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EVALUATION OF FAILURE FREQUENCY AND WATER LOSSES IN MUNICIPAL WATER SUPPLY NETWORK ON THE EXAMPLE OF Z CITY IN THE YEARS 2012-2017

OCENA AWARYJNOŚCI I STRAT WODY W SIECI WODOCIĄGOWEJ NA PRZYKŁADZIE MIASTA Z W LATACH 2012-2017

***Summary**: In 2017, the analysed enterprise ZPWiK (Zabrzańskie Enterprise of Water Supply Network and Sewage System) operated the water supply network of 486.3 km length, constructed mainly (in 76.3%) from PE-DH (polyethylene of high density). The age of as much as 85% of the network is up to 20 years old. The most of failures in water supply network is caused by a corrosion of steel pipelines and the conducted constructional work. It is followed from the studies that the failure frequency is systematically decreasing: from 2.33 failures/km in 2012, to 1.76 failures /km in 2017. The majority of the occurring failures are removed during up to 8 hours but we may observe that since 2015, the number of more difficult failures, being removed during longer period than 13 hours, has been successively increased.*

In spite of a high failure frequency, the level of losses is relatively low and is decreased from 11.36% in 2012 to 8.75% in 2017, what in comparison to the data of IGWP (Economic Chamber "Polish Water Supply Network") is a very good result. The obtained good effects are connected with the renewal of the network materials, purchase and utilization of new equipment for finding out and recovery of the failures and constantly developed and analysed monitoring of work as well as the pressure reduction in the water supply network.

***Keywords**: water supply network, material, failures, water losses, the methods for reduction of losses*

***Streszczenie**: Analizowane przedsiębiorstwo ZPWiK eksploatowało w 2017 sieć wodociągową o długości 486,3 km wykonaną głownie bo w 76,3% z PEHD i aż 85% stanowią sieci o wieku do 20 lat. Większość awarii w sieci wodociągowej spowodowana jest korozją przewodów rur stalowych i pracami budowlanymi. Z badań wynika że awaryjność ulega systematycznemu obniżeniu z 2,33 w 2012 do 1,76 w 2017 awarii/km rok. Większość awarii jest usuwana w czasie do 8 godzin, ale można zaobserwować że od 2015 roku sukcesywnie rośnie liczba trudniejszych awarii usuwanych w czasie dłuższym niż 13 godzin.*

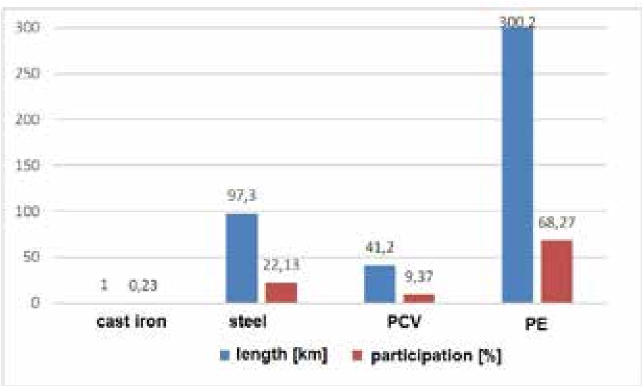
Mino dużej awaryjności poziom strat jest stosunkowo niski i ulega obniżeniu z 11,36% w 2012 do 8,75% w 2017, co w porównaniu z danymi IGWP jest wynikiem bardzo dobrym. Uzyskiwane dobre efekty mają związek z odnową materiałów sieci, z zakupem i wykorzystaniem nowego sprzętu do lokalizowania i usuwania awarii oraz ciągłym rozbudowywanym i analizowanym monitoringiem pracy jak również redukcji ciśnienia w sieci wodociągowej.

***Słowa kluczowe**: sieci wodociągowe, materiał, awarie, straty wody, sposoby obniżenia strat*

Introduction

According to the data of the Main Statistical Office (GUS), at the end of 2017, the analysed enterprise supplied water to 174 thousand inhabitants of the community. Water delivered to the inhabitants comes from different sources which include the purchase of underground and surface water and own production of underground water. The diagrams (Fig.1 and 2) present the changes in the material structure of water supply network during the period of 2012 – 2017. We may observe a considerable decline in the participation of steel pipelines in the discussed structure (by ca. 7%) and successively growing participation of PE (polyethylene) pipelines (increase by 8%) what is consistent with the trends in the discussed sector. The participation of cast iron and PVC (polyvinyl chloride) are varying in a small range. The damages, occurring in the mentioned

Fig. 1. Material structure of pipelines in 2012



pipelines are mostly caused by ground work conducted on their vicinity. Their failure in relation to steel is small, the percentage in the whole structure is also low; the changes occur on the occasion of conducting another work in the pipelines.

Fig. 2. Material structure of pipelines in 2017

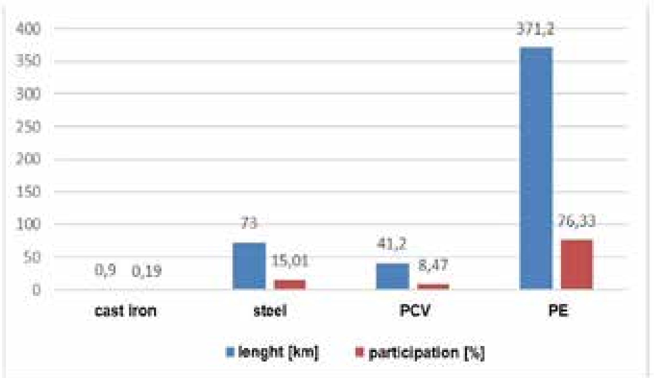


Fig. 3. Length of water supply network in the years 2012-2017

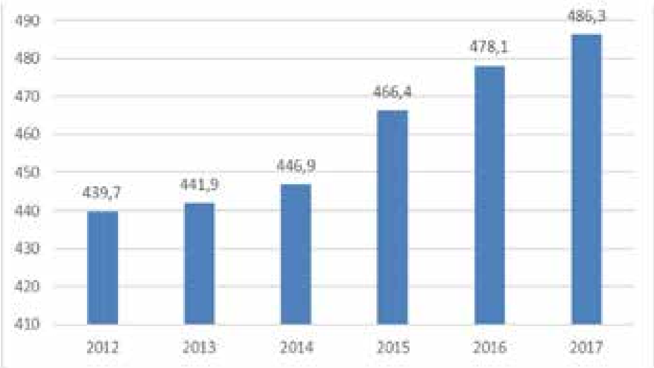
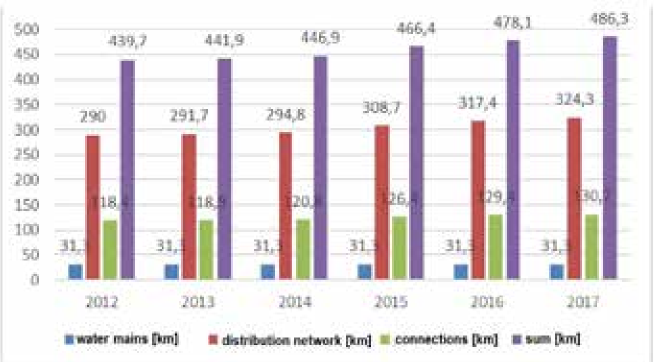


Fig. 4. The length of the water supply network with the division into the share of the water mains, distribution network and the connections in the years 2012-2017



ZPWiK modernizes its networks systematically; at the end of 2017, almost 85% of the water supply network, being under the administration of the company, consisted of the maximum 20-years old pipelines.

In the paper, the range of diameters for water supply connections from d=25 mm to d=80 mm was adopted. The range of diameters from 90 mm to 400 mm will be referred to distributing networks and above d=400 mm, we speak about the water main. As it has been shown in Fig.4, the length of distribution networks in the city is systematically increasing and consequently, the length of the connections. It is connected with the development of the city.

The sites of and the reasons for occurrence of failures in water supply pipeline network

Fot. 1. Point corrosion of water pipeline connection

Failures and leakages are the element, occurring in every system of water supply. It is not possible to anticipate the place and time of leakage; sometimes, we do not know about a failure until the moment when its occurrence causes the visible consequences on a surface, being often equivalent of substantial material losses [1]. Detection and removal of even small leakages brings, from one side, the benefits for the company owing to limitation of water losses in the distribution system and on the other side, the protection from serious failures. The aspect of environment protection and first of all, more reasonable management of water resources, decrease of chemicals use at water treatment and electric energy consumption, necessary for introduction of water into the network, are also important issues. The number of failures and their reasons are determined by many factors; the most important ones include: material defects, the conditions connected with the production technology, corrosion, ground-water conditions in the site of laying the pipelines, hydraulic parameters and, in particular, the range and frequency of the pressure changes in the network, careless performance of the ground work in the vicinity of water supply pipelines, and, finally, a negative effect of mining operations [1].

Fot. 2. Image of corrosion inside the steel pipeline

Fot. 3. Image of point corrosion

Fot. 4. Rupture in the area of tee joint in the distribution PVC network

Fot. 5. Damage of steel connection during performance of jacking

As it can be seen, the most of the failures in water supply networks are caused by corrosion of the pipelines (Fot. 1 – 3). The successive reason for failure occurrence is connected with geological conditions – what can be perfectly seen in Fot.4: how the movements of ground masses have caused the deformation of the pipe and, in consequence, damage of pipe socket at the tee. One of the more frequently occurring causes of failure includes damages, generated during the performance of ground work such as drilling, jacking etc. The damage of water supply connection, as illustrated in Fig.5, is a model example of such situation.

In the area of ZPWiK activity, the number of failures, being recorded in the analysed years, was found on the level of 2.86 failures/day in 2012 and up to 2.3 failures /day in 2017.

The assessment of the indicators of damage intensity in the water supply network

The unitary intensiveness of failures, determining the number of damages per unit of length of the pipeline (most often 1 km) and time unit (most often 1 year) is one of the major indicators of the evaluation of technical state of water supply pipeline network. Fot.5 shows the indicators of the intensiveness of failures. It may be observed that since 2015 until now, the discussed parameter has been decreasing in the networks as well as in connections.

Compared to the indicators given in literature, the analysed network may be classified as being in a very bad technical condition > 0.5 failures /km/year [2]. The index of failure frequency in water supply network of the discussed enterprise, with the connections or without, is high and it would indicate the necessity of undertaking the quick repair measures.

In the light of the data available for water pipeline systems at the territory of the whole country, ZPWiK is not "distinguished" in the respect of the current calculated data on the intensity of damages in the water supply network. The data on the failure frequency in the network contained in the Benchmarking 2016 Report, published by IGWP [3] are given in Fig.6.

Fig. 5. Indicators of failure for the whole city [failures/km/year]

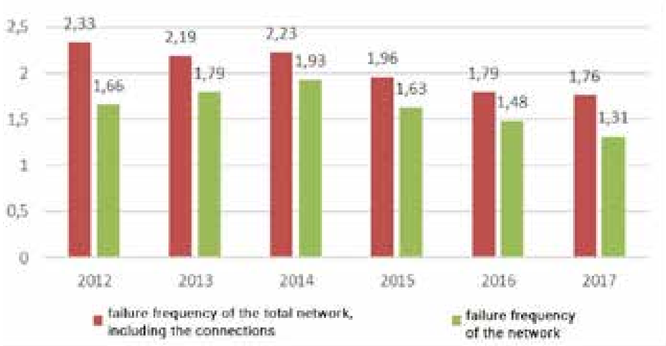
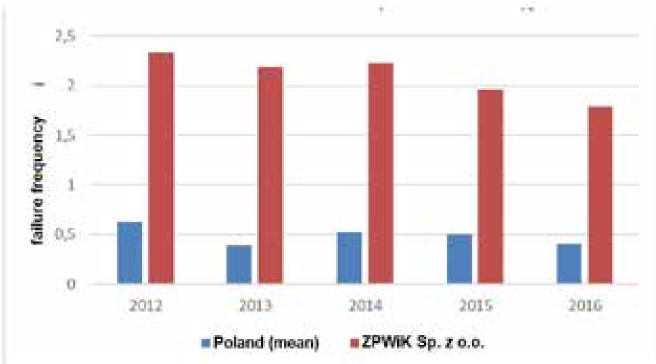


Fig. 6. Index of failure frequency in the water supply network – the comparison. Source: IGWP.org.pl [3] plus own data

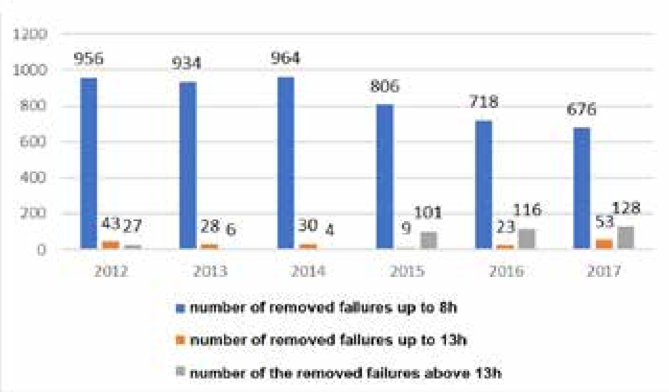


Time of failure removal

In the case of detection of leakage (visible or hidden), the appropriate measures are undertaken with the aim to remove the failure. The failures, occurring in the network of ZPWiK are classified as regard to the size of the leakage: small, medium or big; the place of occurrence: connection, network or the mains. The work on the improvement of the procedures is conducted at the Department of Wod-Kan Network; the park of machines and equipment is carried out and qualified staff is employed. We should also pay attention to the fact that the prevailing part of the brigade operates the equipment of a very good quality and of the recognized producers what affects considerably the limitation of the number of downtime and failure recovery speed. The diagram (Fig.7) illustrates the number of failures and time intervals in which they are removed. As it can be seen, the most of the failures 993 – 78%) are removed during one working shift (i.e. up to 8 hours). It is evident that the equipment and skills of the operating brigades are utilized in a very high degree; however, a certain space exists for improving the effectiveness.

It may be also seen (Fig. 7) that in the years 2015 – 2017, the increase in the number of failures, removed during more than 13 h since the moment of reporting, had place 911-15%). In the case of the discussed enterprise, it is connected with the fact that after the period of network infrastructure development, connected with the stage I and stage II of the project for improvement the water and sewage management, the period of more complicated repairs was commenced; it included such operations as replacement of tees, two-port networks and locks in the central part of the city, what is connected with a high complication of work in respect of logistics (development of plan of respective marking during the period of

Fig. 7. Time of failure removal



Fot. 7. The successive stage of gate tee replacement

Fot. 6. Gate tee, prepared to be replaced (over and next to the tee, the pipelines of rain sewage and, also, telecommunication cables in protection tubes are visible)

Fot. 8. The replaced gate tee (before recovery of the correct water flow, the worker visible in the photo, is checking the force of tightening the screws)

operations, appropriate reporting to the public administration authorities in connection with occupying the traffic lane) (Fot. 6-8).

Water balance and losses

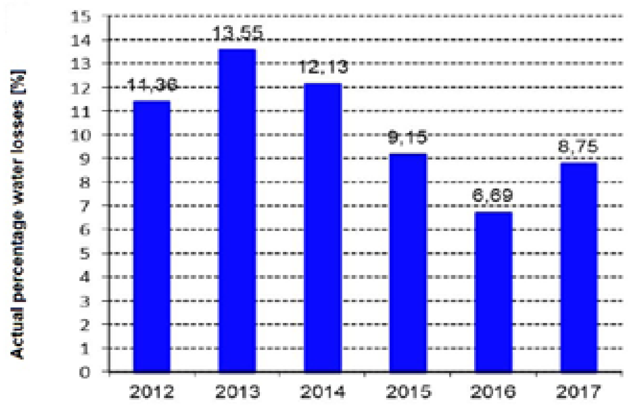
During the recent years, Polish water supply companies have paid a special attention to the volume of unsold water instead of dealing with the real losses. The uniform approach and methodology for determination of the discussed water loss components did not exist. According to IWA (International Water Association) that is what assures water balance. According to the balance, volume of water introduced to the distribution system is principally divided into authorized consumption and water losses. In turn, the authorized consumption consists of invoiced authorized consumption, i.e. such water volume that is sold by the company and of the non-invoiced authorized consumption, i.e. such water volume that the enterprises uses for the own needs. Water losses are classified into apparent losses, connected with the non-authorized consumption (e.g. theft), errors of measurement and readings out of measuring devices and the real losses, including the water losses from leakages – failures [4].

When implementing the water supply and sewage system management, the analyzed ZPWiK enterprise utilizes water, in particular, for the following purposes: living, operation, waste treatment, sewage drain clearing and cleaning, dehydration, venting, rinsing and disinfection of water pipeline network as well as providing the water intake points in the case of its lack, caused by water supply failures. The water volume used for the own company's needs is estimated. The main reason for such procedure is a lack of the possibility of performing all measurements of water consumption, in particular in the direct work in the networks, which – in the opinion of the company – constitute a prevailing part of the discussed consumption. The successive cause of such procedure includes the costs connected with the performed measurements.

From the above diagram, the interesting trend may be observed: year by year, volume of water introduced to the networks has been gradually decreasing and since 2013 until now, the volume of water sold has remained at the same level (it varies from 6.5 million m^3 to 6.24 million m^3).

It is connected, to a greater degree, with the improvement of the quality of water pipeline infrastructure, replacement of steel pipes by PEHD pipes and the speed of finding out and recovery of failures. It is also determined by ecological awareness of the users and saving of water. What is important, the level of losses is also decreasing: in 2012, they constituted 11% of the introduced water and in 2017 – only 8%. The difference of 3% in this case means 285 863 m^3 of water what gives saving of ca. net PLN 1.4 million (considering only water price).

Fig. 9. Comparison of percentage water losses for the whole city in the years 2012-2017



When analyzing the data of water losses at ZPWiK and comparing them with the data contained in Benchmarking 2016 Report, published by IGWP (which also contains the references to the mean data of 2014 and 2015) [3], it may be observed that despite the relatively high indicator of network failures, water losses are found on the level below the mean values, indicated in the IGWP report (Fig. 10).

The selected spectrum of the implemented tasks in the enterprise with the aim to limit the losses in the years 2012 – 2017

Fig. 8. Water introduction to ZPWiK pipeline network, water sales and losses [m³]

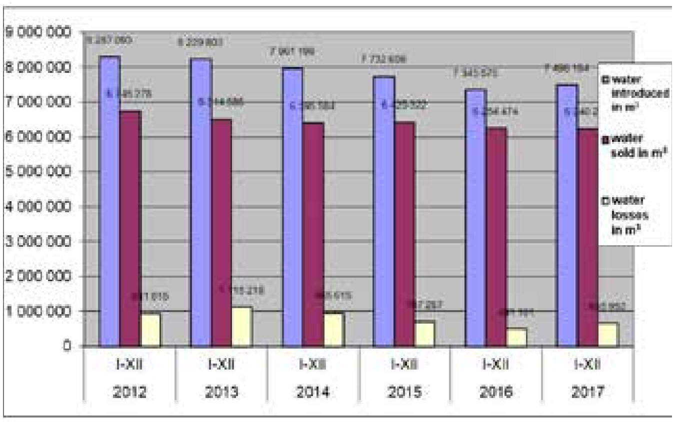
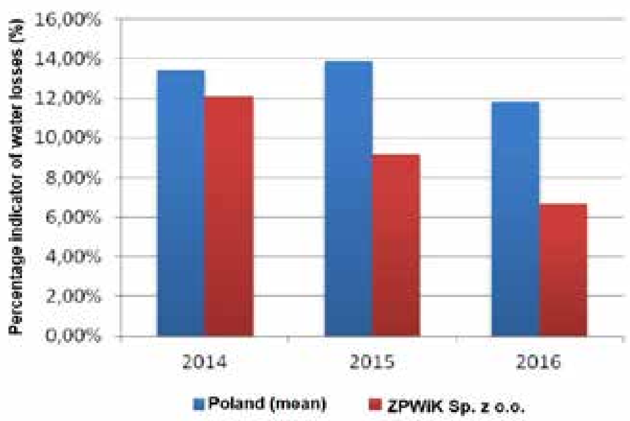


Fig. 10. The percentage indicator of water losses – comparison of the data: IGWP.org.pl [3] and the own data



During the discussed period, the project "Improvement of water-sewage management at the territory of city Z" was a very important undertaking, affecting the failure frequency in the water supply network. Within the frames of the project, the replacement of ca. 31 km of water pipelines had place; it makes 7% of the whole network. The equipment used in detection of the leakages is also subjected to the replacement. In 2015, the company bought a modern digital EUREKA correlator and MICRON 3 geophone. The mentioned equipment replaced their analogue version, utilized until now. In 2014, there was purchased the successive cable tracker type RD7100. The replacement of the equipment for detection and situation of leakages has greatly contributed to the limitation of the number of failures which in 2012 was equal to ca. 1000 cases and in 2017 – 857. The precision of location had the same effect although the 100-% accuracy of indicating the leakage sites is still far away.

To check the leakages and minimize their consequences, ZPWiK conducts the activities, based on three procedures:

- Control of night flows, with the application of monitoring and measuring of wells;
- Periodical control and testing of tightness of water supply pipeline network;
- "Waiting for failures", consisting in assembly of sensors, serving for recording of acoustic signals in the regions, most vulnerable to failure.

In the analyzed company, the telemetry system is successively developed. There are also considered the current market solutions which would enable integration of the telemetry system with the failure evidence system to make them more mobile. The successful fusion of the mentioned two systems would allow the supervising persons to spend less time at the office and more outside, having all available information at the current time. For example, when a supervisor of the water-sewage system goes to the region of failure, he has an access to tablet with the geo-location and is able to introduce the current data to the system: e.g. open armature, accordance of gate diameter, number of gates in junction, diameters of materials in the network, its situation in the region (differences in post-performance measurements), etc.

The leakages, occurring due to the damages of joints, pipelines and water supply fittings [1] are the main reasons for real water losses. The damages as well as water losses are caused by many different factors, affecting the water supply system; the degree of this impact is differentiated very much in the particular materials of the water supply network. The height of the pressure present in a given zone of the water supply system is one of the most important factors. The pressure and its changes in a 24-hour cycle affect the degree of failures as well as intensity of water outflow from the damaged elements of the network, irrespectively of the cause of the damage. The intensity of water outflow via opening with a specified diameter at pressure of 0.6 MPa is by ca. 70% higher than at the pressure of 0.2 MPa [5]. At the constant pressure, the intensity of water outflow is increasing proportionally to the increase of the surface area of the caused damage.

Since November 2005 until July 2005, the enterprise bought and launched system of constant monitoring of water flow and pressure in the selected supplying wells and purchased wells, situated in the operating water supply networks.

In 2006, the stocktaking of the major water supply mains and of the water pipeline supplying wells and of the purchased wells was carried out with the aim to introduce and utilize the launched system of permanent monitoring. In 2007, the stocktaking was completed and the map of the main water supply networks together with supplying sources was developed. Based upon the map, the zones of supply were determined and, at the same time, the alert flows (minimum night flows) under the system of constant monitoring were established. The mean water pressure in the particular zones was lowered. It happens that even now we may find the reducers dating back to 2005/2006, operating in the reduction chambers at the borders of the supply zones. In connection with their high wear, the successive stocktaking should be planned in the near future with the aim to determine the number of the devices to be replaced. It would allow minimizing the probability of occurrence of such events as for example, "hanging up" of reducer what results in maintaining too high pressure in the supply zone (failures in connections) or vice versa – closure of the reducer, what brings about to the decline of pressure on higher floors and deficits of water.

Summing up

Limitation of water losses should be one of the most important activities of the water supply companies as it enables lowering of costs of the sold water and, simultaneously, increase of the quantitative possibilities of water sale. It is estimates that when eliminating a loss of one cubic metre of water, we liquidate also the unnecessary consumption of electric energy on the level of 1 – 1.5 kWh. At present, the water losses at ZPWiK are estimated on the level of ca. 8% what corresponds to 655 000 m3 of water lost per year.

The high level of water losses in Poland is affected by multi-year negligence in respect of modernization, repairs and development of water supply systems, leading to their degradation and also, negligent performance of work during construction of the network during the period of centrally planned economy. At ZPWiK, the subject of water losses is treated as a priority, with a great stress put on their limitation to the economic level. Such activity may be supported by the investment in infrastructure, the successive replacement of the network (which – due to the financial aspects – does not run as quickly as we would wish and as it would be justified) as well as the investment in the equipment and people.

The main directions of the measures which should be introduced in ZWPiK for improvement of the operating conditions of water supply networks include as follows:

- Replacement of water supply networks (at present, in cooperation with WFOŚ (Voivodeship Fund of Environmental Protection), the segments of network characterized by a high failure number, e.g.

steel network are replaced). One of the streets became selected for the replacement due to the number of failures, occurring since the beginning of 2012 to September 2017 - 43 failures had place in the network only (Ø steel pipelines). During the period of 2008 until September 2018, 140 cases of leakage were reported – the length of the network in the considered site was equal to ca. 2.5 km;

- Full monitoring of water flow and pressure in the operated water supply networks (gradual condensation of the existing zones, separation of new zones in the newly constructed settlements of single family houses):
- Further regulation of water pressure in the operated water supply networks (replacement of old models of reducers for the new ones, adding the new points to the telemetry system as to react in a real time).

When referring to the calculated indicators of failure frequency – which as regards to the literature sources are high and predestine the network to be quickly replaced – we should add some words of explanation. High values of failure indicator result partly from the limitations of the program, applied in recording of the events in the network and the integrated glossary of the events. At present, the failure includes such events as e.g. insufficient gate, ineffective reducer, switching of the connection etc. For example, when considering only the events having in the name the word "leakage", the indicator of failures was equal to 0.95 failures /km/year in 2017 and for the wording "leakage from the network" is 0.56 failures/km/year; totally, for all failure events, the discussed index is equal to 1.76 failures/km/year. As it can be seen, ZPWiK experiences a constant and systematic decline of in water supply system. In the case of the mentioned above big differences, it is recommended to consider what failures should be included to the failure indicator.

Despite the high index of failure frequency as compared to the data in the Benchmarking IGWP Report in the years 2012 – 2106, the percentage indicator of water losses is found on the level lower than the mean for the country what is an evidence of good organization and investment activities of the analyzed ZPWiK, directed to the reduction of water losses.

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