Using Component Analysis and Infrastructure Condition Factor (ICF) Field Tests to Prioritize Service Connection Replacement and Reduce Real Loss in a Sustainable Manner

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Keywords: Background leakage, Component analysis, ICF tests, Service connection replacement, Case studies

Abstract

The solution to reducing and sustaining water distribution system leakage to economic levels is different in utilities around the world, however the need to be able to reduce leakage and identify the correct levels of operating and maintenance budget versus capital investment budget to apply to any particular problem over short, medium and long term time horizons can be complex.

This paper will explore a case study on the use of component analysis and practical Infrastructure Condition Factor (ICF) field tests to identify and quantify savings in leakage by the efficient replacement of service connections, the least expensive pipe component in Sao Paulo Water and Sanitation Company (SABESP), Sao Paulo, Brazil. The case will also compare traditional short term solutions with longer term solutions and explore the net present value of operating cost increases versus capital investments to reduce leakage.

This paper will show a real case study in an ongoing major water loss reduction program in a city which is growing by over 80,000 new connections per year and has limited water resources.

Introduction

The Metropolitan Region of Sao Paulo has 19 million inhabitants settled in 800 km². The landscape is mountainous, varying from 730 to 850m above sea level. SABESP supplies water and sanitation services through a distribution network of 30,000 km of mains, with 3.7 million connections for their customers, and bulk sales to six municipalities. The water system is fully metered and consumers have individual building storage tanks.

The average water production of 66.84 cubic meters per second (m³/sec) has been decreasing for the last two years, despite a growth of 82,714 new connections in 2008. The water losses (apparent + real) in 2008 were 452 litres per connection per day (l/conn/day), and SABESP has committed to reduce this significantly with major investments over the next 10 years. Water loss reduction is seen by SABESP as the most effective new source of water for the growing Metropolitan Region of Sao Paulo.

SABESP has been applying International Water Association (IWA) best practice since 2002 and is an active member of the IWA and the water loss task force. For several years SABESP has been working on three of the four key tools (Figure 1.1) to reduce real losses namely decreased response time for repair of reported leaks, more frequent active leakage control (detection and repair of unreported leaks) and pressure management. Only a little has been done to replace faulty infrastructure.

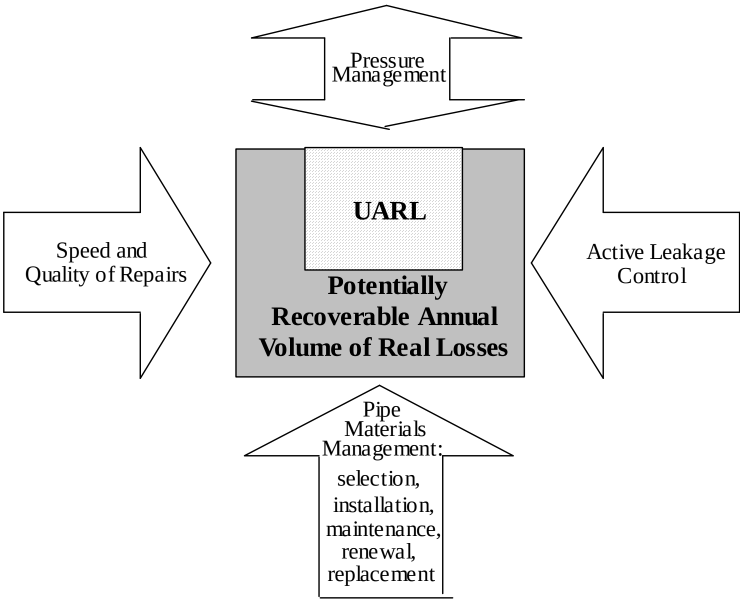

Figure 1.1 - Four key tools to reduce real losses (THORNTON, 2002).

During recent detailed water audits undertaken in the 5 business units of the metropolitan region (SABESP/Restor 2008) more scrutiny was given to the question of the cause of the real loss and the potential solutions and their cost effectiveness. Through detailed Background and Bursts Estimates (BABE) Component Analysis (LAMBERT, 1997) in all cases it was found that the break frequency of reported leaks was far higher than those values from the Unavoidable Annual Real Losses (UARL) formula used to derive the SABESP Infrastructure Leakage Index (ILI) of approximately 7, and used as a baseline for these studies.

Table 1.1: Parameters values used to calculate UBL and UARL at 50 metres pressure (LAMBERT, 2009)

Infrastructure Component	Unavoidable Background Leakage	Detectable Reported Leaks and Bursts	Detectable Unreported Leaks and Bursts
On Mains	20 litres/km/hr	12.4 bursts/100 km/yr. at 12 m^3/hr for 3 days = 864 m^3/burst	0.6 bursts/100 km/yr. at 6 m3/hr for 50 days = 7200 m^3/burst
On Service Connections, Main to Property Line	1.25 litres/conn/hr	2.25/ 1000 conns/yr. at 1.6 m^3/hr for 8 days = 307 m^3/burst	0.75/1000 conns/yr. at 1.6 m^3/hr for 100 days = 3840 m^3/burst
On Service Conns from Property Line to meter, if customer meter is not located at the property line	0.50 litres/conn/hr*	1.5/ 1000 conns/yr.* at 1.6 m^3/hr for 9 days = 346 m^3/burst	0.50/1000 conns/yr*. at 1.6 m^3/hr for 101 days= 3878 m^3/burst

* for 15 metres average length

The basic equation for the calculation of UARL is:

UARL (litres/day) = (18 x Lm + 0.8 x Ns + 25 x Lp) x P ……….(1)

Where; Lm is mains length (km), Ns is no. of service connections (main to property line), Lp is total length of underground pipes (property line to meter) and P is the average 24-hour pressure (metres). In the SABESP case as the meters are at the property line the third part of the equation 25xLp is not used.

During the component analysis the largest volumes of annual real loss were found to occur on the service connections. Although these events tend to have quite small flow rates and even though the time to repair them was relatively fast the high frequency of events indicated that this was a problem area which needed to be resolved. Theoretically it would have been possible to increase the frequency of leak detection and repair (maintenance cost) and further reduce the annual volume of un-reported real losses, however a capital investment solution was sought which would reduce the number of events therefore reducing the need for such high annual maintenance costs, while also attacking the other two components of real loss, background leakage and reported leakage.

Study areas were identified and field testing was intensified in the central business unit of SABESP Metropolitan Region. The Central Business Unit has the following characteristics (SABESP, 2009):

- 705,396 active connections
- 1,427,204 properties
- 5,849 km of distribution mains
- 109 km of transmission mains
- 17 booster stations
- 30 bulk supply zones
- 204 pressure controlled districts covering around 41% of the network
- Average pressure of 45 meters head
- Metric indicator for real losses - ILI of 6.4 (varying from 23.7 to 2.7)
- Process Indicator for total water losses average of 431 l/conn/day
    - Real loss average 289 l/conn/day
    - Apparent loss average 142 l/conn/day

One of the challenges faced by the central business unit is the infrastructure: 17% of the mains are older than 50 years, 56% are between 30 and 49 years, and the rest 27% is less than 30 years old, as shown in Figure 1.2

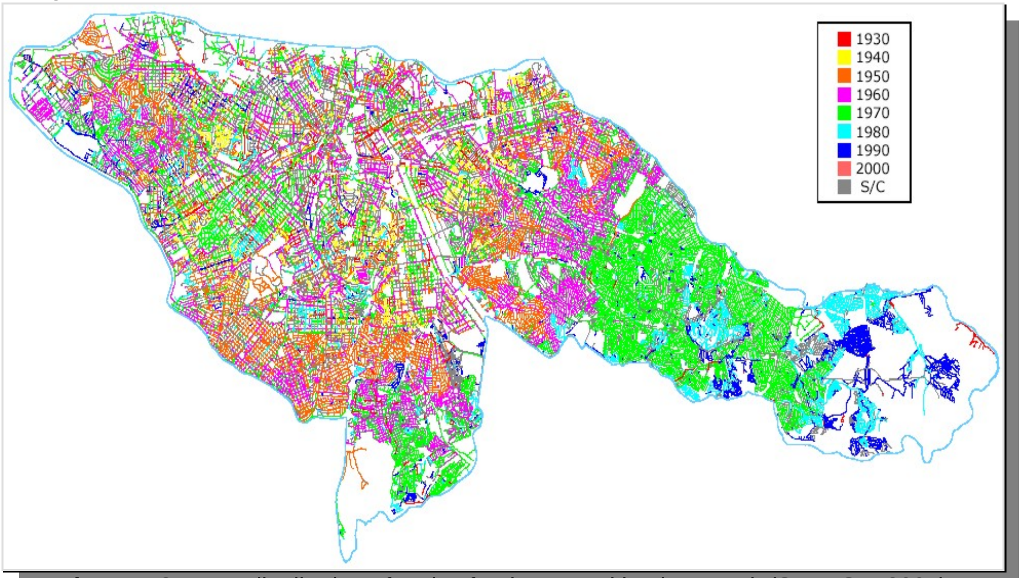

Figure 1.2 – Age distribution of mains for the central business unit (SABESP, 2007)

Due to the relatively high cost of main replacement or rehabilitation (approximately US$ 150 per meter) and limited budget only about 20 km per year (less than 0.5%) of mains have been replaced in critical areas where break frequency is high and water quality, or quantity complaints have been received from customers.

Having said this, a detailed analysis of break statistics showed that the most fragile infrastructure components were the service connections (Figure 1.3). There were 84,761 leak repairs made during 2008 of which 4,299 were on mains (5%). The rest were on service connections, 28,023 on the service pipe (33%) and 52,439 on the meter set (62%). The central business unit has been investing in preventative maintenance of the infrastructure by block replacement of service connections since 2005 at an average cost of US$ 135 per replacement.

Detailed analysis of main and service break frequency, flow rate and response time was undertaken during the component analysis phase of the water audit in order to separate volumes of reported and un-reported leakage. SABESP and Restor also undertook a series of field tests to identify ICF in order to properly allocate volumes of leakage to the background leakage component for each bulk supply area. In this way a comparison of the costs and benefits of different real loss reduction tools could be made for short medium and long terms (as discussed in PARACAMPOS, MELATO & THORNTON, 2009) and areas prioritized for intervention with the most appropriate and cost effective tools to ensure efficient use of budget.

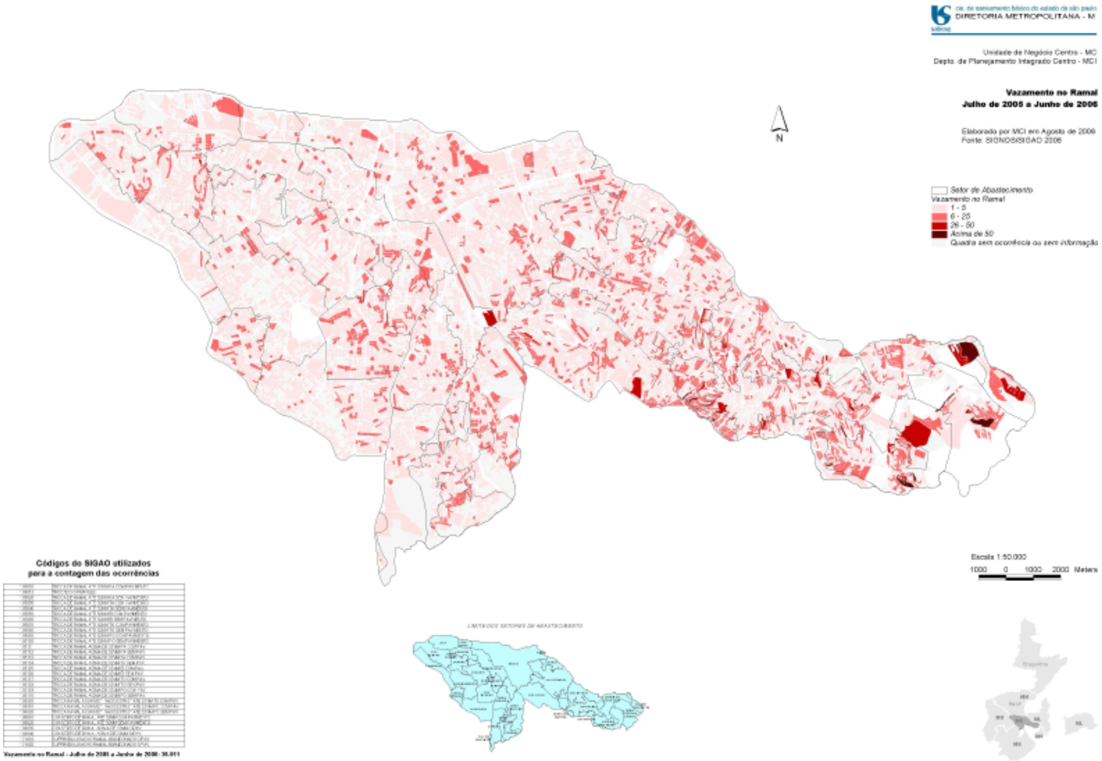

Figure 1.3 – Distribution of service break frequency in 2008 (SABESP, SIGNOS, 2008)

Methods for field testing of ICF

Standard operating procedures were designed and initial ICF tests were undertaken in the Central Business Unit of SABESP. Special care was taken to remove all identifiable leakage from the pilot areas with several leak detection and repair sweeps before the tests were undertaken and fraud identification and removal actions were undertaken before the measurements were made – then isolated representative areas of the system were subject to flow and pressure measurements using carefully placed pressure loggers and properly sized meters to ensure the best possible results (Figure 1.4). All customers were advised before the test by special designed communications and then turned off for the duration of the test so that measurements reflected true background leakage with no need for estimation of consumption. Faulty district valves and customer valves were replaced. Six representative areas were tested during the audit period (see Table 1.2).

Figure 1.4 – Specially sized meter and data logger installed on a bypass for the test

Table 1.2 – Statistics of the six test areas

Area	Main length (km)	Material	Nº active connections	Nº inactive connections	Pressure (m)
Maria Figueiredo	2.64	Cast Iron	143	46	35
Pirassununga	1.45	Cast Iron	411	80	37
Antonio Coutinho	1.8	Cast Iron	385	16	37
Maria Jose	1.15	Cast Iron	209	32	36
Teodoro Beaurepaire	1.5	Cast Iron	321	21	46
Paula Loebestein	1.58	Cast Iron	192	7	34
Jardim São Pedro	0.85	Cast Iron	174	8	34

Validation of alternative technologies and key variables

In one of the areas Teodoro Beaurepaire a test was undertaken to see if tracer gas methods (using hydrogen gas) of leak detection could pinpoint background leaks. One leak was located although the testing method appears to be very costly compared to the benefits (MELATO, MICHELE, 2008).

In another area called Paula Loebestein two ICF tests were undertaken, one before service pipe replacement in December of 2007 and one directly after in January 2008. The idea was to identify how much the ICF and therefore the background leakage could be reduced by replacing only the service connections. Additional work was done to validate the N1 value before and after service pipe replacement.

Results and Discussion

Like the ILI the ICF is expressed as a ratio of the measured background leakage over the minimum technically achievable but just for the background leakage component. The UBL formula is:

$$\text{UBL (litres/hour)} = (20 \times Lm + 1.25 \times Ns) \times (AZNP/50)^{1.5} \quad \text{…….. (2)}$$

Table 3 shows key results from testing in the six areas.

Table 1.3 – Results from the ICF and N1 tests

	Minimum flow (m3/h)		FCI		N1	
Area	**Before replacement**	**After replacement**	**Before**	**After**	**Before**	**After**
Maria Figueiredo	2.52		14.93			
Pirassununga	2.80		8.39			
Antonio Coutinho	5.12		7.40			
Maria Jose	1.25		7.20			
Teodoro Beaurepaire	5.45		2.65			
Paula Loebestein	2.00	0.54	9.76	2.97	0.74	1.43
Jardim São Pedro	0.72		4.58			

In the Paula Loebestein area three leak detection and repair sweeps were undertaken before the ICF test and N1 test on 07/12/07. After this all of the service connections were replaced and on 17/01/08 another set of ICF and N1 tests was undertaken, the results can be seen in Figures 1.5 to 1.9.

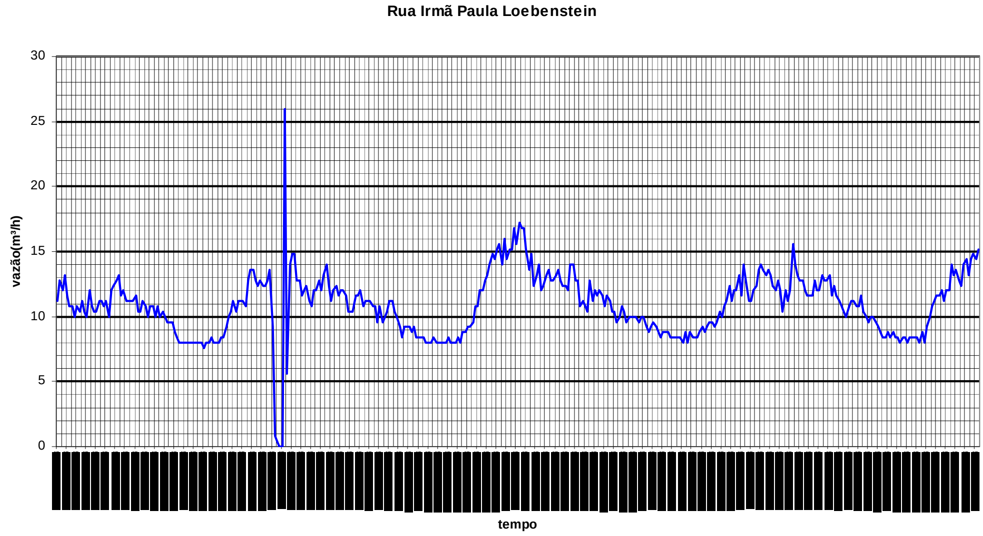

Figure 1.5 – Flow at Paula Loebenstein

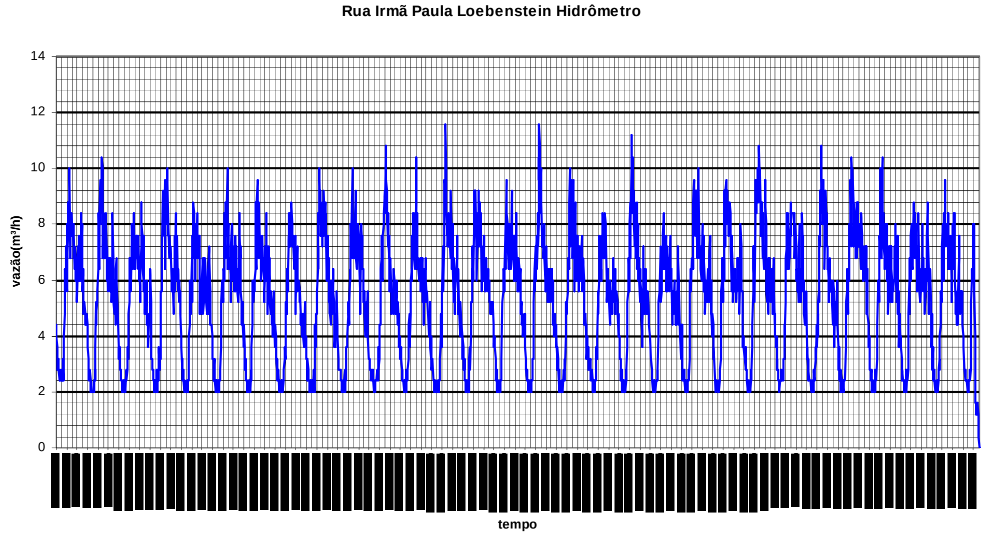

Figure 1.6 – Flow after the third leak detection and repair exercise

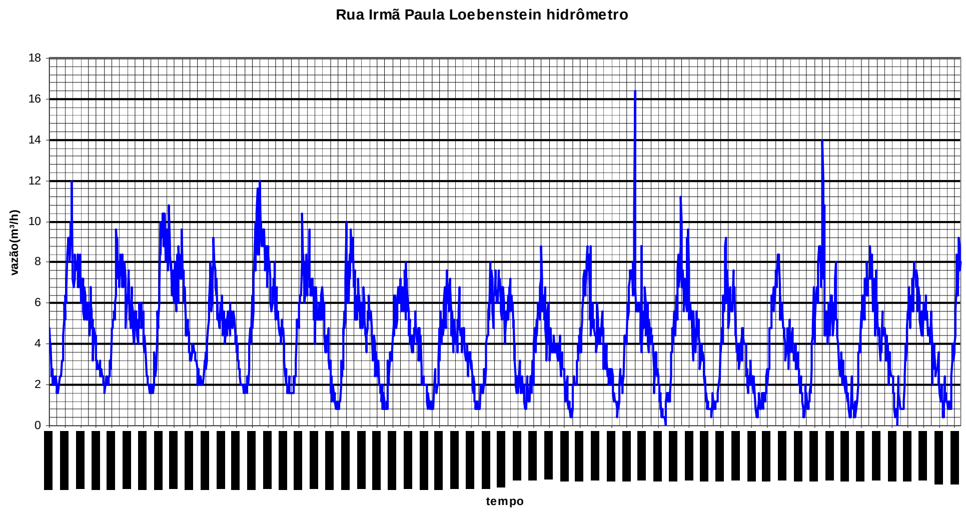

Figure 1.7 –Flow after service pipe replacement

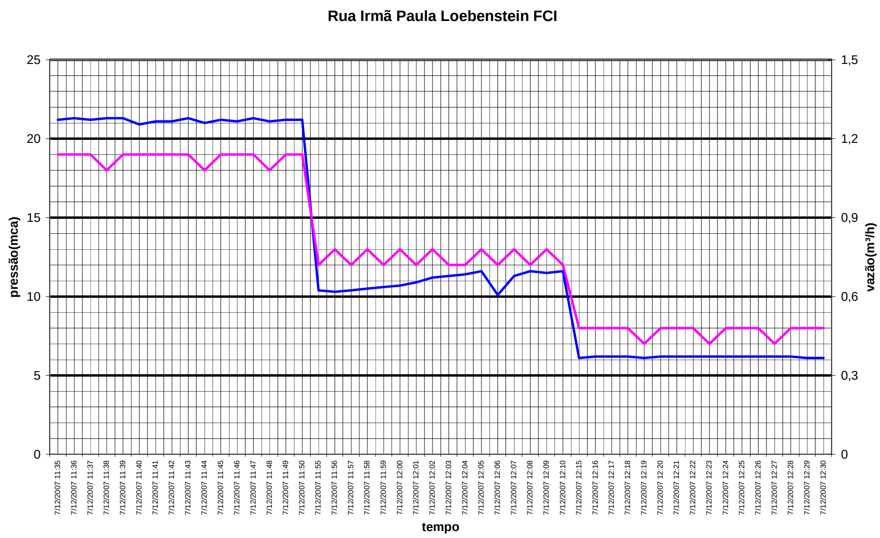

Figure1.8 – N1 test before service replacement

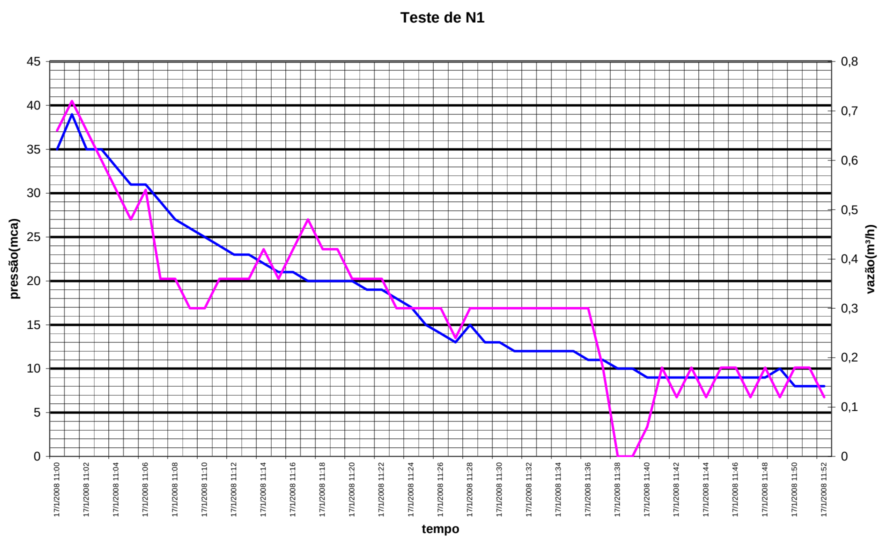

Figure 1.9 – N1 test after service replacement

In Table 1.3 we can see ICF ranges from 2.65 to 14.93 meaning that background leakage was 2.65 to 14.93 times that of a system with an ideal infrastructure condition of 1 as defined in the Unavoidable Background Leakage (UBL) formula shown above. Having identified the ratios and volumes in the test areas the next step was to replace all service connections in one of the test areas. It can be seen that ICF was reduced from 9.76 to 2.97. In this case 70% of savings in background leakage component was attained by replacing the service connections which represents 10% of the investment necessary to replace all, of the infrastructure in this test area.

SABESP has also found that for pure leakage management purposes a service connection replacement on average will repay itself in less than 2 years while a main replacement takes in excess of 50 years (SABESP/RESTOR, 2008). It is also important to mention that in other tests realized in Central Business Unit, the savings for a service connection replacement were 13.2 l/h in areas covered by PRVs and 29.2 l/h in areas not covered by PRVs (CARVALHO, MELATO, 2007).

Conclusions

In the test area the ICF was reduced from approximately 9 to approximately 3 just by service connection replacement showing that it is quite likely that in cases with similar conditions when the cheaper options such as leak detection and repair have reached their economic maximum frequency and pressures have been optimized as much as possible then looking at the fourth arrow infrastructure management is both viable and has a relatively fast pay back if components are correctly identified for replacement.

SABESP has since used ICF measurements coupled with break frequency analysis and component analysis to select areas where a capital investment in service connection replacement is more appropriate than an increase in maintenance cost to increase leak detection and repair frequency further. SABESP is currently tracking rate of rise of new leakage in these areas to establish sustainability curves and are attacking problems with installation quality and materials quality – in order that tomorrows NRW managers do not face the problems that today's managers face.

Due to limited page length for the conference proceedings much information has been omitted from this paper, however additional information on the rationale used can be found in (PARACAMPOS, MELATO, THORNTON 2009) or by contacting the authors of this paper.

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