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Analysis and Evaluation of Water Losses in the Collective Water Supply System

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1. Introduction

One of the main problems of water supply companies is water losses. Among many factors, the greatest impact on water losses is caused by the poor technical condition of the piping system, the level of pressure in the network and its fluctuations within the daily cycle. Rapid pressure changes and the associated hydraulic shocks affect both the failure rate and the outflow rate of water from the network. The amount of losses, regardless of their types, affects the cost of water supplied to consumers and has a negative effect on the financial standing of water supply companies (Nasirian et al., 2013, Venkatesh 2012). By reducing leakages, the production of water treatment agents and energy production are reduced globally, which is highly desirable for environmental reasons. Reduction in losses does not only lead to cost reduction but it also protects the limited water resources available for consumption, which accounts for ca. 2.5% of the world's total (Kuczyński & Żuchowicki 2010). Water losses generate not only resource and environmental costs of lost water, but also other costs resulting from leakages, such as subsidence of buildings or road collapses, and even costs incurred as a result of traffic jams resulting from the elimination of water supply failures (Ashton & Hope 2001). Therefore, companies that manage water distribution systems, in order to reduce operating costs, improve the reliability of the operation of water supply systems and to protect water resources, must perform multifaceted activities aimed at reducing water losses (Rak, et al., 2019). These measures include active leakage control, efficient pressure management, and speed and quality of repairs and regular pipe materials management. The basis for such actions should be a reliable analysis and evaluation of water losses. (Lee & Lam 2012, Clarke et al., 2012, Nasirian et al., 2013, Fujimura 2007, European Environment Agency 2012).

The research indicates that accurate evaluation of water losses and their objective assessment are difficult for many water supply companies. In order to obtain full knowledge of the amount of water lost from the system, many European countries such as Great Britain, Germany, Switzerland, Austria, Denmark, Spain and Denmark have developed and implemented special programs to analyse technical, economic and reliability indices of the operation of water distribution systems. (European Environment Agency 2012, Mutikanga et al., 2013, Jin & Piratla 2016).

The International Water Association (IWA) plays an important role in the implementation of best practices of sustainable water management. The organization has also made a significant contribution to the development and implementation of methods and programs to reduce water losses. An assessment of water losses based on the water balance method and numerous indices provides reliable information on the amount of water lost. The adoption of the standardised methodology for the determination of water losses proposed by the IWA allows for the comparison of losses in different water supply systems and the assessment of their levels (Lambert & Hirner 2000, Michalik &Rak 2017, Hug et al., 2002, Pietrucha-Urbanik & Studziński 2019).

The aim of the paper is to analyse and evaluate water losses in a collective water supply system, compare water loss indices in these systems to Polish and international standards, and to indicated and evaluate the company's activities leading to the reduction of water losses. The paper uses standard testing methodologies (water balance according to the International Water Association and index method). Water losses in the entire distribution system in 2012-2018 were analysed. The evaluation of water loss indices was conducted in accordance with the guidelines of AWWA (American Water Works Association), IWA (International Water Association), and WBI (Water Band Index). The opportunities for reducing the level of water losses and, consequently, increasing the reliability of water supply were indicated.

2. Water loss characterization

Water losses are divided into real and apparent losses. Real losses are caused by leakages of water from the networks and systems, fittings, overflow from compensation tanks and theft of water. Real water losses also occur in internal installations due to leaks smaller than the starting flow rate of the water meters. The causes for apparent losses include inaccuracy and inconsistency of measurement of water supply and consumption (Hotloś 2003). Contrary to real losses, apparent losses do not constitute actual losses, but only affect the numerical result of the balance of the volume of water supplied to the network and that sold to consumers. Since they do not represent real water losses, they are difficult to identify and determine accurately. In practice, a specific amount of water is supplied to consumers, but is not measured due to the metrological properties of the water meters (flows below the starting flow rate). The 1023heoreticcal measurement error should be not higher than 10%, but in practice it is difficult to determine the measurement error of the flow meter. According to Siwoń et al. (Siwoń et al., 2004), apparent losses may amount to ca. 5% depending on the installation and measurement conditions. It is also important to ensure the simultaneous measurement of water supply and intake. Simultaneous measurement affects the accuracy of water balance and thus the reliable determination of apparent losses. The amount of water from the pipeline used for internal purposes is generally difficult to quantify and is therefore often roughly estimated. It means water used mainly for the technological needs of the water supply system, and often for the sewage system (flushing of tanks, water pipes or channels). The values of water consumed for internal purposes are frequently overestimated in order to underestimate the actual water losses.

The difficulty of balancing the volume of water consumption in the distribution system is caused by various factors that can be divided into: dependent and partly independent on the plant operating a given water supply system (Piechurski 2014).

The dependent factors include:

- water leakages from pipes and leaking water supply pipes,
- flushing of the water supply system,
- leakages on water pipe connections.

Factors that are partly independent include:

- water theft,
- water supply failures,
- the accuracy class of the measurement instruments.

3. Characterization of the water distribution system operated by Water and Sewage Company in Końskie

Water and Sewage Company in Końskie operates water supply systems in the city and gmina of Końskie, Poland, in the area of 57 towns and villages. The total length of the water supply network is 287.8 km (data from 2018), including 0.6 km of mains and 287.2 km of distribution pipes. The water supply system is supplied from three underground water intakes located in the villages: Modliszewice, Paruchy and Wąsosz. The company operates 6,894 connections with a length of 187.1 km.

Fig. 1 shows the material structure of the water supply network. The material structure is closely related to the age of the water supply systems used (Fig. 2). The variety of materials used for the construction of water supply networks in Poland resulted primarily from their availability in the market, which was related to the period of construction of water supply systems.

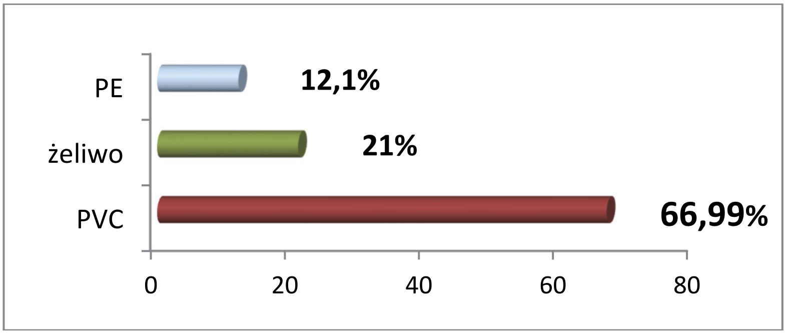

Fig. 1. Material structure of the network

The total percentage of PVC and PE is ca. 88%, which indicates that the networks are relatively recently installed, with their period of use not exceeding 20 years (Fig. 2). The company uses only few percent of old networks built before 1980.

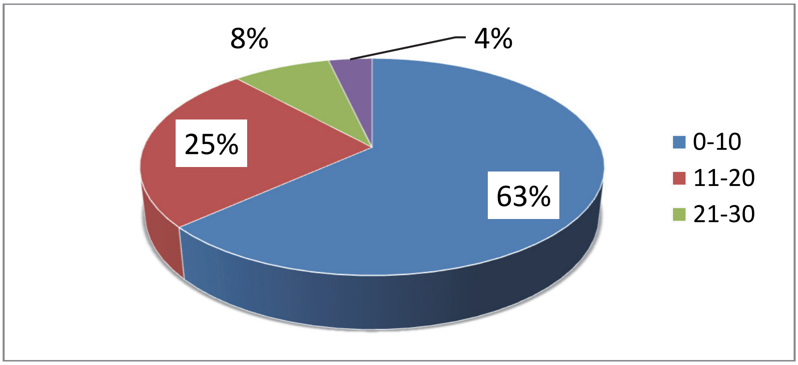

Fig. 2. Age structure of the network

Table 1 presents the length of the water supply network and the number of water supply connections operated by the company in 2012-2018. These data and pressure values are necessary for calculation of water loss indices recommended by IWA and presented in the further part of this study.

Table 1. Characteristics of the water supply network

year	water supply network [km]			number of house connections, L_{wc}	average pressure in the tested network, p – m H_2O
	length of the water supply network, M+R	length of house connections, W_c	total length, M+R+W_c		
2012	266.5	165.7	432.2	6183	40
2013	266.5	168.5	435.0	6290	40
2014	266.5	170.9	437.4	6382	38
2015	268.4	174.7	443.1	6522	38
2016	268.8	178.9	447.7	6670	38
2017	286.5	183.9	470.4	6803	35
2018	287.8	187.1	474.9	6894	35

4. Material and Methods

The analysis of water losses was carried out using the two research methods: balance method according to the International Water Association (IWA) and the index method. The analysis covered the data from the period of 2012-2018, obtained from the Water and Sewage Company which include: water supplied to the network, water used for social welfare purposes, non-production and production purposes, network length, quantity and length of water supply connections, the number of recipients, average pressure in the tested network, and number of failures in individual years.

These data were used to calculate failure intensity index (λ), percentage ratio of water loss (WS) and index of hydraulic load of the network (q_o), and indices recommended by the International Water Association (IWA) (Lambert & Hirner 2000):

- Real Leakage Balance (RLB)
- Non-Revenue Water Basic (NRWB)
- Unavoidable Annual Real Losses (UARL)
- Infrastructure Leakage Index (ILI)

Unit indices of water losses per capita and unit indices of water losses per kilometre of the network were also determined. Water loss indices, widely described in the literature (Hotloś 2007, Lambert & Hirner 2000, Bergel 2012) and characterized in detail in the further part of the study, were calculated from formulae (2) to (13) presented in Table 2 and 3.

Table 2. Compilation of water loss indices

Water loss index	Index formula	
Water loss in the distribution system – V_{los}, m^3/year	$V_{los} = V_{sup} - V_{wł} - V_{sol}$ V_{sup} – water supplied to the network, m^3/year $V_{wł}$ – water for the internal needs of the company, m^3/year V_{sol} – water sold, m^3/year	(2)
percentage water loss index – WS, %	$WS = (V_{los}/V_{sup}) \cdot 100\%$	(3)
unique real leakage balance index – RLB_2, dm^3/connection/day	$RLB_2 = (V_{los} \cdot 1000)/(L_{wc} \cdot 365)$ L_{wc} – number of house connections	(4)
non-revenue water basic index – NRWB, %	$NRWB = [(V_{sup} - V_{sol})/V_{sup}] \cdot 100$	(5)
unavoidable annual real losses – UARL, m^3/year	$UARL = [18 + (M + R) + 25 \cdot Wc + 0.8 \cdot L_{wc}] \cdot 0.365 \cdot p$ M – main network's length, km R – distribution pipes, km W_c – length of house connections, m p – average pressure in the tested network, m H_2O 0.365 – conversion factor per year and m^3	(6)
infrastructure leakage index – ILI, -	$ILI = V_{los}/UARL$	(7)

The failure intensity indices λ in total for distribution pipes and water mains in the companies studied were calculated from the formula (1).

$$\lambda = \frac{N}{L \cdot t} \quad (1)$$

where:
λ – failure intensity index (failure/(km·year),
N – number of failures per year,
L – total length of distribution pipes and water mains (km),
t – time in which a given number of failures occurring was equal to 1 year.

When analysing water losses, one should pay attention to unit indices per capita and unit index of water losses per kilometre of the network that characterize the operation of water supply systems. These indices are determined according to the formulae presented in Table 3.

Table 3. Unit water loss indices

Unit water loss index	Index formula
Amount of water supplied q_{sup}, dm^3/ (inhabitant·day)	$q_{sup} = (V_{sup}\ 1000)/(IN \cdot 365)$ (8) IN – number of inhabitants using the water supply system
Amount of water sold in total q_{sol}, dm^3/ (inhabitant·day)	$q_{sol} = (V_{sol} \cdot 1000)/(IN \cdot 365)$ (9)
Amount of water losses q_{los}, dm^3/ (inhabitant · day)	$q_{los} = (V_{los} \cdot 1000)/(IN \cdot 365)$ (10)
Amount of water consumed for internal purposes $q_{wł}$, dm^3/ (inhabitant · day)	$q_{wł} = (V_{wł} \cdot 1000)/(IN \cdot 365)$ (11)
Amount of non-revenue water q_{nd}, dm^3/ (inhabitan · day)	$q_{nd} = (V_{sup} - V_{sol}\ ) \cdot 1000)/(IN \cdot 365)$ (12)
water loss rate per kilometre of network q_s, m^3/(km h)	$q_s = V_{los}/(M+R)$ (13) V_{los} – water loss in the distribution system, m^3/h

The hydraulic load index was also calculated using the formula 14 due to the effect of the load of the network on water losses. The strong effect of the network load on water losses has been observed in the studies by e.g. Kwietniewski (Kwietniewski 2013).

$$q_o = V_{sup}/(M+R) \cdot 365 \tag{14}$$

where:
q_o – hydraulic loads of water supply, $m^3/(km\ d)$**,**
V_{sup} – water supplied to the network, m^3/year,
M – main network's length, km,
R – distribution pipes, km.

5. Results and discussion

5.1. Pipe failure rate

One of the most important indices for the assessment of the technical condition of a water supply system is failure intensity index for the pipelines (λ). The frequency of failures is mainly related to the age of the pipes, material, pressure, and operating conditions. The number of failures and the time of their elimination may have a substantial effect on the amount of water losses. It should be stressed, however, that failure rate of the network does not always have a significant effect on the amount of water losses. This is indicated, among others, by the studies by Rak for the municipal network of Jasło and Jarosław (Rak & Sypień2013, Rak & Misztal, 2017). Table 4 presents the number of failures in the analysed years and the value of the damage intensity index (λ).

Table 4. Mean values of unit intensity of water pipeline failures λ, failure/(km·year)

Years	2012	2013	2014	2015	2016	2017	2018
Number of failures	25	23	31	28	29	33	40
Distribution network length	265.9	265.9	265.9	267.8	268.2	285.9	287.2
Failure intensity index (λ)	0.094	0.086	0.117	0.105	0.108	0.115	0.139

Research indicates that in the analysed period of time, the number of failures was insignificant and little varied in individual years. Failure intensity indices for the water supply system in the analysed years was low. According to the recommendations of the PN-EN 60300-3-4 2008 standard, the failure intensity for mains should not exceed 0.3 failure/(km·year) and, for distribution pipes, 0.5

failure/(km·year). Kwietniewski proposed the following criteria for failure intensity λ (Kwietniewski 2013):

- Low failure rate = high reliability $\lambda \leq 0,1$
- Medium failure rate = medium reliability $0.1 < \lambda \leq 0.5$
- High failure rate = low reliability $\lambda \geq 0.5$

According to the above criteria, it can be concluded that the network is characterised by high reliability. Failure intensity for to the analysed water supply system is within the European criteria and should not have a significant effect on water losses. The evaluation of the network failure rate was made based on the failures to the water supply network, but undetected failures are also possible.

5.2. Water balance

To prepare water balance, data on the amount of water supplied to the network, the amount of water used for the internal needs of the water supply company, and the amount of water sold to all customers are required. These data were obtained from the company and presented in Table 5. The amount of water losses in the water supply system (V_{los}) was calculated from the formula (2).

Table 5. Summary of water balance for 2013-2017

Year	Water supplied to the network, V_{sup} thousand m^3/year	Water for the internal needs of the company, $V_{wł}$ thousand m^3/year	Water sold, V_{sol} thousand m^3/year	Water loss in the distribution system, V_{los} thousand m^3/year
2012	2 050.7	13.7	1,440.7	596.3
2013	1 822.5	14.3	1,429.9	378.3
2014	1 718.2	15.7	1,402.4	300.1
2015	1 794.1	64.8	1,402.3	327.0
2016	1 685.0	28.6	1,374.9	281.5
2017	1 673.9	21.7	1,355.7	296.5
2018	1,736.9	14.4	1,408.0	314.5

5.3. Water loss indices

Table 6 presents water loss indices in 2012-2018 calculated from the formulae 3-7. Analysis of water loss indices (Table 6) reveals relatively low values of the indices in this collective water supply system. In recent years, all the indices were lower than the average values obtained by Bergel (Bergel 2012) for 67 water supply systems serving 10,000 to 20,000 inhabitants. The value of PWS in 2012 amounted to as much as 29.1% of the amount of water injected into the network. This index reached the level of 17-19% in the last few years and was below the Berger's average of 21.4%. An analysis of the percentage water loss indices shows the lowest levels of leakages in the Netherlands (3-7%), while in most countries, these figures are higher: 15% in the USA, 13.8% in Canada, 42% in Italy, and 34.9% in Greece (Mutikanga 2012). However, it should be stressed that comparison and evaluation of water losses for different distribution systems using only the percentage water loss index is insufficient or even misleading. Distribution systems vary in terms of network length, number and length of connections, material, age of the network, hydraulic pressure and load to water supply networks. These factors have an effect on the amount of water loss. Furthermore, the value of the percentage water loss index is affected by the volume of water used for internal needs of the water supply company, which is provided by the companies as an estimate. For these reasons, it is recommended to use it only to assess the variability of water losses over many years in a given distribution system (Kwietniewski 2013).

Table 6. Water loss indices in 2012-2018

Year	WS, %	RLB_2, dm^3/connection/day	UARL, thousand m^3/year	NRWB, %	ILI, -
2012	29.1	268.9	197.7	29.7	3.01
2013	20.7	164.5	199.9	21.5	1.90
2014	17.5	128.6	201.8	18.3	1.50
2015	18.2	137.0	205.2	21.8	1.59
2016	16.7	115.3	208.5	18.4	1.35
2017	17.7	119.4	194.1	19.0	1.52
2018	18.1	124.9	196.4	18.9	1.60

In order to ensure a comprehensive and more reliable evaluation of water losses, it is recommended to establish loss indices developed by IWA. These include, among others, the NRWB water volume index. This index does not take into account the volume of water used for internal purposes of the water supply system, thus avoiding errors resulting from deliberate overestimation of the volume of this type of water by certain enterprises. In 2016 and 2018, it ranged from 18 to 19%, which shows that it remains at the country's average level and is below the 24% indicated by Berger. It should be emphasised that it was reduced by 10% in the last years of the study compared to 2012.

Another index recommended by IWA to assess the condition of water distribution systems is the RLB_2 index, which measures water losses per day per water supply connection. It is recommended if connection density is greater than 20 per km of the network. This index decreased significantly in the last years of the study, reaching the level of 115-125 dm^3/(connection-day) in 2016-2018, which demonstrates that it is at a lower level than in other collective water supply systems in Poland. The RLB_2 index in Poland was approximately ca. 150 dm^3/(connection·day) in 2015 (Bergel 2012). It should be noted that also this index decreased significantly for the analysed company in the period studied. In 2012, its value was more than twice as high as at present. This index is often very diverse, whereas extensive research presented in the Water Use and Loss Report shows its value in New Zealand ranging from 100 to 290 dm^3/(connection-day) (Water Use and Loss Report 2014). In western European countries, however, the maximum allowable value for RLB_2 is 100 dm^3/(connection-day).

Comparison of different water distribution systems can be made based on the infrastructure leakage index (ILI). This index represents the multiplication factor for actual water losses compared to the minimum level (URAL) to be achieved in a properly operated water supply system. It is recommended to be used when the number of connections in a given water supply system is greater than 5,000 and their density exceeds 20 per km of water supply network and the network pressure is at least 0.25 MPa (Dohnalik & Jędrzejewski 2004, McKenzie & Lambert 2003). The distribution system analysed shall meet the above criteria.

The ILI in 2014-2018 has decreased sharply compared to 2012. In the last five years, it ranged from 1.35 to 1.60 (Tab. 6). According to the IWA standards, the WBI Banding System for developed countries, and the criteria adopted by the American Water Works Association (AWWA), the value of ILI of ≤ 1.5 indicates a very good technical condition of the water distribution network. It should be noted that the value of this index in 2012 was 3.01, which indicated a poor condition of the network (according to IWA criteria).

The results of the Berger's study among of 67 Polish systems supplying water to 10,000-20,000 inhabitants showed that the average ILI for these systems is 1.9. (Bergel 2012). The ILI for the analysed system is lower than the average presented by other Polish authors. The ILI value given by these authors for many Polish cities in recent years ranged from 1.6 to 4.7 (Ociepa et al., 2018, Ociepa et al., 2019, Ociepa-Kubicka &Wilczak 2017, Rak & Sypień 2013, Rak & Misztal 2017). In contrast, the data provided by Lambert and McKenzie for 44 water distribution systems, including 5 systems from New Zealand, 17 from Australia and 22 from Europe, show a very wide range of ILI, from less than 1.0 for two systems to more than 5.0 for eleven of the systems analysed. Research for 16 water supply systems from different countries in Europe such as Austria, Belgium, Bulgaria, Denmark, England, France, Germany, Italy, Malta, Portugal, Scotland, Serbia and Croatia also point to a very wide IMI range, from 0.7 to 5.8 (Water Use and Loss Report 2014, Dohnalik & Jędrzejewski 2004, McKenzie & Lambert 2003).

Table 7 presents unit water loss indices per capita per day and per kilometre of network per hour.

Table 7. Unit water loss indices in 2012-2018

Years	Number of inhabitants served by the water supply system	Unit water loss indices per capita, dm^3/(inhabitant·day)					Unit water loss index per km of the network, m^3/(km h)
		q_{sup}	q_{sol}	q_{los}	$q_{wł}$	q_{nd}	q_s
2012	30,915	181.70	127.67	52.80	1.22	54.02	0.26
2013	31,450	158.70	124.56	32.91	1.25	34.16	0.16
2014	31,910	147.50	120.40	25.73	1.35	27.08	0.13
2015	32,610	150.70	117.82	27.40	5.45	32.85	0.14
2016	33,350	138.40	112.95	23.07	2.35	25.42	0.12
2017	35.000	131.00	106.12	23.20	1.70	24.90	0.12
2018	35.000	135.90	110.20	24.62	1.13	25.75	0.12

Calculation of unit water loss indices per capita per day provided a detailed picture of the use of the water supply system. Analysis of the unit water loss indices in 2012-2018 presented in Table 7 shows that the index of water supplied was the highest in 2012 and amounted to 181.73, whereas it was the lowest in 2017 and amounted to 131.00 dm^3/(inhabitant·day). The unit volume of water sold was the highest in 2012 and the lowest in 2017, with 127.67 and 106.12 dm^3/(inhabitant·day), respectively. The unit water loss index ranged from 52.80 in 2012 to 23.07 dm^3/(inhabitant·day) in 2017. The loss index decreased in recent years by over 50% compared to 2012 and is now at an average level compared to other Polish distribution systems. In the 334 Polish group water supply systems analysed by Bergel, this index ranged from 24.0 to 39.9 dm^3/(inhabitant·day) on average, while the analysis of Hotloś for 10 municipal waterworks indicated an average range of this index from 16 to 35 dm^3/(inhabitant·day) (Bergel 2012, Hotloś 2007).

The unit volume of water needed for the company's own purposes ranged from 1.13 to 5.45 dm^3/(inhabitant·day), whereas the amount of non-revenue water ranged from 24.90 to 54.02 dm^3/(inhabitant·day). A significant reduction in the unit non-revenue water index observed since 2016 confirms the effectiveness of the company's actions aimed to reduce water losses. Another analysed index was unit water loss index per kilometre of water supply system q_s. In the analysed years, it ranged from 0.26 in 2012 to 0.12 m^3/(km · h) in 2016-2018. According to the German criteria, this index is at a recommended level below 0.20 m^3/(km · h).

The analysis of water loss took into account the hydraulic load index for the network q_o, m^3/(km·day). This index shows the mean amount of water supplied per day in reference to unit length of a water supply network. The values of indices for individual companies are presented in Table 7.

Table 7. Summary of indices of individual hydraulic load of a water supply system (q_o), m^3/(km·d)

2012	2013	2014	2015	2016	2017	2018
21.08	18.73	17.66	18.31	17.17	16.01	16.53

Water losses in a distribution system are often related to the hydraulic load of the network. In general, a reduction in the load to the network results in a decrease in water losses. In 2012-2018, the load to the analysed water supply network showed a slightly downward tendency despite the growing number of connections. This is probably due to the constantly decreasing water consumption.

6. Summary

The results of the analysis showed that with its comprehensive activities, the company has significantly reduced its water losses in recent years. The company has been actively managing water losses for several years. The basis for its activity is continuous monitoring of network flows and active leakage control and, consequently, the reduction of water losses. Implementation of monitoring allows for the control of flows and pressure levels. The decrease in the NRWB index in 2012-2018 from 29% in 2012 to ca. 18% in 2018, and the decrease of the ILI value in the respective years from 3.1 to 1.5-1.6 indicates the effective countermeasures used to limit water losses. Currently, the value of IMI according to strict IWA criteria suggests a very good condition of the network. RLB_2 is another indicator that fell sharply over the period analysed. In 2012, its value was more than twice as high as at present. On the other hand, the average condition of the network is indicated by the unit water loss index per capita, which amounted to 52.80 in 2012 and currently is about 23.07 dm^3/(inhabitant day).

In view of the specific nature of operation of each distribution system, the company developed its own programme for reduction of water losses. These solutions are adapted to local conditions, taking into account the causes of water losses and the company's potential. The particularly important problem addressed by the company is to monitor night flows, which allows for detecting excessive flows and water consumption resulting from failures or theft. Correct separation of metered zones allows for identification of the areas with high flows. Consequently, the area of searching for failure or uncontrolled water consumption is narrowed down, which accelerates location of leakages and reduces the amount of water lost. The company indicates the need for detailed monitoring and reduction of network pressures to optimal values. This reduces the amount of leakages in pipes, thus limiting water losses.

Further reduction of losses will be achieved by continuation of the regular control of dishonest water consumers, the use of water meters resistant to magnetic field, their regular verification, control and calibration of measurement devices. It is planned to install water meters with radio sensors. Replacement of water meters with visual reading into water meters with radio devices enables to read all water meters in a given building or a given zone at the same time. Installation of the meters and ensuring simultaneous measurement is necessary to eliminate apparent losses. Furthermore, the use of advanced leakage detection equipment is essential to reduce water losses, including geophones, stethophones or correlators.

7. Conclusions

1. A reliable assessment of the activities of Water and Sewage Company in Końskie in terms of reducing water losses requires preparation of a water balance and determination and analysis of water loss indices.
2. The analysed water loss indices for the tested water supply system are currently lower or comparable to the values obtained in other collective water supply systems in Poland and worldwide. At present, most indicators of water loss are at a very good or good level. In 2012, most of the water loss indices

were high or even very high and showed higher than national average water losses from the network. This shows that the company took effective measures to reduce water losses in the last few years of the study.

3. The values of the failure intensity for the tested water supply system indicate that the impact of failures on water losses is insignificant, assuming that the company responds quickly to remove identified leaks and there are no undetected failures.
4. The networks which had been built relatively recently and a low failure rate suggest that the operator should take measures to evaluate the percentage of apparent losses in the overall value of losses and to pay particular attention to uncontrolled water intake.
5. For the precise determination of the unavoidable real losses index, it is recommended to divide the network into measurement areas (zones). The URAL and ILI evaluation should be performed for separated zones.
6. It is advisable that the company continues to minimize water losses to the economic level of leakage specified for the operated distribution system. Determination of the economic level of leakages requires preparation of an economic analysis that takes into consideration the costs of water intake, treatment and distribution, the costs of active control and disposal of leakages.

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Abstract

The paper presents the analysis and evaluation of water losses in the distribution system used by the Water and Sewage Company in Końskie, Poland. The analysis of water losses was conducted based on the use of numerous indices that provide objective information on the condition of the water supply system. The method of the percentage water loss index was extended by the methods of determination of water losses according to the International Water Association (IWA). The data needed for the calculation of water losses, such as the amount of water supplied to the network, the water sold, water used for the company's own needs, the length of the network, the number and length of water supply connections, number of customers, mean pressure in the network, and number of failures was derived from Water and Sewage Company in Końskie , Poland. These data were used to calculate the amount of water losses in individual years, percentage water loss index (PWS), and the indices recommended by the International Water Association (IWA): Real Leakage Balance (RLB), Non-Revenue Water Basic (NRWB), Unavoidable Annual Real Losses (UARL), Infrastructure Leakage Index (ILI) and unit indices of loss per capita and per kilometre of network. Due to the likely relationships of the load and failure rate of the network with water losses, the failure intensity index and index of hydraulic load to the network.

The results of the analysis showed that with its comprehensive activities, the company has significantly reduced its water losses in recent years. Currently, most of the water loss indices have reached a level considered good compared to the national data and average according to the standards used in Western European countries. In 2012, most of the analysed loss indices were at a high or even very high level and showed higher than the national average loss of network water. The decrease of the NRWB index from 29% in 2012 to ca. 18% in 2018, and the decrease of the ILI value in the respective years from 3.1 to 1.5-1.6 indicate the effective countermeasures used to limit water losses. Currently, the value of IMI according to strict IWA criteria suggests a very good condition of the network. RLB2 is another indicator that fell sharply over the period analysed. In 2012, its value was more than twice as high as at present. On the other hand, the average condition of the network is indicated by the unit water loss index per capita, which amounted to 52.80 in 2012 and currently is about 23.07 dm3/(inhabitant day). Very low values of the failure intensity index of the water supply system indicate that the impact of failures on water losses is insignificant, assuming that the company responds quickly to remove identified leaks and there are no undetected failures.

The several years of analysis and evaluation of numerous indices of water loss presented in the paper reveals the effectiveness of the adopted strategies of reducing leakages in the distribution system. It should be noted that the company has been involved in comprehensive activities aimed at limitation of water losses for several years.

Keywords:
water losses, percentage water loss index, infrastructure leakage index,
unit water start index, failure intensity index

Analiza i ocena strat wody w wybranym wodociągu grupowym

Streszczenie

W artykule przedstawiono analizę i ocenę strat wody w systemie dystrybucji eksploatowanym przez Przedsiębiorstwo Wodociągów i Kanalizacji w Końskich. Analizę strat wody przeprowadzono w oparciu o liczne wskaźniki pozwalające na obiektywną informację o stanie sieci wodociągowej. Metoda procentowego wskaźnika strat wody rozszerzona została o metody określania strat według International Water Association (IWA). Niezbędne dane do obliczeń strat wody jak: ilość wody dostarczanej do sieci, wody sprzedanej, zużytej na potrzeby własne zakładu, długość sieci, ilość i długość połączeń wodociągowych, liczbę odbiorców, średnie ciśnienie w sieci, liczba awarii otrzymano z Przedsiębiorstwa Wodociągów i Kanalizacji w Końskich. Na ich podstawie wyznaczono: ilość strat wody w poszczególnych latach, procentowy wskaźnik strat wody (PWS), a także zalecane przez International Water Association (IWA) wskaźniki: Real Leakage Balance (RLB), Non-Revenue Water Basic (NRWB), Unavoidable Annual Real Losses (UARL), Infrastructure Leakage Index (ILI) oraz wskaźniki jednostkowe strat na mieszkańca i kilometr sieci. Z uwagi na możliwy związek obciążenia i awaryjności sieci

ze stratami wody wyznaczono wskaźnik intensywności uszkodzeń i wskaźnik hydraulicznego obciążenia sieci.

Wyniki przeprowadzonej analizy pozwalają stwierdzić, że dzięki wszechstronnym działaniom przedsiębiorstwo w ostatnich latach zdecydowanie obniżyło straty wody. Obecnie większość wskaźników strat wody osiągnęło poziom uznany za dobry na tle danych krajowych a średni w odniesieniu do standardów krajów Europy zachodniej. W 2012 roku większość analizowanych wskaźników strat była na wysokim a nawet bardzo wysokim poziomie i świadczyła o wyższych niż średnie krajowe ubytkach wody z sieci. Spadek wskaźnika strat NRWB z 29% w 2012 roku do ok. 18% w 2018, spadek wartości wskaźnika ILI w tym okresie z 3,1 do 1,5-1,6 świadczy o skutecznym przeciwdziałaniu stratom wody. Obecnie wartość ILI według rygorystycznych kryteriów IWA świadczy o bardzo dobrym stanie sieci. Kolejnym wskaźnikiem, który uległ w analizowanym okresie poważnemu obniżeniu jest RLB_2. W 2012 wartość jego była ponad dwukrotnie wyższa niż obecnie. Natomiast na średni stan sieci wskazuje jednostkowy wskaźnik strat wody na mieszkańca, który wynosił 52,80 w 2012 roku a obecnie ok. 23,07 dm^3/(mieszkańca·dobę). Bardzo niskie wartości wskaźnika intensywności uszkodzeń sieci wodociągowej wskazują na mało znaczący wpływ awarii na straty wody przy założeniu, że Zakład szybko reaguje i usuwa stwierdzone wycieki i nie występują awarie nieujawnione.

Analiza i ocena na przestrzeni lat licznych wskaźników strat wody przedstawiona w artykule świadczy o skuteczności przyjętych strategii ograniczania wycieków w systemie dystrybucji. Należy podkreślić, że przedsiębiorstwo od kilku lat prowadzi wszechstronne, kompleksowe działania zmierzające do ograniczania strat wody.

Słowa kluczowe:
starty wody, procentowy wskaźnik wody, infrastrukturalny indeks wycieków,
jednostkowe wskaźniki start wody,
wskaźnik intensywności uszkodzeń sieci wodociągowej