Performance measures of water supply system functioning in terms of belonging to critical infrastructure

1 INTRODUCTION

Critical infrastructure according to European Programme for Critical Infrastructure Protection (EPCIP) include among other things infrastructure connected with water supply. The major aim of EPCIP is to protect the critical infrastructure by implementation some standards of subsidiarity, complementarity, confidentiality, stakeholder cooperation, proportionality, sector-by-sector approach. Therefore assessment procedures of functioning water supply system should be implemented. The assessment of concerned vulnerabilities, threats and risks, is characterized by indicators, which help to provide comparison of critical infrastructure systems and at the same time and to improve its functioning. CIP Programme identify undesirable events by describing it, in qualitative and quantitative way, and taking into account the consequences, which can have different effect as i.a. number of population affected, significance of economic loss also degradation of products or services, impact on environment, health consequences concerning recipients and political and psychological effects. Some of the effects are difficult to measure, so it is important to provide different way of determination of water recipients losses, as for example through survey conducting among recipients of drinking water. Such a survey can consist of question concerning inconveniencing and losses occurring during undesirable events and crisis situations. The issue related to the amount of fees that recipients would be willing to bear as to obtain a given level of services provided by the water company and therefore the Contingent Valuation Method (CVM) and the so-called Willingness to Pay (WTP), as well as Willingness to Accept (WTA) in case of interruption of water supply were described in works [7, p. 453] and [8, p. 117]. The test results contained in [8, pp. 115-124] indicate that the continuity of the water supply is an important factor in the assessment by consumer of water, who is willing to pay more for a reduction in the frequency and duration of interruptions in water supply [9, s. 326]. The average rate of willingness to pay (WTP) estimated in [6, p. 31] on the basis of the maximum amount that the recipient would be willing to pay for obtaining improved service is 17.67% of the water charges in a given period.

Failure characteristics of accidental events can be characterized in two groups: failure of the quality of water supplied and the unreliability of the amount of water delivered, which in turn may be due to failure of water distribution elements, water supply subsystem and the unreliability of the environment (eg. in water intake source) [10, p. 12].

Taking into consideration the need of critical infrastructure control, in the paper the water network exploitation indicators associated with failure and water loss were presented. Detailed analysis of the water network failure and water losses occurrence should be main element of the managing system of the urban water networks, particularly in strategic modernization plans [1, 4, 5]. The analysis was made on the basis of the operational data on the water-pipe network in one of the Polish cities, as well as on the failure protocols received from the Municipal Enterprise for Communal Economy, in the years 2008÷2012.
2 FAILURE INDICATOR OF WATER NETWORK

Water pipes failure is one of the most important indicators used to evaluate the technical condition of the network and the operational situation of water supply. In the technical literature, this indicator is called "intensity failure" and expresses the number of failures per one kilometer of water pipes throughout one year. It is not entirely defined, which damages are eligible for this statistic, but most often it is the total number of failures of pipelines and its armature. In Table 3 the number of failures and intensity failure for water supply system in relation to the length of 1 km in the unit of time equal to one year using the formula:

\[ \lambda = \frac{k}{L \cdot \Delta t} \]  

where:
- \( k \) – the total number of failures on the type of network [-],
- \( L \) – length of the given type of network [km],
- \( \Delta t \) – unit of time equal to one year.

Tab. 1. Values of intensity failure of water network

<table>
<thead>
<tr>
<th>Indications</th>
<th>Year of observation</th>
<th>Limit values for different types of network - ( \lambda_{\text{lim}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of main network failures</td>
<td>2008 2009 2010 2011 2012</td>
<td>0,3</td>
</tr>
<tr>
<td>Intensity failure of main network - ( \lambda_{M} )</td>
<td>0.00 0.06 0.06 0.09 0.12</td>
<td></td>
</tr>
<tr>
<td>Number of distribution network failures</td>
<td>2008 2009 2010 2011 2012</td>
<td>0,5</td>
</tr>
<tr>
<td>Intensity failure of distribution network - ( \lambda_{R} )</td>
<td>0.30 0.52 0.66 0.71 0.91</td>
<td></td>
</tr>
<tr>
<td>Number of water supply connections failures</td>
<td>2008 2009 2010 2011 2012</td>
<td>1,0</td>
</tr>
<tr>
<td>Intensity failure of water supply connections - ( \lambda_{\text{pw}} )</td>
<td>0.47 0.47 0.54 0.65 0.47</td>
<td></td>
</tr>
<tr>
<td>The total number of water supply network failures</td>
<td>83 107 130 154 153</td>
<td></td>
</tr>
<tr>
<td>Intensity failure of water supply network - ( \lambda )</td>
<td>0.34 0.43 0.52 0.60 0.59</td>
<td></td>
</tr>
</tbody>
</table>

The number of failures on the main network ranges from 0 to 4, so it is very small in comparison to the total number of failures on the network. Distribution network failures represent a significant percentage of the total number of failures in 2009-2011, nearly 50% in 2012, significantly exceeded this threshold. The failure intensity of the main network and water supply connections do not exceed the limit values \( \lambda_{\text{lim}} \), but the problem is the distribution network for which failure intensity in all years apart from 2008, are beyond the limit.

3 CONSUMPTION AND WATER LOSS INDICATORS OF WATER NETWORK

Proper water balance in the network is a key element in assessing the efficiency of the water supply in terms of consumption and water loss, so as to make a water balance in the water supply system, the following parameters should be taken into accountant [2]:
- volume of water from the intakes,
- volume of water from the intakes used for own treatment,
- volume of treated water,
- volume of treated water used in the treatment station,
- volume of water supplied into the network,
- volume of water supplied into the network for own needs of water network,
- volume of water invoiced and supplied to consumers.
3.1 Water balance

In Table 2 the water balance for water supply was shown.

**Table 2. Summary of water balance production**

<table>
<thead>
<tr>
<th>Year</th>
<th>Volume of water supplied into the network $V_{sw}$ [m$^3$/a]</th>
<th>Volume of sold water $V_{sw}$ to households $V_{a}$ [m$^3$/a]</th>
<th>Volume of water for own needs of water network $V_{on}$ [m$^3$/a]</th>
<th>Volume of water loss $V_{loss}$ [m$^3$/a]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>1223400</td>
<td>780100</td>
<td>99500</td>
<td>343800</td>
</tr>
<tr>
<td>2009</td>
<td>1155900</td>
<td>789000</td>
<td>88300</td>
<td>278600</td>
</tr>
<tr>
<td>2010</td>
<td>1179600</td>
<td>796900</td>
<td>93400</td>
<td>286600</td>
</tr>
<tr>
<td>2011</td>
<td>1166400</td>
<td>785300</td>
<td>96500</td>
<td>284600</td>
</tr>
<tr>
<td>2012</td>
<td>1194400</td>
<td>836800</td>
<td>68500</td>
<td>289100</td>
</tr>
</tbody>
</table>

After 2008 in which there was a major accident on the water supply network (leak into drains very difficult to locate), both the level of losses of sales and the volume of water used for their own needs in the water supply is maintained at a constant level. In the year 2012, sales of water increased while the volume of water consumed for own needs of water network was reduced. Water sales divided into groups of recipients are shown in Table 3.

**Table 3. Water sales**

<table>
<thead>
<tr>
<th>Year</th>
<th>Household [m$^3$]</th>
<th>Units socialized, economic activities [m$^3$]</th>
<th>Industry, construction [m$^3$]</th>
<th>Total [m$^3$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>604025.92</td>
<td>165417.10</td>
<td>8172.00</td>
<td>777615.02</td>
</tr>
<tr>
<td>2009</td>
<td>605510.50</td>
<td>175086.00</td>
<td>8434.67</td>
<td>789031.17</td>
</tr>
<tr>
<td>2010</td>
<td>614656.61</td>
<td>177307.90</td>
<td>7693.00</td>
<td>799657.51</td>
</tr>
<tr>
<td>2011</td>
<td>606083.30</td>
<td>168481.00</td>
<td>10751.00</td>
<td>785315.30</td>
</tr>
<tr>
<td>2012</td>
<td>637813.46</td>
<td>189233.40</td>
<td>10241.00</td>
<td>837287.86</td>
</tr>
</tbody>
</table>

The largest recipient of water are households that buy on average about 75% of sold water. Moreover, it can be noted that in 2012 the water sale to households has increased. One-fourth of water consumers constitute socialized units and economic activity, and the smallest group is the construction sector and industry. Such a small share of industry is due to the fact that two of the largest manufacturing plants have their own internal water intake, which fully meet their needs.

3.2 Analysis of consumption and water loss indicators

Indicator analysis of consumption and water loss in water supply system allows to obtain detailed picture of the water distribution system also the calculation of the standardized indicators allows comparisons between the water distribution systems in the cities of similar size and diverse technical condition of water supply systems [2, 3].

The main indicators used to characterize the consumption and water loss in water supply are:

- Non-Revenue Water Benchmark,
- Unavoidable Annual Real Losses,
- Infrastructure Leakage Index,
- Real Loss Benchmark.

An important factor that affects the amount of water loss is the age and the material from which pipes are made. Currently operated water network are made in approx. 40% of the steel and grey iron. It is characterized by old age, significant technological limitations, high vulnerability to corrosion and cracks, possible defects in material and poor quality of workmanship of pipes in the seventies and eighties of the twentieth century. The rest of the pipe is made of PVC and PE. Permanent changes in the level of water consumption, which have been observed in recent years may be due to the marketisation of water prices and the introduction of individual metering of water consumption. In the spring and summer are also common sporadic attempts to steal water from the hydrants. Water from them is used for irrigation of crops or construction work.
Detailed age of examined pipes is difficult to determine because of the non-updated documents. More than half of the length of the water supply network have more than 40 years, corrosion of materials in pipes can cause significant loss of water when the pipes are in natural soils that shows corrosion properties.

### 3.2.1 Non-Revenue Water Benchmark

NRWB indicator is calculated according to the equation:

\[
NRWB = \frac{(V_{sp}-V_{sw})}{V_{sp}} \times 100, \% \tag{2}
\]

where:

- \(V_{sw}\) – volume of sold water [m\(^3\)/M\(\cdot\)d],
- \(V_{sp}\) – volume of water supplied into the network [m\(^3\)/M\(\cdot\)d].

#### Tab. 4. Summary of non-revenue water benchmark

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>NRWB [%]</td>
<td>36.23</td>
<td>31.74</td>
<td>32.21</td>
<td>32.67</td>
<td>29.94</td>
</tr>
</tbody>
</table>

As can be seen from Table 4 non-revenue water benchmark for water supply has been at the same level in 2009-2011, while in 2012 it is observed a decrease in comparison to previous years. The values of NRWB in the analyzed period are approximately 30%.

### 3.2.2 Unavoidable Annual Real Losses

Unavoidable Annual Real Losses (UARL) is the annual volume loss, which is considered to be inevitable and economically viable. This means that the removal of small leaks do not cause significant water losses and damages in the vicinity of the water supply and greatly exceeds the material damage caused by these leaks. The indicator is determined from the relation:

\[
UARL = [18 \cdot (M + R) + 25 \cdot PW + 0.8 \cdot L_{PW}] \cdot 0.365 \cdot p, \ [m^3/\text{year}] \tag{4}
\]

where:

- \(M\) – the length of the main network [km],
- \(R\) – the length of the distribution network [km],
- \(PW\) – water supply connections length [km],
- \(L_{PW}\) – number of water connections [-],
- \(p\) – the average amount of pressure in the present measurement zone [mH\(\text{O}\)],
- 0.365 – conversion factor for a year and m\(^3\).

The weighted-average pressure in the water mains is calculated by distinguishing three key pressure zones and their territorial scope: 70 mH\(\text{O}\) – 70-40%, 40 mH\(\text{O}\) – 20%, 20 mH\(\text{O}\) – 40%, so in average \(p = 44\) mH\(\text{O}\).

Table 5 summarizes the values of Unavoidable Annual Real Losses.

#### Tab. 5. Summary of Unavoidable Annual Real Losses

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lpw [no]</td>
<td>3870</td>
<td>3935</td>
<td>3991</td>
<td>4057</td>
<td>4136</td>
</tr>
<tr>
<td>UARL [m(^3)/y]</td>
<td>133261.1</td>
<td>135750.4</td>
<td>137953.8</td>
<td>140807.7</td>
<td>143484.9</td>
</tr>
</tbody>
</table>

As can be seen from Table 5 Unavoidable Annual Real Losses has a clear upward trend and increase each year by about 2000 to 2500 m\(^3\)/year, this increase is close to linear. This is due to the extension of the network in the years of research - distribution cables came 6.6 km (an increase of 7.4% compared to 2008) and water supply connections of 12.2 km (10.1%), an increase of 266 units (7% - noted an increase in the average length of water supply connections).
3.2.3 Infrastructure Leakage Index

Infrastructure Leakage Index (ILI) is the ratio of the annual volume ratio of losses to UARL, which is described by the relationship:

\[ ILI = \frac{V_{loss}}{UARL}, [-] \]  \hspace{1cm} (5)

where:

- \( V_{loss} \) – annual volume of water unsold, \([\text{m}^3/\text{year}]\),
- \( UARL \) – unavoidable losses, \([\text{m}^3/\text{year}]\).

<table>
<thead>
<tr>
<th>Tab. 5. Summary of ILI indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>ILI, [-]</td>
</tr>
</tbody>
</table>

As shown in Table 5, water supply leakage indicator remained at the stable level no more than 2, what classify a water supply state by category IWA as an average (2<ILI≤2,5) [3]. Whereas, according to the ranking of WBI for developed countries water supply condition is classified as good, almost on the border of very good [12]. Only in 2008 ILI value exceeded 2.5, which is determined according to the IWA classification as weak state of water supply (2,5<ILI≤3,0). According to AWWA state of water supply network can be considered as very good (ILI ≤ 3,0). It should be noted that the resulting value of the ILI indicates the appropriate state water supply system, which contradicts the unsold water volume accounting for about 24% of the volume of water dosed into the network. This is due to a substantial length of the network in relation to sales volume and a high rate of UARL. This is due to the fact that the ILI indicator is referenced to the water supply network parameters (length, pressure) and the obtained results are good, or very good, even though the unsold volume water is more than twice the value of the losses is accepted as economically viable - 10%.

3.2.4 Real Loss Benchmark

There are two versions of Real Loss Benchmark (RLB) indicator:
- when the number of connections per kilometer water pipeline water supply system (M+R) is less than 20, calculated using the equation:
  \[ RLB_1 = \frac{V_{loss}}{(M+R)\cdot 365}, \text{[m}^3/\text{km}\cdot \text{d}] \]  \hspace{1cm} (6)

where:

- \( V_{loss} \) – annual volume of water unsold, \([\text{m}^3/\text{year}]\),
- \( M \) – the length of the main network, \([\text{km}]\),
- \( R \) – the length of the distribution network, \([\text{km}]\).

This indicator enables the assessment of the technical condition of the water supply system.
- If the number of connections per kilometer of water pipe network is at least 20, the RLB is obtained through relationship:
  \[ RLB_2 = \frac{V_{loss}\cdot 1000}{L_{pw}\cdot 365}, \text{[dm}^3/\text{d}\cdot \text{water connections}] \]  \hspace{1cm} (7)

where:

- \( L_{pw} \) – number of water connections, \([\text{m}^3/\text{year}]\).

In Table 6 summary of the RLB for the water supply was presented.
On the basis of the Table 5 a slightly downward of RLB can be observed, ranging from 243.39 to 191.50 dm$^3$/d per water connection, but the obtained value is comparable to separate water consumption by two residents and should be considered as high.

3.2.5 Calculation of individual indicators of the water consumption and losses

The following unit indicators are used [11, p. 42]:

- Individual volume of water supplied into the network:

\[ q_{\text{sn}} = \frac{(V_{\text{sn}} \cdot 1000)}{(LM \cdot 365)}, \text{[dm}^3/\text{M} \cdot \text{d}] \]  

(8)

- Unit volume of total sold water:

\[ q_{\text{sw}} = \frac{(V_{\text{sw}} \cdot 1000)}{(LM \cdot 365)}, \text{[dm}^3/\text{M} \cdot \text{d}] \]  

(9)

- Unit volume of water sold to households:

\[ q_{\text{sh}} = \frac{(V_{\text{sh}} \cdot 1000)}{(LM \cdot 365)}, \text{[dm}^3/\text{M} \cdot \text{d}] \]  

(10)

- Unit volume of water loss:

\[ q_{\text{loss}} = \frac{(V_{\text{loss}} \cdot 1000)}{(LM \cdot 365)}, \text{[dm}^3/\text{M} \cdot \text{d}] \]  

(11)

- Unit volume of water used for own needs:

\[ q_{\text{on}} = \frac{(V_{\text{on}} \cdot 1000)}{(LM \cdot 365)}, \text{[dm}^3/\text{M} \cdot \text{d}] \]  

(12)

- Unit volume of nonprofit water:

\[ q_{\text{nd}} = \frac{(V_{\text{sn}} - V_{\text{sw}})}{(LM \cdot 365)}, \text{[dm}^3/\text{M} \cdot \text{d}] \]  

(13)

- Hydraulic loading rate per unit of water supply network:

\[ q_{\text{h}} = \frac{V_{\text{sw}}}{(LM + R \cdot 365)}, \text{[m}^3/\text{km} \cdot \text{d}] \]  

(14)

- Water loss rate per unit for the entire length of the line:

\[ q_{\text{lossL}} = \frac{V_{\text{loss}}}{(L \cdot 365)}, \text{[m}^3/\text{km} \cdot \text{d}] \]  

(15)

Table 7 summarizes the unit volume of water and indicators of individual water supply system hydraulic loads.

### Tab. 7. Summary of the unit water volume and indicators of individual water supply system hydraulic loads

<table>
<thead>
<tr>
<th>Year</th>
<th>$V_{\text{loss}}$ [m$^3$/r]</th>
<th>M [km]</th>
<th>R [km]</th>
<th>Lpw [no.]</th>
<th>RLB$_s$ [dm$^3$/d wc]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>343800</td>
<td>32.5</td>
<td>89.4</td>
<td>3870</td>
<td>243.39</td>
</tr>
<tr>
<td>2009</td>
<td>278600</td>
<td>32.5</td>
<td>90.4</td>
<td>3935</td>
<td>193.97</td>
</tr>
<tr>
<td>2010</td>
<td>286600</td>
<td>32.5</td>
<td>92.2</td>
<td>3991</td>
<td>196.74</td>
</tr>
<tr>
<td>2011</td>
<td>284600</td>
<td>32.5</td>
<td>94</td>
<td>4057</td>
<td>192.19</td>
</tr>
<tr>
<td>2012</td>
<td>289100</td>
<td>32.5</td>
<td>96</td>
<td>4136</td>
<td>191.50</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>$q_{\text{sn}}$ [dm$^3$/M·d]</th>
<th>$q_{\text{sw}}$ [dm$^3$/M·d]</th>
<th>$q_{\text{sh}}$ [dm$^3$/M·d]</th>
<th>$q_{\text{on}}$ [dm$^3$/M·d]</th>
<th>$q_{\text{nd}}$ [dm$^3$/M·d]</th>
<th>$q_{\text{h}}$ [dm$^3$/M·d]</th>
<th>$q_{\text{lossL}}$ [dm$^3$/M·d]</th>
<th>Consumers no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>176.178</td>
<td>112.340</td>
<td>88.103</td>
<td>49.509</td>
<td>14.329</td>
<td>63.838</td>
<td>27.496</td>
<td>19025</td>
</tr>
<tr>
<td>2009</td>
<td>166.519</td>
<td>113.663</td>
<td>88.035</td>
<td>40.135</td>
<td>12.720</td>
<td>52.855</td>
<td>25.768</td>
<td>19018</td>
</tr>
<tr>
<td>2011</td>
<td>166.447</td>
<td>112.063</td>
<td>86.934</td>
<td>40.613</td>
<td>13.771</td>
<td>54.384</td>
<td>25.262</td>
<td>19199</td>
</tr>
<tr>
<td>2012</td>
<td>170.487</td>
<td>119.444</td>
<td>90.953</td>
<td>41.266</td>
<td>9.778</td>
<td>51.043</td>
<td>25.466</td>
<td>19194</td>
</tr>
</tbody>
</table>
The increase of the unit indicator for water sold and for water sold to households while reducing water consumption for own purposes is observed in 2012. Individual water loss rate was maintained at a constant level. When assessing the water loss rate one should take into account the network load. Separate hydraulic load indicator for the entire length of the pipe network in the last five years ranges from 3.0 to 3.9 m³/km·d.

4 PROCEDURES ASSESSMENT IN CASE OF NOT FULLFILING WATER QUALITY PARAMETERS

Services should be maintained at a certain level by the supplier, by which the supplier is gaining the confidence of the recipients. Recipient can precisely express his needs (for services), and the service provider can recognize these needs.

The most important criteria regardless the assessment should contain:

2. Amount of water supply (pressure, capacity).
3. Economic efficiency.

In order to find out the recipients opinion about the procedures assessment of not meeting the parameters of water supplied the questionnaire was conducted. The answers allow for clear description of the system for both the water supply system exploiter and the water recipient.

To the question what losses or nuisances lack of water supply causes, usually the recipient pointed that it was financial losses (approx. 92% of all responses).

Another question concerned an increased willingness to pay in exchange for a reduction in water supply interruptions, so-called Willingness to Pay WTP. 34% of respondents agreed to the increased fee for the supply of water, provided that this bill would not increase in comparison to the current of about 10% (54% of respondents), and 50% (3% of respondents).

4% of the respondents filed a complaint for failure for not meeting quality standards, while only 2% of them received compensation, to the question of compensation amount, respondents answered that this was a compensation in the form of a reduction in water bill.

CONCLUSIONS

Calculation of unit water loss indicators allowed to obtain a detailed picture of the operational situation waterworks. An increase in the unit indicator for water sold to households while reducing water consumption for own purposes water supply in 2012 is observed. Individual water loss rate was maintained at a constant level.

It can be concluded that all unit volume indicators relating to water losses show a downward trend in the considered period.

The analysis shows that the volume of water loss resulting from the failure of the water supply system reported no significant effect on the size of the annual water loss.

Conducting periodic analyzes associated with the operation of water supply systems, and therefore water loss, failure pipes, water consumption and assessment water consumers is a very important factor determining its proper operation.

Abstract

The thesis presents an analysis of water loss, failures occurring in water supply system and a method concerning the assessment of recipients of functioning water supply system. This analysis was made on the base of the examined water supply system, the data was obtained from the Communal Utilities Association Ltd. during period of the system exploitation between 2008-2012. The thesis also constitutes a review of fundamental information about the structure of water network influencing the loss analysis. In the work unitary
quantities of water consumption were presented. Moreover, the presented thesis constitutes calculated water indicators losses, which were contributed to recommended by International Water Association (IWA). The values characterizing water supply systems, should be performed regularly as to control the system functioning.

It can be concluded that all unit volume indicators relating to water losses remain at a satisfactory level and show a downward trend in the period considered.

Wskaźniki efektywnej eksploatacji systemu zaopatrzenia w wodę w aspekcie przynależności do infrastruktury krytycznej

Streszczenie

W pracy przedstawiono analizę strat wody w sieci wodociągowej oraz metodykę oceny funkcjonowania zaopatrzenia w wodę przez odbiorców wody. Analiza została przeprowadzona na podstawie danych uzyskanych z przedsiębiorstwa wodociągowego Związku Komunalnego Sp. z o.o. podczas eksploatacji sieci wodociągowej w latach 2008-2012. Praca stanowi także przegląd podstawowych informacji o systemie zaopatrzenia w wodę wpływających na pojawiania się strat w systemie. Przedstawiono jednostkowe wielkości zużycia wody, a także ustalono podstawowe wskaźniki strat wody, które odniesiono do wartości wskaźników zalecanych przez The Instemational Water Association. (IWA).

Można stwierdzić, że wszystkie jednostkowe wskaźniki objętościowe dotyczące strat wody utrzymują się na zadowalającym poziomie oraz wykazują tendencję malejącą w badanym okresie.

BIBLIOGRAFIA

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