Influence of Measurement Inaccuracies at a Storage Tank on Water Losses

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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>
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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.

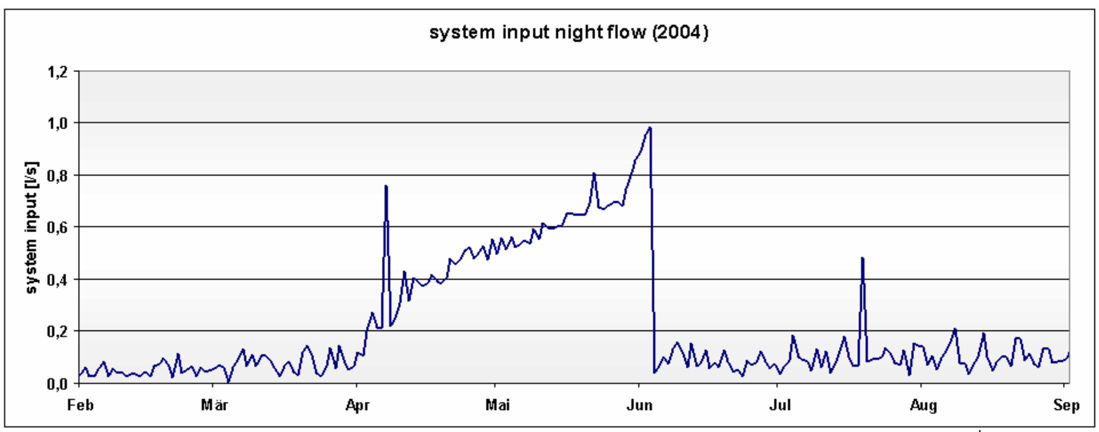

Figure 1: Graph of the night minimum system input in a small meter area (repair of failure on 3rd June)

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).

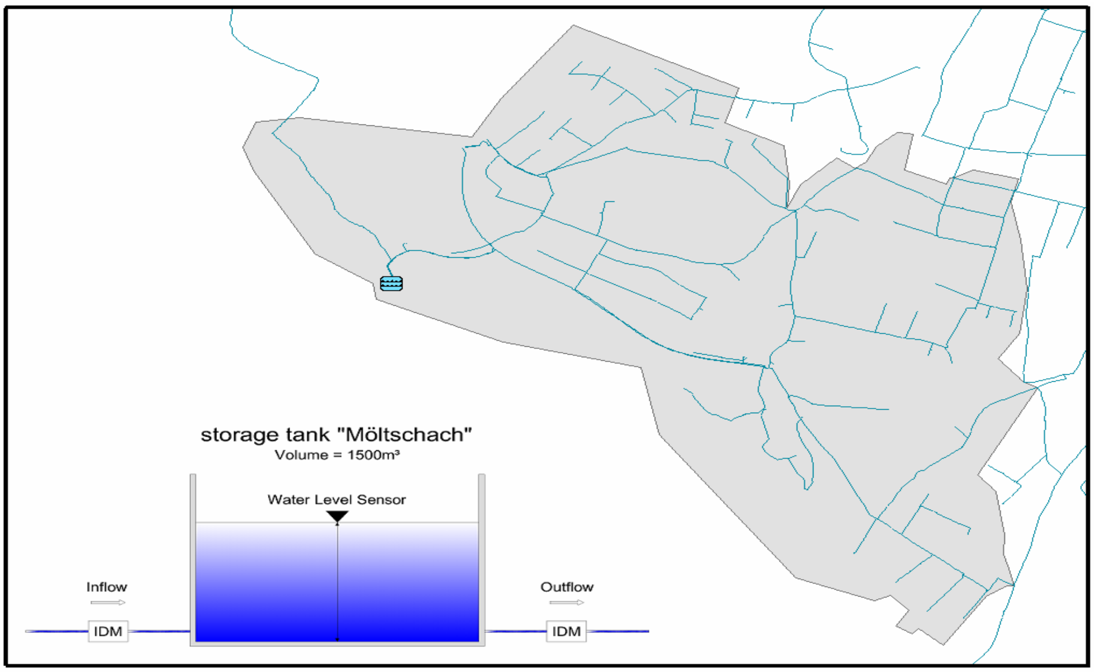

Figure 2: Map of Möltschach DMA with storage tank

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).

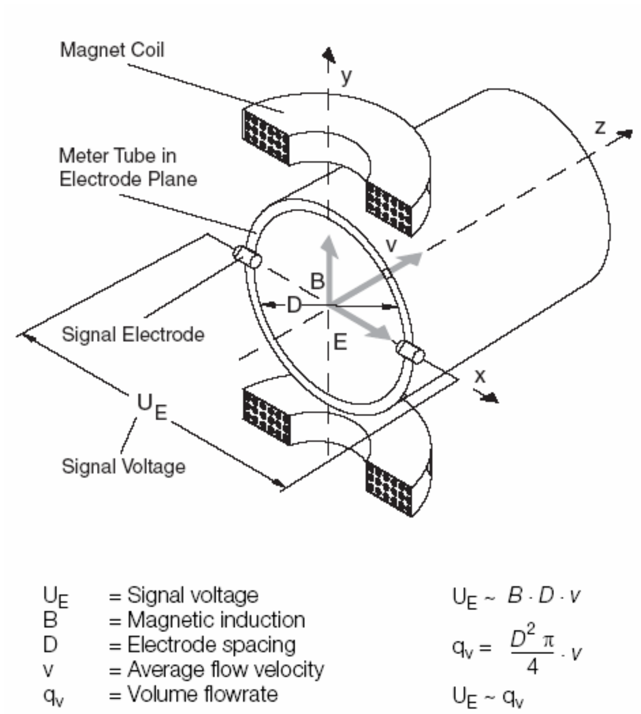

Figure 3: Diagram of installed electromagnetic flow meter (ABB FXM2000)

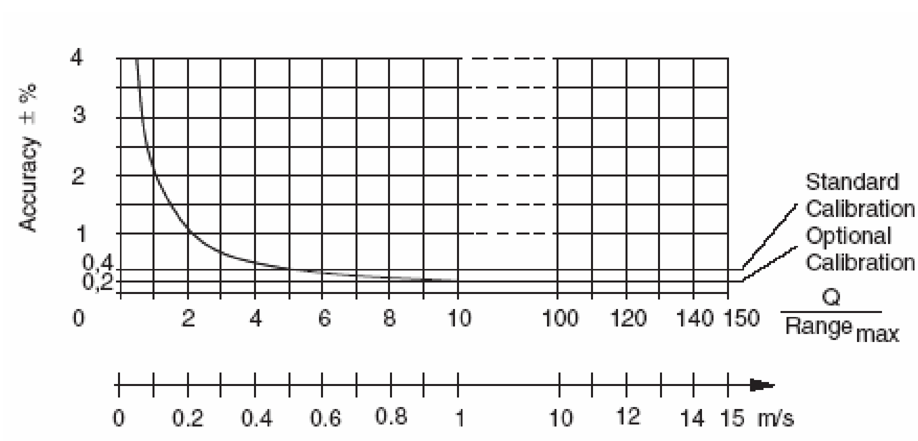

Figure 4: Accuracies depending on flow velocity

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).

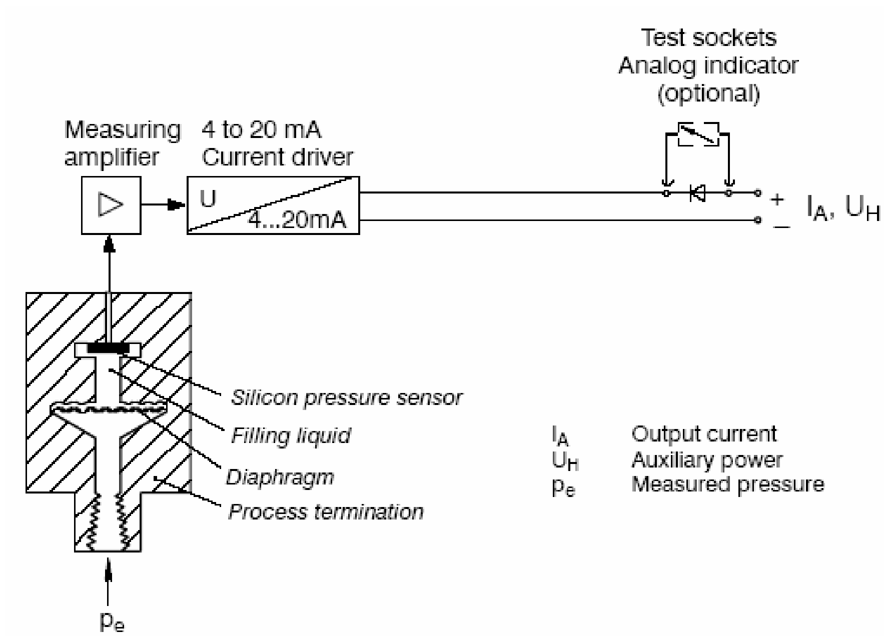

Figure 5: Diagram of pressure transmitter (Siemens SITRANS P, MK II)

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).

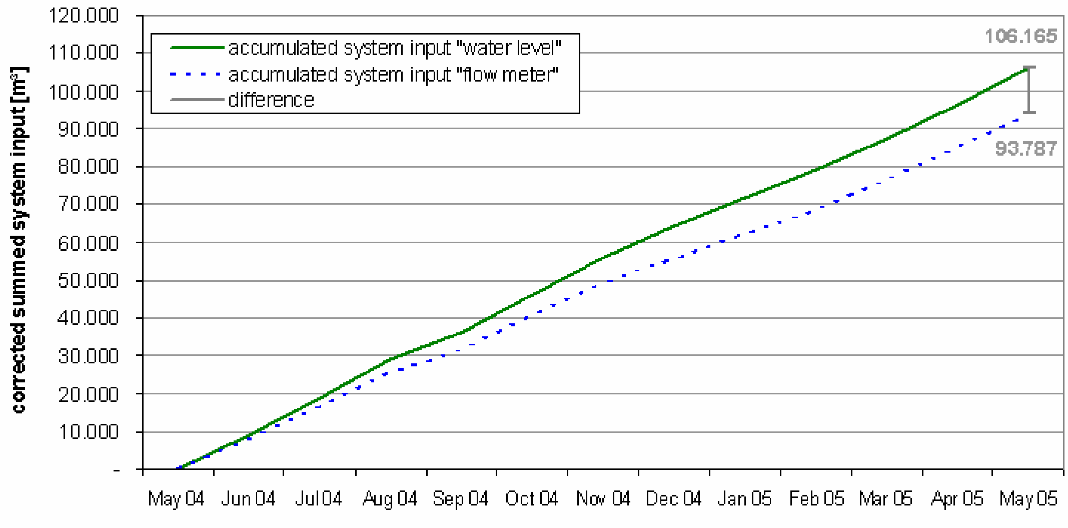

Figure 6: Corrected accumulated meter reading

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.

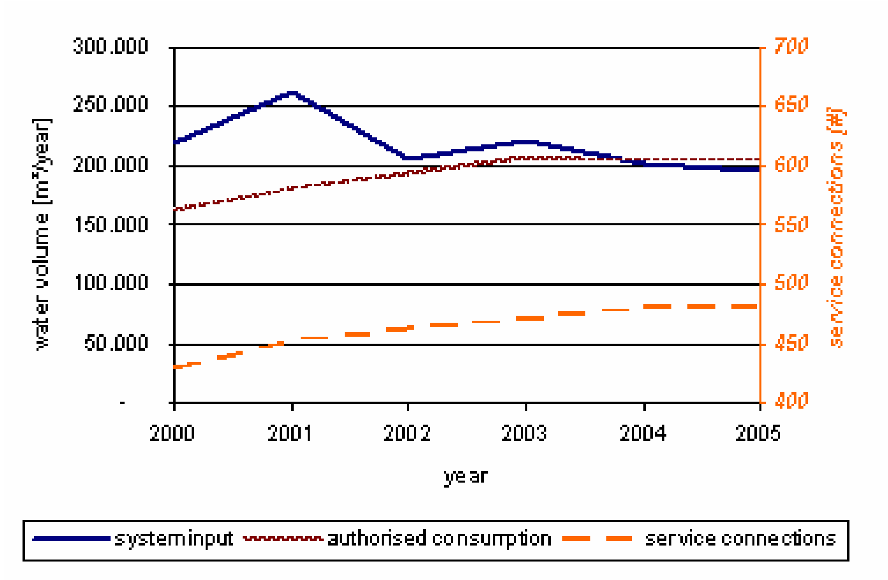

Figure 7: Original distribution of service connections, system input, and authorised consumption

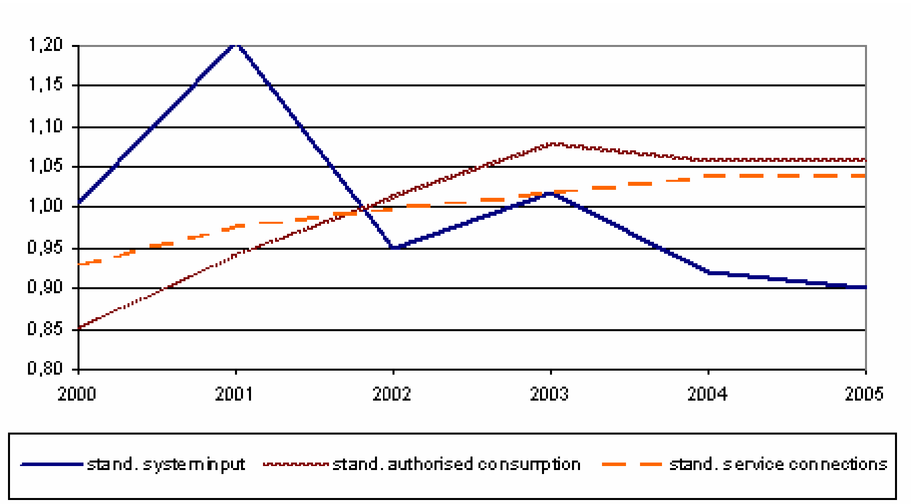

Figure 8: Standardised original distribution of service connections, system input and, authorised consumption

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,

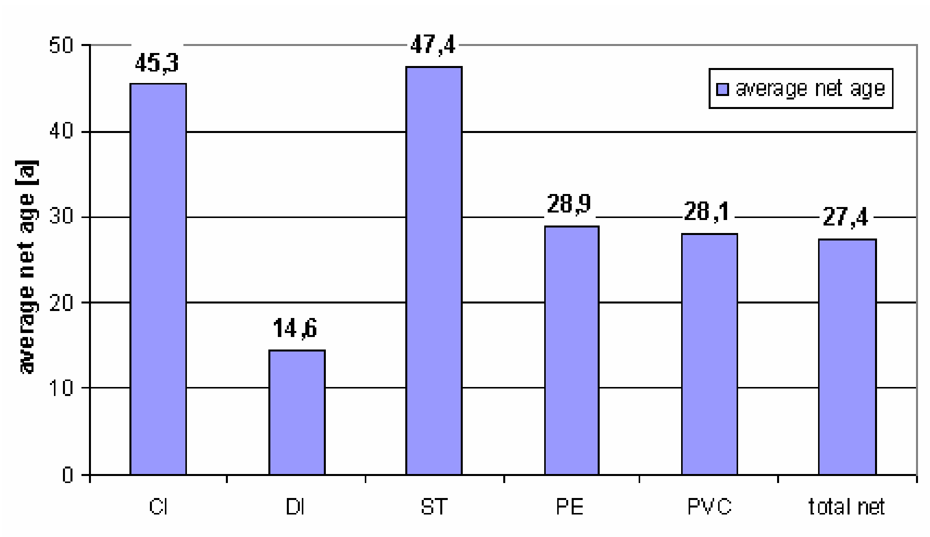

Figure 9: Average net age of Möltschach DMA

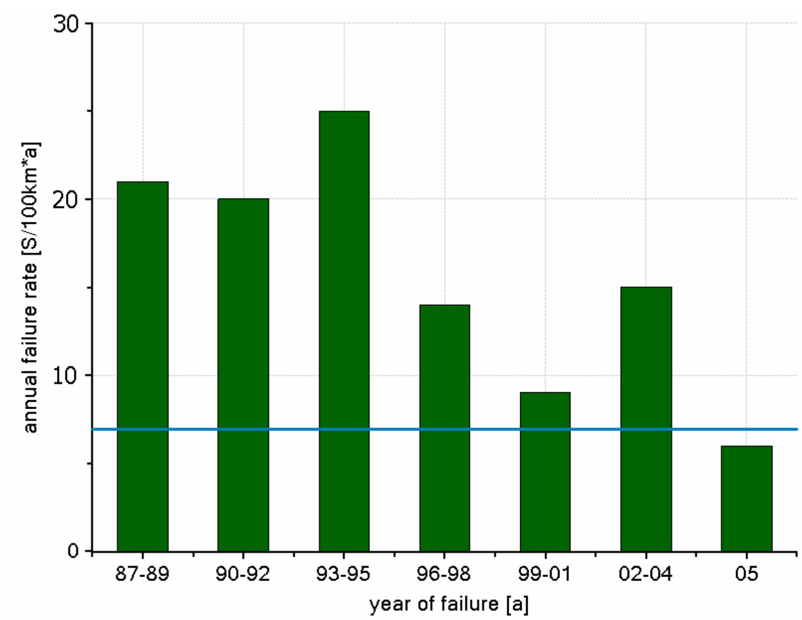

Figure 10: failure rate in 3-year steps of the Möltschach DMA

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.

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