DOI: 10.1051/e3sconf/20171902015

Water Loss Reduction as the Basis of Good Water Supply Companies' Management

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Abstract. Companies using water distribution systems to reduce the operating costs and increase the reliability of water supply systems, as well as to protect disposable water resources, must search for ways to reduce water losses. The article points out the economic and environmental aspects of water losses. The possibilities of using international water loss assessment standards have been analysed. The reflections presented in the paper refer to the current trends and world standards in the field of water distribution systems management. The article presents the results and analysis of water losses for the water supply network operated by the Water Supply and Sewerage Company in Gliwice (Przedsiębiorstwo Wodociągów i Kanalizacji w Gliwicach, PWiK). The losses were determined on the basis of numerous indicators and compared with other distribution systems. At present, most indicators of water loss are at a very good or good level. The Infrastructure Leakage Index (ILI), as one of the most reliable loss indicators for the surveyed distribution system, assumed values from 3.33 in 2012 to 2.06 in 2015. The recent drop in ILI values indicates the effectiveness of the Company's strategy for water leakage reduction. The success comprises a number of undertakings, such as ongoing monitoring, pressure reduction and stabilisation, repairs and replacement of the most emergency wires.

1 Introduction

Water losses occur in every water distribution system but only in some of them their levels can be considered as acceptable. Pipeline failure can be a result of design, engineering and operating mistakes, or natural wear and tear of materials. Among many factors, the most important influence on the actual water losses has: the incorrect technical condition of the wiring network and the level of network pressure and its fluctuations in the daily cycle. It should be stressed that the work of the waterways in the workplace has the effect of mining. Rock mass movements, land subsidence, bumps and corrosivity of groundwater are major causes of damage to water supply systems.

Due to the optimisation of water production costs and the need to protect water resources, rational reduction of water losses must be a priority ask for water supply companies. Poland, with a resource index of 1460 m3/M a year, has been seen in the World Water Council report since 1990 as a country with a water deficit.

The International Water Organisation (IWA) plays an important role in the implementation of sustainable water management, including the reduction of water losses [1,2]. The IWA guidelines for determining, analysing and evaluating water losses in the distribution systems will enable comparing the regularity of the operation of water supply networks by different plants. Many countries like Germany, Switzerland, Austria, United Kingdom, Denmark, Spain have been provided by IWA and have developed professional programs in economic documentation of technical, economical and reliability with investigation systems [1-4].

The purpose of this article is to analyse and evaluate water losses in the water supply network operated by the Water Supply and Sewerage Company in Gliwice (PWiK). These losses were considered in the context of system reliability and water supply to customers. The percentage water loss indicator and the standardised international methodology based on indicators recommended by IWA were used to determine the water losses. The obtained values of indicators for the discussed system were compared to the Polish and international standards.

The results and evaluations presented in this paper are based on the data obtained from the PWiK Gliwice and literature analysis.

2 Economic and environmental aspects of water loss

Water supply companies are required to supply the right amount of water, at the right pressure and of the right quality. By implementing these tasks, water companies must strive to optimise the costs and revenues of their operations. The financial policy of the plants should protect the recipients of services against undue,

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DOI: 10.1051/e3sconf/20171902015

excessive increase in the rates of water charges. Calculation of the prices of water and sewage disposal must be based on the costs incurred for the provision of services [5]. Each m^3 of the produced and pressed into the system water, entails various costs of, among others, energy costs and water treatment. It is estimated that the removal of each cubic meter of water is a gain of approximately 1.0-1.5 kWh of energy needed to produce and transport water in the distribution system [6]. According to the regulations, the costs of activities resulting from the production of unsold water, including losses, are charged to all users of the water supply network. It should be emphasised that in Poland, average prices for water consumption and wastewater discharge systematically increase. As compared to 2008, the average price in 2011 was by 27%, and as of January 1, 2016 by 70% higher (Price formation 2016). Based on the analysis of water and wastewater prices for households in Polish cities of over 50 thousand, in 2016, the lowest gross prices were PLN 6.56 (Zamość and Biała Podlaska) and the highest PLN 18.0 (Mysłowice and Dąbrowa Górnicza).

The results of the NIK (The Supreme Audit Office) audit, indicate that in 2013, 2014 the share of household expenditure on water purchase and sewage disposal in the income of a given farm was for large Polish cities from about 2.50 to 4.00%. Studies indicate that the upper social acceptability index should not exceed 3%. In Poland, these indicators are significantly higher than in the Netherlands, Italy, Great Britain, Germany and Portugal where the index is significantly lower than 1.0%.

Therefore, limiting water losses should be the key task of water supply companies. In this way, the plants can save on the costs of running the network, as well as on long-term capital costs, as the smaller the amount of water injected into the network affects the investment costs. It is also obvious that reducing losses is not only financial savings. There are also benefits of the use of the water supply system improvement, and also the image of an enterprise whose primary responsibility is to provide reliable water supply.

Also taking into account the need to protect water resources, the rational reduction of water losses by distribution system operators must be a priority. Controlling and limiting water losses not only affects the cost of water supply, but also protects the world's drinkable water resources, of which there are only around 3% in the world. Losses should include not only the costs of waste and the environmental costs of lost water, but other costs resulting from leaks, such as subsidence or road crashes, and even the costs of street crashes caused by the removal of water supply breakdowns [7]. It should also be stressed that water shortages are a problem not only for African countries or other desert areas but also for our country. Poland, with the resource index of 1460 m^3M^{-1} a year, has been noted in the World Water Council Report since 1990 as a country with a water deficit. The unfavourable situation is deepened by the small amount of water retained in water bodies and the degree of certain water bodies' pollution [8].

3 Materials and methods

The analysis covered the data from the years 2012-2015, obtained from the Water Supply and Sewerage Company in Gliwice, which included: water supplied to the network, used for social welfare purposes, non-production and production purposes, network length, quantity and length of water supply connections, material and age structure of the network, the number of recipients. On this basis the Percentage Water Loss Indicator(PLI) andUnitary Water Loss per Capita Indicator(Qlos) were estimated, as well as the IWA recommended indicators [9]:

- Unique Real Leakage Balance Indicator (RLB1 and RLB2)
- Non-Revenue Water Basic Index (NRWB)
- Unavoidable Annual Real Losses Indicator (UARL)
- Infrastructure Leakage Index (ILI).

The above ratios are calculated on the basis of the formulas presented in Table 1 and on the basis of data obtained from the waterworks.

4 Water losses on the example of the Water and Sewerage Company in Gliwice

4.1 Operating range

The Waterworks and Sewerage Company in Gliwice covers the towns of Gliwice and Pyskowice and the communes of Kozłów, Smolnicka, Taciszów, Kleszczów, Rzeczyce and Ligota Łabędzka in the municipality of Rudziniec. Water is supplied to about 200.000 people and the total length of the water supply system is 813.59 km.

The results indicate that 49% of the treated water meets the quality requirements for water intended for human consumption. The remaining 51% is treated.

4.2 The material structure and the age of the water supply network

In the material structure of the network, the grey cast iron dominates, which is currently mainly referred to as polyethylene, and, in the range of large diameters – spheroidal cast iron. Exchanges are necessary because of the internal incrustation of wires or significant deterioration of pipe strength due to the graphitisation of old grey cast iron, often even more than 100 years old.

Approximately 50% of the water supply network has been operated for over 30 years. There are less than 30% of the lines built in the last decade. Cables operated for over 50 years are mostly made of grey cast iron and have a small share of steel. On the other hand, wires of the age range of 31-50 years are mostly made of steel, whereas in the last 20 years, the networks have been built mainly of polyethylene and nowadays also in a small share of ductile cast iron.

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4.3 Water balance and indicators characterising water loss

Balancing water in the network is the basis for evaluating the operation of the water distribution system in terms of water consumption and loss. Based on its results, the companies decide to initiate actions aimed at liquidation of water losses [10-12]. The amount of water loss in the water supply network is due to the difference between the water introduced into the grid and the water sold and consumed for the needs of the water supply. This can be expressed by the formula:

$$Vlos = Vsup - Vts - Vsol \qquad (1)$$

where:
Vlos – water loss in the distribution system, m^3
Vsup – water supplied to the network, m^3
Vts – volume of water consumed on so-called own needs of the water supply, i.e.: rinsing of water and sewage networks, tanks, for business purposes etc., m^3
Vsol – water sold, m^3.

The PLI water loss percentages are the most commonly used water loss indicators. The indicator allows to determine the share of water losses in relation to the volume of water entering the water supply (Table 1). For the reliable and objective assessment of water losses for PWIK Gliwice, the loss indicators recommended by IWA were also calculated, which are summarised in Table 1
All indicators presented in Table 1 are described in detail in numerous papers [4,12,13].
Tables 2 and 3 summarise the distribution system data that are needed to calculate the IWA recommended water loss rates.
Table 4 presents the water loss indicators for the water supply system analysed, calculated from the formulas 2-8.

Table 1. Compilation of water loss indicators [4,12,13].

Water loss indicator	Indicator formula
Percentage Water Loss Indicator **PLI**	***PLI*** $= (V_{los}/V_{sup}) \cdot 100$ [%] (2) V_{los} – water loss in the distribution system, m^3/year V_{sup} – water supplied to the network, m^3/year
Unique Real Leakage Balance Indicator– **RLB**	$\boldsymbol{RLB_1} = V_{los}/[(M+R)\cdot 365]$ $[m^3 \cdot km^{-1} \cdot d^{-1}]$ (3) M – main network's length, km R – ramification network's length, km $\mathbf{RLB_2} = (V_{los} \cdot 1000)/(L_{wc} \cdot 365)$ $[dm^3 \cdot supply^{-1} \cdot d^{-1}]$ (4) L_{wc} – number of water connections
Non-Revenue Water Basic Index **– NRWB**	***NRWB*** $= [(V_{sup} - V_{sol})/V_{sup}] \cdot 100$ [%] (5) V_{sol} – water sold, m^3/year
Unavoidable Annual Real Losses Indicator– **UARL**	***UARL*** $=[18\cdot(M+R)+25\cdot Wc+0{,}8\cdot L_{wc}]\cdot 0.365\cdot p$ $[m^3 \cdot year^{-1}]$ (6) Wc– length of water connection, km p – average pressure in the tested network 46 m H_2O 0.365 – conversion factor per year and m³
Infrastructure Leakage Index– **ILI**	***ILI*** $= V_{los}/UARL$ [-] (7)
Unitary Water Loss per Capita Indicator $\mathbf{Q_{los}}$	$\boldsymbol{Q_{los}} = (V_{los} \cdot 1000)/(LM \cdot 365)$ $[dm^3 \cdot d^{-1} M^{-1}]$ (8) LM – number of inhabitants using the supply

Table 2. Compilation of water balance for 2012 – 2015.

Year	**Supplied water [m³]**	**Own post-supply use [m³]**	**Water to be sold [m³]**	**Sold water [m³]**	**Loss [m³]**	**Loss [%]**
2012	11 452 004	113 692	11 338 312	9 625 983	1 712 329	14.95
2013	11 072 530	153 521	10 919 009	9 417 694	1 501 315	13.56
2014	10 363 660	125 296	10 238 364	9 304 428	933 936	9.01
2015	10 700 283	118 805	10 581 478	9 513 710	1 067 768	9.98

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Table 3. Compilation of the network length, quantity and length of water connections.

Year	Length of main network M [km]	Ramification networks length R [km]	Length of water connections [km]	Number of connections [items]	Total [km]
2012	103.19	465.85	234.85	181334	803.89
2013	103.19	469.90	234.54	18123	807.63
2014	102.69	472.70	235.62	18159	811.01
2015	102.69	475.49	235.41	18150	813.59

Table 4. Compilation of water loss indicators for 2012-2015.

Year	PLI [%]	Q_{los} [$dm^3 \cdot d^{-1} M^{-1}$]	RLB_1 [$m^3 \cdot km^{-1} \cdot d^{-1}$]	RLB_2 [$dm^3 \cdot supply^{-1} \cdot d^{-1}$]	NRWB [%]	UARL [$m^3 \cdot year^{-1}$]	ILI [-]
2012	14.95	23.5	8.2	258.7	15.95	514129	3.33
2013	13.56	20.8	7.2	227.0	14.95	515076	2.91
2014	9.01	13.1	4.5	140.9	10.22	516708	1.81
2015	9.98	15.0	5.0	161.2	11.09	517342	2.06

The ILI leakage rate infrastructure assumes a value of between 3.33 in 2012 and 2.06 in 2015. According to the American Water Association (AWWA), the state of the water supply network is rated as very good for values lower than 3.0 or weak for values greater than 5.0. The average ILI leakage index values in the Polish cities ranged from 3.16 to 16.62 [6], which may lead to the conclusion that the state of the analysed network is currently very good.

5 Discussion of the results

Percentage loss of water, still widely used in Poland and in the world, is unreliable because it does not take into account such important factors as: the length of the network, the number of connections and their length, and the pressure and hydraulic load of the water supply network. However, it can be used to assess the variability of water losses in a multi-year distribution system. It is therefore recommended that the use of the classical method of calculating the percentage of losses be supplemented by the IWA standardised methodology, which will allow us to obtain more complete information on the amount of wasted water lost from the network. It should be emphasized that PWiK Gliwice has complete information allowing for a comprehensive assessment of water losses according to the recommended international standards.

It should be emphasised, however, that more and more water losses are being analysed in line with international standards. Bergel's comprehensive water loss analysis for 334 small group waterworks is an example. The author sets the range of percentages in the analysed water groups at 18.8-23.6%, but also determines the per capita net loss per unit and determines all indicators recommended by IWA [14]. Comparison of the percentage water loss indices for different systems can be unjust to plants. For example, in 2014, the percentage loss index for the distribution system operated by the Water Supply and Sewerage Company in Częstochowa was 9.0% and ILI 1.54 [13]. In the same year, the wastage rate for the Water Supply and Sewerage Company in Myszków was 17% at ILI 1.48 [15]. For the above water supply systems, with a clearly differentiated percentage of water loss index, the ILI values are comparable.

The analysis of loss indicators for the distribution system of PWiK Gliwice shows that the plant has taken effective measures to reduce the leakage. In recent years, losses have been reduced to a level that demonstrates good technical condition of the water supply network. The percentage of water start-up has decreased from about 15 in 2012 to about 9.0% in recent years. The infrastructure leakage rate during the period under review has been systematically reduced to ca. 2.0. It should be noted that in the literature a slightly different scales of interpretation of ILI can be found in the literature. According to the more rigorous state of the network, it is a good level [16] according to others at very good level [17]. Also, the value of the unit real RBL loss at 160 $dm^3 \cdot dl^{-1} \cdot d^{-1}$, against the background of Polish systems, indicates that the losses are maintained at a good level. Currently in Western countries, permissible actual losses are assumed at 100 $dm^3 \cdot dl^{-1} \cdot d^{-1}$ [14]. The next indicator recommended by IWA for comparison of the state of water distribution systems is the NRWB, Non-Revenue Water Basic Indicator, which is defined in Poland as a volume of unsold water. Similarly to previous indicators, it has decreased in recent years from about 16% in 2012 to about 11% in 2015. It shows a good technical state of the network against the national data where the weighted average for this system size is about 24% [18] The net water loss per capita is also a good indicator of water quality, with a value of 15.0 $dm^3 \cdot d^{-1} \cdot M^{-1}$ in 2015. In Bergel group water systems, this indicator ranged from 24.0 to 39.9 $dm^3 \cdot d^1 \cdot M^{-1}$ on average, while the Hotloś links analysis for 10 municipal waterworks indicated the average range of this indicator from 16 to 35 $dm^3 \cdot d^{-1} \cdot M^{-1}$ [13]. With a hydraulic loading indicator of about 50.0 $m^3 d^{-1}$ km^{-1}, the unit losses for the system under review are 5.0 $m^3 \cdot km^{-1} \cdot d^{-1}$, which gives approx. 0.2 $m^3 \cdot km^{-1} \cdot d^{-1}$. In accordance with German requirements, a loss of 0.2 $m^3 \cdot km^{-1} \cdot d^{-1}$ is allowed at such hydraulic system load.

6 Conclusions

There are several positive trends in water intake in Poland, consisting in the reduction of the overall water consumption especially for production purposes, the reduction of underground water consumption by industry, and more efficient use of water from the collective water supply. Important factors influencing water saving should be the implementation of water-saving technologies and the reduction of losses in water supply systems.

In this respect, reducing water losses should be a key task for plants operating water supply systems. In addition, water companies must strive to optimise the costs of their operations to protect their service recipients from undue and excessive increases in water charges. By reducing the losses, plants can reduce the costs of the current network exploitation and save on the investment costs. However, it should be noted that the complete elimination of water losses is not often possible and unprofitable. Plants operating water distribution systems in Poland and in other European countries must implement and apply modern standards for water loss management.

The calculated water loss rates allowed for the analysis and assessment of the technical condition of the water supply system, and it can be concluded that the plant has succeeded in successfully reducing water losses. Based on the analysis of water losses in the distribution system operated by the Water Supply and Sewerage Company in Gliwice, it can be stated that the process of loss reduction takes place in a multidirectional plant, progressively and systematically achieving more and more satisfactory results. At present, most indicators of water loss are at a very good or good level. The success comprises a number of undertakings, such as ongoing monitoring, pressure reduction and stabilisation, repairs and replacement of the most emergency wires. Monitoring allowed, among other things, for the monitoring and pressure management, which made greater pressure stability possible, and thus, less failure and loss. Active network control was implemented to quickly detect failures by providing operational teams with specialist equipment such as noise loggers and correlates.

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