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Analysis of the Water Distribution Subsystem in the Waterworks "X" in the Light of its Losses

Analiza podsystemu dystrybucji wody w zakładzie wodociągowym „X" w świetle jego strat

The activities aiming at the limitation of frequently significantly high water losses in the distribution systems exploited by waterworks ought to be preceded by a complete water loss analysis. Components of the analysis should include the comprehensive water balance in the waterworks, as well as the collection of information on the water supply system itself (length, age, material, number of recipients, number of connections). The article aims at presenting the water loss analysis conducted in the "X" Waterworks' distribution system. The analysis was prepared with the use of the indicators recommended by the International Water Association (IWA) and the percentage loss indicator in order to present the differences between the results obtained using the percentage indicator in relation to the remaining indicators. The average pressure prevailing in the water supply system exploited by the plant equals 35 mH_2O. Based on the data obtained from the plant and the results of the analysis it can be observed that the waterworks undertakes activities aiming at the decrease of the water loss rates. It is proved by the reduction of the Infrastructure Leakage Index (ILI) from 4.93 (unacceptable rate) to 3.31 which, according to the IWA assessment classifies the system as very poor. Evaluating the water supply system according to the guidelines of the American Water Works Association (AWWA), it can be stated that in 2010 the condition of the system was very good and did not change in the following years for which the analysis was conducted. Based on the WBI Banding System's guidelines, the evaluation of the water supply system's condition is good in 2015, in the earlier years, however, the system's condition is reported as weak. Due to the very serious nature of the water loss issue and with the aim of its highest possible restriction, the water supply system analysis is recommended to be done according to the most rigorous IWA guidelines.

Keywords: **water loss limitation, water losses, water loss analysis, IWA indicators, percentage index, infrastructure leakage index**

Introduction

The issue of water losses has been encountered in all the countries in the world. It is a highly complex problem requiring increased activities and researching the solutions allowing for a successful water loss prevention. The issue of complete water losses is complex and comprises the real and apparent water losses. The notion of the real water losses refers to the leakage on the fittings, connections and the installation itself. The apparent water losses are the mistakes stemming from the imprecise water use measurements. Generally, water loss means the total of the real and the apparent losses. The notion of the Non-Revenue Water Basic (NRWB) is the differential between the amount of the produced water and the amount of the water sold, with the water used for own purposes considered. Waterworks should aim at the strict monitoring of water from the source to the final customer. The finances spent by companies on water treatment and making it fit for consumption are higher and higher which is related to the quality of the obtained water. So-called "invoiced" water, i.e. the registered discharge of water from the water access points located behind the water meter sets constitutes the waterworks' income [1]. Apart from the adverse economic aspect, water losses contribute to indirect environmental degradation associated with the declining drinking water resources worldwide. Therefore, the elimination and maximum reduction of losses, has a positive influence on the financial condition of the waterworks and contributes to the protection of the natural water resources [2, 3].

The correct determination of water losses is complex and requires reliable knowledge of the waterworks being analysed. The knowledge of the specificity of the plant's operations, the nature of the site in which it is located, the quantity and type of the material the water supply system is built from, and the frequency and the nature of failures are some of the very important information to be learned before undertaking any water loss analysis in the plant [4]. Many plants seek to reduce or eliminate leaks from the water supply, however, not always it is done satisfactorily well so as to achieve the expected results. It is therefore important to make extensive analyses based on different methods of balancing water quantities and numerous water loss indicators. In many countries, also in Poland, there are numerous studies on how to optimise the water supply systems for limiting water losses and enhance the support systems [5]. At the moment, the International Water Association, considered the pioneer in the field, has developed a methodology for conducting water loss calculations based on which reliable assessment of the water supply network is obtained. The application of a uniform calculation methodology allows to some extent to compare the companies in terms of indicators included in the study [5, 6].

This article aims to present the issue of water loss based on the analysis performed for the "X" company distribution system. The analysis was based on the recommended IWA guidelines and the percentage loss of water, which allowed for an objective evaluation of the system. A comparison of the obtained results with the ones received from the plant, whose analysis is only based on the percentage loss index, has also been made.

1. Subject of research

The subject of the analysis is the "X" waterworks located in north-western Poland, the supply source of the system is 14 deep wells. The complete analysis of water losses was possible thanks to the cooperation it was based on with the plant from which the necessary information and data were obtained.

On the basis of the data, a summary of the materials from which the water supply system is constructed was made. The results are presented in Figure 1.

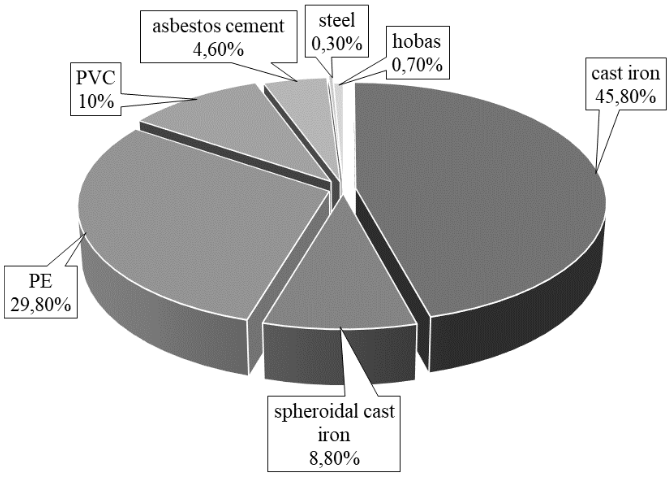

Fig. 1. Materials used to build a water supply system [7]

According to Figure 1, it can be stated that the most abundant material is cast iron, the second is PE followed by PVC and spheroidal cast iron. Less than 5% of the network constitutes asbestos cement. According to the plant's policy, the most frequently failing sections of the water supply system are exchanged. Figure 2 shows the age structure of the exploited network. Unfortunately, the company does not have information on the period of the average use of systems built from the particular material.

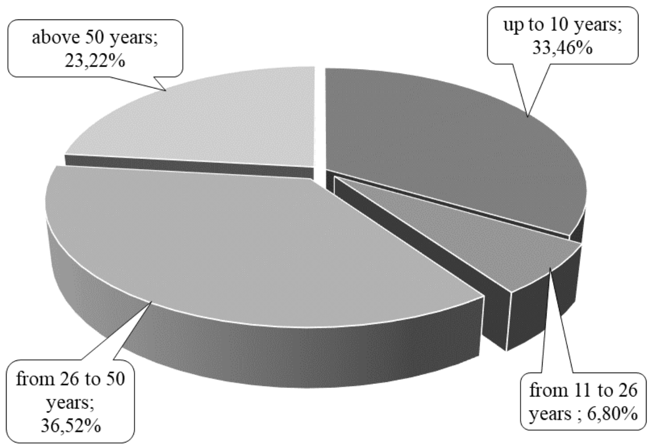

Fig. 2. Water supply system age structure [7]

Analysing Figure 2, it can be observed that about 60% of the network is operated for from 26 to over 50 years. Referring to Figure 1 and general technical knowledge, it can be concluded that the networks made of cast iron, asbestos cement and steel are the oldest. Long service life makes the above-mentioned materials the most prone to breakdowns and leaks. The corrosive effect of water can cause multiple leaks, thus causing unregistered water outflows, which in combination with highly permeable soils creates leaks that are particularly difficult to detect. In the range of 10 to 26 years, the materials are: spheroidal cast iron, hobas, PE and PVC, which are modern materials more resistant to corrosive effects of water, and other external factors.

Waterworks "X" operates a total water supply network of 315.62 km, supplying water to 7251 facilities. Detailed information on the water supply network of the enterprise under consideration is presented in Tables 1 and 2.

Table 1. **Summary of the network's length in the waterworks plant [7]**

Year	Network and connections' length			Lengths' total	Number of connections	Average network pressure
	Main M	Ramification R	Connections P_w	$\sum = M + R + P_w$	L_{Pw}	p
	km	km	km	km	item	mH_2O
2010	18.62	161.26	90.35	270.23	6941	35
2011	18.62	174.38	91.82	284.82	7012	35
2012	18.62	180.92	93.04	292.58	7071	35
2013	18.62	187.74	102.50	308.86	7113	35
2014	18.62	190.30	103.50	312.42	7159	35
2015	18.62	192.50	104.50	315.62	7251	35

As shown in Table 1, the length of distribution networks and connections is systematically increasing in the enterprise. This is also a trend observed in other waterworks in Poland. The length of the main systems, however, remains the same throughout the period under consideration.

Table 2. **Water balance in the analysed plant [7]**

Year	Produced water V_{sup}, $m^3 \cdot year^{-1}$	Sold water V_{sol}, $m^3 \cdot year^{-1}$	Own usage V_{own}, $m^3 \cdot year^{-1}$	Water loss V_{los}, $m^3 \cdot year^{-1}$
2010	4 460 400	3 321 300	442 900	696 200
2011	4 209 700	3 297 700	323 300	588 700
2012	4 205 500	3 220 000	312 600	672 900
2013	4 196 400	3 235 200	336 300	624 900
2014	4 115 200	3 235 000	326 600	553 600
2015	4 067 000	3 308 000	242 800	516 200

Table 2 presents the information on the water balance of the plant in question. Analysing the years 2010-2015, a downward trend is observed starting from the amount of water produced, the amount of which decreased to over 393 thousand m^3. Also, the decrease in own water consumption by about 45.00%, and the loss of water by 180 thousand m^3 can be noticed.

2. Brief characteristics of water loss indicators

The objective assessment of water loss and water supply system according to the IWA guidelines is dependent on a reliable water loss balance and a number of indicators presented below.

The percentage loss of water (WS) allows to calculate what portion of water with respect to the water supplied to the network constitutes a loss. Due to its simple way of determining it is the most commonly used indicator. It can be determined from the formula [5, 8-11]:

$$WS = (V_{los} \cdot V_{sup}^{-1}) \cdot 100, \% \tag{1}$$

where:
V_{sup} - produced water (supplied to network), $m^3 \cdot year^{-1}$,
V_{los} - water losses, $m^3 \cdot year^{-1}$.

Real Leakage Balance Indicator (RLB) is used in order to determine the amount of water loss, taking into account the number of water connections. The RLB is calculated according to the number of connections per kilometre of the water supply network. For the enterprise under, therefore, the calculation was made according to the formula [5, 8-12]:

$$RLB2 = (V_{los} \cdot 1000) \cdot (L_{pw} \cdot 365)^{-1}, \ dm^3 \cdot d^{-1} \cdot \text{water connection}^{-1} \tag{2}$$

where L_{pw} - number of network connections, items.

Non-Revenue Water Basic Index (NRWB) is used to eliminate own overconsumption of water. This gives more accurate results. Calculations are made according to the formula [5, 6, 8-11]:

$$NRWB = [(V_{sup} - V_{sol}) \cdot V_{sup}^{-1}] \cdot 100, \% \tag{3}$$

where V_{sol} - sold water, $m^3 \cdot year^{-1}$.

Unavoidable Annual Real Losses Indicator (UARL) - unavoidable losses represent the annual loss of water in distribution systems. It is the amount of water lost due to the very difficult leakage detection and the economically unjustified liquidation of some of them. To calculate the index, the below formula is used [8]:

$$UARL = [18 \cdot (M + R) + 25 \cdot P_w + 0{,}8 \cdot L_{pw}] \cdot 0.365 \cdot p, \ m^3 \cdot year^{-1} \tag{4}$$

where:
18 - unavoidable leakage on main and ramification networks, $dm^3/km \cdot d \cdot 1\ mH_2O$,
25 - unavoidable leakage on water connections, $dm^3/1$ m connections$\cdot d \cdot 1\ mH_2O$,
0,8 - unavoidable leakage related to the number of water connections, $dm^3/1$ connection$\cdot d \cdot 1\ mH_2O$,
M - main network's length, km,
R - distribution network's length, km,
P_w - connection lenght, km,
p - average pressure in the network (p = 35), mH_2O,
0.365 - calculated per year and m^3.

Infrastructure Leakage Index (ILI) is used to provide a real loss multiplies with reference to the minimum level that can only be obtained in a properly operated water distribution subsystem [6, 8, 10]:

$$ILI = V_{los} \cdot UARL^{-1} \quad (5)$$

Table 3. **Categories of water supply assessment according to ILI [5]**

ILI scope and categories according to IWA (condition)	ILI categories	ILI scope according to WBI Banding System		ILI scope according to AWWA
		Developing countries	Developed countries	
ILI ≤ 1.5 (very good)	very good	ILI ≤ 4.0	ILI ≤ 2.0	ILI ≤ 3.0
1.5 < ILI ≤ 2 (good)				
1.5 < ILI ≤ 2 (satisfactory)	good	4.0 < ILI ≤ 8.0	2.0 < ILI ≤ 4.0	3.0 < ILI ≤ 5.0
2.5 < ILI ≤ 3.0 (poor)	poor	8.0 < ILI ≤ 16.0	4.0 < ILI ≤ 8.0	5.0 < ILI ≤ 8.0
3.0 < ILI ≤ 3.5 (very poor)				
ILI > 3.5 (inadmissible)	inadmissible	ILI > 16.0	ILI > 8.0	ILI > 8.0

The assessment of the water supply network was made by comparison of the calculated ILI value for the distribution subsystem with the ranges in Table 3. The results are shown in Figure 7.

3. Results

The water loss analysis in the "X" waterworks used the percentage water loss index and the IWA recommendations. The previously mentioned methods were described in Section 2 and also in other articles [1, 5-12].

Figure 3 shows the distribution of the percentage water loss during 6 years of the waterworks operation.

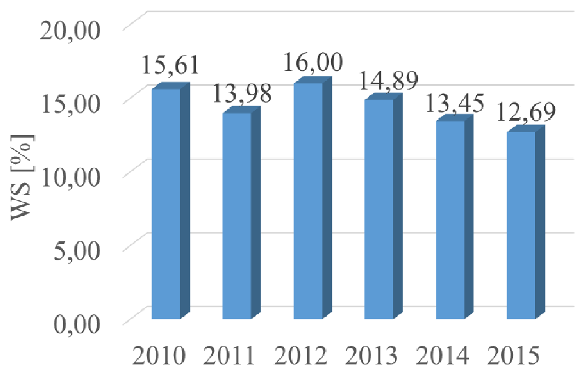

Fig. 3. Percentage water loss indicator [7]

The period in question is characterised by a decrease of the percentage water loss indicator from 15.61% recorded in 2010 to 12.69% in 2015. The increase of the percentage to 16.00% in 2012, according to the information provided by the enterprise was related to numerous network failures due to mechanical damage.

Figure 4 presents the results of the calculation of dm^3 number of water loss for one water connection per day (RLB2).

Figure 4 shows a systematic decline in RLB2, which in 2010 equalled 274.80 $dm^3 \cdot d^{-1} \cdot$water connection^{-1}, and within six years decreased to 195.04 $dm^3 \cdot d^{-1} \cdot$water connection^{-1}, which proves the effectiveness of the leakage prevention in the plant. As in the case of the percentage loss indicator, the increase in value in 2012 was observed as compared to the previous year.

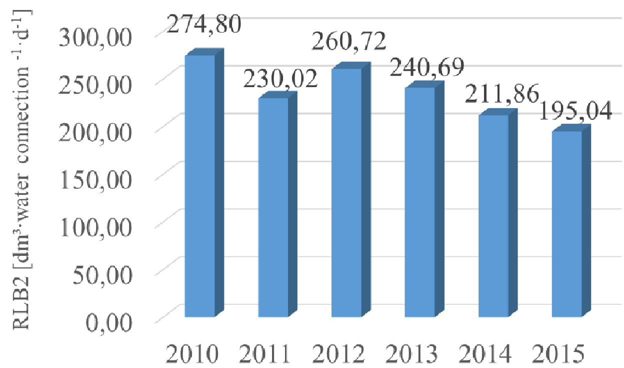

Fig. 4. Real Leakage Balance Indicator (RLB2) [7]

Taking into account the number of connections greater than 20 per kilometre of the water supply network, the downward trend is observed, similar to that of the percentage loss indicator. The period considered is characterised by a decrease in the value of the indicator by approximately 29%. Taking into account the higher density of network connections, it is a satisfactory result.

In further analysis, the calculation of the Non-Revenue Water Basic Index (NRWB) was performed. The results are shown in Figure 5.

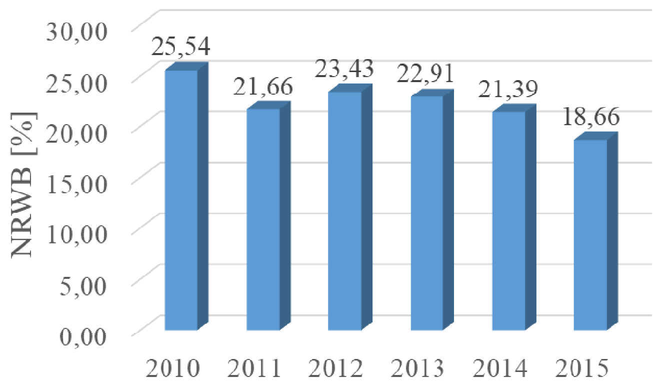

Fig. 5. Non-Revenue Water Basic Index (NRWB) [7]

In 2010, over 25.00% of the volume of produced water did not constitute the enterprise's income. It is a great value proving the necessity of efforts to eliminate the losses and improve the situation of the plant. In the following years, the value of the indicator has fallen to 18.66%, which is a decrease of 6.88%.

Performing a water loss analysis based on the IWA guidelines, it is necessary to calculate the Unavoidable Annual Real Losses Indicator (UARL). The calculation values are shown in Figure 6.

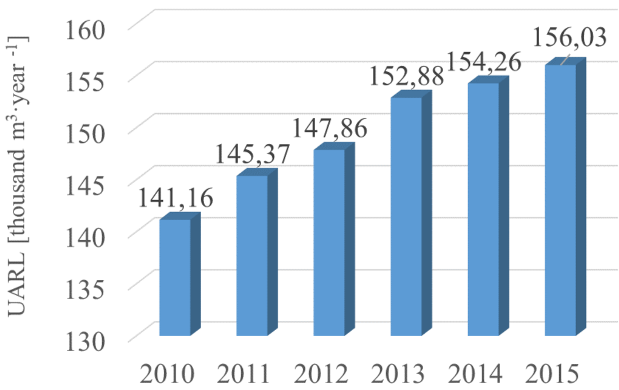

Fig. 6. Unavoidable Annual Real Losses Indicator (UARL) [7]

As observed, the indicator's increase is similar in the following years. Between 2010 and 2015 an increase in the value of the index is noticed, from 141.16 to 156.03 thousand $m^3 \cdot year^{-1}$. The increase in the value is related to the increasing length of the water supply network in the analysed period.

Based on the results of the analysis, the calculations of the Infrastructure Leakage Indices (ILI) were made. Figure 7 shows the distribution of ILI values for the analysed period.

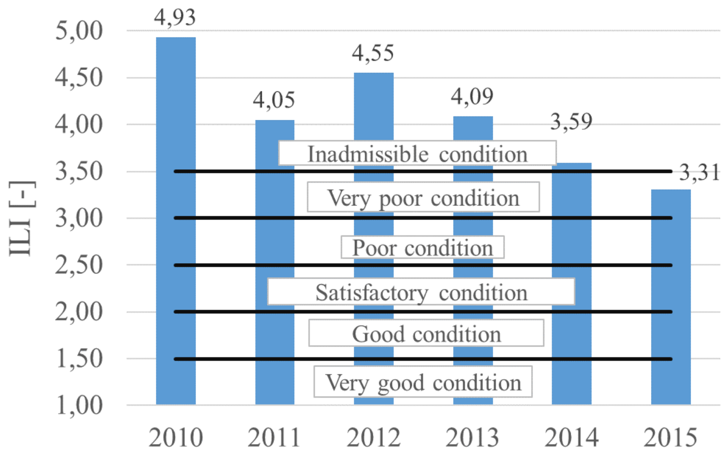

Fig. 7. Infrastructure Leakage Index (ILI) [5-7, 11]

Figure 7 shows the distribution of the indicator's values over a 6-year period. At this time, the the enterprise effectively reduced the ILI rate from 4.93 recorded in 2010 to 3.31, thus changing the water supply system ratings based on the IWA guidelines from the inadmissible to very poor network conditions. The graph also indicates the levels of the individual network ratings according to IWA.

Conclusions

The comparison of the results obtained during the percentage loss indicator calculations with the results obtained after the full analysis of water losses, illustrates large discrepancies between these methods. It should be noted that the average pressure in the waterworks system is 35 mH_2O. According to the results of the calculations presented in Figure 3, the waterworks in 2015 recorded a WS indicator value of 12.69%, which could seem to be a very good result. Only after a deeper analysis and calculation of the ILI can we get the information on the state of the network, which is considered very poor by the IWA guidelines, as reflected in Figure 7 (2015). In earlier years, the condition of the network was estimated as inadmissible. Already at the NRWB indicator calculation stage (Fig. 6), the information is received that over a quarter of the water in 2010 did not constitute income for the enterprise, which allows to observe a considerable difference between the NRWB and the percentage loss indicators.

The analysis illustrates large discrepancies between the percentage indicator and other methods. It shows how important it is to perform a fuller analysis using multiple indicators. It is only after collecting a sufficiently large amount of information about the company under consideration that a reliable and valid analysis of water losses can be made [3, 12].

The analysed waterworks continues to largely (around 60%) exploit old networks made of materials such as cast iron, asbestos cement or steel, i.e. corrosive materials prone to damage. The fight against water losses in the plant mainly consists in replacing the oldest and most emergency-prone sections of the network and connections.

In order to improve the condition of the plant, further modernisation of the system is necessary, additional metering of the water supply system should be installed, and the designation of zones in the system would allow for more accurate pressure control [1, 5, 9-14].

Acknowledgements

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References

[1] Speruda S., Radecki R., Ekonomiczny poziom wycieków, Wydawnictwo Translator, Warszawa 2006.

[2] Clarke M., Boden P., Mcdonald A., DEBTOR: debt evaluation, benchmarking and tracking - a water debt management tool to address UK water debt, Water and Environment Journal 2012, 26, 292-300.

[3] Zambrano J.A., Gil-Martinez M., Garcia-Sanz M., Irizar I., Benchmarking of control strategies for ATAD technology: a first approach to the automatic control of sludge treatment systems, Water Science and Technology 2009, 60, 2, 409-417.

[4] Tuz P., Straty pozorne wody w systemie wodociągowym, Magazyn Instalatora, 2007, 12.

[5] Rak J., Trojan D., Analiza i ocena strat wody w wodociągu Łańcuta, Czasopismo Inżynierii Lądowej, Środowiska i Architektury 2014, 61(1/14), 245-256.

[6] Lambert A., McKenzie R., Practical experience in using the Infrastructure Leakage Index, Paper to IWA Conference Leakage Management - A Practical Approach, 2002.

[7] Opracowanie własne w oparciu o materiały udostępnione przez Przedsiębiorstwo Wodociągowe „X”.

[8] Kwietniewski M., Zastosowanie wskaźników strat wody do oceny efektywności jej dystrybucji w systemach wodociągowych, Ochrona Środowiska 2013, 35(4), 9-16.

[9] Ociepa E., Merc K., Analiza strat wody w systemie wodociągowym eksploatowanym przez Przedsiębiorstwo Wodociągów i Kanalizacji Okręgu Częstochowskiego S.A., Gaz, Woda i Technika Sanitarna 2016, 7, 249-253.

[10] Ociepa E., Kędzia W., Analiza strat wody w wybranych wodociągach województwa śląskiego, Inżynieria i Ochrona Środowiska 2015, 18, 3, 277-288.

[11] Lambert A., Hibner W., Losses from Water Supply Systems: Standard terminology and recommended performance measures, The Blu Pages, Copyright by IWA, nr 10/2000, 320-338.

[12] Mendoza F.M., Verdu C.S., Use of permanent noise monitoring for leakage detection, Kongres IWA, Berlin 2001.

[13] Piechurski F.G., Sposoby zmniejszania strat wody, Rynek Instalacyjny 2011, 11 i 12, 74-76; 72-75.

[14] Zheng Yi Wu i inni, Water Loss Reduction, Bentley Institute Press, 2011.

Streszczenie

Działania zmierzające do ograniczenia często bardzo wysokich strat wody w systemach dystrybucji eksploatowanych przez zakłady wodociągowe poprzedzone powinny być wykonaniem kompletnej analizy strat wody. Do elementów składowych analizy należy zaliczyć wykonanie kompleksowego bilansu wody w zakładzie, a także zebranie informacji na temat samej sieci wodociągowej (długość, wiek, materiał, liczba odbiorców czy też liczba przyłączy). Niniejszy artykuł ma na celu przedstawienie wykonanej analizy strat wody w systemie dystrybucji zakładu wodociągowego „X". Analiza sporządzona została przy użyciu wskaźników zalecanych przez International Water Assotiation (IWA) oraz procentowego wskaźnika strat w celu zobrazowania różnic pomiędzy wynikami uzyskiwanymi z zastosowania wskaźnika procentowego w odniesieniu do pozostałych wskaźników. Średnie ciśnienie, jakie panuje w sieci wodociągowej eksploatowanej przez zakład, wynosi 35 mH_2O. Na podstawie danych uzyskanych z zakładu oraz wyników przeprowadzonej analizy można stwierdzić, że zakład wodociągowy podejmuje działania zmierzające do obniżenia poziomu strat wody. O tym świadczy obniżenie infrastrukturalnego indeksu wycieków (ILI) z poziomu 4,93 (stan niedopuszczalny) do poziomu 3,31, co według oceny IWA klasyfikuje sieć jako znajdującą się w stanie bardzo słabym. Dokonując oceny sieci wodociągowej na podstawie wytycznych American Water Works Association (AWWA), stwierdzono, że w 2010 roku stan sieci oceniany był jako dobry, stan ten nie zmieniał się przez pozostałe lata, dla których przeprowadzono analizę. Ocena stanu sieci przeprowadzona z zastosowaniem wytycznych WBI Banding System ukazuje stan sieci jako dobry w 2015 roku, natomiast w latach wcześniejszych według wytycznych sieć znajduje się w stanie słabym. Zaleca się ocenę sieci wodociągowych w oparciu o najbardziej rygorystyczne wytyczne IWA ze względu na bardzo poważny problem, jakim są straty wody, w celu ich wyeliminowania w możliwie najwyższym stopniu.

Słowa kluczowe: **ograniczanie strat wody, straty wody, analiza strat, wskaźniki IWA, wskaźnik procentowy, infrastrukturalny indeks wycieków**