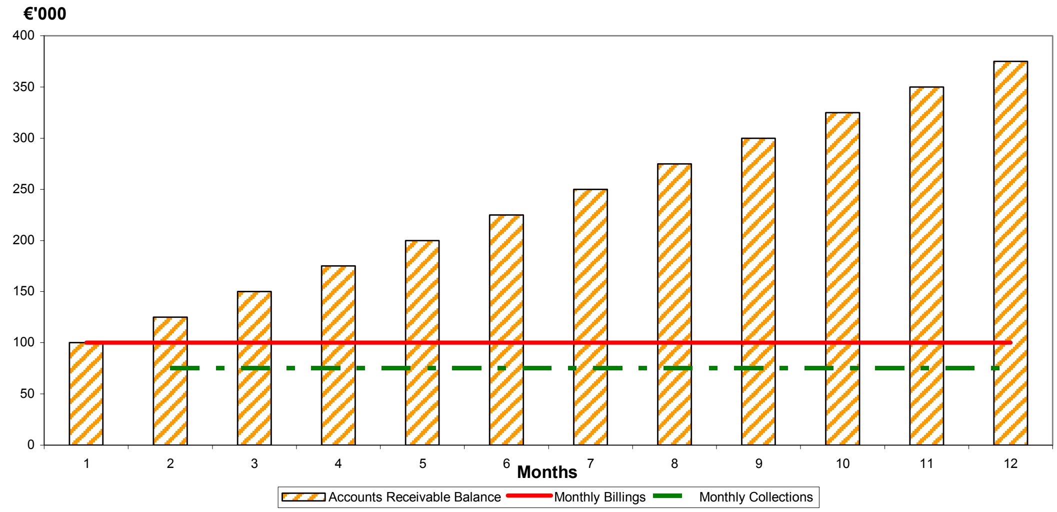

Figure 4

But **even a steady, but slow, improvement in both collections and billings still results in a doubling of the investment in accounts receivable after a few months**, as in Table 2.

Table 2

Accounts Receivable Balance with improving Billing and improving Collections at 1% per month												
Month	1	2	3	4	5	6	7	8	9	10	11	12
Monthly Billings with improvement	100	101	102	103	104	105	106	107	108	109	110	111
Monthly Collections with improvement		75	77	79	80	82	84	86	88	90	92	94
Accounts Receivable Balance	100	126	151	175	199	222	244	265	285	304	322	339

What does this increasing debt balance consist of? Inter alia . . . .

- Bills for the previous month and prior months, but still within any prescribed time period before disconnection can take place
- Bills for earlier months still outstanding and which are NOT the subjects of formal customer service requests for investigation – **it is the value of this component that really drives up the investment in accounts receivable**
- Bills which are being investigated due to complaints by customers that they are too high in terms of normal consumption
- Bills for customers who are no longer at the service connection address
- Bills for dormant or deceased customers but which have not been identified and cancelled by the utility's internal business processes

These various components are not completely offset by sufficient collections which themselves may be further reduced by fraud in the absence of suitable internal controls to confirm that receipts are duly banked and credited to the customers' accounts.

At the same time, operating costs are increased due to illegal connections and reconnections, other theft (some consumers steal water because they are able to; contrast this with electricity), use of flat assessed consumption for unmetered customers, the labour-intensive nature of (any) formal disconnections, and so on; emerging technology in water meters and flow limiters (including the ability to carry out remote cut-offs) holds some promise for future efficiencies.

While remedial action to reduce errors and system problems must necessarily be addressed, ***water utility management MUST recognise that the accounts receivable balance is almost certainly overstated, because with every month that goes by and a debt remains unpaid, the less likely is eventual repayment, especially if legal countermeasures are non-existent or slow***.

Water flow and cash flow: the cash reservoir

Cash flow can be likened to water flow in a semi-closed system (figure 5). If the cash reservoir runs dry, so will the water reservoir.

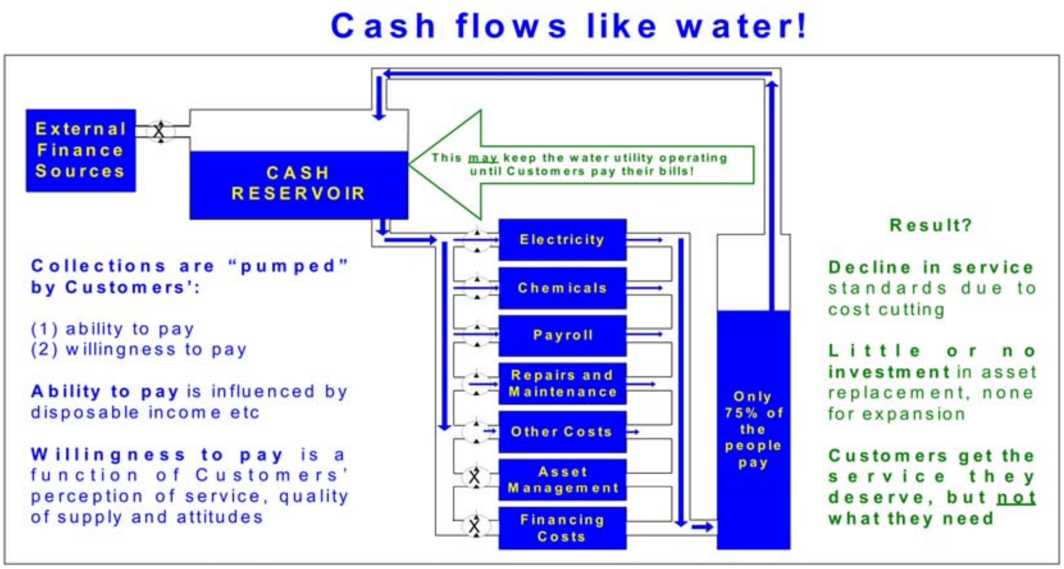

Figure 5

The Situation: Insufficient Provision for Doubtful Debts

The previous process chain diagrams are complemented by the link to rising investment in accounts receivable, along with a cash outflow link back to the Operations and Water Flow.

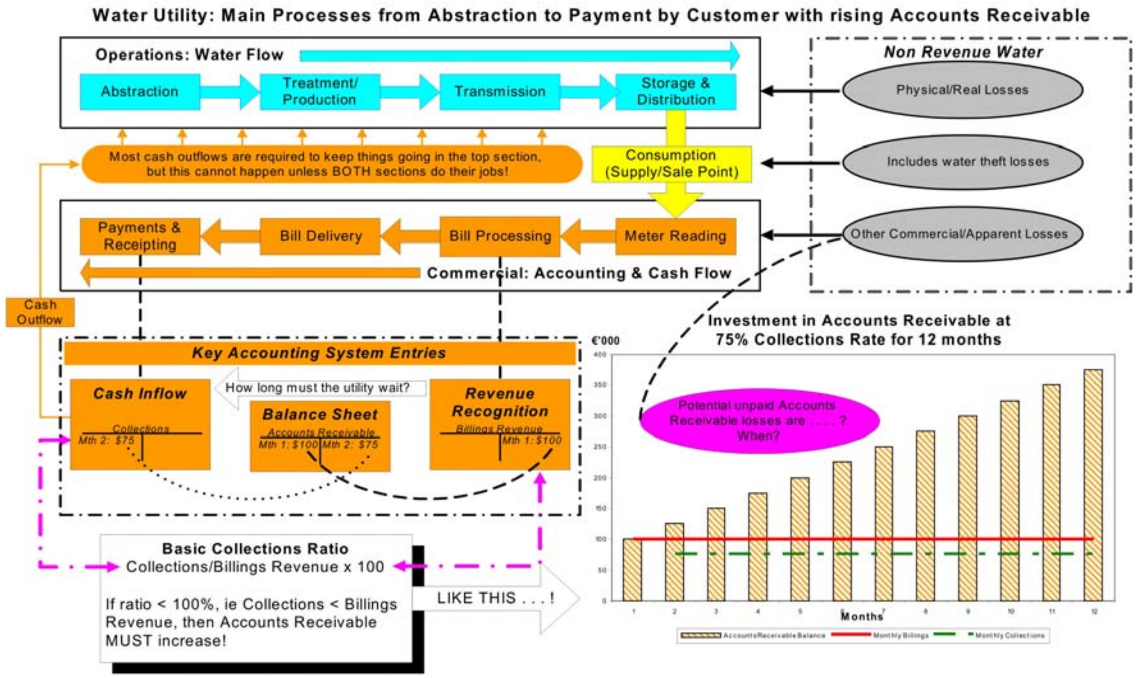

Figure 6

The outstanding balance is often monitored every month, but no provision is made until the financial year-end. **The standard year-end provision is too late and is usually too low.** Many (but not all) countries' accounting practices and tax legislation only allow a standard percentage of the accounts receivable balance as a provision for doubtful debts. This percentage is often based on an average for all businesses, eg 5%.

The problem is aggravated by directors/management/other stakeholders' refusal or unwillingness to make a realistic provision for doubtful debts (in reality, doubtful debts and any overstated billings from errors). It is the six monthly or annual accounts preparation that can give rise to the following situation:

The finance director meets with the external auditors who ask, "Of the €5,000,000 owed by customers, how much can reasonably be expected to be paid within the next few months?"

The commercial director and the revenue/billings manager are called in to present their findings; they state that due to the age of the debt and probable system/data errors, only €3,750,000 can be assessed as realistic.

At this point chaos threatens. A provision or write-off of €1,250,000 will either turn the year's preliminary financial performance into a loss or worsen an existing loss. Also, the standard allowance for doubtful debts in terms of national accounting policy guidelines may only be 5%, or €250,000.

Management knows that the directors are almost certainly going to refuse such a provision or adjustment to be made. So after the board of directors has said things like, "Management must focus on collecting old debt, step up disconnections etc etc", a standard provision of 5% is applied.

And so the balance grows.

Not only, but also: other problems

The situation can give rise to another problem. Management reviews the monthly accounts which show revenue as billed, but not necessarily cash collected. This may present a positive profits picture and some managers may base their operating and capital expenditure decisions on the strength of reported revenue and profits instead of the cash position. **Unless there is an unremitting focus on cash flow and communication at a management level, the water utility will slip into the vortex of failure.**

Yet another problem: when the day comes to consider a water utility as a candidate for corporatisation or for a management contract, both the quantity and quality of the existing investment in accounts receivable will come into sharp focus (along with the fixed assets etc as well). **Who would want to take over a balance equivalent to three years or more of monthly billings? Which entity will take the decision to write off ancient and/or fictitious debt? The day of reckoning for accounts receivable WILL come!**

Non revenue water (NRW) as currently defined by the IWA does not include unpaid bills that may never be paid, ie revenue water is billed water only. But what if the bill is never paid? **There is nothing "apparent" about an unpaid bill that has to be written-off, whatever the cause (over-age, data error, amnesty), it is a "real" loss.**

The Proposal: A Monthly Provision for Doubtful Debts

In order to make a provision for doubtful debts that will (a) handle true debt write-offs for irrecoverable balances, (b) provide some cover against fictitious debt resulting from errors and customer data problems and (c) focus on the issue through regular monthly reports, **it is recommended that the water utility adopt the following**:

Make a provision for doubtful debts EVERY MONTH based on the difference between the actual collections for the month and the consumption billings for a realistic previous month (or an earlier month before that, depending on local circumstances).

Accounting entries

The accounting entry is:

Debit:	Doubtful debts adjustment (a "negative" revenue account)
Credit:	Provision for doubtful debts (a balance sheet account)

Tlhe collections and billing figures used should only relate to consumption billings and receipts, and not non-consumption revenue or cash transactions, such as connection and reconnection charges, penalties etc.

A simple example is:

Consumption billings for the month of May		€125,000
Consumption receipts for month of August		€ 92,750
Accounting journal entry for August		
Debit:	Doubtful debts adjustment	€ 32,250
Credit:	Provision for doubtful debts	€ 32,250

If as a result of a disconnections campaign, or a big payment by government for overdue accounts, the collections total exceeds its billing "base", there will be a positive doubtful debts adjustment and a corresponding reduction in the balance of the provision account.

It is important to note that the above entries are ONLY processed in the accounting system. An advantage of this is that one can always check that the accounts receivable balance without the provision is equal to (or should be equal to!) the sum of the total customers' balances in the billing system.

It is also important to note that the accounts receivable balance in the accounting system is the same as the closing balance in the billing system. Only when the delinquent customer balances have been formally reviewed and authorised for write-off can a matching entry be processed in accounts receivable with the debit entry going to provision for collections write-down. The source documentation for calculating the actual write-off will come from the billing system.

Note on accounting standards and tax

Let it be stated: the proposal outlined may NOT reflect the standard accounting policy contained in legislation or international accounting standards etc. It is intended to be a management accounting approach which focuses on the issue constantly and highlights collections performance (the NUMBER ONE non-technical/financial/commercial Key Performance Indicator) **EVERY MONTH** in the operating reports. It ensures that an adequate, conservative provision is made where the historical and current collections ratio performance is lower than it should or can be and is threatening viability. It focuses on the cash performance of the water utility by reducing consumption billings to a cash or near-cash equivalent. This does not replace the cash flow schedules, but it does highlight the cash revenue as the main source for affordable expenses and capital investment.

It is NOT a cop-out that permits actual debts to be written off just because there is an adequate provision. There STILL needs to be a focused and rational review of which debts really have no hope of ever being repaid and thus will become non-revenue water (NRW).

There is nothing to prevent the auditors etc adjusting the provision for year-end reporting and tax calculation purposes, but the proposed approach is aimed at facilitating management of the problem. Another advantage is that monthly reporting and monitoring of collection trends may assist the water utility in obtaining special relief from existing tax provisions; this because of the incidence of lower collections than that "enjoyed" in the cash economy elsewhere.

Action This Day

- **Make a monthly provision NOW**, throw the problem into the spotlight, do not wait until the end of the current financial year.
- **Get a PROPER billing system (fit for purpose)** which enables the customer to be managed properly. What is referred to as the billing system should be a comprehensive customer management system. Such a system will have several integrated modules (customer service including contracts, meter management and meter reading, bill processing and printing, receipting, debt management including disconnections management); the system should have tight links with other important functional information systems, such as operations, GIS/cadastral, and accounting.

- **Look at the cost benefits from emerging technology in metering and meter reading** as the costs of these devices and associated systems comes down. Assess what a remote cut-off capability could do for the utility and slow-paying customers.
- **Make sure management and supervisors understand the basics of water utility economics. Educate customers and stakeholders** in the need to pay bills and why this means sustainability and continued benefits for the consumers.
- **Lobby the people that can make things happen to see if legislative countermeasures for unpaid bills can be improved** to enable the utility to obtain what rightfully belongs to it – the unpaid debt.
- **Monitor collections hourly, daily, weekly, and monthly.** Review trend data such as moving annual totals/averages/growth rates to offset seasonal factors. Question anomalies and get answers. Do not use the monthly budget as your sole benchmark; do frequent projections, remembering the three golden rules: reforecast, reforecast, reforecast.

The IWA Water Balance - A Necessary Revision?

Billed water volume and revenue that is not paid and has to be written off is a LOSS. As such it represents another component of Non-Revenue Water; ONLY water volume which has been BILLED AND PAID FOR can truly be labelled as Revenue Water. This requires a modification in the standard IWA balance and its components.

IWA Water Balance: Alegre et al, amended Jones, Whiting

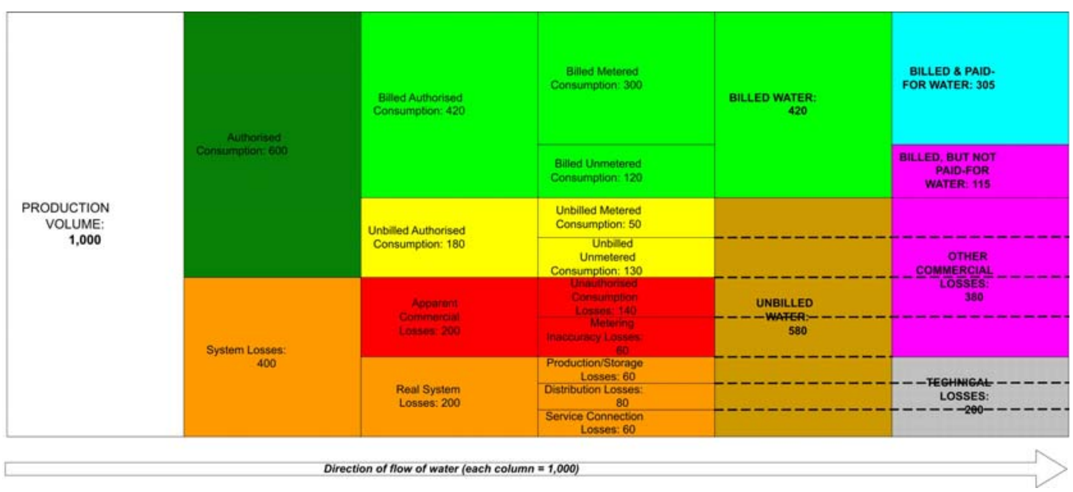

Figure 7

Note that Revenue Water and Non-Revenue Water have been replaced by Billed and Unbilled Water, <u>because this is what they are</u>. The author and select colleagues recommend that other IWA water balance current labels/definitions be reviewed so that the link between volumes and revenue be tightened to reflect a more integrated approach.

The terms "Real" and "Apparent" should be re-assessed to enable a more realistic consideration of each to be realised. For example, what is "apparent" about water volume that is billed, but never paid for? It is a real loss! Perhaps "Real" should be described as "Leakage" or "System/Technical Losses"; similarly, "Apparent" should be viewed as "Revenue Losses".

Outside the immediate scope of this paper is **the effect of targeted losses/leakage yardsticks** which can influence the reporting of performance and the relationship with tariffs.

Conclusion

High and escalating levels of accounts receivable are a feature of many water utilities, especially those in developing, transition or recovering regions. Review of the investment in accounts receivable cannot be left to an annual event. **The problem must be tackled on an ongoing basis.**

A pragmatic approach will permit a adequate provision to be made and therefore enable an equally more realistic presentation of revenue and financial performance.

The current labels applied to the IWA water balance components need to be addressed. **The relationship between volume performance and revenue performance should be tightened.** Physical system sustainability and financial sustainability cannot be separated.

Final Note

An expanded version of this paper with illustrative examples of accounting transactions and management accounting report formats is available from the author.

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- David Baker, independent consultant (Dar es Salaam, Tanzania)
- Valued colleagues engaged in operational utility management and consultancy (various)
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References

Kingdom W, Liemberger R, Marin P; The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries – How the Private Sector Can Help: A Look at Performance-Based Service Contracting; World Bank, Water Supply and Sanitation Sector Board Discussion Paper Series, Paper No 8, December 2006.

Managing leakage economically

Ing. D Rogers [1], Prof M Gastaldi [2], Ing. A Figliolini [3]

(1) Managing Director DEWI S.r.l., Perugia, Italy. email: dewiltd@tin.it

(2) University L'Aquila, Italy. email: gastaldi@ing.univaq.it

(3) Managing Director INGEA S.r.l., Avezzano, Italy. email: a.figliolini@ingeasrl.com

Keywords: Economic Leakage Management, Decisional Support System, District Meter Areas

ABSTRACT

The need to keep a low leakage level is a priority for most water utilities. It has been demonstrated in many parts of the world that the most effective way of doing so, is by dividing the network into a number of sectors called District Meter Areas (DMAs), each supplied by a single pipe on which is installed a flow meter. In this way it is possible to permanently control the level of leakage, identify the presence of a new leak and more efficiently eliminate it. Leakage is an economic problem and as such needs to be managed accordingly. This paper describes an innovative Decisional Support System (DSS) which compares the cost of repair with the value of the water recovered, to decide whether an intervention is economically justifiable. In addition, it has a self-teaching algorithm which allows the prediction to be tailored to the characteristics of each individual DMA.

Introduction

There are many reasons for attaining and subsequently maintaining a low leakage level in water networks, chief amongst which is the environmental and social damage that the over exploitation of such a valuable natural resource can cause. Of even more significance perhaps to many water utilities, is the economic impact of pumping and treating almost twice as much water than is delivered to the customers.

Historically, leakage location was undertaken either in a passive way, whereby a repair was executed only when the leakage become visible, or in more advanced situations, by systematically surveying the whole network using acoustic instruments. Although reasonably successful in locating leaks, neither method was particularly efficient. What was needed was a control system which allowed the leakiest parts of the network to be targeted at the most appropriate moment.

The recognition of the need to permanently control leakage, occurred in the UK around 25 years ago with development and application of the District Meter Area (DMA) concept. The basis of the approach is to divide the network into a number of discrete areas, preferably supplied by a single pipe, on which is installed a flow meter. In this way, it is possible to quantify the leakage level in each district. When the presence of a new leak becomes evident, the leakage location activity can be directed to that part of the network where the leak is located. This approach has been applied with universal success all over the world, to such extent that it is now considered the optimum method for controlling leaks. Some difficulty has been experienced in dividing very complicated and inter-connected networks, but this can be overcome with the application of mathematical simulation models. New, advanced GSM logging and transmitting technology has been developed to allow on-line control of leakage to such an extent that leakage teams can be on site locating a leak almost before it has occurred. The Guidance Notes of the IWA Water Loss Task Force describes in detail the process of defining, and setting up DMAs.

As the number of DMAs to be managed has increased, so have the availability of automatic decisional systems to prioritise the leakage location activity. Invariably, such systems are based just on the quantity of water lost. What they don't take account, is that leakage is first and foremost an economic problem. It costs money to extract, treat and distribute water. To loose a large part of it through burst in the pipe, represents therefore a very significant economic loss. But to eliminate a leak is also costly. So the question that needs to be addressed is whether it is economically worthwhile to intervene. This paper outlines a Decisional Support System, developed by the University of L'Aquila in central Italy in collaboration with DEWI S.r.l., which has extensive experience of applying leakage control technology all over the world and INGEA S.r.l. which is currently involved in undertaking what is probably the largest leakage control project ever undertaken in Italy, with the aim of answering this question. The project was funded primarily by the European Union and the Region of Abruzzo.

Technical approach

There are a few basic principles that need defining at the outset, which are summarised below:

- any DSS aimed at the management of DMAs assumes that they already exist in the field;
- that the flow data is transmitted to the control centre at regular intervals, at least weekly and preferably daily.

Leakage is most accurately quantified at night when the consumption of the customers is minimum. It can be calculated with the following expression:

$$Ln = Qnf - (Cd * Me * DFdn + Cc * Me * DFcn + Ci * Me * DFin + Spnf * Me)$$

where:

- Ln = night time leakage
- Qnf = Minimum night flow into the DMA
- Cd = Total domestic consumption in the DMA read by the meters
- Me = correction for meter error, ideally determined by monitoring a sample of properties in the field or alternatively using typical values from publications
- DFdn = typical night Demand Factor of domestic properties obtained ideally by monitoring a sample of properties in the field or alternatively using typical values from publications
- Cc = Total commercial consumption in the DMA read by the meters
- DFcn = typical night Demand Factor of commercial properties obtained ideally by monitoring a sample of properties in the field or alternatively using typical values from publications
- Ci = Total industrial consumption in the DMA read by the meters which don't have a significant night-time consumption
- DFin = typical night Demand Factor of industrial properties ideally obtained by monitoring a sample of properties in the field or alternatively using typical values from publications

- Spnf = Consumption of large consumers or at least those having a significant and irregular night consumption, monitored directly from the meter.

The advantage of quantifying the leakage in this way is that even if the precise demand factors and meter accuracy values are unknown, they have little impact on the final values, unless the leakage level is exceptionally low in the first place. It should be remembered that night time leakage will usually be greater than the average value, due to higher night time pressures.

The same approach can also be applied to networks with intermittent supply, just that it has to be related to a period when there is water in the network. Although it is likely that the accuracy of the final leakage value will be much reduced in this way, it is largely irrelevant as the probable cause of the interrupted supply is the high leakage level. For management purposes, it is sufficient to be able to compare values for the same period.

In the DSS which is presented in this paper, a module was developed to quantify automatically the current leakage level on a daily bases. Checks were built in to ensure that no anomalies existed in the flow data which could result in erroneous leakage vales and consequently incorrect decisions. This relates in particular to problems with the flow meters, open boundary valves or pipe closure for undertaking maintenance in the DMA. A weekly average leakage value is then calculated to even-out any slight fluctuations in real consumption from one day to another.

There are three factors which need to be assessed in order to decide whether it is economically viable to undertake a leakage reduction intervention:

- the cost of the intervention;
- the quantity of water which can be recovered;
- the value of the water.

These are discussed in more detail in the following paragraphs.

Cost of intervention

Leakage is probably one of the most important elements to be considered when rehabilitating water networks, not just because it usually yields an immediate economic return, but because it is likely to be the cause of other standard of service non-compliances. As such, the cost of the intervention to eliminate a leak should always be considered in any system based on economic evaluation and not simply the cost of leakage location which is often insignificant anyway in the overall costs. DEWI S.r.l. has undertaken numerous leakage control projects all over the world and has derived a curve which relates the recovery of leakage to the cost of intervention. Figure 1 shows the curve relative to the Italian condition based on real data. It shows how the cost of intervention gets progressively more expensive with increased recovery, reflecting the significant impact of pipe replacement.

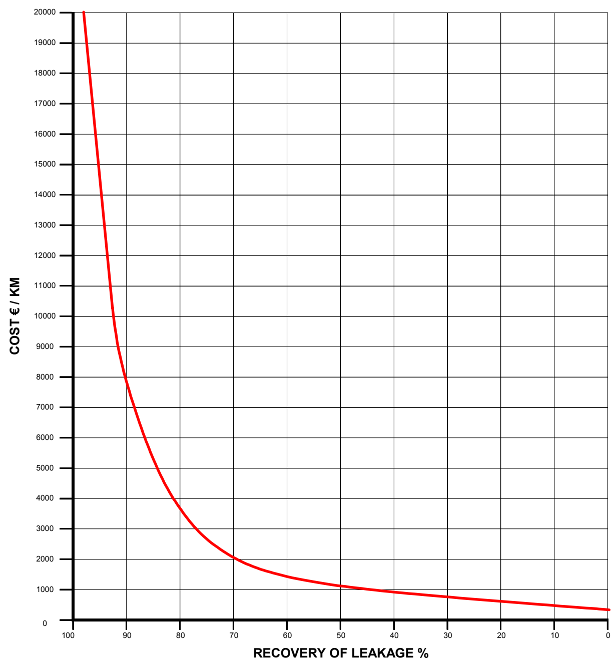


Figure 1: Typical Cost / leakage recovery

Quantity of water to be recovered

The quantity of water that can be saved, is composed of two components: the short term recovery which results from the intervention and the long term return frequency as the leakage tends to return to its original level. These values will depend on the type of the intervention (repair or pipe replacement etc) and the initial condition of the network; but again, based on the results in real projects it is possible to make estimates. Figures 2 and 3 for instance show the return frequency of two districts in southern Italy. It can be seen that the return frequency differs from one DMA to another, but in both cases the frequency is less than 1 l/s every 4 months.

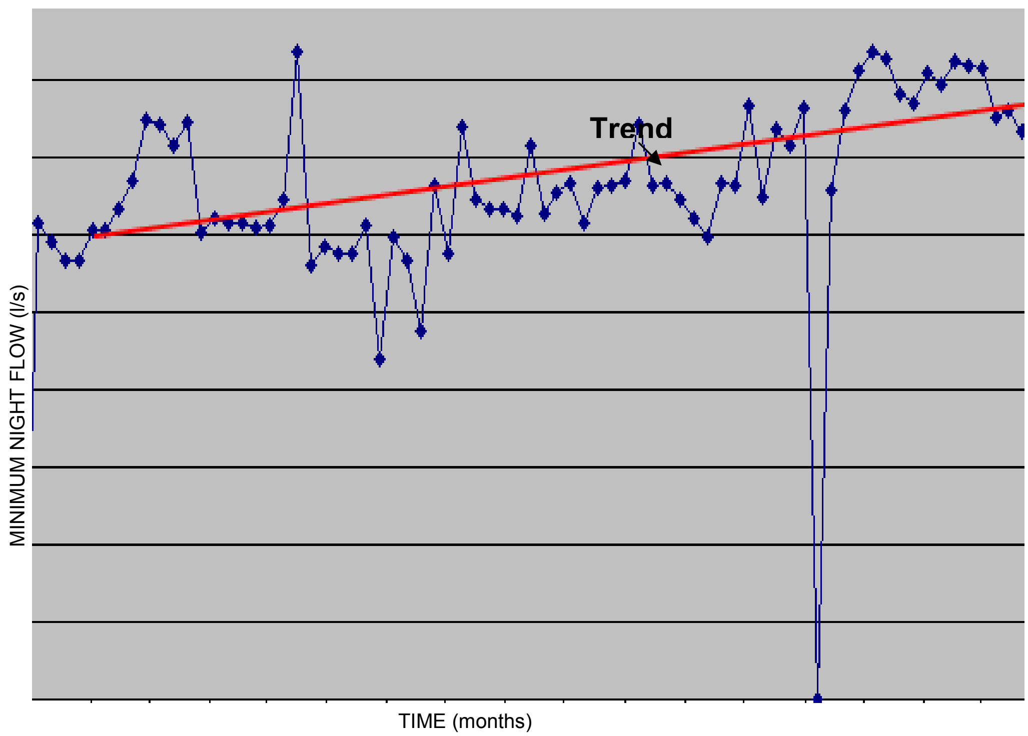


Figure 2: Return Frequency 1: 4.6 in Italian DMA

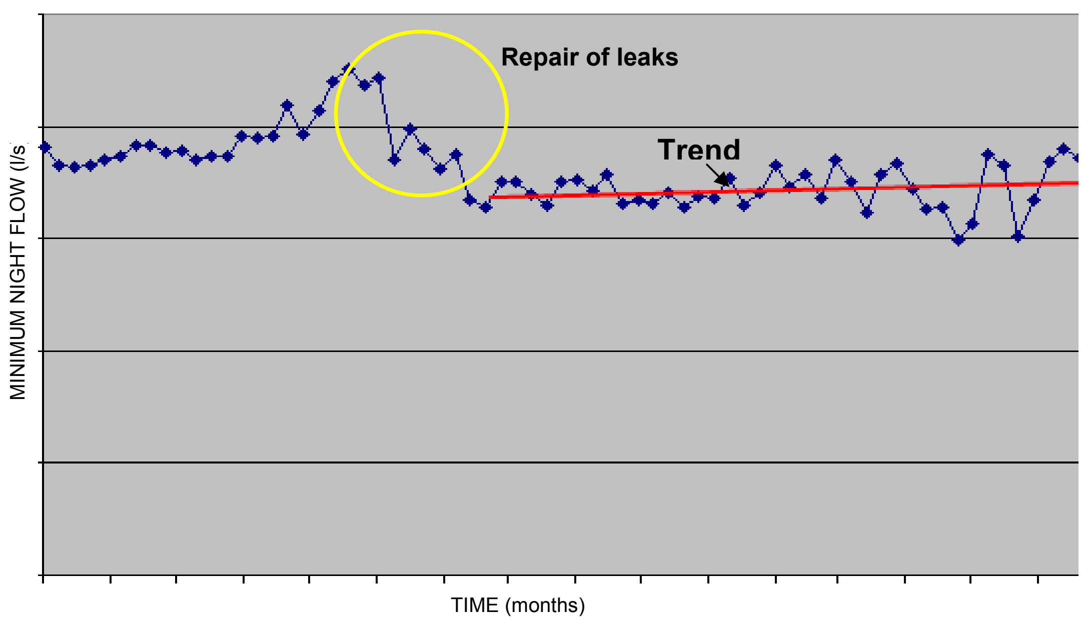


Figure 2: Return Frequency 1: 14.3 in Italian DMA

Value of the water

The value of the leakage is dependent primarily on pumping and treatment costs. In networks which suffer intermittent supply, the investment required to find and create a new source of water should also be considered, provided that the recovery of the leakage is sufficient to satisfy the existing short fall in supply. Typical values range from € 0.15/m^3 for ground water to over € 0.5/m^3 for desalinated water.

Operating mechanism

The operating mechanism of the DSS is illustrated below in Figure 4.

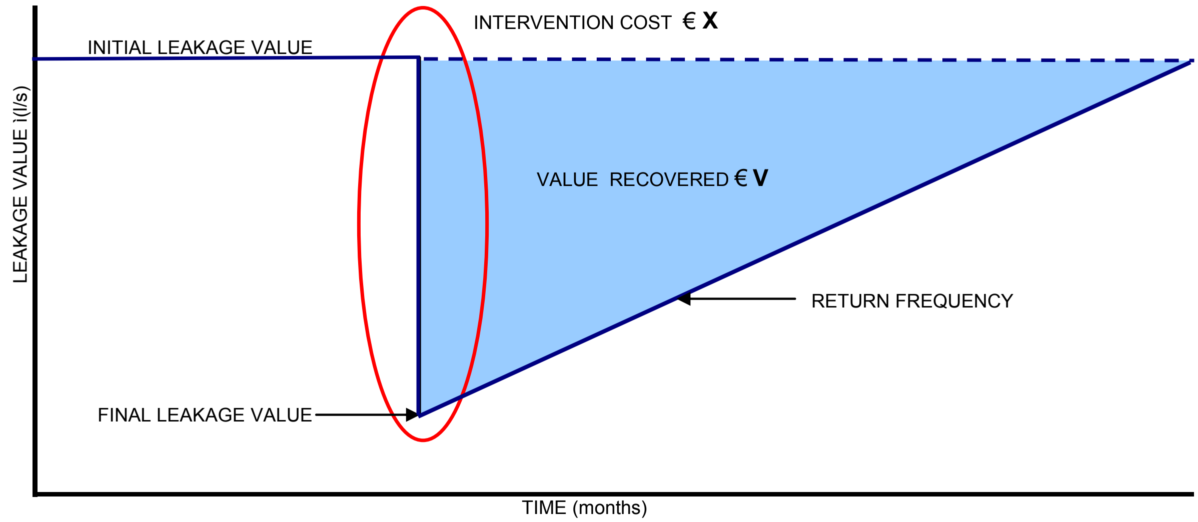


Figure 4: Operating mechanism of DSS

It starts from the initial leakage level and estimates the recovery which is based on a combination of the final leakage level and the return frequency. The intervention is economically viable if:

V > X

where:

- V is the total recovery and is made up of the cost of water x total volume recovered.
- X is the cost of the intervention

It is assumed that the existing leakage level remains constant over time if no intervention is undertaken, which is not a totally accurate reflection of reality, but as it slightly under estimates the real quantity that can be recovered, is considered acceptable.

It is clear that in the initial assessment, before any leakage work has ever been undertaken in the DMA, that most values have to be estimated based on typical historical data. It is possible therefore that the leakage recovered is less than anticipated or that the return frequency is greater. It could be argued that this is a flaw in the system, but it should also be remembered that it is already significantly more accurate than the manual assessment that is applied to the management of most DMAs where decisions are often based just on sensations.

What is clear is that the operation of a DMA cannot be generalised. This means that the amount that can be recovered, the intervention required and even the return frequency, will almost certainly vary, not just from network to network, but from DMA to DMA. For this reason, the DSS presented in this paper has a self-teaching mechanism which once the first data is recorded, continuously updates the prediction based on the real operation of each DMA. This is done by determining the average trend over time.

Consequently, as each new leakage value is added, the trend is updated and projected forward. This results in an unique return frequency for each DMA, based on its historical behaviour.

The definition of an unique return frequency curve for the DMA is very important for the long term management of the DMA. Whilst the first prediction is a one-off occurrence which inevitably has to be based on the historical data, the system also continuously evaluates the feasibility of intervening each time a new leak breaks out. It does this by allocating to the current leakage level, the unique return frequency for that DMA to predict what will happen if no intervention is undertaken and simply compares it with the same trend when applied to the lowest recorded leakage value as illustrated in Figure 5.

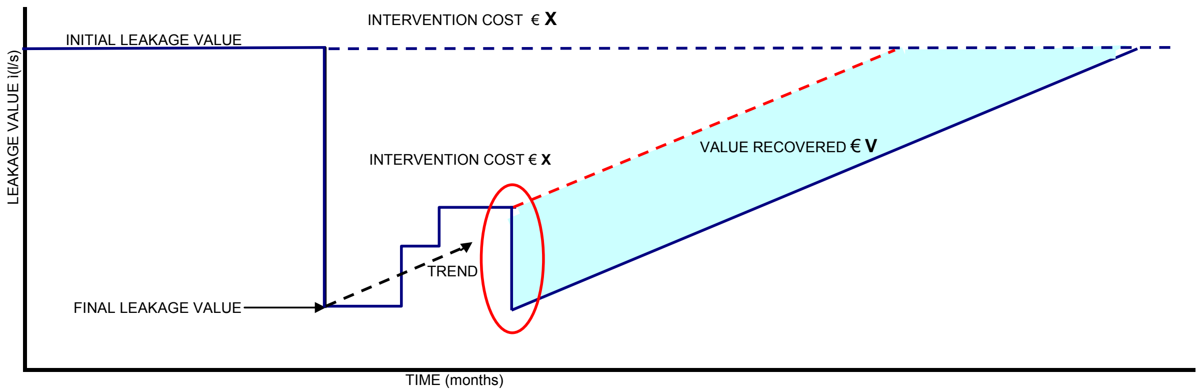


Figure 5: Management of DMAs

The value of the extra volume recovered is related to the estimated cost of the intervention to determine the validity of the operation. The difference this time is that the prediction will be significantly more accurate as it is now based on real data. The cost of the intervention is calculated by the typical recovery / cost curve as previously illustrated in Figure 1, suitably updated with the real data for the DMA.

Future development

The DSS is currently being tested on one of the largest leakage control projects ever undertaken in Italy at Avezzano, in central Italy. Although it early days, the results are very encouraging with the real network showing surprisingly good correspondence with the prediction. This is probably a reflection of the effectiveness of pressure control system to significantly reduce the occurrence of new leaks. In particular, the testing has shown the following:

- it is cost effective to intervene to repair leaks once they occur, particularly if there is a pressure control system which significantly reduces the return frequency;
- that the cost of replacing pipes changes significance the cost / benefit relationship;
- the higher the return frequency, the more need there is for costly pipe replacement.

Future developments which are planned for the DSS involve linking it to the GIS system, so that the historical repairs can be directly incorporated into the decision making process to improve the quantification of the interventions. In this way, it will be possible to include automatically in the intervention cost for the replacement of pipes which have an excessive break frequency.

Another aspect requiring further investigation is the definition of the real value of the water, particularly in networks subjected to intermittent supply. It is clear that in such cases, the value of the water is much greater than the simple production costs as there is a significant social impact to the shortage.

Conclusions

The social and environmental impact of a high leakage in a world facing acute water shortages is very evident. But almost as important for the operators and customers alike is the economic consequence of pumping and treating water which is then lost even before it arrives at the customer connection.

It doesn't always follow that it is economically viable to achieve and maintain a very low leakage level in every network. In extreme cases, where there is a plentiful supply of pure water supplied by gravity, it might be more economical to leave a leak, than to intervene. Conversely, when water is scarce or expensive to produce, it could be beneficial to locate and eliminate even the tiniest drop of leaking water. As such, any attempt to define a minimum technical level of leakage is probably irrelevant. It depends on local economic factors.

International experience has clearly shown that the most effective way to reduce and maintain a low leakage level in a water network, is to divide it into permanent sectors called DMAs. Ideally they are supplied by a single pipe on which is installed a flow meter. In this way, by analysing the minimum night flow, it is possible to not only quantify with accuracy the leakage level, but immediately identify the presence of new leaks.

Application of this methodology in many parts of the word has yielded significant reductions in the leakage level. What has been less impressive is the long-term management of these systems, which has often resulted in the leakage level returning near to its original level. There are many reasons for this, not least the lack of priority given to monitoring the system when it doesn't cause any operational problems.

The solution is an automatic decisional support system which allows the optimum economic leakage level to be maintained irrespective of the individual characteristic of the network. This is achieved by comparing the estimated value of the water recovered over time with the cost of intervention. What is unique in this system is its self-teaching algorithm which allows the return frequency trend to be defined for each individual DMA enabling the DSS to simulate more realistically the network that it manages. As more data is accumulated, the better will be the prediction will be.

The significance of this DSS, is that not only does it manage leakage economically, it integrates the control of leakage with the definition of the rehabilitation requirements which is an often overlooked factor in water distribution management. In addition, it combines the latest optimising techniques with a solid practical bases which is readily available on the market, offering water companies and contractors alike the possibility of finally achieving the goal, of managing leakage economically.

RESEARCH FOR THE ESTABLISHMENT OF AN OPTIMUM WATER LOSS REDUCTION LEVEL FROM THE ECONOMIC POINT OF VIEW

PhD. Eng. **Al. Manescu****, MSc. Eng. **B. Manescu***;

** Lecturer at the Technical University of Civil Engineering – Bucharest;
e-mail: manescu88@gmail.com

***** PhD Student at the Technical University of Civil Engineering – Bucharest;
e-mail: brindusa88@yahoo.co.uk

Key words: water distribution network, water loss, optimum rehabilitation level

1. Introduction

Water supply systems in Romania are presently not in an appropriate condition:

- appreciatively 40% of the population does not have access to a controlled / supervised water supply system;
- in rural areas only 20% of the population has access to a water supply system;
- the existing systems are very old and a great part of the pipes are made from inadequate materials (asbestos cement, unprotected steel)
- in some cases the water losses are greater than 50%
- the rehabilitation process is very slow due to the insufficiency of funds and also to a low water tariff (0.2-0.7 Euro/m^3).

Since Romania has just joined the European Union, this means that during the next 10 years all water supply systems have to be rehabilitated and 100% of the population must have access to clean and safe water (drinking water by law 458/2002).

Network rehabilitation, especially in towns, is complicated and expensive. Investment needs have to be correctly identified as well as the mains to be renewed in order to ensure the maximum benefits. The target is to ensure that operational and maintenance policies are met while the operating costs are minimized. Therefore, the rehabilitation has to be done with precautions. The problem that arises is to identify the rational water loss reduction limit. This paper intends to find this limit starting from some real data collected.

2. Water loss. Dynamic of water loss phenomena

Water losses can be minimised by:

- a better structure of the water supply system that will help maintaining a minimum water pressure within the network;
- using good quality materials for the pipes and an appropriate and advanced execution technology;
- a continuous and good management.

Regardless of the precautions and the care that are taken in order to preserve the network at its best, the structure will still get old eventually. This will end up in an increased water loss and all the problems directly connected to this. In order to keep this loss under control some investments have to be made. Continuously the remediation costs have to be compared with the lost water costs. When the expenses arisen from the water loss are bigger than the repairing costs, it is the time to take action. In the later stages of the pipe's life (usually due to the corrosion) the pipe can be deteriorated up to such a degree that when a pipe suffers the disturbance required for fixing (isolation, draining down and recharging), the pipe itself can initiate more leaks than previously existed. This is why the water loss needs to be kept under control by a permanent and continuous surveillance.

Water leakage is based on 2 major activities:

- identifying water losses (location and magnitude);
- repairing the defection that produces these losses.

In this situation there are 2 problems that need a decision:

(1) between what limits the losses have to be maintained rationally (see fig. 1, level A and B)

(2) what is the optimum period of time in which the rehabilitation has to be done (see fig. 1, values D and D1)

In the figure below (see fig. 1) it is represented the relation between the pipe aging (meaning increased water losses) and the investments made for the water loss reduction

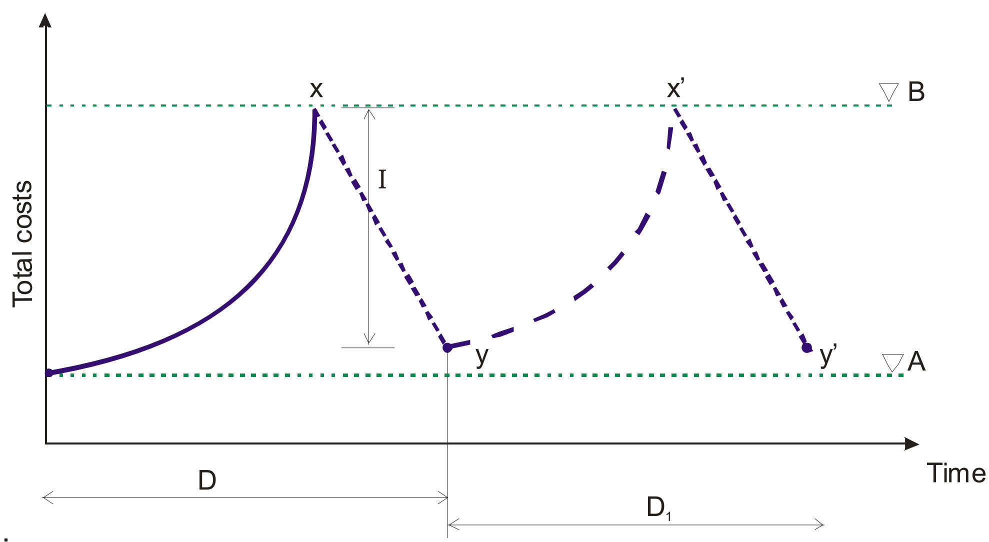


Figure 1: Cyclic rehabilitation of water distribution network

A = initial investment for the value of water loss technically accepted by standards; in Romania this value is set by standards at 10%;

B = exploitation costs level that the system reaches in time (point x, x');

I = the investment made for the water loss reduction up to the initial level or other level (A, y, y');

D = time period assigned for rehabilitation - "network rehabilitation cycle".

3. Case study

The losses are way above standard's requirements / acceptance but the problem is that due to the fact that the water tariff is very low the water providers cannot get the funds necessary for the rehabilitation of the networks. Therefore, the repairing / replacing process is very slow and insufficient. The question that arises is "***Up to what limit the water losses must be reduced in order to get maximum results at a minimum financial input?***

3.1. Basic Data:

- Population number = 330000;
- Network length = 600 Km out of which 50% is made from unprotected steel;
- Average pipe diameter = 250 mm;
- The network is supplied through a direct one step pumping system, specific energy consumption - 0.26 kWh/m^3;
- Type of water = surface water, water from a river;
- Pumped water volume is 24 mil. m^3/year;
- Pipe material: 50% unprotected steel, 10% asbestos cement, 30% grey cast iron, 10% PEHD;
- Estimated water loss = 45%;
- The rate of repair = 30 defections / week; 5.2 km of network / year (usually PEHD);
- Network age: 35% has over 40 years; 65% has over 20 years;
- Water tariff = 0,22 EURO/m^3.

3.2 Helpful information:

- the network, having a specific length of 1.88 m/inhabitant, is intensely used;

- the network works with a reduced energy consumption, 0.26 kWh/m^3;

- the network is old; average pipe life is 27 years; having in mind that a steel pipe has an estimated life of 30 years, the iron – 100 years and PEHD – 50 years, it can be said that the average pipe life is around 55 years;

- water consumption is o.k., around 200 l/person and day; all water is metered;

- water intake is around 43.6 mil m^3/year;

- water supplied value is 0,22*24 mil. m^3/year = 5,28 mil. Euro/year, which means the average water intake cost is around 5.28 mil Euro divided by 43.6 mil m^3/year equals with 0.12 Euro / m^3;

- total investment cost for the network, with new cast iron pipe is of 280 mil. Euro;

- the volume of water loss is around 0,45 * 43,6 = 19,6 mil m^3/year;

- therefore the value of the water lost is of 19,6 mil m^3/year *0,12 euro/m^3 = 2,35 mil euro/year.

3.3. Hypothesis for calculations

- According to the effectual norms, initial water loss (as per the Romanian standard SR 1343-1/95)) is around 10% (for a new pipe);

- The water that is lost it is considered to be supplied through a “fictive system” who’s costs are similar to the one in case;
- Annual redemption rate is 168 mil EURO/ 55 years, resulting in 3.05 mil EURO / year.
- The cost for 1% water loss reduction is 3.05 mil EURO / year
- Water loss reduction is proportional with the necessary investment increased rate = 1.63% / year;
- Water tariff is constant in time (in reality it is constantly growing);

3.4. Determining the rational limit up to where the water loss has to be reduced

The values used for calculations are given in table 1 and are graphically represented in figure 2

There have been considered 6 levels of water losses reduction: zero, 10%, 20%, 30%, 40%, 45%.

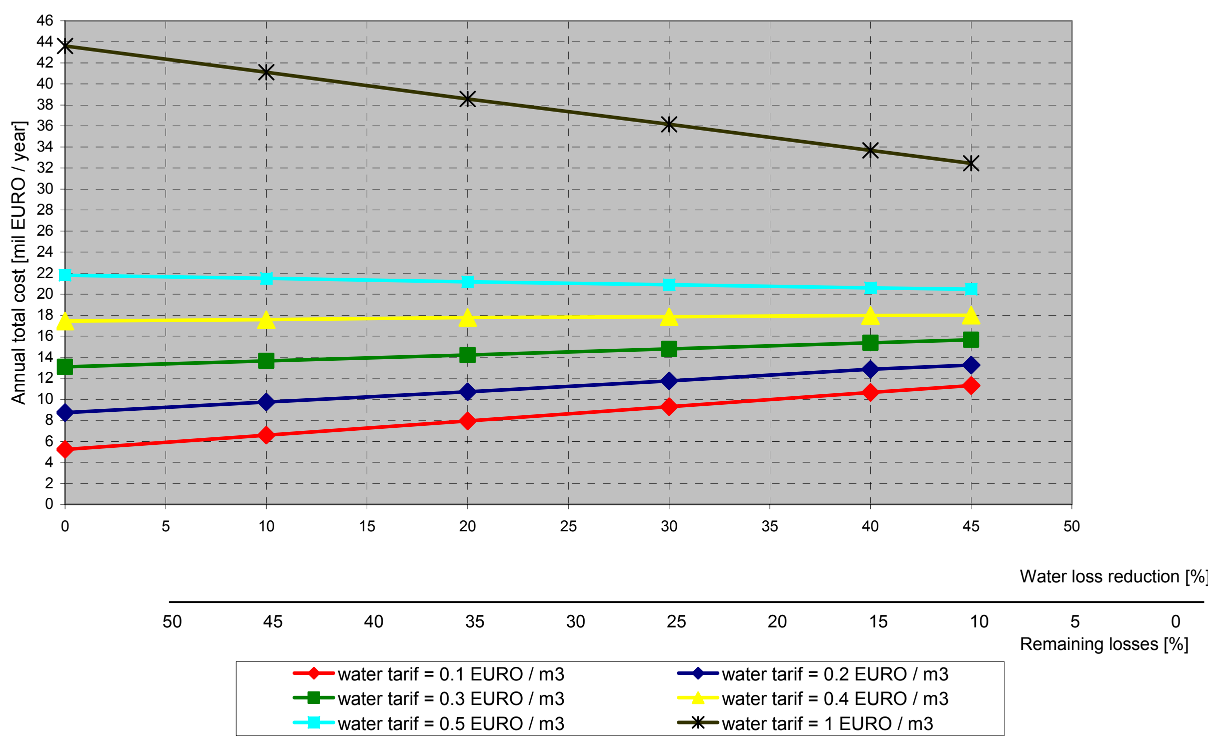
Making simplified calculations, the results indicate that in the case of a low water tariff, it is “*more economically advantageous”* to pay for the lost water instead of rehabilitating the network. In order to obtain a more rational solution (aiming to a more rational / responsible water use), water tariff has to be increased. Different water tariffs were used. The results show that when an intermediate solution is offered in the case of water tariff equal with 0,5 E/ m^3; here the rational solution has to be identified, see figure 2.

Table 1: Exploitation total cost at several water tariffs

Water loss reduction		Amount of water supplied by the system		Annual investment	Water annual cost
%	*Water volume [mil m^3/an]*	*Water volume [mil m^3/an]*	*Value [mil EURO/an]*	*Value [mil EURO/an]*	*Value [mil EURO/an]*
Water tariff 0.1 EURO / m^3					
0	0	43.6	5.23	0	5.23
10	4.36	39.24	4.71	1.88	6.59
20	8.64	34.88	4.18	3.76	7.94
30	13.08	30.52	3.66	5.64	9.3
40	17.44	26.2	3.13	7.52	10.65
45	19.6	24	2.88	8.46	11.3
Water tariff 0.2 EURO / m^3					
0	0	43.6	8.72	0	8.72
10	4.36	39.24	7.85	1.88	9.73
20	8.64	34.88	6.96	3.76	10.72
30	13.08	30.52	6.1	5.64	11.74
40	17,44	26.16	5.23	7.52	12.84
45	19.6	24	4.8	8.46	13.26
Water tariff 0.3 EURO / m^3					
0	0	43.6	18.8	0	13.08
10	4.36	39.24	11.78	1.88	13.65
20	8.64	34.88	10.44	3.76	14.2
30	13.08	30.52	9.5	5.64	14.79

40	17,44	26.16	7.84	7.52	15.36
45	19.6	24	7.2	8.46	15.66
***Water tariff* 0.4 EURO / m³**					
0	0	43.6	17.44	0	17.44
10	4.36	39.24	15.7	1.88	17.58
20	8.64	34.88	13.95	3.76	17.79
30	13.08	30.52	12.21	5.64	17.85
40	17,44	26.16	10.46	7.52	17.98
45	19.6	24	9.6	8.46	18
***Water tariff* 0.5 EURO / m³**					
0	0	43.6	21.8	0	21.8
10	4.36	39.24	19.62	1.88	21.5
20	8.64	34.88	17.61	3.76	21.17
30	13.08	30.52	15.26	5.64	20.9
40	17,44	26.16	13.08	7.52	20.6
45	19.6	24	12	8.46	20.46
***Water tariff* 1 EURO / m³**					
0	0	43.6	43.6	0	43.6
10	4.36	39.24	39.34	1.88	41.12
20	8.64	34.88	36.18	3.76	38.58
30	13.08	30.52	36.16	5.64	36.16
40	17,44	26.16	33.68	7.52	33.68
45	19.6	24	32.46	8.46	32.46

Figure 2: Exploitation costs depending on the water loss reduction degree and water tariff



4.Conclusions

(1) WATER SUPPLY SYSTEMS ARE IN A DEEP NEED OF REHABILITATION DUE TO THE LARGE AMOUNT OF LOST WATER; SINCE IN ROMANIA THERE ARE ONLY FEW TOWNS THAT HAVE A MONITORING SYSTEM INSTALLED, THE REAL WATER LOSS LEVEL CANNOT BE PRECISELY ESTIMATED BUT THERE ARE INDICATIONS THAT THIS MIGHT BE AROUND 20-50%.

(2) Since a lot of water supply systems are old they have already reached a stage when they need to be rehabilitated. The aim is to establish the limit value of water losses in order to get maximum results at a minimum financial input.

(3) From the data that we used we can once again see the importance of having correct and accurate information:

a) a dynamics of water consumption;

b) accurate values of the costs for a good system exploitation (costs needed for a continuous leak detection, maintaining a database with the data from the rehabilitation of pipes, costs of rehabilitation, etc).

(4) Looking at the costs used for this simplified application (without taking into consideration the variation in time of all costs involved in network rehabilitation) it can be obtained a rational solution from the economical point of view. In order to get precise results, more accurate values need to be used. Also, since the water tariff is set for the entire water network, a direct connection is set between the rehabilitation of a particular water supply system and the whole network.

5. References:

J.M. Parker, 2005, Leakage and link to asset management; Halifax Conference
MANESCU B., 2006, BENCHMARKING FOR WATER MANAGEMENT IN URBAN AREA; CONFERENCE OF YOUNG PROFESSIONAL / ROMANIAN WATER ASSOCIATION, BUCHAREST
Manescu Al., Daraban O.,Ciataras D., 2002, Leakage management in Romania; IWA congress, Berlin

Technical and economical evaluation of integrated approach to the water loss management in the Czech Republic

Zdeněk Sviták, Eva Radkovská, Iva Čiháková

DHI Hydroinform a.s., Na Vrších 5, 100 00 Praha 10, Czech Republic, z.svitak@dhi.cz

Veolia Voda Česká Republika, Pařížská 11, 110 00 Praha 1, Czech Republic, eva.radkovska@veoliavoda.cz

Czech Technical University in Prague, Thákurova 7, 166 29 Praha 6, Czech Republic, cihakova@fsv.cvut.cz

Keywords: water loss management efficiency; best practices in water loss management; leakage reduction project

Introduction – An integrated approach

The modern solution to the problem of water management not invoiced in the Czech Republic has a relatively long history, in which all interested subjects are endeavouring towards maximum efficiency and effectiveness in this field. This article provides an overall presentation of the results and experiences of Veolie Voda – a leading operating company in the Czech Republic, which co-operates with leading consultancy and contractor firms in order to constantly improve standards of water supply, including reduction of non-revenue water.

One of these firms is the company DHI, which is engaged in the solution of a whole range of operational and conceptual tasks in water supply systems, in which it makes use of the latest approaches such as mathematical models, GIS application, modern measuring systems etc. The General Agreement concluded by both companies reflects the good mutual relationships between the parties.

CTU in Prague, Faculty of Civil Engineering, Department of Sanitary and Ecological Engineering co-operates on projects and technical solutions. Problems of losses, accumulation, and transit and water quality are addressed within the framework of dissertations and doctoral theses. In addition to classic computation solutions, this concerns e.g. monitoring of the dependence of water losses and breakdowns in conduits in relation to other factors which affect breakdowns and the condition of piping. These factors are the traffic burden in the immediate proximity of the route, quality of laying, subsoil material, groundwater level etc. DHI software is used very frequently for calculation and modelling of individual states.

As demonstrated below in this article, Veolia Voda is achieving a long-term improvement in its results from the perspective of non-revenue water. This is due primarily to its integrated approach to the employed long-term measures in combination with careful preparation and planning of measures with the target of attaining the maximum effect. This article represents an overview of the main application measures. It examines primarily the problem of hidden water leakages as the most fundamental components of NRW under our conditions.

An evaluation of the economic impacts of measures in the field of water loss management is a very complex task, for which it is very difficult to determine objective calculation functions and obtain input data. Despite this, a simple calculation is stated for each chapter, showing the general effectiveness of the method. The source materials for these calculations were taken from the data of Veolie Voda operating companies and from the processed projects of DHI. The authors are aware that the conducted evaluations are not universal and may differ considerably depending on local conditions.

Veolia Voda in the Czech Republic

Veolia Voda has been operating in the Czech Republic since 1996, when under the name of Vivendi Water it obtained an operation in Plzeň. In 2005 the group changed its name to Veolia Voda.

At present the company is in control of more than 45% of the Czech water management market, and is the majority shareholder of 13 operating companies.

Current data for 2007:

- 4.3 million supplied citizens
- 1 200 partners from the ranks of municipalities and districts
- 26 industrial contracts
- 6 000 employees approx. CZK 12.5 billion turnover for 2006

Veolia Voda places emphasis on the quality of provided services and environmental protection. In all companies an "operational model" is used, which enables municipalities and districts to decide on strategic questions such as the level of water and sewerage rates, investments etc., but relinquishes the responsibility for activity in connection with the production and distribution of drinking water, collection and sewerage treatment of waste water and customer services to a professional firm. It also respects the goal of not only providing quality services within the field, but of co-operating with the network owner.

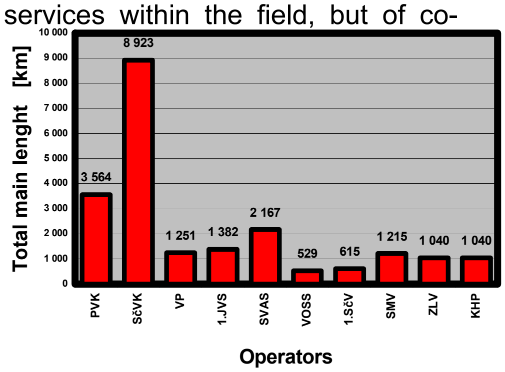


Figure 15 Branches of Veolie Voda in the Czech Republic and composition of operated water management network

Results of Veolia Voda from the perspective of water management

Monitoring, presentation and evaluation of water management is the basis for monitoring the effectiveness of supply, which is in the forefront of interest of every operating company. If efficiency of supply is achieved, i.e. the relationship between water produced and water invoiced, the method of operation is economical. It is of fundamental importance to transport treated water to the consumer – client within the maximum volume. The size of the proportion of non-revenue water here provides clear information, reflecting the ability of the company to operate a network efficiently.

The availability of quality water sources, the price of production and transport of water and knowledge of the network enable us to referentially determine the limit for the volume of water loss which is manageable for the development of the operating company. On the basis of these evaluations the targets for water loss for the individual operating companies to achieve and further maintain are then set.

In order to attain the required status, a whole range of measures is introduced, of which the most fundamental are outlined below in this article. It is necessary to take into account that in addition to the quality of operation, water management is also influenced by the owner of the water mains network, particularly in the field of investments in reconstructions, reduction valves, measurements etc. The summary results of the Veolie Voda group in the Czech Republic in the field of NRW are illustrated by the following graphs:

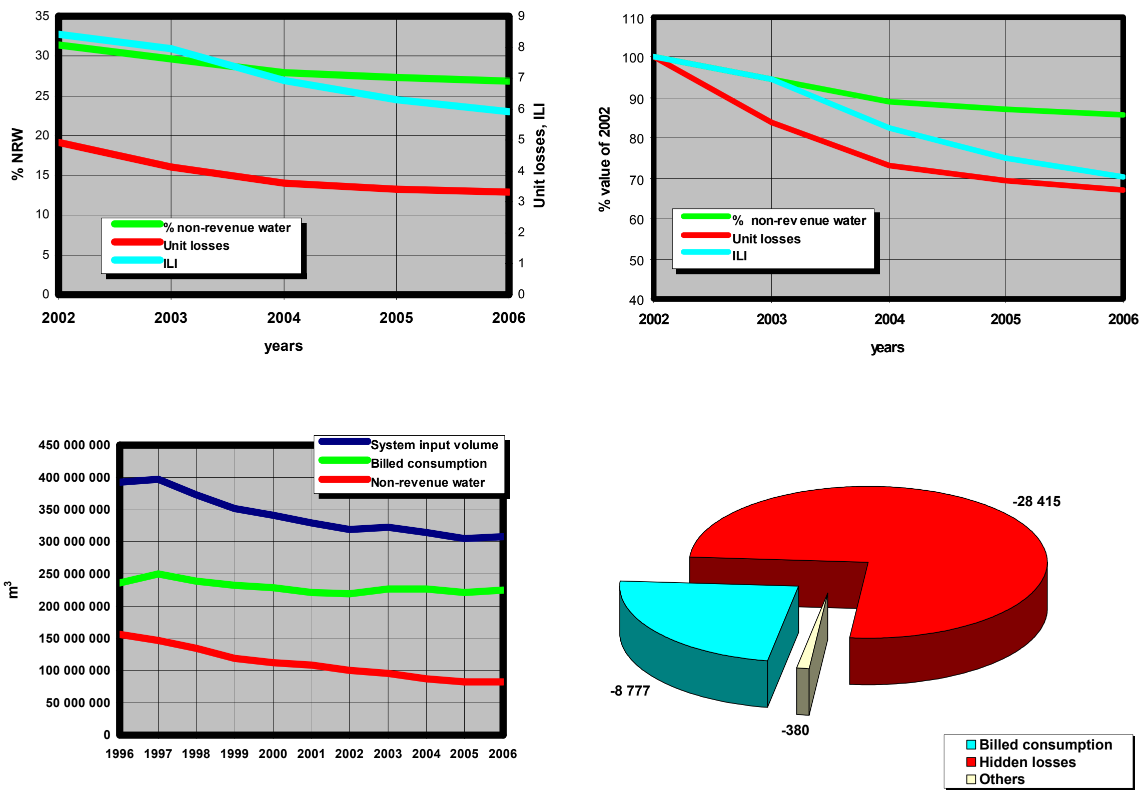


Figure 16 Results of Veolia Voda company in management of non-revenue water

Introduction of system for analysis of components of water for implementation and NRW

Enumeration of the volume of non-revenue water components is fundamental and necessary for the orientation and targeting of further procedures. In most cases discussions in connection with non-revenue water concern only leakages from the piping system, but localities are known where the main cause is large deficiencies in the area of invoicing. The system for evaluating individual non-revenue water components in the Veolia Voda company ensues in principle from a method derived from the IWA method, taking into account local conditions.

Analysis of losses is possible if we have at least basic information from measurements and we know detailed information about the evaluated area; composition of network, number of inhabitants, large consumers.

In addition to leakages, the most fundamental component of losses is *reserve in invoicing.* The volume thereof is the remainder from non-revenue water following deduction of previous outputs. The possibility of comparing the volume of hidden leakages and reserve in invoicing is the aim of the calculation.

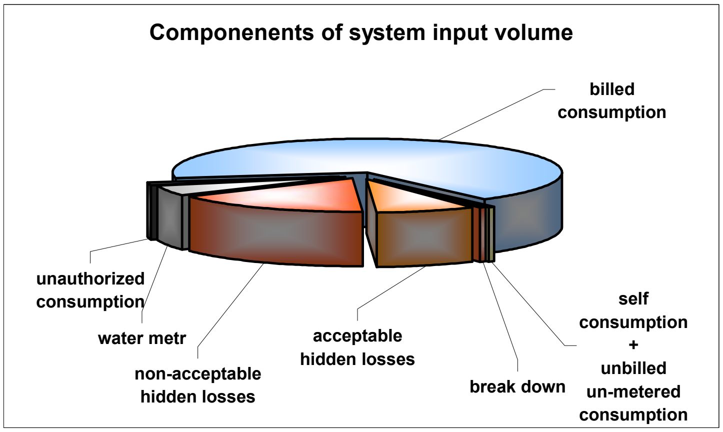


Figure 17 System Input Volume - evaluation of components in a supply zone

It is necessary to be aware that an evaluation of the distribution of leakages at the beginnings of the introduction of systematic management of non-revenue water in principle encounters the obstacle of a low level of flow measurements. The introduction of sufficient areal measurement, together with a division of the network into measurement sectors is highly demanding in terms of time and financial resources. For this reason operating companies make successful use of projects concentrating on surveys of leakages on the basis of temporary measuring campaigns and modelling of the water mains network. Thanks to the topological distribution of consumption and measurement of night inflow into part of the system, together with measurement of night consumers, we obtain initial information on the distribution of leakages. The results are used for identification of hidden leakages and immediate reduction of non-revenue water. The results are also very important for determining locations where it is necessary to commence permanent measures such as installation of measurement and division of the network into measurement sectors, limiting of pressures etc. in order to attain maximum effectiveness of expenditure of financial resources, as well as fast results.

The following table shows a number of results from projects performed by DHI concentrating on research of the distribution of leakages in the network.

Table 4 Example of results of the leakage distribution projects realized by DHI

Daruvar, Croatia	Identification of 80% of leakage in 21% of total length of pipelines	Reduction of leakage from 47% to 25% in 2 years
Ganovce, Slovakia	Identification of 97% of leakage in 16% of total length of pipelines	Reduction of leakage from 52% to 26% in 3 months
Plzen, Zone Litice, Czech Republic	Identification of individual leak 4.8 l/s in 960 m pipeline, negligible leakage was identified in the rest of the net work of 15 km	
Usti nad Labem, Czech Republic	•Identification of 90% of leakage in 36% of total length of pipelines after first	Reduction of 16.9 l/s of NRW in 3 months

Economic view

Introduction of a system of monitoring non-revenue water components in the water mains network is one of the fundamental steps which is the first condition for improving water management and the efficient introduction of further measures. The economic impact, although fundamental, is difficult to enumerate separately. For this reason, in this section we state only an evaluation on the basis of 2 examples of projects realised by DHI. Naturally from the perspective of effect the high level of the initial leakage also plays a role. Costs for repairs are not stated in the evaluation. It is possible to assume that each hidden leakage over the course of time becomes apparent, and it shall be necessary to perform a repair anyway, whereas repairs of hidden leakages are approximately 20% cheaper than when a breakdown subsequently occurs.

Table 5 Investment return – leakage distribution projects

Project 1		
Achieved leakage reduction	16.9	l/s
Achieved leakage reduction	519 817	m3/y
Cost - water production	4.03	CZK/m3
Savings per year	**2 094 862**	**CZK/y**
Project cost	900 000	CZK
Project cost - part of leakage distribution	360 000	CZK
Leakage detection (5 days, 1900 CZK/hour)	76 000	CZK
Total cost	**436 000**	**CZK**
Investment return period	**2.5**	**Mon.**

Project 2		
Achieved leakage reduction	3	l/s
Achieved leakage reduction	92 275	m3/y
Cost - water production	3.82	CZK/m3
Savings per year	**352 491**	**CZK/y**
Project cost	340 000	CZK
Project cost - part of leakage distribution	238 000	CZK
Leakage detection (5 days, 1900 CZK/hour)	30 400	CZK
Total cost	**268 400**	**CZK**
Investment return period	**9.1**	**Mon.**

Conditions for monitoring losses – sectorising, measurement

The first step for more precise monitoring of water management is sectorising – the division of the network into supply zones and measurement sectors, which are separated from the surrounding network, have measured water for realisation and separately evaluated revenue water, and the composition of the network is known. The periodicity of evaluation of water management is determined by the possibility of allocating invoice to individual localities. Usually evaluation takes place quarterly, but due to the lack of sequence of deductions of water for realisation and revenue water it is necessary also to monitor the preceding data.

The aim is to evaluate the status in assessed localities in order to propose measures for improvement and work in the terrain, performed particularly in non-compliant areas. This guarantees effectiveness of works, maximum use of expensive diagnostic technology and the procedure for reducing losses is faster. The optimum areas for monitoring are within the range of 10 – 15 km of the network.

Preparation works

The task of the hydraulic model in proposing districts is irreplaceable. For topologically more complex networks it is possible, with the help of a calibrated model, to set division of the network into suitable sectors without impact on consumers in such a manner that the possibility of their use is clear in advance, meaning whether it is possible to close a sector permanently, in co-operation with other closed sectors, or only separately, or separately and only at the time of minimum consumption. The model thus clearly indicates cases where it is necessary to supply water to the sector via a larger number of water meters.

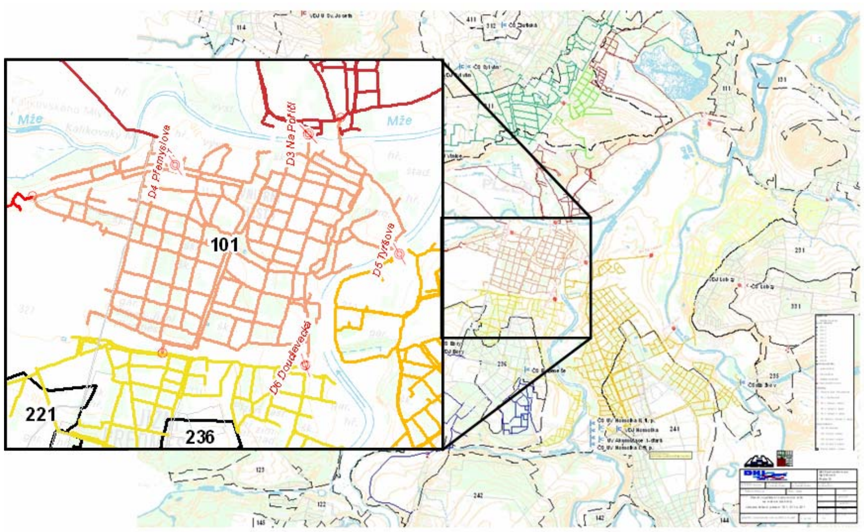


Figure 18 Planning of separation of individual districts and flow measurement location and type

Optimisation of pressure ratios

Another possibility is to reduce operational pressures within the network, by which it is possible to remove almost 10 – 13% of the volume of leaking water. In addition, reduction of pressures has a favourable impact on the life span of lines and connections, on reducing breakdowns and the quality of distribution. The principle is either permanent reduction of leakages or reduction of water pressure at the time of lower consumption, mostly during night hours, when more water would logically escape through existing leakages due to greater pressure.

An excellent aid for monitoring water distribution including hydrostatic pressures is *hydraulic models.* Assessment of optimisation of pressure ratios in hydraulic models ensues from an evaluation of the height of the supplied estate.

For proposing measures to reduce pressure in the water mains network it is possible to make use of hydraulic models to resolve the following tasks:

- optimisation of limits of supply zones
- optimisation of location of reduction valves on entry to zones

- optimisation of pressure output at pumping stations
- optimisation of time control of input pressure (pump, reduction valve)

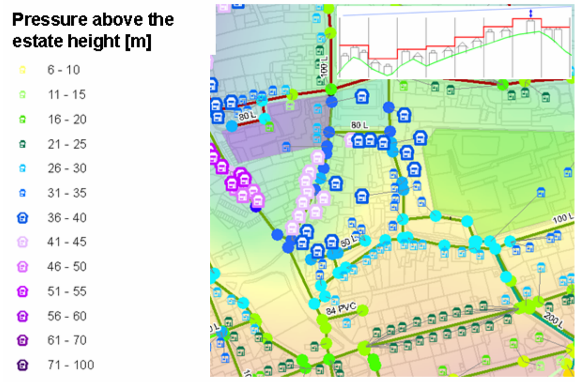


Figure 19 Optimization of pressure in the network – calculation of the pressure above the estate hight.

Reconstruction of water mains network

All the above-mentioned measures must concurrently follow also the continuous renewal of the network – reconstruction in areas where it is no longer economical to constantly repeat repairs of hidden leakages and breakdowns.

The reasonable water and sewer network rehabilitation has become a major problem of the urban water sector in many cities. Adequate and goal-directed approach is needed in order to optimize one of the most considerable annual expenses as well as avoid negative impacts on urban environment and minimize operational costs.

Decision support system for network rehabilitation provided by DHI is based on complex multi-criteria evaluation of technical parameters such as: age, material, failure rate, leakage, pressure, significance of a pipe segment, etc. The system takes into account investment coordination and influence on the conception of the network. Rehabilitation is treated as an annual iterative process. Automatically suggested sets of rehabilitated pipe segments of each year of analyzed time period depends on the optional system of decision criteria. Time progression of the technical parameters is set in an aging model.

Evaluation of technical and financial results in a comprehensive system of thematic maps, graphs and tables can give an overview of the contiguity of technical requirements and financial sources and can be used to adjust the network rehabilitation strategy. Apart from automatic production of the rehabilitation program, manual adjustment of investment measures is enabled in order to take into account any real-life influence.

System of technical evaluation and rehabilitation planning is developed as extension of MIKE URBAN and it derives benefit from its asset management and hydraulic evaluation features. The system of technical criteria evaluation, rehabilitation strategy rules and age management is stored in the MIKE URBAN data model and it is fully optional, i.e. it is possible to fill in and/or adjust it according to the technical input data, conditions and relationships, financial limits and corporate/specific decision strategies.

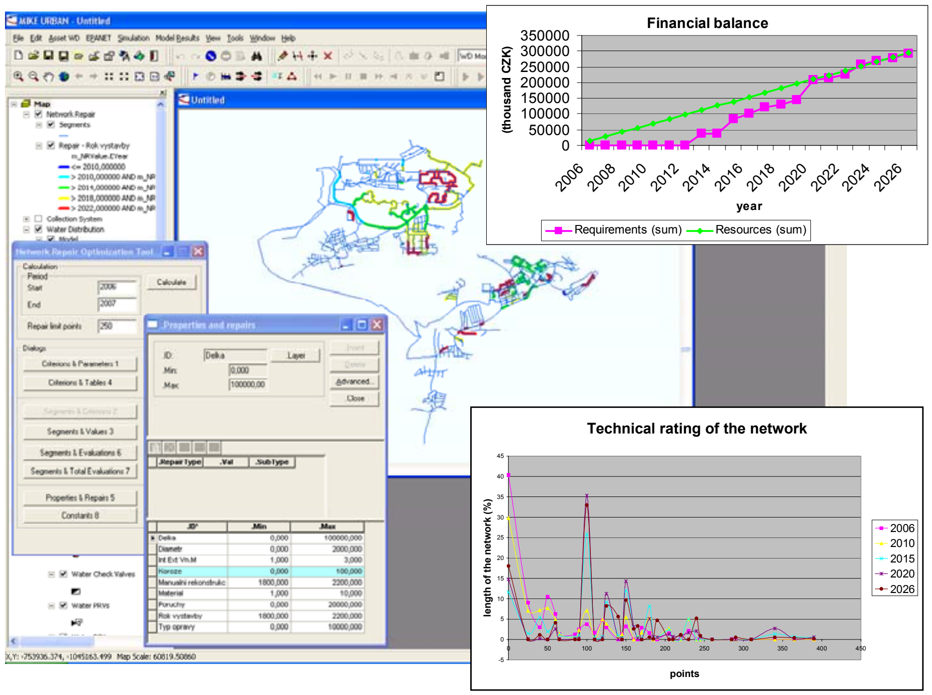


Figure 20 Planning of the water supply network rehabilitation – Rehabilitation planning tool in MIKE URBAN

Economic perspective

An economic view of the return on reconstructions of the water mains networks is very complex, since reconstruction brings a whole range of benefits which are difficult to enumerate economically. Other “formal” problems reside in the fact that investment costs of reconstruction are very often borne by the owner of the infrastructure, in which the majority of savings are manifested in the business of the operator. It is also necessary to take into account the fact that financial resources for reconstructions almost everywhere do not cover actual needs, and for this reason the problem resides more in optimising the selection of reconstructed parts than in an economic calculation of the return on investments.

In this the result of evaluation of return on investments is strongly influenced by the approach used. The stated evaluation ensues from the assumption that reconstruction of the network must be performed in future and calculates savings or costs in comparison with a situation in which the reconstruction would be deferred for 10 years. Bank yields from investment costs for a period of 10 years are considered as a cost in the case of performance of immediate reconstruction. The case provided here calculates with the current level of prices and does not perform indexing thereof.

Table 6 Investment return – water supply net work reconstruction

Length of pipes	43	km
Length ofr rehabilitated pipes	26	km
Leakage reduction (existing situation)	740 000	m3/year
Leakage reduction (after 10 years)	962 000	m3/year
Total leakage reduction (linear increasing)	8 510 000	m3/10 years
Cost - water production	6.4	CZK/m3
Reduction of failures-water mains (existing situation)	40	pcs/year
Reduction of failures-water mains (after 10 years)	52	pcs/year

Total reduction of failures - water mains	460	pcs/10 years
Reduction of failures - connections (existing situation)	64	pcs/year
Reduction of failures-service connections (after 10 years)	83	pcs/year
Total reduction of failures - service connections	736	pcs/10 years
Cost of repair works - water mains	53 830	CZK/failure
Cost of repair works - connection pipes	26 625	CZK/failure
Savings on leakage	54 464 000	CZK/10 years
Savings on repair works	44 357 875	CZK/10 years
Total savings after 10 years	98 821 875	CZK/10 years
Unit costs for network rehabilitation	8 200	CZK/m
Total costs for rehabilitation	213 200 000	CZK
Bank interest	3	%
Beneficial interest - 10 years	63 960 000	CZK
Investment return	**6.5**	**years**

Searching for hidden leakages

The greatest part in the volume of losses as a rule is *hidden leakages of water* and the most effective measure to reduce this volume is searching for and rectifying hidden water leakages. This always concerns the first and significant measure in rectification, since hidden leakages are generally not large in volume, does not impair distribution, but the problem is the length of their duration. At the same time this activity contributes to the *prevention of breakdowns*, by which non-rectified hidden leakages manifest themselves over time.

On the basis of an *evaluation* of water management or surveys of distributions of leakages we select non-compliant supply zones. The frequency of evaluations depends on the possibility of obtaining revenue values, but quarterly periodicity is suitable.

Preliminary survey – searching for signal, noise detectors, ballast waters

During preliminary research we search for an acoustic signal indicating water leakage. The fundamental method is physical monitoring “by direct listening” or using an “electronic ear”.

Noise monitoring **– newly developed detectors automatically monitor noise in the surrounding area during night hours, perform analysis, store data in memory and report whether there is a leakage signal in the area. They do not require removal for evaluation, but are capable of data transmission, e.g. to control centre or to passing vehicle. Performance of preliminary research is thus technically improved. In the case of long-term fitting of readers with remote deduction there is a considerable time saving on the necessary and preliminary localisation.**

Within the framework of preliminary research we make successful use of the results from research of the sewerage network, which is performed physically or by inspection camera. The recorded inflow of *ballast water* is often an indication of a hidden leakage, particularly where networks are in concurrence. It is suitable to confirm the source by an analysis of a sample of inflowing water, but the conditions for sampling are not always possible. Repair of a breakdown and attendant removal of ballast waters is important also due to subsequent damage to sewers.

It is appropriate to implement a survey of sewers, particularly by camera system, within a locality where searching for hidden leakages is being conducted.

Precise localisation – electro-acoustic and correlation, new methods

Precise localisation of hidden leakages means processing a signal indicating the possibility of leakage. Measurement takes place by electro-acoustic and correlation method.

The electro-acoustic method ensues from the assumption that the location where there is the maximum signal on the surface is the same as the place of leakage. The signal is detected continuously above the path of the water conduit by a sensitive microphone and processed by a receiver, which enables frequency analysis and saving into memory.

The correlation method analyses the noise of a leakage expanding along the piping. In the section where the breakdown is assumed to be, detectors are placed from both sides in order to ensure contact with the piping (via armature or directly). Signals are transmitted to instruments, which on the basis of input data (length of measured section, material and profile of piping) determine the time lag of the signal to the further detector by correlation calculation, and thus determine the location of the leakage.

Cross correlation – new, progressive technology for prevention and simultaneously also precise localisation of water leakages, enjoying rapid growth under the name of “cross” correlation.

Realisation of correlation or determination of the time shift of the signal can be performed from a number of locations thanks to this method. The basic composition of the instrument known under the name of Enigma comprises a correlation unit for evaluation and programming and a set of 8 noise detectors. More information is thus obtained from the monitored network, and it is possible to localise a number of defects at once due to 28 correlations.

Experiences from testing conducted during the last year at branches of Veolia Voda have been very positive. Good results were confirmed not only during ordinary measurement, but also in extreme selected conditions such as complex distribution junctions, plastic piping and in cases where diagnostic instruments failed.

Recently use of measurement using gas (nitrogen, hydrogen) has been tested, in which the water is infused with the gas and the location of the leakage is sought using a gas detector. Gas molecules are capable of passing even through relatively dense material, and their direct path is thus used. This method has good potential for plastic piping and in the case that there is no signal. It is advantageous in that it is not necessary to discharge the piping and the gas is not harmful to health.

Experiences and recommendations

With regard to the price of instruments for equipment of the measuring vehicle, it is advantageous to divide works into preliminary research and precise localisation of leakages. This guarantees full use of diagnostic technology, because the activities link together smoothly, and at the same time we speed up attainment of a satisfactory status.

Due to the high costs for excavations, wherever possible we use both methods of precise localisation. In case of doubt or disturbance from the surrounding area we perform further measurements by an electro-acoustic instrument during the night.

Upon measurement of larger profiles it is possible to expect a change in the behaviour of sounds. As with plastics, sound spreads to shorter distances and does not correspond to the table speeds. The depth of laying and insufficient number of touch points present obstacles to measurement. However, these leakages are not frequent and above all their proportion in losses is not large.

After completion of research of the problem locality a report should be processed in which all information and findings are summarised.

The success of measurement, thus precise determination of the point for excavation, is influenced by the specific conditions and the quality of the signal is not directly proportional to the quantity of leaking water.

The problem of losses is very serious, and searching for hidden leakages is at the forefront of interest. It is thus necessary to emphasise that in addition to good technical support, experience and thoroughness of the network diagnostic technicians are of fundamental importance for a successful solution.

Economic perspective and effectiveness

Measures to reduce inadmissible water losses are always economically advantageous and the return on investments is quick, but it is necessary to respect the boundary between admissible and inadmissible leakages. We consider searching and rectification of hidden leakages to be most effective, but only until the time when costs for continuous works in areas with repeated leakages do not exceed costs for reconstruction.

Searching and removal of hidden leakages is not only a matter of saving on water, but also serves as prevention of breakdowns. This also shares in prolonging the life span of the entire system and to improving the supply of water to consumers. On the basis of monitoring statistics of interventions in the network there is an evident decline in flowing breakdowns with intensive rectification of hidden leakages. Repair of a hidden leakage is obviously cheaper than repair following a breakdown, in the case of which there may be damage to property and works are performed under time pressure and on a larger scale.

For economic analyses it is important to monitor all information with regard to production, distribution, maintenance up to costs for repairs of breakdowns. At the same time all information serves for proposals for investment events – reconstruction of network or distribution nexuses, installation and measurement of valves etc.

For monitoring water management and organisation of works to reduce water losses within the terrain centralisation is optimal, enabling compliance with the operational requirements and respecting quality of distribution. In practical terms it is possible during the period of larger occurrence of breakdowns (in winter) to concentrate capacity on liquidation of breakdowns and in the summer period concentrate more on preventive activity. It is also possible to be flexible in case of a defect of diagnostic instrument or measuring vehicle, thus ensuring a smooth emergency service.

Also important for quality of works are the technical background care of instruments and possibility of transmitting experience amongst diagnostic technicians, including regular training sessions and monitoring of technological development.

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ROMANIAN WATER ASSOCIATION

The Romanian Water Association (RWA) is the national network of water professionals, spanning the continuum between research and practice and covering all facets of the water cycle.

Through RWA, members collaborate to lead the development of effective and sustainable approaches to water resources management, drinking water, wastewater and storm water management in areas through the country, creating value and driving the advancement of both the science and best practice of water management.

The ultimate strength and potential of RWA lies in the professional and geographic diversity of its membership - a “mosaic” of members communities including academic researchers and research centers, utilities, consultants, industrial water users and water equipment manufacturers. RWA members from each of these communities represent the leading edge in their fields of specialty, and together are building new frontiers in national water management through interdisciplinary exchange and collaboration.

In the environment, RWA and its members are committed to furthering sustainable and holistic resource management and service provision, built on the concept of the water cycle.

Contac us:

Address:

202A, Splaiul Independentei., 9th floor

6th district , Bucharest, Romania.

Phone / Fax:

004 021 316 27 87 / 004 021 316 27 88

004 0747 029 988

E-mail: info@ara.ro

Website: www.ara.ro

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