Detailed analyses of water loss management processes in support of network asset management

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Abstract
The efficiency in managing water supply networks is reflected in failure rates, water losses, water quality and reliability of service. While in industrialised countries the past centuries were characterised by huge investments in building-up communal water supply systems the challenge for the upcoming decades is the preservation of the network asset substance and the optimisation of operational and capital costs. This requires an integrated and sustainable network asset management.

During the past years the Austrian water sector gained much experience in water loss management and implemented a new and innovative water loss guideline. This development was driven by the sectors association, scientific organisations, water utilities and the industrial sector. One of the main reasons for revising existing water loss management practices and considering international developments were unsatisfying classification schemes in the existing guidelines, which did not allow meaningful assessments of water losses and comparisons of water loss performance indicators between utilities.

This paper shows how detailed analyses of water loss management practises under consideration of international experiences and innovative guidelines support an effective and sustainable network asset management. Answer on essential questions of asset managers is given. One of the highlights is the linkage of water loss data, failure rates and network age data with the BABE concept (Bursts and Background Estimates) to identify root causes of water losses and derivate improvement measures.

Keywords
Network asset management, water loss, process analyses, BABE concept, performance assessment

UNHAPPINESS IS THE FIRST PRECONDITION FOR PROGRESS

This statement of Thomas A. Edison became true in an early stage of benchmarking in the Austrian water sector. It turned out that comparisons of water loss performance indicators on basis of existing performance indicators and classifications schemes and without adequate consideration of network structure and network age do not allow meaningful interpretations of the network condition and the water loss situation.

In the following international practices were studied, experiences of water utilities evaluated, a benchmarking system for the process of water loss management was developed (Koelbl, 2009) and finally the existing water loss guideline of OVGW (Austrian Association for Gas and Water) was revised. But the implementation of the new OVGW W 63 guideline (2009) was not the end of the journey. Moreover it was a milestone and starting point for deeper analyses focusing on understanding root causes of water losses and making the right decisions to reduce water losses and for preserving good network asset condition. Water loss management became one of the core tasks in the broad spectrum of network asset management.

WATER LOSS MANAGEMENT PROCESS ANALYSES

Koelbl (2009) developed a process benchmarking system which was successfully implemented in the Austrian OVGW benchmarking in 2007 and was presented at IWA Water Loss 2009 conference (Koelbl et al., 2009).

Detailed process analyses are based on a process structure shown in Figure 1 which allows an assessment of quality and efficiency of main tasks of water loss management. For the assessment of quality criteria a quality matrix with about 100 single criteria was developed to evaluate the quality of process operation which complements the process performance (Table 1).

The qualitative information can be transformed into semi-quantitative comparisons by using classifications for calculating performance indexes – for instance of the sub-processes shown in Figure 2. To answer the question "where exactly to improve" further individual analyses might be necessary. At the end, a bridge has to be built from benchmarking data to state-of-the art knowledge and analytical tools (Theuretzbacher-Fritz 2011).

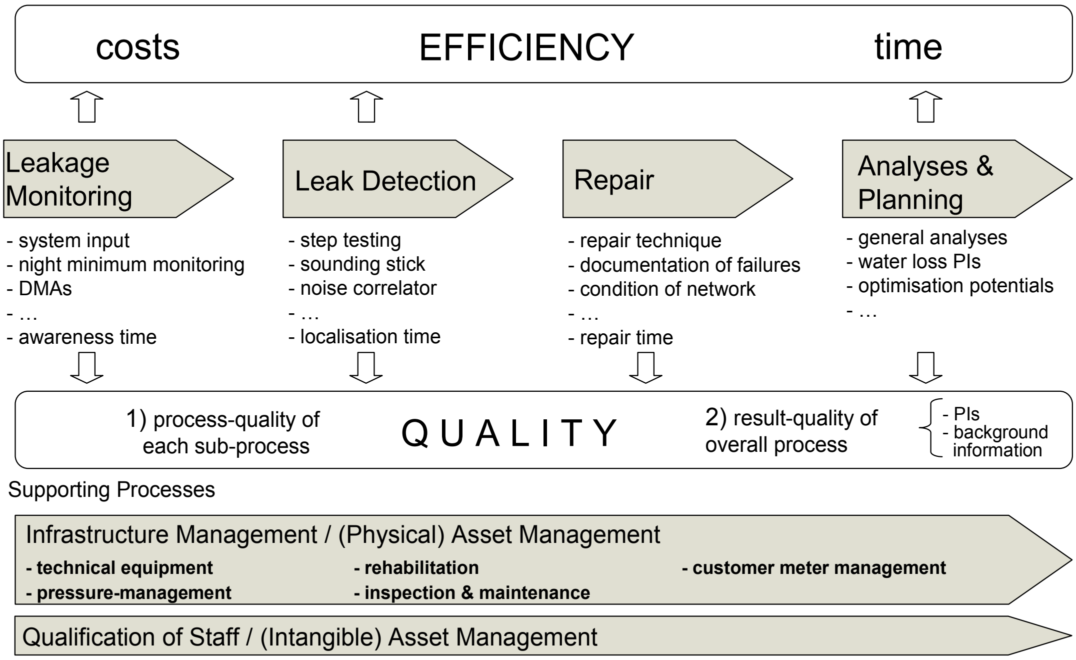


Figure 1. OVGW process structure for physical water loss management (Koelbl 2009)

Table 1. Selected part of quality matrix (Koelbl 2009)

Level Topic Questions	low 1	2	3	4	high 5
Leakage Monitoring (flow, pressure)					
System Input Metering	Most of our system input is not metered	Not all, but > 50% of our system input is metered	Our system input is metered but we are not sure about the accuracy of these (partly old) meters	Our system input is metered with mechanical and/or magnetic flow meters that are rarely calibrated	Our system input is metered with magnetic flow meters that are regularly calibrated
District Metered Areas (DMAs)	We have no DMAs and have no plans to establish DMAs	We plan to install DMAs and have started to establish the first DMAs	The first DMAs are established and we have already the first results	We have several DMAs and check and analyse inflow data sporadically	We have several DMAs and monitor flow and pressure on a regular basis
Night Minimum Measurements	Up to now we did not make night minimum measurements	The night minimum consumption is metered and analysed sporadically with external instruments	The night minimum consumption is metered daily but evaluated only in larger intervalls (e.g. once in a week or month)	We analyse the night minimum consumption of the whole system every day	We analyse the night minimum consumption of each DMA every day

Figure 2. Performance indexes on the quality of sub-processes (Theuretzbacher-Fritz 2011)

THE BABE CONCEPT AS LINK TO ROOT CAUSES OF WATER LOSSES

Within the latest water loss management benchmarking project in Austria, finished in February 2011, some innovations have been implemented in the existing benchmarking system. The idea was linking pipe condition data (pipe age and failure rates) with water loss data and using the BABE concept to analyse the problems and the root causes of water losses. The results of these analyses are the basis for decision making on concrete measures in maintenance and rehabilitation planning. Theuretzbacher-Fritz (2011) highlights the additional system development of the OVGW water loss benchmarking system which resulted from simple utility needs. They just wanted to know

- where exactly the problems exist
- where to take action
- and how?

Individual data on age indexes for different pipe materials, on their failure rates and on the leak detection modes (externally reported / detected by network monitoring systems / detected by field campaigns) were analysed together with actual water losses and expected water losses on the basis of the UARL values of the ILI formula. Since the data were broken down to the transmission, distribution and service connection subsystems, water loss component analyses could be carried out according to the BABE concept of Lambert et al. (1999). Table 2 shows the parameter values used to calculate UARL.

Table 2: Parameter values used to calculate 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

Table 3: Components of Unavoidable Annual Real Losses (Lambert, 2009)

Components of Unavoidable Annual Real Losses at 50 metres pressure (metric units)					
Infrastructure Component	**Unavoidable Background Leakage UBL**	**Reported Breaks**	**Unreported Breaks**	**Unavoidable Annual Real Losses UARL**	
Mains	**480** litres/km/day	**290** litres/km/day	**130** litres/km/day	**900** litres/km/day	**18** litres/km/day/ metre of pressure
Service Connections, main to property line	**30** litres/conn/day	**2** litres/conn/day	**8** litres/conn/day	**40** litres/conn/day	**0.80** litres/conn/day/ metre of pressure
Service Connections, property line to meter	**800** litres/km/day	**95** litres/km/day	**355** litres/km/day	**1250** litres/km/day	**25** litres/km/day/ metre of pressure

Typical FAVAD N1	**Close to 1.5**	**0.5 to 2.5, depends on pipe materials and types of leaks**		**Assumed as average of 1.0 for UARL formula**	

Table 3 shows the components of UARL which is the basis for the analyses of water loss data. Figure 3 gives an overview about this linkage of different components for individual analyses. The upper tables give a linked view on the pipe network status. Although badly visible here in shades-of-grey format, colour coding of age index values and failure rate values allows for a quick, but comprehensive interpretation alongside the different material groups. Of course, such tables cannot substitute sophisticated asset management tools like rehabilitation planning software, but they can be utilised for communicating the rehabilitation, repair and maintenance requirements to shareholders and stakeholders.

VERIFICATION AND INTERPRETATION OF RESULTS

As the outcome of this analysis is a theoretical result, it is necessary to carry out plausibility checks and verify these theoretical results on basis of actual water loss data from SCADA systems, DMA data or other monitoring systems.

The first question to be answered will be, if the recorded pipe failures can explain the certain amount of water losses. The question could be answered by comparing leakage data (from SCADA, DMA or any other monitoring system) like leak rate, run time, night-flows and total loss of water from documented leakages with the results of the calculation based on the parameter values of the BABE concept. In case the amount of water losses cannot be explained by documented leakage data, there might be undetected leakages in the system. In the example in Figure 3 one can find from the lower table that the current annual real losses (CARL) are more than twice the unavoidable real losses (UARL) for the whole system (ILI 2.6). It might be interpreted that the current water losses from unreported, but detectable failures of distribution mains could be much higher than the expected values coming from the UARL empiric values. In this case the recommendation will be the revision of the leakage monitoring and leak detection strategy, and to find the rest of the unreported, but detectable leaks, e.g. by intensifying active leakage control.

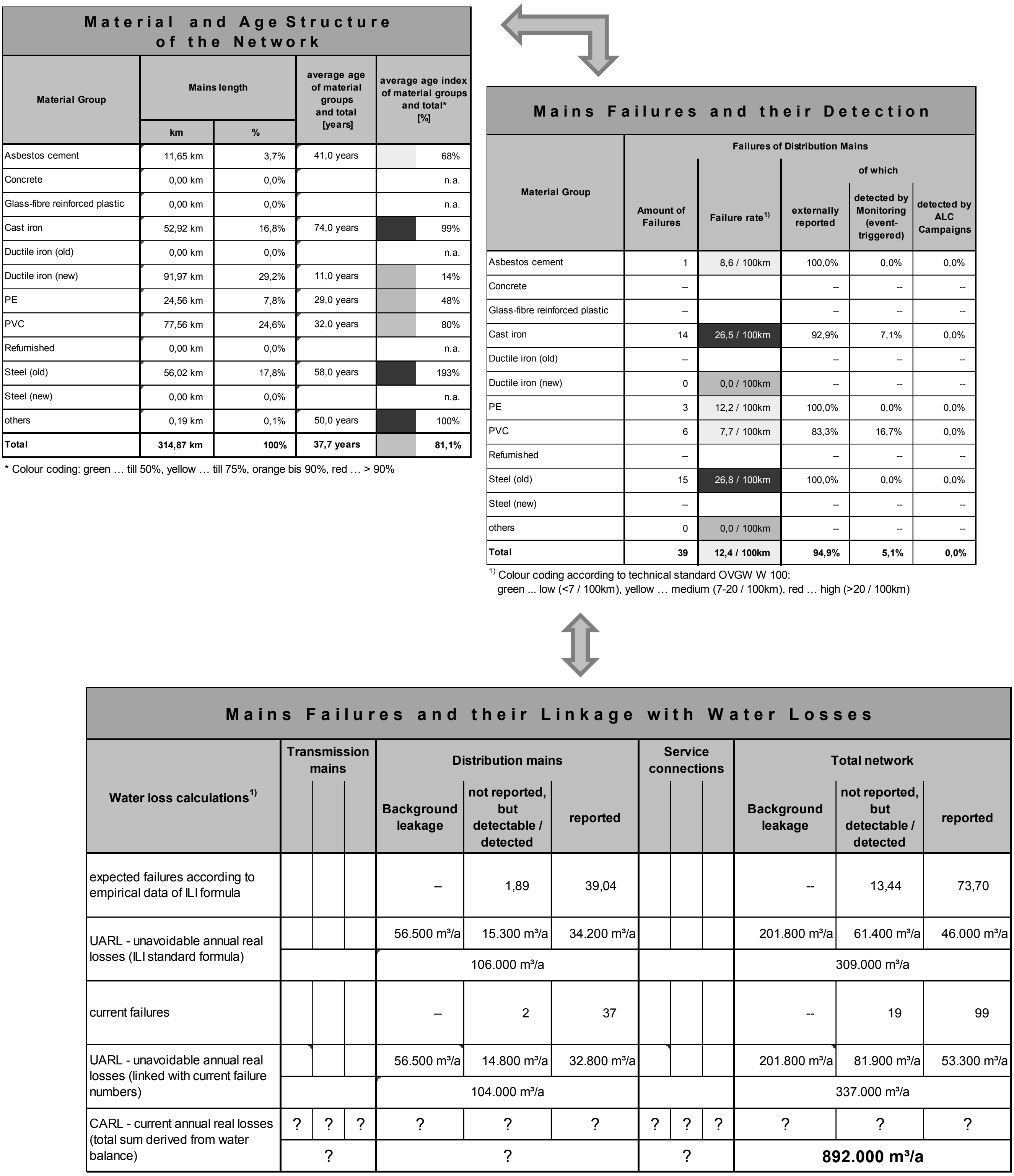
Another question might be, if the recorded percentages for type of failure detection meet the expectations based on the current leakage monitoring and leak detection activities? Or for example, are the leaks mainly reported externally, despite an expensive leakage monitoring system is in place? If so, the effectiveness of current leakage monitoring practices has to be analysed. Qualitative comparisons of single practices with those of leading utilities (see quality matrix in Table 1) could support the discussion and implementation of possible improvements.

Although it is not possible to split up the actual water loss volumes accurately to different parts of the distribution system (transmission mains, distribution mains, service connections) because the single volumes are not measureable, the analysis supports in process optimisation and as well as in defining action plans for further investigations. Such action plans might include:

- Optimisation of leakage monitoring sub-process, e.g.
    - Implementation of an effective network monitoring systems like DMAs or systems for monitoring hydraulically not separated large zones (compare OVGW W 63, 2009)
    - Optimisation of monitoring practises (e.g. daily night flow analysis, automated alarming systems)
- Optimisation of leak detection sub-process, e.g.
    - Regular active leakage control campaigns
    - Leak detection surveys at service connections, e.g. during meter reading
    - Consequent leak detection for alarms of monitoring systems
    - Inspection of transmission mains by acoustic and visual in-pipe technologies
    - Special methodologies like gas testing for sections where acoustic methodologies are not effective
- Optimisation of repair sub-process
    - Increasing speed and quality of repair
- Optimisation of analysis sub-process
    - Detailed investigation of root causes of water losses

For heterogeneous network structures with different failure characteristics due different network age, pipe materials or other frame conditions, it could be useful to break down the component analyses for single sections of the networks. Figure 3 gives an example of such a component analyses which is based on data collected in the Austrian water loss process benchmarking.

Despite the calculations of the lower table in Figure 3 might need some “customisation” to utility-specific frame conditions (e.g. pressure is assumed as a linear effect on losses, and hence errors rise the more the pressure height differs from the empirically calibrated 50 m), these analytical extra efforts help to step into a sound discussion on water loss management and moreover, on physical asset management and leave the discussions on PI comparisons (even on ILI, too) far behind (Theuretzbacher-Fritz, 2011).



Material and Age Structure of the Network

Material Group	Mains length		average age of material groups and total [years]	average age index of material groups and total* [%]
	km	%		
Asbestos cement	11,65 km	3,7%	41,0 years	68%
Concrete	0,00 km	0,0%		n.a.
Glass-fibre reinforced plastic	0,00 km	0,0%		n.a.
Cast iron	52,92 km	16,8%	74,0 years	99%
Ductile iron (old)	0,00 km	0,0%		n.a.
Ductile iron (new)	91,97 km	29,2%	11,0 years	14%
PE	24,56 km	7,8%	29,0 years	48%
PVC	77,56 km	24,6%	32,0 years	80%
Refurnished	0,00 km	0,0%		n.a.
Steel (old)	56,02 km	17,8%	58,0 years	193%
Steel (new)	0,00 km	0,0%		n.a.
others	0,19 km	0,1%	50,0 years	100%
Total	**314,87 km**	**100%**	**37,7 years**	**81,1%**

* Colour coding: green … till 50%, yellow … till 75%, orange bis 90%, red … > 90%

Mains Failures and their Detection

Material Group	Failures of Distribution Mains				
			of which		
	Amount of Failures	Failure rate[1]	externally reported	detected by Monitoring (event-triggered)	detected by ALC Campaigns
Asbestos cement	1	8,6 / 100km	100,0%	0,0%	0,0%
Concrete	--		--	--	--
Glass-fibre reinforced plastic	--		--	--	--
Cast iron	14	26,5 / 100km	92,9%	7,1%	0,0%
Ductile iron (old)	--		--	--	--
Ductile iron (new)	0	0,0 / 100km	--	--	--
PE	3	12,2 / 100km	100,0%	0,0%	0,0%
PVC	6	7,7 / 100km	83,3%	16,7%	0,0%
Refurnished	--		--	--	--
Steel (old)	15	26,8 / 100km	100,0%	0,0%	0,0%
Steel (new)	--		--	--	--
others	0	0,0 / 100km	--	--	--
Total	**39**	**12,4 / 100km**	**94,9%**	**5,1%**	**0,0%**

[1] Colour coding according to technical standard OVGW W 100:
green ... low (<7 / 100km), yellow … medium (7-20 / 100km), red … high (>20 / 100km)

Mains Failures and their Linkage with Water Losses

Water loss calculations[1]	Transmission mains			Distribution mains			Service connections			Total network		
				Background leakage	not reported, but detectable / detected	reported				Background leakage	not reported, but detectable / detected	reported
expected failures according to empirical data of ILI formula				--	1,89	39,04				--	13,44	73,70
UARL - unavoidable annual real losses (ILI standard formula)				56.500 m^3/a	15.300 m^3/a	34.200 m^3/a				201.800 m^3/a	61.400 m^3/a	46.000 m^3/a
				106.000 m^3/a						309.000 m^3/a		
current failures				--	2	37				--	19	99
UARL - unavoidable annual real losses (linked with current failure numbers)				56.500 m^3/a	14.800 m^3/a	32.800 m^3/a				201.800 m^3/a	81.900 m^3/a	53.300 m^3/a
				104.000 m^3/a						337.000 m^3/a		
CARL - current annual real losses (total sum derived from water balance)	?	?	?	?	?	?	?	?	?	?	?	?
	?			?			?			**892.000 m^3/a**		

Figure 3. Linkage of different components for individual analyses (Theuretzbacher-Fritz 2011)

INTEGRATED PERFORMANCE ASSESSMENT TO DEFINE ASSET MANAGEMENT TARGETS

How to link performance assessment and water loss management process analyses to physical asset management was tested with data of an Austrian utility. The utility is structured into DMAs and provides ILI calculations. For all DMAs a failure database exists. Therefore not only water loss PIs can be taken into account for asset management task setting but also trends of failure rates can be derived to define the most critical pipe sections. One purpose of the integrated analyses of failure rates and water loss PIs was to involve the knowledge about water losses into pipe rehabilitation prioritisation. As a first step of the rehabilitation planning concept, it was examined if deficits exist in water loss management and in pipe rehabilitation. Therefore the following assessment was made for each DMA.

- Are the failure rates of the distribution system sections above the defined service level (ÖVGW W 100)?
- Is the ILI above the defined service level (ÖVGW W 63)?
- Is there a rising trend in the ILI?
- Is there a rising trend in the failure rates?
- How high was the leak detection rate in the investigated years?

Based on these analyses for each region asset management deficits were derived and the DMAs were categorized in category A, B, C or D:

A) For zones with high failure rates, high water losses and rising trends in both water losses and failure rates, failure repair as selective measure obviously does not reduce water losses. As the pressure level is balanced in a range of 4 to 5 bar at this utility the decision is to intensify **rehabilitation** efforts. Figure 4 shows an example for category a. It can be seen in the graph that the failure rates are above the service level given in the Austrian standard ÖVGW W 100, which is 10 failures per 100 km and year. Further the water losses increase continuously although a high leak detection grade is given in this DMA.

B) For zones with high or increasing water losses and low failure rates **leak detection campaigns** are intensified. This step is necessary to increase the information grade about the deteriorated system parts which are responsible for water losses.

C) For zones with low failure rates and low water losses and no trends in both PIs the strategy is to further **observe** minimum night flow.

D) For zones with balanced failure rates and balanced water losses the utility **proceeds** the current strategy of water loss management and infrastructure maintenance and rehabilitation. For example Figure 5 shows a DMA where obviously several service connections were responsible for an increase in water losses. Having repaired these weak points efficiently has reduced water losses.

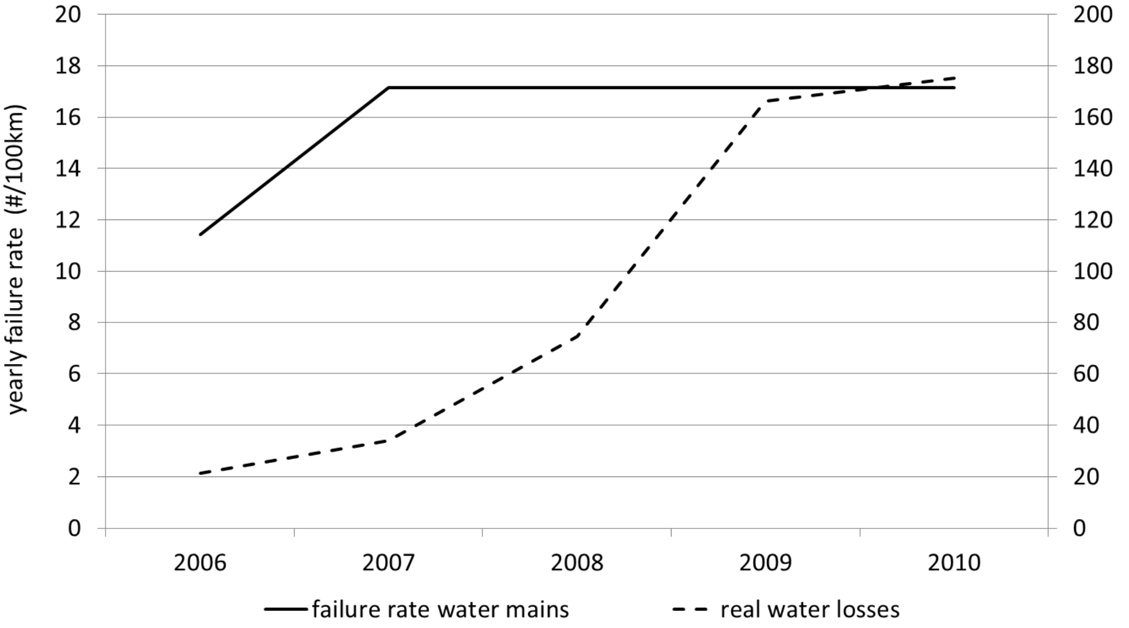


Figure 4: DMA (category A) with high failure rates of water mains and increasing water losses

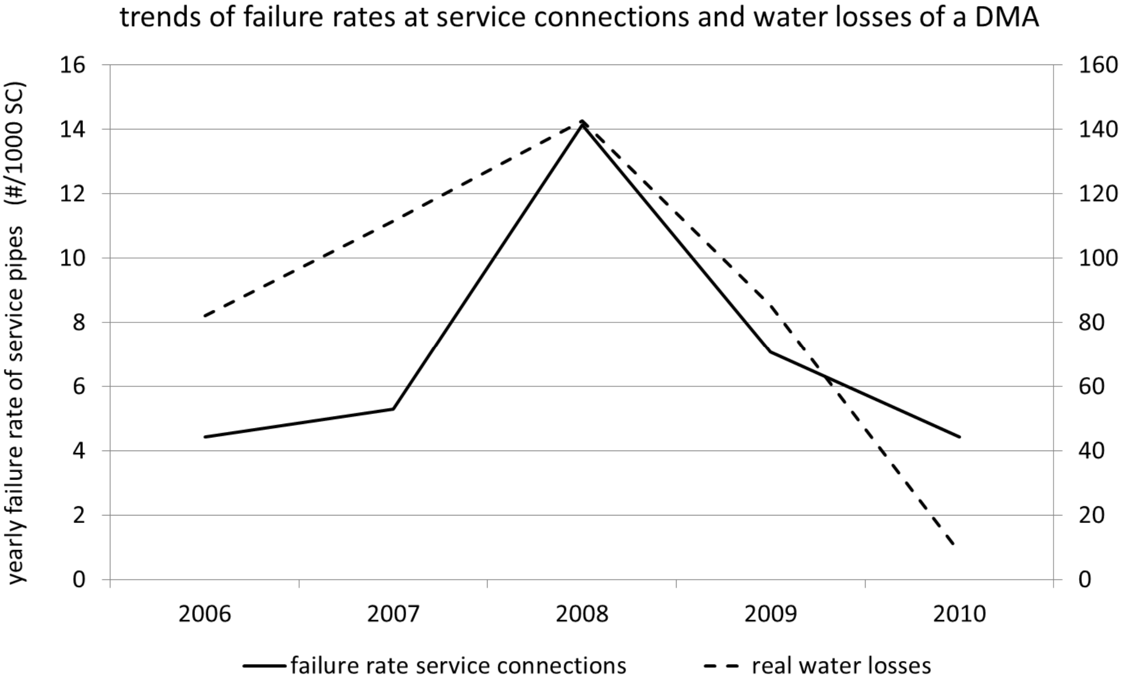


Figure 5. DMA (category D) with correlation of service connection failures and water losses

In a further pipe section oriented analyses, the knowledge, generated in the planning steps described above was involved in a prioritisation concept. Generally the prioritisation concept is based on economic replacement time calculations which take into account failure prediction of specific pipe sections (Fuchs-Hanusch et al., 2011). Such a concept guarantees an economically sustainable rehabilitation planning, focusing on pipes which reach the economic rehabilitation time. To take into account DMA based information, e.g. water losses, the pipes with the same failure cost history but belonging to DMAs categorized in category A are further prioritized.

CONCLUSIONS

The approach described in this paper shows that detailed analyses of water loss management practices provide useful support to network asset management. Information gained in benchmarking projects and detailed process analyses could give an overview about the water loss situation and the effectiveness of water loss management practices. Nevertheless, for decision making in maintenance and rehabilitation planning it is sometimes necessary to gain more detailed information. The approach of using component analyses (BABE model) leads to a better understanding of possible root causes and shows up optimisation potentials in water loss and maintenance management practices. Even if an unambiguous assignment of water losses to the components is technically not possible, such studies help asking the right questions in further analyses.

The example given in the case study shows that deeper analysis of failure rates and water losses on basis of DMA data (respectively other monitoring systems) provide essential information for asset management decisions. From a financial point of view it is of highly interest to invest the money of limited rehabilitation budgets effectively. To ensure this, accurate monitoring data and failure statistics allow a categorisation of the situation and further a prioritisation of measures. Especially, it helps answering the question if the focus should be on rehabilitation or on intensifying leak detection campaigns with repair as selective measure.

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