The Technical Audit of Water Distribution Network Using the Different Leakage Indicators

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Introduction

Various statistics and overviews publish every year the basic statistical ad balance data concerning the water supply sector. However, basically none of these statistics , although elaborated only for a certain water company or a drinking water supply region, contain indicators that would allow for a comprehensive audit of the technical condition of the presented water distribution network. Such a technical audit is performed by each owner, i.e. operator separately and usually internally. Various methods, procedures and indicators are used for the evaluation.

This paper briefly describes one of the possible approaches to the comprehensive technical audit of the water distribution networks. Based on practical experience, discussions with various domestic as well foreign operators and knowledge gained from international projects and grants, the paper proposes technical indicators, method of their determination and criteria of evaluating the values reached by these indicators(Tuhovcak et al, 2004). The proposed procedure is based on the FMEA method (Failure Modes Effects and Analysis), used in the general theory of risk analysis. The results of this method employed for evaluation of the technical condition of the water distribution network in Pilsen. These were obtained are presented as a part of GZVP- Master Plan of Water Supply of Pilsen City (Case study I). The second part of the paper presents the first results of implementing the IWA methodology in the field of water losses in water companies in Slovakia (Case study II).

The Methodology of Technical Audit

The technical condition of the evaluated water distribution network is determined by the historical development and the ability of the operator to identify its actual condition. The technical condition is affected mainly by the following: quality of the design already during its elaboration, selection of suitable pipe materials, valves and fittings, the quality of their manufacturing, keeping of proposed procedures and the quality during installation and construction, the age, i.e. service life of the individual parts of the network, pressure and flow ratios, quality of conveyed water, the operation system, maintenance and repair and availability of the owner's or operator's funds.

The used indicators

When evaluating the technical condition of the water distribution network, a comparative analysis of the individual elements of the network (separate water pipeline, pressure zone, measurement district etc.) is conducted using a wide range of technical indicators. With respect to the scope and availability of the necessary supporting documents, we recommend that the following technical parameters should be considered for the evaluation of the technical condition of the network:

Age of pipes – the service life of the pipe materials depends on many factors. For each pipe material in the evaluated part of the water distribution network(water pipeline, pressure zone) it is necessary to take into account the local factors and operating experience and to determine the theoretical service life of the pipe materials and to compare it with the structure and age of the operated network;

Failure rate – the evaluation of failures is an important tool for maintenance, repair and reconstruction planning. The main indicator of the failure analysis for the needs of the evaluated technical condition is the failure rate expressed as a number of failures related to the unit length and time unit (usually number of failures/km/year) and dynamics of failures;

Water losses – a number of indicators are used to express the level of water losses. However, not al the indicators include the effect of the technical condition of the network. For evaluating the technical condition of the water distribution network we recommend using the unit leakage JÚVNF, the Infrastructure Leakage Index (ILI) and the Economic Leakage Index (ELI) in our conditions;

Water quality – the technical condition of the distribution network may also have an adverse impact on the quality of transported water. The category of drinking water quality evaluation criteria can be set for the individual selected indicators on the basis of the permissible percentual exceeding of the recommended values, i.e. limit values according to the applicable regulation for selected water quality indicators.

Pressure – from the point of view of the effect of the operating pressure on the technical condition of the network it can generally be stated that high values of operating pressures and not too desirable. What is even less desirable is rapid deviations of the hydrodynamic pressure during the day. The operating pressure value also affects other indicators of evaluating the technical condition of the network: water losses, failure rate, theoretical service life of the pipe material, etc;

Reliability – using the reliability indicators (quantitative, qualitative) it is possible to identify the critical parts of the network and prioritise them in the reconstruction planning process.

For each of these indicators it is possible to clearly define the procedures for their determination, the physical dimension and method of presentation. Each indicator is also a means of monitoring the technical condition of the evaluated network.

The categories of evaluation

Based on the determined and reach values of the indicators, the individual parts (elements) of the evaluated systems are classified into relevant categories. A total of 5 basic categories of evaluation of the individual indicators can be set for each indicator for the need of the technical audit according to FMEA:

K1 (very good) – optimum condition of the relevant indicator, it dies not require any special measures leading to changes in this indicator;

K2 (good) – low level of risk of the relevant indicator of the technical condition and no principal measures are needed;

K3 (average) – these are average values of the relevant indicator that do not require immediate solution;

K4 (critical) – critical values of the relevant indicator. This means that potential planned measures addressing the situation should be implemented;

K5 (unacceptable) – undesirable condition requiring an immediate solution according to the operator's possibilities resulting in improvement of the values of the relevant indicator.

As regards the evaluated drinking water distribution network, each evaluated part (the whole water distribution network, pressure zone etc.) is audited by means of the selected indicators and it is classified in the appropriate evaluation category, which makes it possible to identify critical parts of the evaluated network and prioritise them in the reconstruction and repair planning.

Case study I - The Technical Audit of Water Distribution Network of Pilsen City

The aforementioned methodology has been applied in the technical audit of the water distribution system , being a part of the Master Plan of Water Supply of Pilsen City. The evaluated network includes a total of 28 hydraulically independent pressure zones and 5 pumping mains of the main distribution system. With respect to the availability of data, the technical audit of the individual pressure zone made use of the following *Technical Indicators* (TI):

TI 1 – Structure of pipe materials

TI 2 – Age of pipe material

TI 3 – Water Losses

TI 4 – Failure rate

TI 5 – Pressure

Each supply zone was classified in an evaluation category for the individual indicators. Based on the evaluation using the individual technical indicators it was possible to prepare a final comprehensive evaluation of the technical condition of each of the pressure zones using the final indicator TI. All indicators TI 2 - TI 5 were given the same weight in the final evaluation.

The Used Indicators of Water Losses

The volume NRW_{PZ} determined by the „balance method“ using the measured inflows is the basic input parameters for calculation of the selected water losses indicators. The total inflow to the zone was evaluated for each pressure zone on the basis of the data provided by the control room and it was compared with the total consumption using the billing system. The following four sub-indicators were selected for the evaluation of the technical condition according to indicator TI 3 Water Losses.

TI 3.1 – NRW - non-revenue water

The total volume of non-revenue water in each pressure zone is presented as a percentage of produced water (WP) delivered to each pressure zone.

$$\mathrm{NRW} = \frac{\mathrm{NRW_{PZ}}}{\mathrm{WP_{PZ}}} \cdot 100 \qquad [\%] \qquad (1)$$

where

NRW_{PZ} - non-revenue water of the pressure zone [th.m^3/year]

WP_{PZ} - water produced ad delivered to the pressure zone [th.m^3/year]

TI 3.2 - JUVNF - specific leakage per km

The calculation of specific leakage is defined as a ratio of a volume of water unbilled over a certain time period to the total length L of the evaluated system. The following formula was used for the JUVNF calculation:

$$\mathrm{JUVNF} = \frac{\mathrm{NRW_{PZ}} \cdot 10^3}{\mathrm{L}} \qquad [m^3 / km / year] \tag{2}$$

where

NRW_{PZ} - non-revenue water in the pressure zone [m^3/year]

L - total length of water mains in the pressure zone [km]

The specific leakage is a more objective indicator of water losses from the viewpoint of the technical condition of the network. Its partial disadvantage is that it dos not include the affect of pressure relations in the pressure zone.

TI 3.3 - ILI - **Infrastructure Leakage Index**

The ILI indicator is defined as a ratio of *Real Losses* (RL) and *Unavoidable Annual Real Losses* (URAL). It is a new indicator of water supply systems expressing the technical condition of the system from the point of view of water losses. This indicator is proposed and recommended by the International Water Association IWA (Lambert, 2002). As the operating records kept by the operator do not make it possible to determine the actual *Real Losses* (RL) individually for each pressure zone, the ILI calculation uses simplified values of NRW

$$\mathrm{ILI} = \frac{\mathrm{NRW}}{\mathrm{UARL}} \qquad [-] \tag{3}$$

where NRW - non-revenue water [th. m^3/year]

UARL - unavoidable annual real losses [th.m^3/year]

The UARL is based on the results of an international survey containing data from 27 various water systems in 19 countries (Lambert, 2002). Based on the density of the house connections and the average operating pressure , the values of theoretically unavoidable annual real losses were determined by interpolation for the individual pressure zones. A calibrated hydraulic model for the weekly cycle of water consumption was developed for each pressure zone. The average operating overpressure for each pressure zone was calculated on the basis of the results of the hydraulic model and it concerns an average hydrodynamic pressure in the relevant pressure zone.

Another possibility of determining ILI is the use of an approximate relation between ILI and JUVNF

$$\mathrm{ILI} = 1{,}14 + 0{,}001 \cdot \mathrm{JUVNF} \qquad [-] \tag{4}$$

This relation was determined on the basis of evaluation of data from 1997 - 2002 for 44 water companies in the CR. (Tuhovcak, Vrbkova, 2002). Using this relation, the values

ILI were determined for 2 pressure zones „111 – Bílá Hora II. Březová " and „142 - Hradiště ".

TI 3.4 - ELI - **Economical Leakage Index**

What is the most important for the operator of the water systems is to determine the economically acceptable values of water losses indicators. These are values the further reduction of which is not economically efficient for the operator. The *Economical Leakage Index* (ELI) values can be determined using the following simple relation.

$$\mathrm{ELI} = \mathrm{EI} \cdot \mathrm{LI} \qquad [-] \tag{5}$$

where

EI - economical index can reach the following values

1,5 - water in the audited system is treated in a two-stage process and pumped to a minimum height of 50 m of water column.

1 - water in the audited system is treated in a two-stage process but it is conveyed to the system by gravity, the water for the audited system requires only disinfecting, i.e. simple treatment, but it must be pumped into the system

0,5 - water in the audited system requires only disinfecting i.e. simple treatment and it is conveyed to the system by gravity

As Vodárna Plzeň provides two-stage water treatment, the economical index can reach the values of 1 or 1,5. The selection is based on two data. The first determines whether the evaluated pressure zone is supplied with water by gravity or by pumping stations and the second determines whether the average hydrodynamic pressure in the zone exceeds the limit of 50 m of water column.

LI – losses index is based on the following relation

$$\mathrm{LI} = \frac{\mathrm{JUVNF}}{3600} \qquad [-], \tag{6}$$

where the JUVNF valued is calculated according to the relation (3). The JUVNF = 3600 [m^3/km/year] value represents the recommended value of the unit leakage indicator for networks that are in a very good technical condition. For evaluating water losses using the ELI indicator, the following simple methodology was prepared

If **ELI > 1,3** it is a pressure zone where the water losses cause significant economic operating losses and where it is desirable that the operator should focus intensively on their reduction.

0,8<ELI<1,3 it is a pressure zone where the present water losses do not cause any major economic operating costs

ELI < 0,8 it is a pressure zone where the water losses are adequate in technical and economic terms and execution of further measures focusing on losses reduction would not be economically efficient

The definition of levels for evaluation categories

The next step in the technical audit was the estimation of the levels of categories for each sub-indicator. The levels of evaluation categories were estimated individually for each sub-indicator and they are presented in Table 2.

Table 1 The levels of evaluation categories for sub-indicators

category	TI 3.1 NRW [%]		TI 3.2 JUVNF [m^3/km/year]		TI 3.3 ILI [-]		TI 3.4 ELI [-]	
	from	to	from	to	from	to	from	to
K1	0	**10**	0	**3000**	0,0	**2,5**	0,0	**0,6**
K2	10	**12**	3000	**4500**	2,5	**4,0**	0,6	**0,8**
K3	12	**16**	4500	**6000**	4,0	**6,0**	0,8	**1,0**
K4	16	**20**	6000	**8000**	6,0	**9,0**	1,0	**1,3**
K5	20	0	8000	..	9,0	..	1,3	..

The limits of the individual categories the water losses sub-indicators TI 3.1 - TI 3.4 were determined for the purpose of this study on the basis of the author‘s experience and knowledge. When determining the limits, use was made of the average indicator values ILI = 6,7 [-] and JUVNF = 4017 [m^3/km/year] in the CR. Setting of the limits for indicator ELI is based on the proposed methodology of water losses evaluation using indicator ELI (see the previous part). The calculated values of the individual sub-indicators of each pressure zone were evaluated according to the limits shown in Table 2. However, the user can change the limits of the individual categories for the water losses sub-indicators TI 3.1 - TI 3.4 at his/her own discretion and the classification of the individual sub-indicators concerning the relevant pressure zones will change dynamically.

The final evaluation of pressure zones

Evaluation of the technical conditions of the individual pressure zones seen from the point of view of pressure losses and the values of sub-indicators for each pressure zone are shown in Table 2. Detailed evaluation is presented in the digital version of a separate attachment to the audit of the technical condition of the water network in GZVP.

The overall evaluation of the pressure zone from the point of view of the final indicator of water losses TI 3 was based on a simple average of evaluations using sub-indicators TI 3.1 - TI 3.4. Categories K1 – K5 were allocated numerical values 1 – 5 and the simple average determined the final value for the whole pressure zone. This numerical value was converted back to the pressure zone evaluation category.

Table 2 Evaluation of pressure zones using the water losses sub-indicators

pressure zone	TI 3.1 NRW		TI 3.2 JUVNF		TI 3.3 ILI		TI 3.4 ELI		**TI 3 water losses**
	%	category	m^3/km/year	category	-	category	-	category	
101	8	K1	3 060	K2	2,8	K2	0,9	K3	K2
* 111	21	K5	1 760	K1	2,9	K2	0,5	K1	K2
112	36	K5	2 208	K1	1,2	K1	0,6	K2	K2
113	5	K1	49	K1	0,1	K1	0,0	K1	K1
121	55	K5	5 412	K3	4,2	K3	2,3	K5	K4
122	81	K5	4 358	K2	9,4	K5	1,2	K4	K4
123	77	K5	5 163	K3	9,4	K5	1,4	K5	K5
124	51	K5	6 309	K4	6,6	K4	1,8	K5	K5
125	11	K2	5 108	K3	3,7	K2	2,1	K5	K3
131	14	K3	919	K1	1,3	K1	0,4	K1	K2
141	38	K5	1 643	K1	1,7	K1	0,5	K1	K2
* 142	78	K5	2 161	K1	3,3	K2	0,9	K3	K3
211	10	K2	3 288	K2	4,7	K3	0,9	K3	K3
221	33	K5	8 962	K5	17,7	K5	3,7	K5	K5
222	6	K1	2 390	K1	5,0	K3	0,7	K2	K2
231	27	K5	1 557	K1	2,5	K2	0,6	K2	K3
232	24	K5	6 043	K4	5,8	K3	2,5	K5	K4
233	14	K3	883	K1	0,7	K1	0,2	K1	K2
234	22	K5	6 932	K4	8,2	K4	2,9	K5	K5
235	7	K1	429	K1	0,3	K1	0,1	K1	K1
236	5	K1	1 911	K1	1,8	K1	0,5	K1	K1
237	5	K1	2 389	K1	3,1	K2	1,0	K3	K2
241	25	K5	3 554	K2	3,1	K2	1,0	K3	K3
242	37	K5	2 910	K1	7,0	K4	0,8	K3	K3
243	52	K5	293	K1	0,4	K1	0,1	K1	K2
311	14	K3	6 999	K4	12,3	K5	1,9	K5	K4
312	5	K1	9 561	K5	13,9	K5	4,0	K5	K4
341	8	K1	318	K1	0,4	K1	0,1	K1	K1

*) in these pressure zones the value of indicator ILI is determined using a relation describing the dependence between the unit leakage JUVNF and indicator ILI.

TI 3.1 – NRW - non-revenue water

As regards thus sub-indicator, a total of 15 pressure zones are in category K5 (unacceptable), which represents 202 km of the water mains (40.5 %) of the total length of the water distribution network without the main distribution system. Other pressure zones are classified in categories K1 – K3.

TI 3.2 - JUVNF - specific leakage per km

This sub-indicator evaluated two 2 pressure zones was unacceptable (category K5) and four pressure zones were evaluated as critical – K4. The pressure zones falling within categories K5 and K4 represent a total of 27.5 % of the length of the network.

TI 3.3 - ILI - Infrastructure Leakage Index

In this case, a total of 5 pressure zones are in category K5 and 3 pressure zones are in category K4. Category K5 represents 21.6 % and K4, 2.9 % of the total length of the water supply network.

TI 3.4 - ELI - Economical Leakage Index

Indicator ELI included 9 pressure zones in category K5 (unacceptable condition), which is 30.8 % of the length of the water mains and one pressure zone (critical condition) in category K4, which is 0.8 %. The leakage indicator evaluated 31.6 % of the length of the water mains in categories K5 and K4.

TI 3 – Final evaluation of water losses

As regards water losses, four pressure zones are evaluated as being in „unacceptable condition“. These are zones 123, 124, 221 and 234. As regards zones 123, 124, 221 and 234, evaluation K5 in all water losses indicators applies to zone 221. Zones falling within category K5 represent 17.1 % of the total length of the water network. Pressure zones 121, 122, 232, 311 and 312 are considered to be in a „critical condition“. They represent 13.7 % of the total length of the water network. In total, 9 pressure zones are in a critical (K4) and unacceptable condition (K5) from the point of view of water losses, which represents 30.9% of the total length of the water mains without the main distribution system.

Case study II - Assessment of water losses in the Slovak Republic

The issue of water losses has been given a great attention in Slovakia recently. Water companies went through privatisation waves and currently 8 regional water utilities operate in Slovakia - only one of them has a foreign equity participation. The economic pressure forces the companies to follow world trends of network operation, new information and possibilities of water losses reduction, their estimation and evaluation. Both in Slovakia and in the neighbouring counties, there is a lack of a common terminology and of the water losses evaluation methodology. The Slovak Office for Regulation of Network Industries as a state regulatory body within the field of the water supply endeavours to unify a practice and methodology of water losses evaluation for the purpose of determining the water prices. The Office takes concern in an experience from the IWA and its Task Force for Water Losses sources. The first works under the methodology of IWA was done at the Department of Sanitary Engineering Slovak University of Technology in Bratislava within a framework of a grant project solution.

Performance indicators of the water distribution networks focusing on water losses in water supply systems in Slovakia were evaluated in the first stage of the research project solution. In the second stage of the research project, smaller operation units will be evaluated, i.e. water supply systems for towns and villages in different size categories.

Data from only two selected larger water companies have been processed in detail until now. The data have been processed for individual water mains divided into 6 categories according to a number of supplied inhabitants. Average values of individual indicators of water losses are mentioned in the following table for the created size categories. Indicators in table 3 are not calculated from an annual volume of water losses but from the volume of unbilled water, because the value of unbilled water is much more exact than the value of water losses. It is a problem of how the water companies account for the unbilled authorised volume of water.

Other problems of water network assessment often consist in inaccurate records of pipes and house connections and missing information about the proper pressure in the network. That is why the values of Unavoidable Real Annual Losses (URAL) are not calculated according to a recommendation of IWA. Thus, the results in table 3 are affected by mistakes that are multiplied mainly in smaller villages.

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Table 3 Average values of indicators of water losses in dependence on the number of supplied inhabitants

indicators \ Number of supplied inhabitants		to 1000 inhab.	to 2000 inhab	to 5000 inhab.	to 10.000 inhab.	to 50.000 inhab.	up 50.000 inhab
non-revenue water NRW	%	32,3	31,8	30,9	22,5	27,2	24
unit leakage per km	m^3/km/year	2136	2382	2948	3405	4790	4720
unit leakage per service connection	l/ser.conn./day	172	183	204	216	365	403
ILI	-	3,1	3,5	4,1	4,4	6,6	7,2

Conclusions

Over the past decade, the water supply system in the Czech and Slovak Republic has undergone significant changes both in terms of the proprietary relations and the reliability for drinking water supplies and the quality of services. The issue of water losses has been one of the key problems encountered by the operators in the Czech Republic and handled by the management of new water companies. Auditing of the technical condition of the water networks in water supply systems using a uniform methodology makes it possible to define the hot spots in the system and it is also used as a background for the Active Leakage Control (ALC) and planning of water mains reconstructions. The presented methodology and its implementation in one of the biggest water companies in the Czech Republic has suggested a possibility of using various indicators of water losses including the data required for their determination. Based on the performed technical audit, the next part of the Master Plan of Water Supply of Pilsen City recommends operating and investment measures improving the technical condition of the network including further reduction in water losses.

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