# Strategic planning to maintain the high quality of Vienna's water supply system

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## *Abstract*

Keeping pipe damage rates and hence water losses low is a central task of drinking water utilities. A maintenance planning approach that adopts strategic objectives is the basis for a targeted deployment of future reinvestments in water distribution networks. Pipe networks are subject to a variety of influences that impact and change the condition of pipes and valves. These changes can be described by means of mathematical models. A key basis for describing the deterioration status of pipes by means of mathematical models stems from the detailed documentation of the system in question and its status, as given by geographic network information systems.

The present article describes the steps implemented in recent years to ensure condition- and risk-oriented maintenance and rehabilitation planning for Vienna's water supply network. Condition and risk assessments were carried out over several phases for parts of the network and for pipe sections as well as for the installations pertaining to them. Damage forecasts were conducted for this purpose, which permitted to derive a procedure for establishing rehabilitation priorities.

## *Introduction*

According to the Austrian guidelines ÖVGW W 100 (2007), ÖVGW W 104 (2010) and ÖVGW W 105 (2010) of the Austrian Association for Gas and Water, pipe- and damage-related data are essential for any condition assessment. The most relevant attributes of pipe data listed in the guidelines are location, material, nominal diameter, vintage and length of the pipe section. Further it is recommended to keep historical data, including the date of rehabilitation. This data is also essential for the calibration of survival time and failure prediction models.

The Vienna Waterworks operate a network of approx. 3.000 km length supplying around 100.000 house connections. Incidents of damage to mains, distribution and connection pipes and fittings are recorded since the 1970s. From 2005 up to the present a comprehensive Network Information System (NIS) (Figure 1) is used to collect information about the water supply system, to geographically analyse these information's, to provide an assistance platform and finally to assist planning processes. This NIS unambiguously allocates damage incidents including the date and type of the damage to the pipe sections affected. Annually, approximately 310 of these damages involve pipes while roughly 1000 involve valves or service connections.

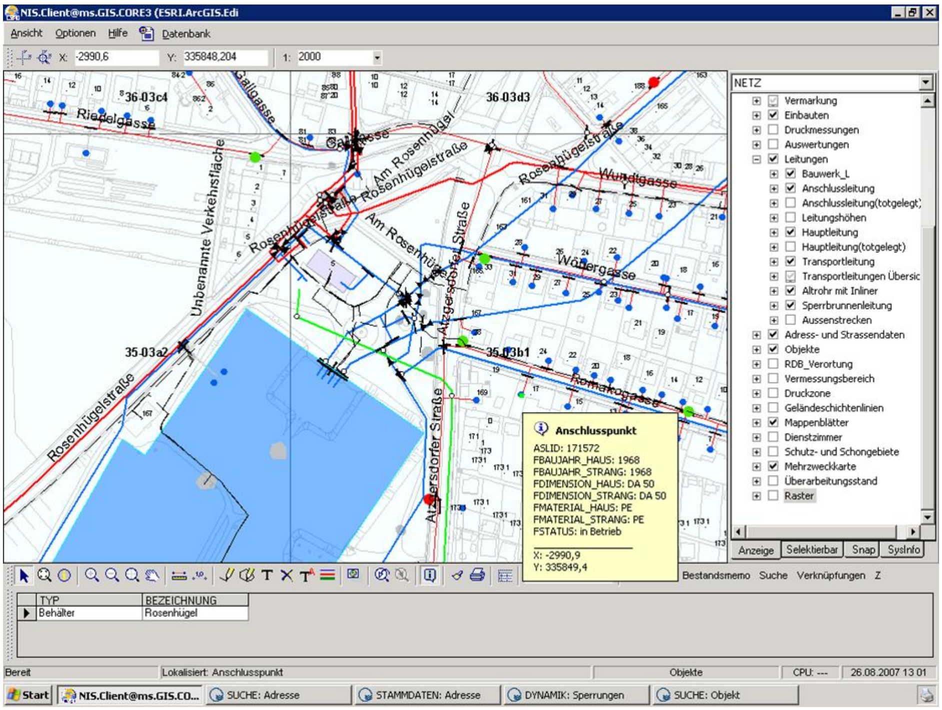



**Figure 1:** Network Information System (NIS) of Vienna Waterworks (Source: M. Hladej)

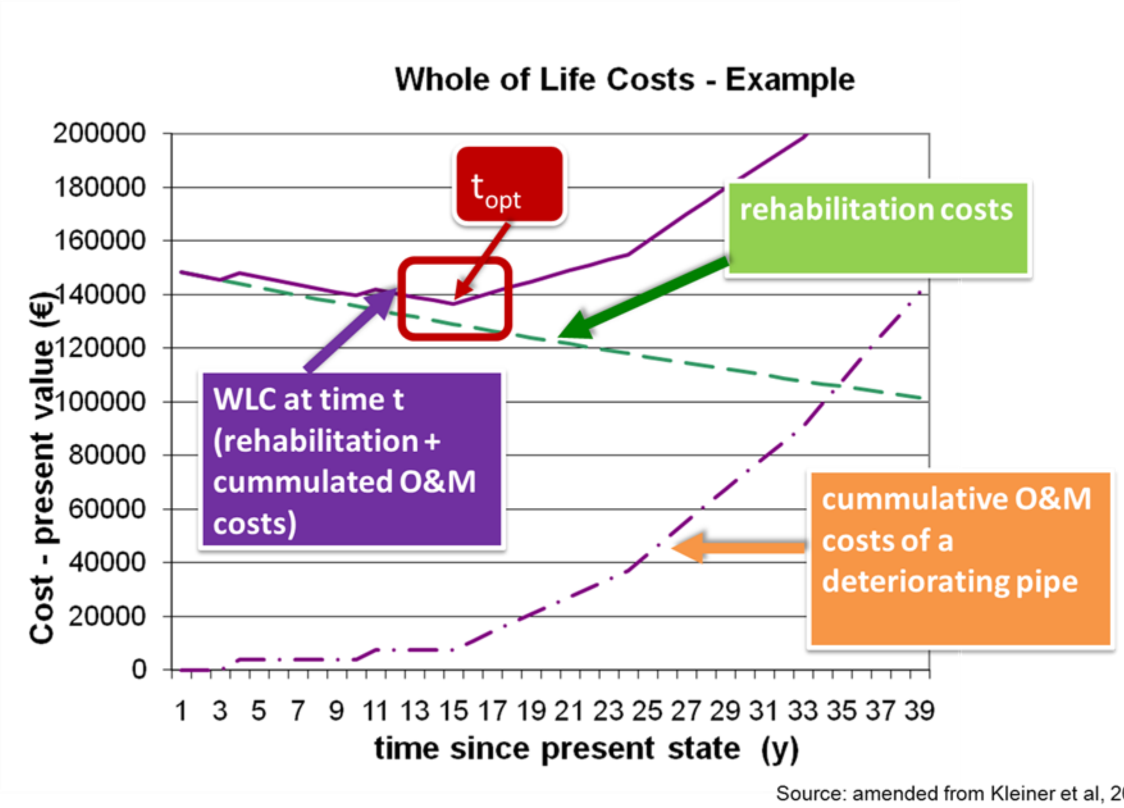
## *Group based analyses to define long term rehabilitation rates*

The rehabilitation planning process for Vienna's water distribution system contains two steps. The first step is the long-time rehabilitation planning, where different rehabilitation scenarios are compared due to their effects on future failure rates and rehabilitation needs. The second step is the mid-term planning process which provides a pipe section classification for prioritisation. To predict failure rates of the entire systems and compare them with service levels given in the Austrian standards of the ÖVGW W 100, both steps have to be combined in the simulations. In the first step, the pipe network is subdivided into groups characterised by varying levels of damage probability. Critical groups whose damage incidents further contribute significantly to water losses in Vienna include grey cast iron pipes with screwed sleeve joints (CISJ) and grey cast iron pipes (CI) with socket-and-spigot joints from the interwar period (installed between 1921 and 1945) with nominal diameters of less than 250 mm. These two groups involve not only high damage probability but also build the major length of the network. Since the late 1990s, the group of first-generation ductile cast pipes (SG, non-galvanised, installation period 1970 to 1985) with nominal diameters of up to 250 mm (500 km of network length) present an annual damage rate increase by approx. 10%. Based on lifetime estimations for these pipe groups an average yearly rehabilitation rate for the next ten years of 1,5% was derived.

## *Prioritisation of Pipe Sections for Rehabilitation*

In order to define the replacement priorities, whole of life cost analyses were drawn upon to calculate the economically most feasible moment for replacement of specific pipe sections. This is equal to the moment when the aggregate costs of replacement and long-term maintenance of the old pipe are lowest (Shamir and Howard, 1979) (Figure 2).

The used whole of life cost (WLC) model was amended from Kleiner at al., 2010. To investigate which of the included cost factors influence the model results most, a global sensitivity analyses was made (Fuchs-Hanusch et al., 2012). The purpose was to define for which factors detailed information may improve the model results and which factors should be involved into such calculations in general. The analyses have proved a well-known fact, that especially the estimation of repair and rehabilitation costs are of high significance, but further the amount of water losses per break, which also depend on the water loss management strategy, has an influence as well. Factors like maintenance costs or background leakage have shown only a slight influence on result variations and hence were neglected in the final analysis.




Source: amended from Kleiner et al, 2010

**Figure 2: The principle of WLC Calculations**

As the sensitivity analysis has shown that per pipe unit detailed information about expected rehabilitation and repair costs and the expected price indices are of the highest interest followed by the water losses per failure, for Vienna's Supply System e.g. the repair costs are calculated on the basis of extent of damage (assessed as monetary damage cost) and frequency of damage (by means of a probabilistic model). Damage costs (costs of pipe and road repair) were determined subject to the respective types of repair work and road cover (Figure 3). The rehabilitation costs were derived from data of former construction sites.

For predicting pipe failure a proportional hazards model (PHM) is used (Fuchs-Hanusch et al.; 2012). For each number of failure (first, second, third,….) the significant parameters are derived separately. By knowing the number of previous failure on a pipe the time to the next failure can be predicted with a certain probability.

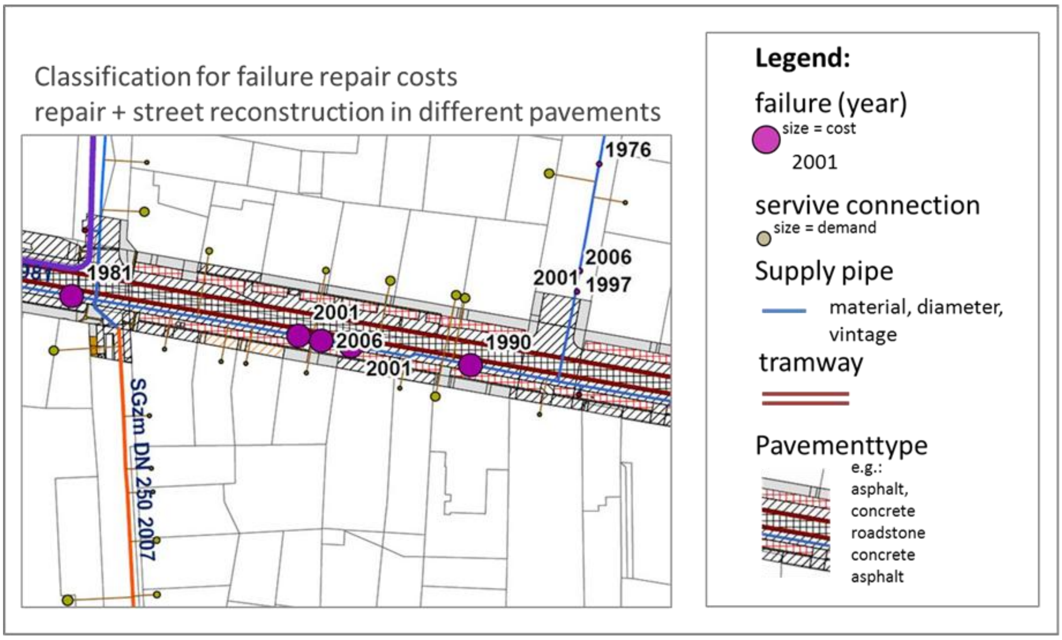



**Figure 3: Detailed failure cost specification based on street and pavement type and repair type**

The calculations allowed for the determination of rehabilitation priorities for 35 km of pipes in Vienna.
In a final step, simulations where carried out where the prioritized pipe sections were virtually rehabilitated by the means of PiReM (2010). This virtually rehabilitation of pipes is the basis for calculating the effects of rehabilitation decisions on the future amount of failures. Figure 4 shows simulated future failure trends of Vienna's supply system for a defined scenario of 1,5% rehabilitation rate, rehabilitating 50% pipes prioritized in the way described above and 50% rehabilitated due to coordinated construction sites. An amount of 10 failures/100km/y in the entire system is the targeted long-term failure rate (based on OVGW W 100). According to the simulations, this rate can be realised following the described strategy.

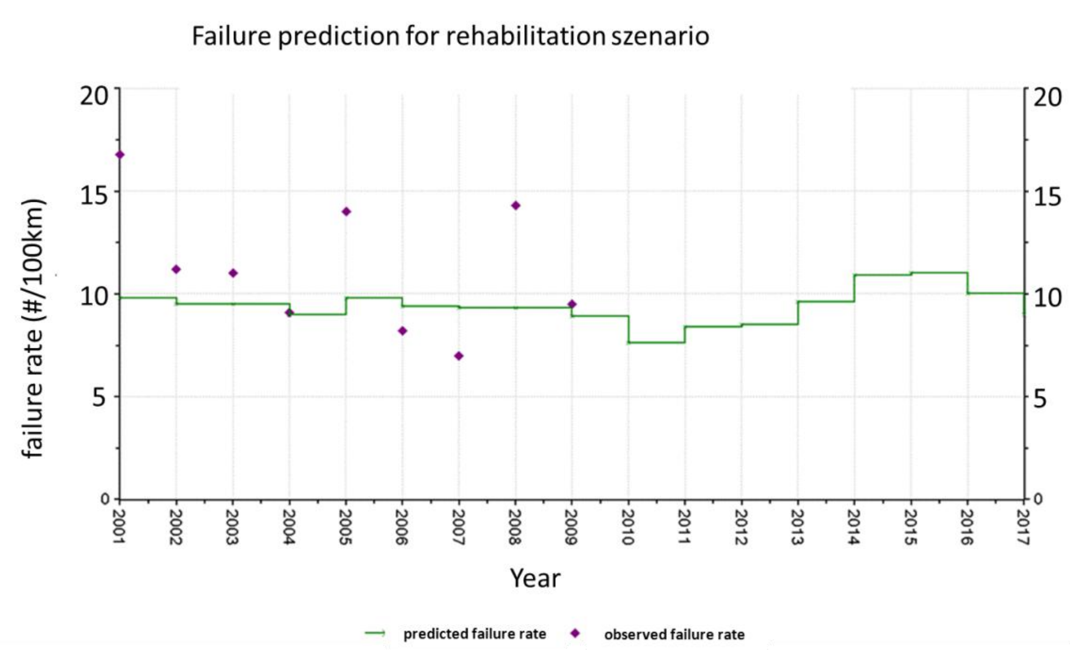



Figure 4: Failure prediction for the chosen rehabilitation scenario of the Viennas Water Supply network (PiReM; 2010)

### *Conclusions and Outlook*

Long-term plans to bring water loss and damage rates in line with the reference values defined in Austrian guidelines can be implemented through the optimised distribution of rehabilitation works across critical pipeline groups. Risk- and condition-oriented planning allowed for formulating optimum reinvestment strategies that moreover take indirect account of potential water loss sources. Developing forecasts for modified replacement strategies helps to pinpoint potential effects on future damage incidents, and hence water loss, as well as the extent of future investment needs to improve the pipeline network status.

In the future, the decision-making process to identify pipe sections in need of rehabilitation should also take into account of water losses as those are relevant for results variation of $t^{opt}$. An application of pipe network hydraulics will support water loss estimations at the pipe level.

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