SUSTAINABLE NETWORK MANAGEMENT PRACTISES

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ABSTRACT

The efficiency in managing a water supply network is reflected in failure rates, water losses, water quality and reliability of service. In industrialised countries, the past centuries have been characterised by huge investments in building-up communal water supply systems. These systems have grown over decades and each pipe has its own history. Aging water supply networks lead to higher operation and maintenance costs due to higher failure rates and increasing water losses. The challenge for the upcoming decades is the preservation of the substance and the optimisation of operational and capital costs. This requires an integrated and sustainable asset management.
This paper describes a case study about successful long-term management of the historical grown water supply network of the city of Salzburg in Austria. Parts of the network are more than 100 years old, but water losses and failure rates are low compared to international values. The good condition of the pipe network and the high service quality provided to the clients are a result of a consequent asset management strategy using latest asset management tools.

Salzburg's Water Supply System

Salzburg's water supply system has a long tradition. The first verifiable assets are roman cisterns. The discovery of wooden pipes meant that spring water from the surrounding mountains was directed to the city already in roman times. From the medieval draw and pump wells are known. An increased population in the 15th century required the construction of a bulk line from the mountains.
To improve the economic development of Salzburg, the water supply system was fully restructured from 1861 on. With the availability of cast iron pipes it was possible to use the natural spring "Fuerstenbrunnquelle", which became one of the main water resources. After World War II the water supply system suffered from war damages which led to frequent supply shortfalls. In the decades after WWII the network was renewed and enlarged.
Today Salzburg AG, a multi-utility infrastructure provider in the city and province of Salzburg (water, power, district heating, natural gas, telecommunication and public transport services), uses two main groundwater resources and a connection to a trans-regional bulk supply system. From two large water reservoirs the four main zones of the city, each with 3,900 to 5,900 service connections, are served. In addition seven small, higher situated zones with 9 to 272 service connections each are supplied by pumping stations. In almost all streets of Salzburg lie water pipes. 98% of the population is connected to the public water supply system.
Historically, the 531 km system of mains is a mix of several pipe materials mainly of cast iron and ductile iron and partly fibre cement, steel, concrete and plastic (see Table 1). The average age of the mains

Table 1: Network key data

pipe group related to material	lenghts of pipe groups [km] bulk lines	mains	proportion of pipe group in network [%]	average age of pipe group [years]
fibre cement	0.00 km	59.47 km	11.2%	44.6 years
reinforced concrete	8.38 km	0.00 km	1.6%	28.1 years
cast iron	30.84 km	184.15 km	40.5%	62.4 years
ductile iron old (before 1975)	0.27 km	54.60 km	10.3%	28.9 years
ductile iron new (after 1975)	1.24 km	115.70 km	22.0%	16.2 years
PE	1.95 km	16.87 km	3.5%	18.9 years
PVC	0.59 km	1.87 km	0.5%	35.7 years
renovated pipes	0.00 km	0.06 km	0.0%	0.0 years
steel old (without coating)	4.30 km	11.20 km	2.9%	70.0 years
steel new (PE coating, cement-mortar lining)	0.90 km	36.10 km	7.0%	4.6 years
others	1.78 km	0.65 km	0.5%	51.0 years
total	**50.25 km**	**480.66 km**	100%	40.7 years
	530.91 km			

network is around 41 years. 27% of the 320 km of service connections are zinc-coated steel pipes which have been installed up to the 1960ies. Today only polyethylene (PE) is used for the renewal of service connections and in the meantime PE has a share of 67% of all service connections. Since 2006 all service connections made of lead or copper are replaced by PE.

The average supply pressure is around 4.4 bar with maximum values of 6.5 bar.

Network Condition

Two criteria are mainly characterising the condition of a pipe network:

- Physical Water Losses
- Failure rates

The failure dynamics of a network is influenced by (OVGW W 63, 2009):

- Structure of the network (e.g. rural or urban)
- Type of soil and soil movements
- Traffic load
- Excavations near pipes
- Pressure variations, water surges, operating pressure
- Service connection density

Also the qualities of the used pipe materials, fittings and the construction procedures are affecting the lifetime and failure dynamics essentially. Therefore, Salzburg AG uses only high quality material with OVGW (Austrian Association for Gas and Water) approval. This might lead to slightly higher investment costs but pays back multiple in long-term because of lower failure rates and therefore lower operation and maintenance costs due to less repair demand and lower water losses.

The condition of Salzburg's pipe network in general is very good considering the heterogenic material and age structure, which is normal for historically grown networks. Actual failure rates of mains are around 12 failures per 100 km mains per year, which is close to other Austrian urban systems and low in international comparison.

An investigation in 2010, done within the OVGW benchmarking on the process of water loss management, makes the failure behaviour of different pipe groups transparent. Figure 1 shows that the most critical pipe groups are mains of cast iron with a failure rate (average between 2007 and 2009) of 24.6 per 100 km per year and PVC pipes with 17.9 failures per 100 km per year.

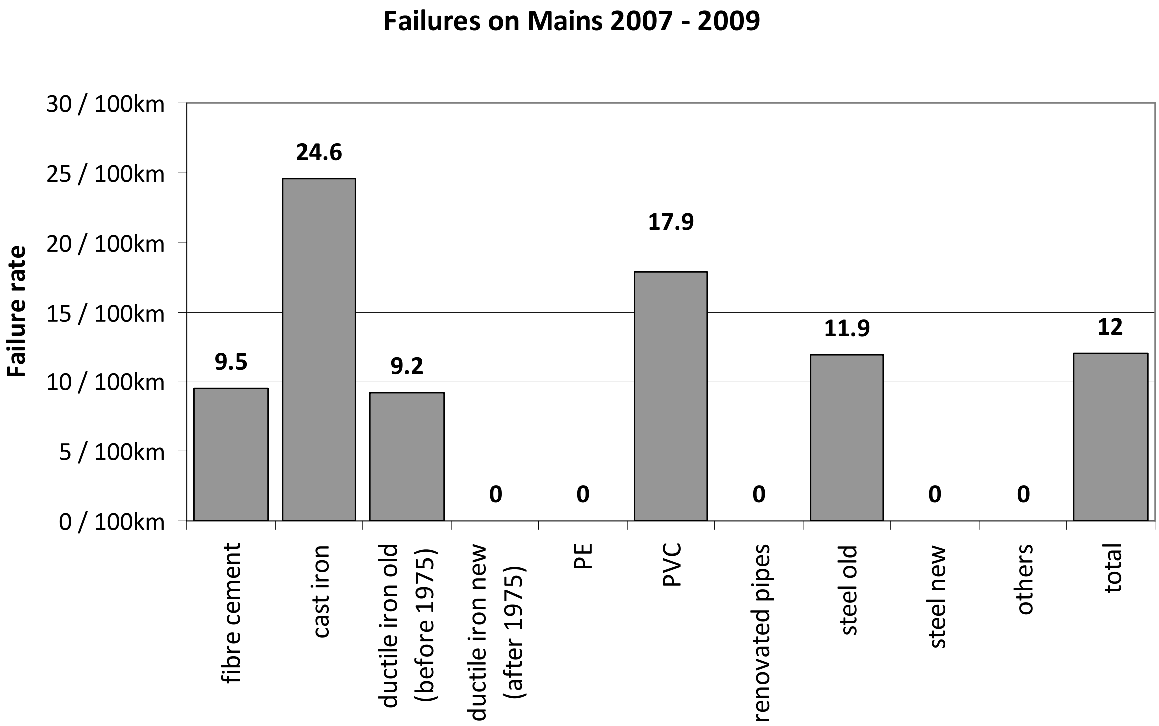

Figure 1: Failure rates of pipe groups

Classified according to OVGW W 100 (2007) steel old (11.9 failure per 100 km per year), fibre cement (9.5 per 100 km) and ductile iron old (9.2 per 100 km) have average failure rates. Recently installed pipe materials like ductile iron new, PE and steel new, representing a third of mains with an average age of 14 years, did not have any failures in this three year assessment period.
Most likely basic causes for the failures are fatigue, ground motion, traffic load and frost damages.

Water loss performance indicators are evaluated regularly and according to OVGW W 63 (2009), the water loss guideline of OVGW. Water losses for the total network are classified as low with an ILI lower than 2 (Table 2). Non-revenue water is at a low level of around 7%. On the one hand this is due to 100% customer metering and good payment moral of clients and on the other hand the physical losses are low. The multi-utility approach with one bill for several services of Salzburg AG is an advantage for the payment moral and increases the customer satisfaction with the provided infrastructure services. The low physical losses indicate a well maintained network and are a consequence of the water loss management and rehabilitation strategy.

Table 2: Water Loss PIs (year 2009)

Performance Indicator	2009 Value	Unit
ILI	1.8	-
Losses per mains length	0.185	m³/(km*h)
Losses per connection per day	118	l/(conn.*d)
Non-Revenue Water	7.3	%

Water Loss Management Strategy

Salzburg AG's water loss management strategy is similar to many other water utilities in Austria and Central Europe. It is in accordance with OVGW guide-line W 63 (2009) and is in principal also based on the IWA water loss management strategy described by

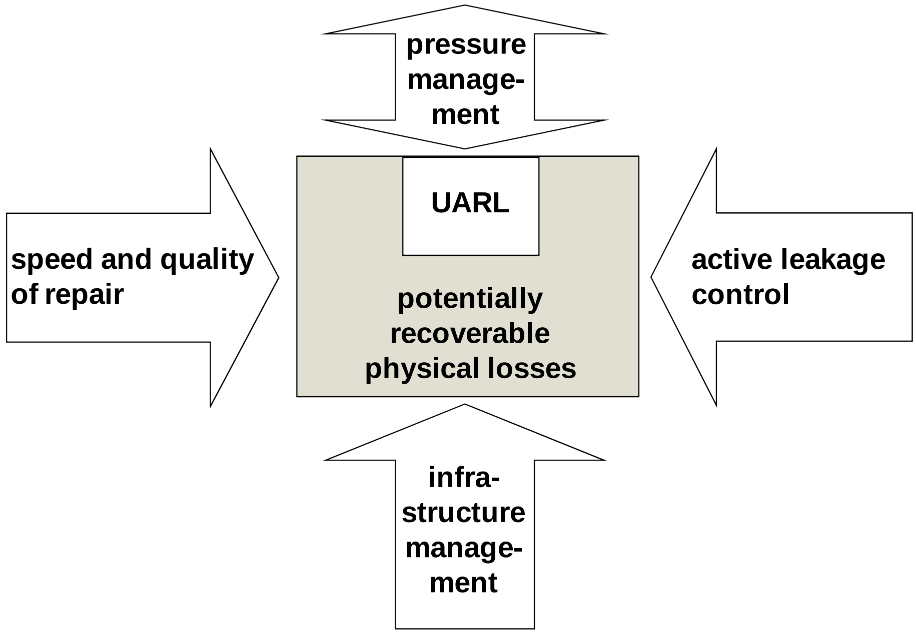

Figure 2: IWA basic methods of water loss management

several publications e.g. Farley & Trow (2003) or Pilcher et al. (2007).

Referring to Figure 2, water loss management methodologies include active leakage control, the repair process, pressure management and infrastructure management.

Regarding active leakage control Salzburg AG uses a mixed methodology of network monitoring and routine inspection campaigns. The network is divided into four main zones and seven small zones. Each of these zones is permanently metered and the flow data are transferred to a central control room. On daily basis the night minimum input of each zone is evaluated. In addition to the zone measurements, the main traffic routes are equipped with permanent noise loggers which are read on weekly basis and on demand. In case there is an increasing trend in night minimum input, leak detection campaigns are initiated. For the purpose of step testing the four main zones can be easily divided into 15 small temporary zones. For leak detection and pinpointing all common leak detection technologies are available. In case one or more of the noise loggers give an indication for leakage, the leak detection is focused on a small area and location time is kept short.

In addition to the on-demand leak detection, also routine leak detection campaigns are carried out every year to detect small leakages which are not detectable by the network monitoring system.

Speed and quality of repair is a must to keep water losses low. With the multi-utility structure, which means there is one maintenance team for water, natural gas and district heating networks, run times of leaks are kept short. For repairs only high quality material is used and relevant repair standards are followed.

Concerning pressure management it has to be mentioned that the pressure management philosophy in central Europe, especially in Austria, Germany and Switzerland, is clearly different from the IWA philosophy. In these countries pressure reduction under a level of 30 m to 40 m service pressure head (3 to 4 bars) is seen as an urgent measure in a system of poor infrastructure condition and it is seen more as a fight against symptoms rather than against the real cause.

Since most of the leak detection methodologies use acoustic technologies, leak detection in systems with low service pressure becomes very difficult or even impossible. To assure a sustainable infrastructure management with pipe networks in good condition it is necessary to operate the supply systems under adequate pressure (Koelbl, 2009). Therefore no classical pressure management is carried out in Salzburg. However, unnecessary high pressures and water surges are definitely avoided.

Infrastructure Management

Infrastructure management includes a very broad field of tasks and is therefore described in more detail. In general, infrastructure management activities are long-term measures. One aspect is the general configuration of the supply system and the technical equipment in use. The central tasks of infrastructure management are the duties of maintaining all kind of assets: storage tanks, pumping stations and also the supply network, including all kinds of valves and joints, hydrants and flow meters. Figure 3 gives an overview of the maintenance duties described in OVGW W 100 (2007).
One of the core questions in infrastructure management is: Which pipes should be replaced and which pipes should be repaired? The questions for the optimal replacement time of a pipe is not easy to answer and requires intensive analyses of failure behaviour, expected lifetimes of pipes as well as cost analyses, besides replacement activities triggered by overall reconstructions of streets and/or other media. During the last years Salzburg AG participated in a research project, where a Pipe Rehabilitation Management Software (PiReM) has been developed (Fuchs-Hanusch et al., 2008b). PiReM is a decision support tool, which allows long-term and mid-term planning of rehabilitation measures based on individual calibrated aging behaviour of pipe groups. Several relevant costs like repair and rehabilitation costs but also socio-economic costs of construction sites can be considered. However, the basis for a software based rehabilitation planning is a detailed asset and failure documentation. All assets of Salzburg AG are recorded in a GIS system (Geographic Information System). The GIS system also includes detailed failure documentation according to the Austrian guideline OVGW W 100 (2007).

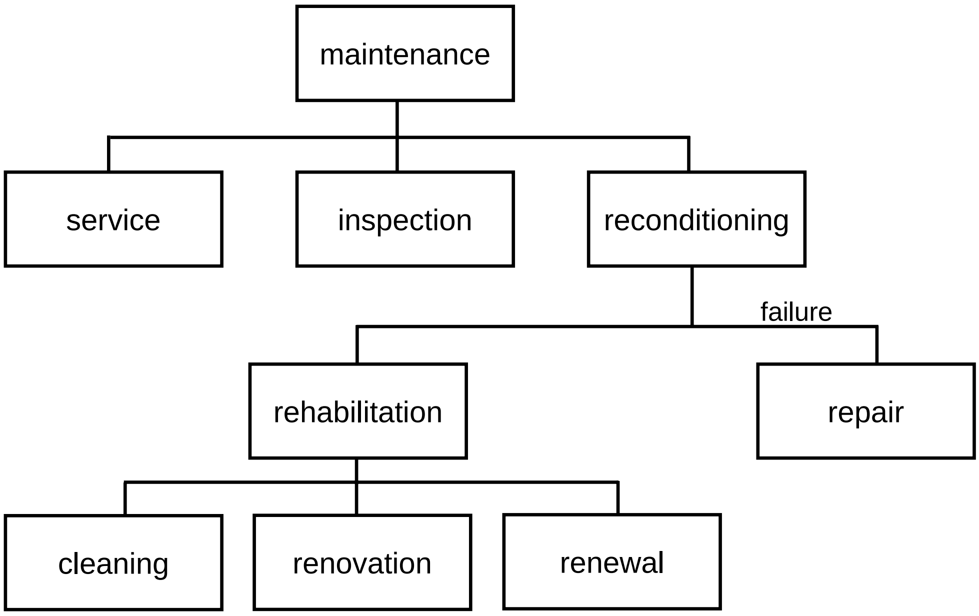

Figure 3: Maintenance duties (OVGW W 100, 2007)

Also historical failures at pipes which have already been replaced are available in the system, which are required for the analyses of the aging behaviour. For each pipe failure, several criteria are documented, e.g. location of failure, date and time of failure, year of construction, diameter, pipe material, type of failure (break, crack, hole, connection failure, joint defect), cause of failure (construction failure, material failure, corrosion, soil movement, external impact) and total expenditure for remedying of damage. In addition all maintenance activities and costs are recorded.

These data are the basis for a state of the art rehabilitation planning which allows a prioritisation of pipes which shall be replaced.

Rehabilitation Planning

On basis of failure data the aging behaviour of different pipe groups can be analysed and critical pipe groups can be identified. Combined with cost data for repair and replacement, economic models for short and long term periods allow finding the optimal rehabilitation time for each pipe section (Figure 4).

According to Fuchs-Hanusch et al. (2008a) one methodology is to predict hazard rates of pipe groups which are the basis to define long-term future rehabilitation needs. Therefore, the hazard rates have to be calibrated to the failure behaviour of the investigated network.

Four different statistical functions for the calibration of aging functions are implemented in PiReM: Herz, Weibull, Logistic and Lognormal functions.

Herz (1994) used the cohort survival model to predict the aging processes of water supply systems. Furthermore, Herz defined a special distribution to reproduce the aging processes of main pipes. In general, the plausibility of the prediction strongly depends on the quality and quantity of the data base, especially on historic failure and replacement data (Fuchs-Hanusch et al., 2008a). Figure 5 describes the rehabilitation planning process.

Once the pipe grouping and calibration of the aging behaviour for each group are completed, the rehabilitation demand per pipe group can be simulated. Groups with the highest yearly failure costs and failure probability (= maximum risk) have the highest priority to be rehabilitated.

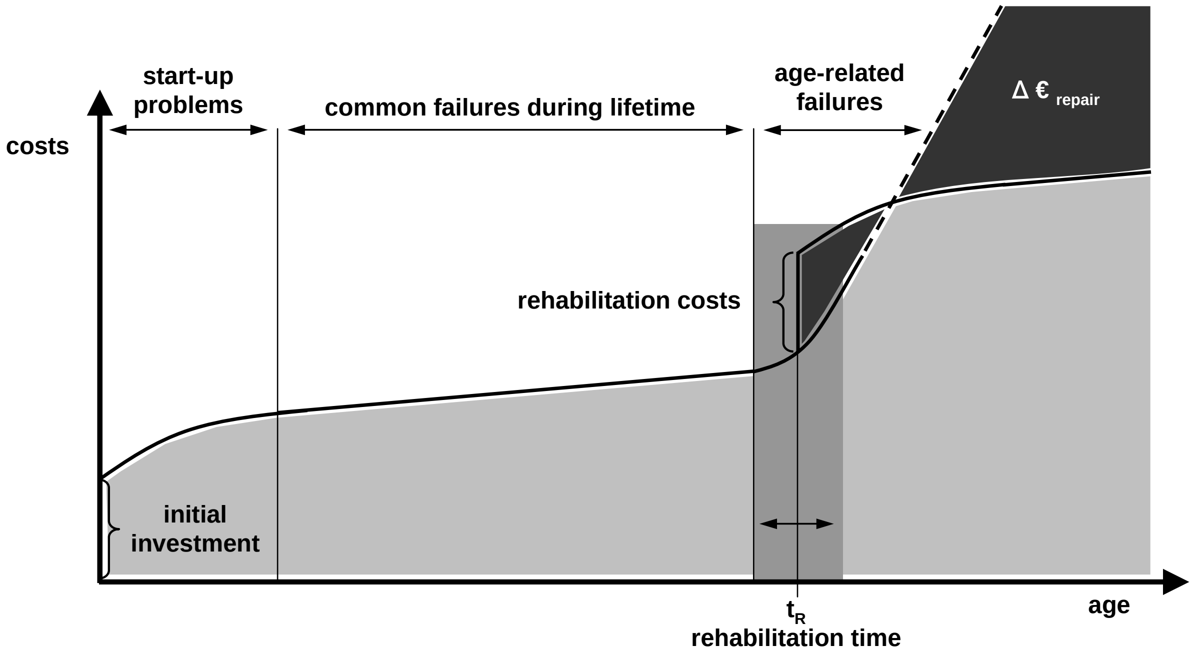

Figure 4: Optimal rehabilitation time

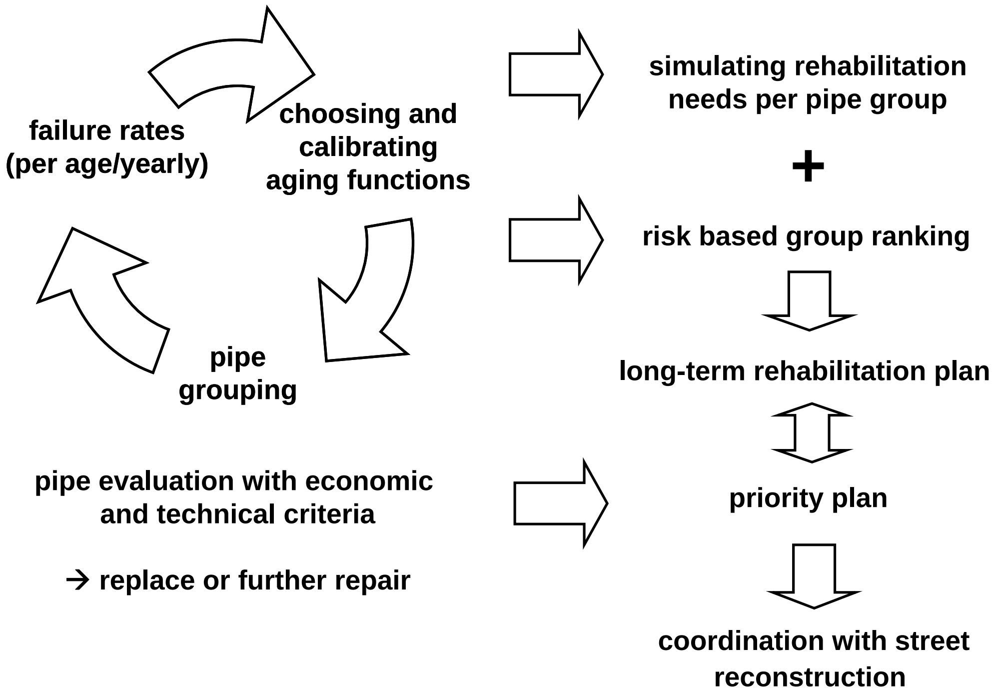

Figure 5: Rehabilitation planning scheme (Fuchs-Hanusch et al., 2008a)

A long-term rehabilitation plan defines the rehabilitation needs for a 10 to 20 years scope. In combination with economical and technical criteria priority plans for pipe rehabilitation with 3 to 5 years scope can be deduced from the long-term plan. The fine tuning of definite annual rehabilitation measures is done by coordination of street reconstruction and measures of other pipe infrastructures. This leads to cost optimization of rehabilitation budgets and decreases the repair costs if the most critical pipe groups are removed systematically. However, there is enough flexibility to shift rehabilitation measures within a timeframe of a few years if this leads to cost benefits.

Key Success Factors for Sustainable Network Management

The issues described above are core tasks for successful infrastructure management. Based on the experiences of more than 100 years as owner and operator of Salzburg's water supply system following key success factors for a sustainable network management can be summarised.

High quality materials need to be used and highest construction standards applied to ensure low failure rates and keep operation costs low. A strong commitment to related guidelines and high level standards is essential for quality assurance. Also the requirement of proper supervision of construction works and quality checks, e.g. pressure tests of pipes before starting asset operation need to be addressed.

An adequate network monitoring system is essential. Without monitoring it is not possible to become aware of failures and take corrective actions in time. Depending on frame conditions like availability of resources or water reclamation costs the monitoring system will be designed more or less advanced.

Regular monitoring and adequate effort in reducing water losses by quick and consequent repair is important for successful water loss management. For proper asset management, it is required to perform regular assessments of the network condition with a detailed documentation of all failures. A comprehensive asset and failure data base is a precondition for reliable analyses of network aging behaviour and rehabilitation planning. The aim of long-term cost optimisation and minimised lifecycle costs can only be achieved with long-term service contracts. Short-term O&M contracts are often counterproductive, because the operator's main concern is maximizing profit then comes the aspect of sustainability. From the viewpoint of Salzburg AG as an owner and operator, the long-term scope in asset management is crucial for cost optimisation.

To ensure sufficient financial capabilities, long-term cost recovery is required. Therefore, cost recovering tariffs and a minimised ratio of non-revenue water are necessary.

Another key success factor is the commitment to a continuous improvement process. This requires permanent performance analyses, orientation at national and international benchmarks and the implementation of improvement measures. Salzburg AG has been benchmarked as a best practice utility in the Austrian water supply sector and is regularly participating in national and international benchmarking projects on utility and process level.

In conclusion, it becomes clear that an integrated approach considering all the described factors is necessary to ensure sustainability in a network management. This aspect is the basis to conserve water supply networks for future generations.

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