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Thesis abstract

Water Losses. A critical analysis over performance indicators

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Water losses. A critical analysis over performance indicators

1 INTRODUCTION

In the last years a growing attention was given for water loss management by the Romanian water utilities, especially due to the Regional Operational Programs implemented at the national level. The main reason for including this type of activity in almost all the Projects of this particular type is the high level of water losses (more precise – of non-revenue water) in the water supply networks.

The truth is that water loss management is not a new idea, the water utilities in Romania had this preoccupation since they started (there is even a report from the early 1930s in which is presented a flow and pressure measurement campaign during night-time in the district ”Obor” in Bucharest) but even so the results didn’t match the level of expectations.

Firstly, instead of using the traditional water balance which took into consideration only the volume entering the system and the billed consumption, water companies started to use the terminology and the methods recommended by the International Water Association. In this approach a clear distinction is made between real water losses and the non-revenue water. So, for the water balance calculation there is a necessity of information and data with a high degree of accuracy and confidence. Sadly, in almost all cases, the water companies didn’t have a historical record of this type of information because it wasn’t considered relevant until that point. The direct consequence was that both water companies and consultancy firms were forced to use simplified hypothesis, the most common being the equivalence of non-revenue water with the physical water losses. It is obvious that in this scenario the target performance indicators lead to unrealistic situations (both in favor and against water utilities).

Secondly, assuming that the indicators values are based on correct data, there is still confusion regarding the actual distribution network and the company/branch that operate that particular network. In this case the water operators must ask themselves if the NRW(non-revenue water) expressed as percentage is actually good for the distribution network or if the ILI (Infrastructure Leakage Index) is good for the water company/branch? Regardless, the values of these indicators must be compared to certain ”standard” figures in order to say if the water network is in a good or bad situation. Here there is another issue due to the evaluation matrix, and the end result may be quite different depending on the matrix used (it is enough to compare the values form the normative *NP 133/1-2013* and The *National Manual for Water and Waste-water Operators* in order to demonstrate this issue).

In this respect, this thesis analyzes the methodologies used at the moment in Romania regarding water balance and performance indicators calculation, with results for a number of water systems / networks from Romania.

2 WATER LOSSES

Due to the great diversity of formats and definitions used at international level for water balance calculation (sometimes within the same country) there was an urgent need for a common international terminology. This task was put into practice by the IWA (International Water Association) who elaborated a standardized best practice approach for water balance calculation, including definitions and terminology. The table below illustrates the water balance components.

Table 2-1 IWA/AWWA Water Balance

System Input Volume (SIV)	Authorized Consumption (AC)	Billed Authorized Consumption (BAC)	Billed Metered Consumption (BMC)	Revenue Water (RW)
			Billed Unmetered Consumption (BNMC)	
		Unbilled Authorized Consumption (UAC)	Unbilled Metered Consumption (UMC)	Non-Revenue Water (NRW)
			Unbilled Unmetered consumption (UNMC)	
	Water Losses (WL)	Apparent Losses (AL)	Unauthorized consumption (UC)	
			Meter-errors (MIWL)	
		Real Losses (RL)	Real losses on raw water mains and treatment plants	
			Leakages in the distribution network	
			Reservoir overflow	
			Leakages on connections	

Although it is always useful to calculate the water balance, there are some disadvantages if someone rely exclusively on this approach in order to estimate the real losses:

- The errors accumulated from the other components will be associated with the real losses
- A water balance covers a 12-months period in retrospective, so there is limited value as an “initial warning” in order to identify new unreported breaks and leakages
- The water balance offers no indication over the individual components of the real losses or over way in which they are influenced by the company policies

Because of this, it is a good idea that the real losses should be estimated by means of additional methods, such as analysis of real losses components and night-time flows.

The main goal of any performance indicators system is to offer information. Early on the difference between data and information must be made. An information is a type of data that can be used for taking actions.

The components of performance indicators systems are as follows:

Data	Basic elements that can be either measured or easily obtained. Based on their nature and function within the performance indicators system data can be considered variables, contextual information or simply explanatory factors.
Variables	A variable is a type of data that can be processed in order to define the performance indicators. The variable comprises a value (along with the corresponding measuring unit) and a degree of confidence that indicates the quality of the data.
Performance indicators	The performance indicators measure the efficiency and the efficacity of the services provided by the water utility and is the combination of different variables. The provided information is the result of a comparison (against a target value, past values of the same indicator or values of the same indicator form different networks). Th performance indicator comprises a value and a degree of confidence.
Contextual Information	Represents data elements that provide information over the inherent characteristics of a water supply system and highlight the differences between several systems. .
Explanatory factors	Any element of the performance indicators system that can be used to explain the values of the indicator.

3 SOFTWARE TOOLS FOR WATER BALANCE

The third chapter reviewed a number of five software tools dedicated for water balance and performance indicators calculations. The common characteristics of these tools is that they are simple applications, and based on the time period in which were developed, they reflect the accepted concepts of the time regarding definitions for water balance and performance indicators. Other characteristics for these software tools are that they were developed by a very small group of water loss experts (sometimes just one person) so for this reason they tend to have a simple and clear interface for the specialists, but often they lack a User Manual.

Most of the applications are made in Excel, the main goal being to ensure a fast way to calculate the water balance with a minimum of input data. A first review of these software tools was made in 2015 an published in the *WaterLoss Detectives Magazine* in which some of the presented applications were described based on the versions at the time.

The review follows the same approach as the presentations made at the WaterLoss World Conference from 2016, that is not to analyze these software tools by traditional methodology with pros and cons, but rather to concentrate on the features offered by each software against the features that an water loss expert might need. However, a number of common criteria was used in order to differentiate between them, such as: water balance calculation, possibility of working with DMAs, possibility to works with hydraulic measurements, evaluation of the network's status and proposal of new strategies for water loss reduction, language preferences.

The software tools that were reviewed are: WB-EasyCalc, CalcuLEAKator, AWWA Free Audit Software, EurWB&PICalcs and Sigma. Figure 3-1 illustrates the starting page of the WB-EasyCalc application that was extensively used for the water balance calculations in this thesis.

The main conclusion of the review is that the choice of using a certain software solution makes sense only when the system that is to be analyzed cab offer sufficient information that can lead to the best approach. In cases where the information is scarce or with a low degree of confidence, the real challenge is actually how to interpret this information regardless of the chosen software solution.

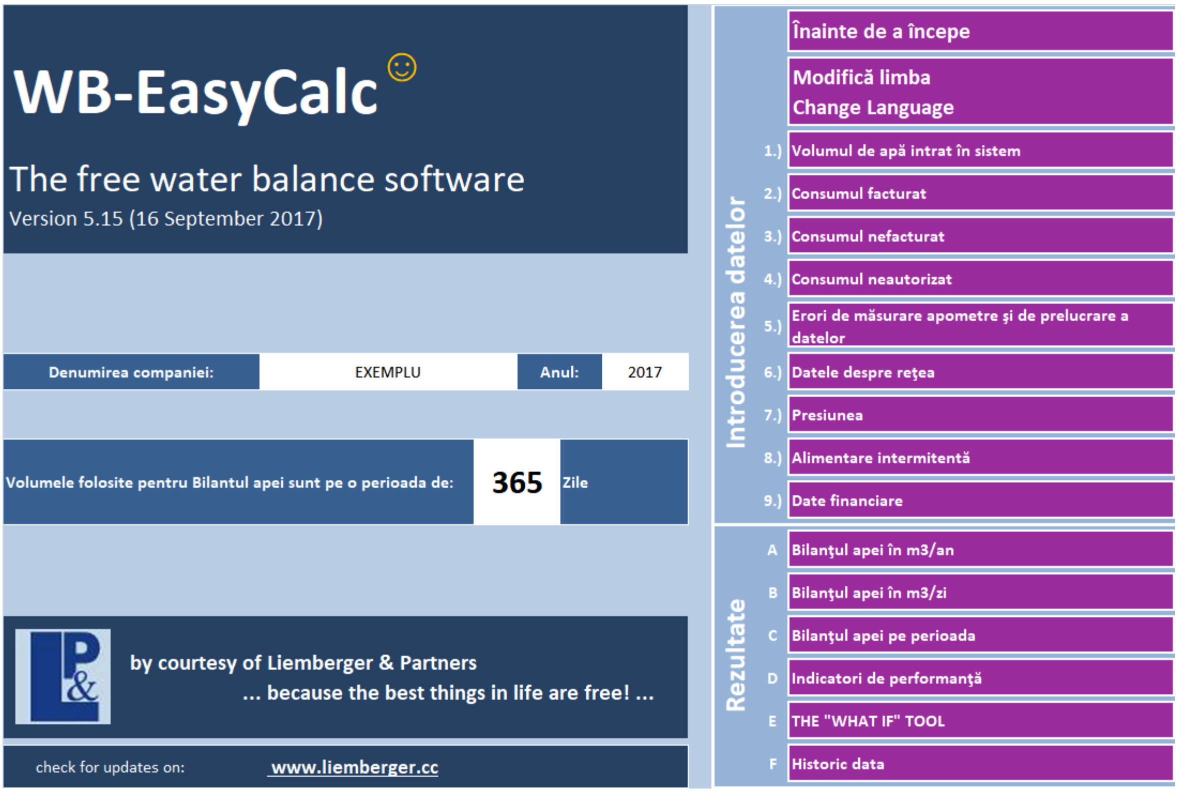

Figure 3-1 Start page of *WB-EasyCalc*

4 INTERCONNECTION WITH GIS, SCADA AND HYDRAULIC MODELING

The water loss management activity is usually corelated with the other three activities concerning GIS, SCADA and hydraulic modelling. It is important to specify that all these four connected tasks mustn't be thought as separated tasks in the management process, but rather distinct integrated modules. The most likely interoperability scenarios are presented as follows.

The water loss management starts with information gathering about the existing network / networks operated by the water utility. Although this information may come from different sources (hard-copy / CAD plans, utility personnel etc.) it is necessary to be centralized and verified, so they can offer a coherent updated error-free system.

The table below briefly illustrates the way in which the GIS and water loss management should interact with each other:

Information	**From GIS**	**To GIS**
Network topology	Pipe layout, connections	Any inconsistency between GIS data and field data
Pipe attributes	Length, diameter, material, age	Any inconsistency between GIS data and field data
Information about equipment (tanks, valves, pumps)	Specific data for each type of equipment	Any inconsistency between GIS data and field data
Clients	Corresponding connection, consumption	Any inconsistency between GIS data and field data / information about water theft etc.
Breaks log	Breaks report for the specified area	*Reporting breaks / leaks*

This approach leads very rapidly to elimination / correction of erroneous data and at the same time it will decrease the respond time of intervention teams.

SCADA will provide information on the measured hydraulic parameters of the network and possibly the states of the valves (closed / open or degree of opening). When opting for a district metering, this information is particularly valuable for water loss management.

Because the parameters are measured at very short intervals, an "unnatural" change can be seen quickly and thus the response time of the intervention team improves dramatically. SCADA is a vital component for active loss control. The table below briefly illustrates how interoperability between the two activities

Information	**From SCADA**	**To SCADA**
Hydraulic parameters entering the system	Flow and pressure at the pumping station, inlet tank, etc.	
Hydraulic parameters in the network	Pipe flows and pressures in nodes	
Position of measuring equipment	Flow meter and pressure transducers location	*In the initial phase, the information for the positioning of the district meters will be provided*

It should be noted that from the hydraulic modeling activity only the data and results related to the distribution networks will be the subject of discussion.
This information is particularly useful for all aspects of water loss management. With the help of the calibrated hydraulic model of the network, estimates can be made in the first phase on the problem areas in the network.
The hydraulic model in turn uses GIS data (already validated) and provides data on hydraulic network parameters (flow rates on pipes and node pressures). The table below briefly illustrates how interoperability between the two activities occurs.

Information	**From Hydraulic Model**	**To Hydraulic Model**
Hydraulic parameters entering the system	Flow and pressure at the pumping station, inlet tank, etc.	Any mismatch between GIS data and field measurements (model calibration)
Hydraulic parameters in the network	Pipe flows and pressures in nodes	Any mismatch between GIS data and field measurements (model calibration)
Real and / or apparent losses		*All data verified after interventions and measurements (rebuild of the hydraulic model)*

5 PERFORMANCE INDICATORS – CASE STUDIES

5.1 Methodology

The general methodology for calculating the water balance for water supply systems followed the IWA methodology presented in the related chapter. The general rules for drawing up the water balance for the networks under the administration of the analyzed water companies were the following:

- Depending on the available data and their accuracy, the water balance was calculated either for the entire water supply system or strictly for the distribution network.
- Consumption was divided into two categories (metered and non-metered).
- The apparent losses have been estimated for the moment at a percentage of 3% - 5% of the authorized metered consumption, representing an estimated value of water meter errors.
- Technological consumption was introduced in the category of unauthorized unbilled authorized consumption.

The calculated performance indicators took into account the existing recommendations for the POIM program, the table presented indicating both the coding in the recommendations and the coding in the Good Practice Manual Performance Indicator for Water Supply Services - 2nd edition, H. Alegre, J.M. Baptista, E. Cabrera Jr. IWA Publishing, 2010.
The water balance was performed at the maximum possible level of detail in accordance with the data and information received from the Regional Operators at the level of 2014 - 2016. The information necessary to achieve the water balance was taken as follows:

Water balance input data	Description / Interpretation
A3 – System Input Volume	Information provided by the Operator based on annual records. The input volumes from the main meter for each locality were taken into account
A8 – Billed Metered Consumption	The information was extracted from the Operator's billing system for each locality separately for domestic and non-domestic consumption.
A9 – Billed Unmetered Consumption	Information provided by the Operator, correlated with the value of the billed metered consumption
A11 – Unbilled Metered Consumption	Information provided by the Operator

A12 – Unbilled Unmetered Consumption	This value was estimated as the technological consumption related to tank washing
A16 – Unauthorized Consumption	Information provided by the Operator
A17 – Meter errors	An overall error of 3% was taken into account

Where possible, the values resulting from the water balance for actual losses were verified with the estimated values from the flow measurements.

The other components of the water balance were calculated according to the methodology presented in **Chapter 2.2 Water balance**. Consequently, the water balance is presented in the following sections for each study area.

The water consumption forecast was made for a period of 30 years with the highlight of the current situation, at the end of the implementation of measures to reduce losses and at the end of the period considered (30 years) for the supply networks considered in the Study. The Deva-Mintia water supply system is managed by the DEVA Operational Center and serves the city of Deva together with the related localities Com. Veţel and the Mintia power plant area. The existing data at the level of the Regional Operator, as well as the configuration of the system allowed the realization of the water balance, the forecast and the performance indicators separately on the three listed supply areas.

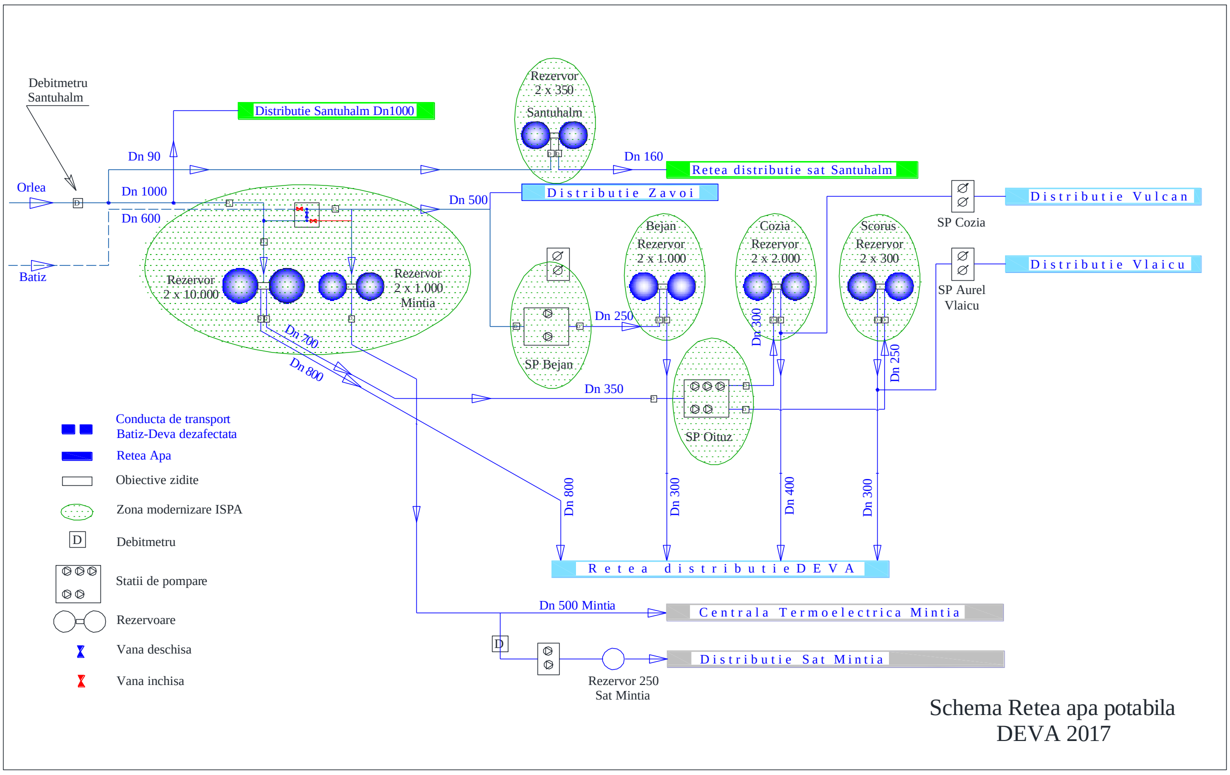

Fig. 5.1-1 Distribution scheme of the DEVA-MINTIA Water Supply System *(the parts shaded in green represent the areas for which the water balances were made)*

<table>
<tr><td rowspan="7">Volumul de apă intrat în
6.390.706 m3/an
Marja de eroare [+/-]: 0,0%</td><td rowspan="4">Consumul autorizat
3.478.104 m3/year
Marja de eroare [+/-]: 0,0%</td><td rowspan="2">Consumul autorizat facturat
3.448.104 m3/an</td><td>Consumul contorizat facturat
3.447.678 m3/year</td><td rowspan="2">Apa facturată
3.448.104 m3/an</td></tr>
<tr><td>Consumul necontorizat facturat
426 m3/year</td></tr>
<tr><td rowspan="2">Consumul autorizat nefacturat
30.000 m3/year
Marja de eroare [+/-]: 0,0%</td><td>Consumul contorizat nefacturat
0 m3/year</td><td rowspan="5">Apa nefacturată
2.942.602 m3/an
Marja de eroare [+/-]: 0,0%</td></tr>
<tr><td>Consumul necontorizat nefacturat
30.000 m3/year
Marja de eroare [+/-]: 0,0%</td></tr>
<tr><td rowspan="3">Pierderi de apă
2.912.602 m3/an
Marja de eroare [+/-]: 0,0%</td><td rowspan="2">Pierderi aparente
106.629 m3/year
Marja de eroare [+/-]: 0,0%</td><td>Consumul neautorizat
0 m3/year
Marja de eroare [+/-]: 0,0%</td></tr>
<tr><td>Erori de măsurare apometre şi de prelucrare a datelor
106.629 m3/year
Marja de eroare [+/-]: 0,0%</td></tr>
<tr><td colspan="2">Pierderi reale
2.805.973 m3/year
Marja de eroare [+/-]: 0,0%</td></tr>
</table>

Fig. 5.1-2 Water balance for the city of Deva for 2016 *(source: data processing received from the Operator).*

Table 5.1-1 *Consumption forecast for the city of Deva (period 2016 - 2047)*

SZA ORLEA-DEVA - Deva		2016	2023	2047
POPULATION	Nr. loc.	57.827	57.327	55.503
Percentage connected	%	100,0%	100,0%	100,0%
Water consumption	**urb**			
Consumers	Nr. loc.	57.827	**57.327**	55.503
Specific consumption	l/ om / zi	114	**100**	**115**
Domestic consumption	mc /an	2.413.873	2.092.437	2.329.746
Non-domestic consumption	mc /an	882.695	**1.010.192**	1.418.679
Total consumption	**mc/an**	**3.296.568**	**3.102.628**	**3.748.425**
Non-revenue water				
Real losses	%	44,97%	42,97%	32,89%
Real losses	mc/an	2.805.973	2.476.111	1.945.426
Apparent losses	%	1,71%	2,69%	3,17%
Apparent losses	mc/an	106.629	155.131	187.421
Utility consumption	%	0,48%	0,49%	0,58%
Utility consumption	mc/an	30.000	**28.235**	34.112
NRW	%	47,16%	46,15%	36,63%
NRW	**mc /an**	**2942602**	**2659477**	**2166959**
System Input Volume	**mc /an**	**6239170**	**5762105**	**5915384**

Table 5.1-2 *Performance indicators for the city of Deva (period 2016 - 2047)*

PERFORMANCE INDICATORS - SZA ORLEA-DEVA - Deva						
POIM	IWA	Indicator	MU	2016	2023	2047
2.5.1	A3	System Input Volume (input raw water)	m3/day	17093,62	15786,59	16206,53
2.5.2	A21	Non-revenue water	m3/day	8061,92	7286,24	5936,87
2.5.3	Fi46	Non-revenue water	%	47,16%	46,15%	36,63%
2.5.4	**A19**	**Real losses in the network**	**m3/day**	**7687,60**	**6783,86**	**5329,93**
2.5.5		Percentage of real losses in the network	%	44,97%	42,97%	32,89%
2.5.6	Op27	Real losses on connection	l/conn./day	1120,31	988,61	776,73
2.5.8	Op29	ILI	-	25,68	22,20	17,44
	Op27	Real losses per km of pipe length (LKN)	m3/km/day	45,19	37,66	29,59

5.2 Influence of primary data on indicators

In most cases, utility companies that have not had previous experience with the IWA methodology have insufficient data or a low degree of accuracy required to calculate water balance and performance indicators. This is especially reflected in the definition of target indicators, which, compared to unrealistic situations, often make water companies unable to reach them.

A common example refers to target indicators (in this case real losses / connection) calculated based on erroneous initial information. Regardless of the real situation, the NRW level will remain the same. The figure below illustrates the variation of the Op27 indicator compared to the estimated apparent losses A18 (as a percentage of the authorized consumption) in the idea of proposing a “what-if” scenario. The initial and updated data refer to the number of connections (a difference of 30% between the two data sets), the length of the network (a difference of 22%) and a decrease in the authorized consumption charged of 25%.

The conclusion in this case is that from the analysis of the results the target indicators are more difficult to achieve for the real situation.

There are discrepancies between the data used in the initial study and the current data of the water company regarding the number of connections (3400 in the initial study and 405 in the data of the water company), the length of the transmission pipes (0.2 km in the initial study and 3.35 km in the data water company) and the length of the distribution network (30 km in the initial study and 7.5 km in the water company data).

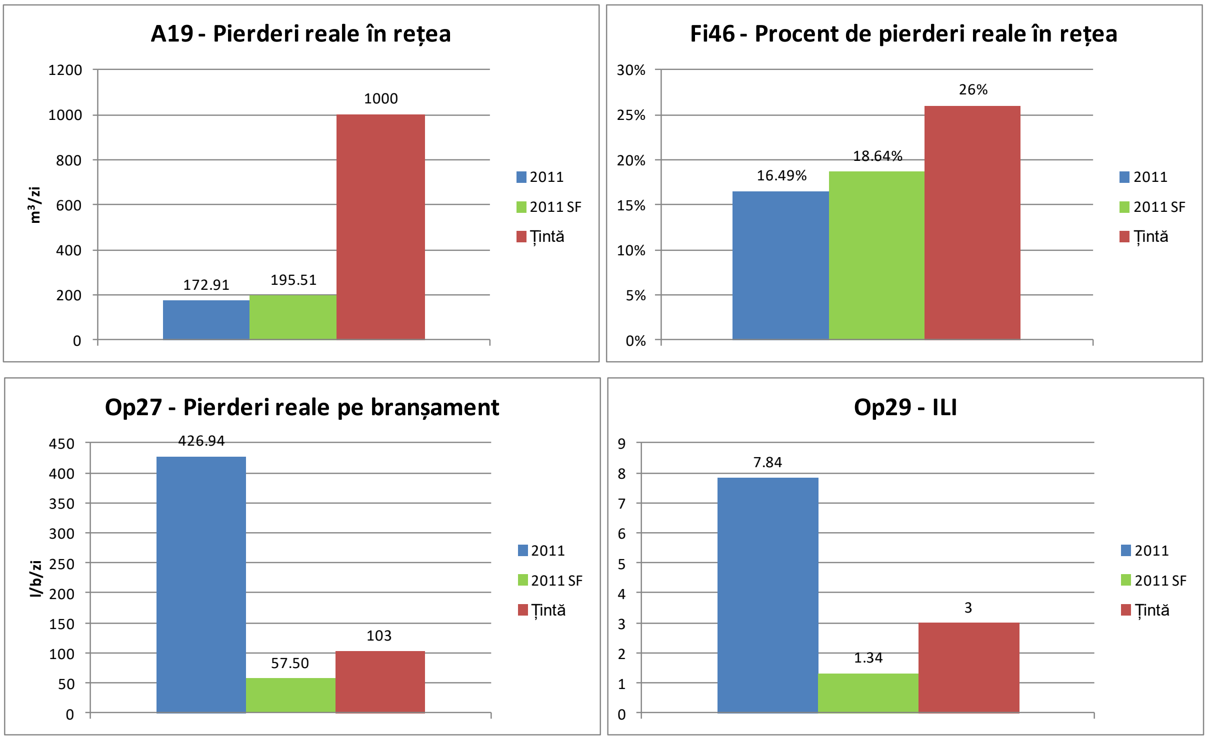

Figure 5-1 Variation of performance indicators according to input data. Plopeni case study

Of course, the initial premises may in some cases favor water companies, when there is an underestimation of these input data. The example shown below refers to the same performance indicators, but for a different distribution network. And in this case the NRW values remain constant. The figure below illustrates the variation of the Op27 indicator compared to the estimated apparent losses A18 (as a percentage of the authorized consumption) in the idea of proposing a "what-if" scenario.

The initial and updated data refer to the number of connections (a difference of 35% between the two data sets), the length of the network (a difference of 32%) and a decrease in the authorized consumption charged of 20%.

The conclusion in this case is that from the analysis of the results the target indicators are more difficult to achieve for the real situation.

6 PERSONAL CONTRIBUTIONS

Currently, the system of performance indicators used by various water companies in Romania derives either from the good practice manual IWA Performance Indicators for Water Supply Services - second edition (Alegre et al., 2010) or from the National Manual of Water Operators and Sewerage (2008, 2010) and compared to the World Bank Matrix or the National Manual Matrix. The most popular and commonly used indicators in terms of water loss are NRW as a percentage of the volume entered in the system, LKN, ILI and different percentages of the volume entered in the system for physical and apparent losses.

This paper proposes a critical comparative analysis of the identified evaluation systems starting from three essential aspects:

- Analysis of the calculation method of the water balance following the definitions of the components and the description of the calculation methodology
- Analysis of calculated performance indicators and how to calculate them
- Analysis of how to assess the state of the system in terms of water loss

In this regard, the following documents were identified and analyzed:

- Best Practices Handbook *Performance Indicator for Water Supply Systems, 2nd edition* edited by the International Water Association
- National Manual of Water and Sewerage Operators (2008, 2010 editions)
- Norm on the design, execution and operation of water supply and sewerage systems of localities - indicative NP 133/2013
- ANRSC Order 88/2007

Although each document taken as such has a logical structure and provides details on how to calculate the water balance and performance indicators, the results of the comparative analysis revealed that there are a number of major incompatibilities between them, as well as certain aspects that require further clarifications. Some of the aspects analyzed in the doctoral thesis were disseminated in detail in previous articles presented at the profile conferences but were resumed and put in a broader context for this paper.

A possible explanation for this situation is that the purpose of the analyzed documents is different, which leads to the idea of harmonizing at least some of the relevant documents to eliminate incompatibilities.

Romanian water companies are defined as Regional Operators, each Operator being composed of 1 to 20 water supply systems, depending on local conditions. This quickly becomes a problem when comparing different entities for the following reasons:

- Many branches operate independent systems and consequently IP calculated for the whole branch is of little relevance when trying to prioritize investments and rehabilitation at the level of independent systems
- The regulator only requires compliance for a certain percentage of the NRW in the CIS for the whole water company, otherwise many utilities tend not to take into account other performance indicators and therefore do not have a tradition of keeping the necessary data for the calculation other indicators.

Consequently, additional contextual factors are needed to make a relevant comparison, in other words to determine which systems are "more similar" to others in terms of the characteristics and behavior of the distribution network. For this purpose, the following information was verified for more than 30 water supply systems in Romania:

Connection density (connections / network length)

- The ratio between active and inactive connections
- The ratio between the length of the adductions and that of the distribution network
- Annual profile of authorized consumption (only where data have been available for several years)
- Per capita consumption

Power systems vary in size, from small villages to medium-sized or large cities. Figure 3 provides an overview of the different systems used in this studio, highlighting the length of the networks, the number of connections and their density.

At the same time, this overview served the initial grouping of the studied systems, ie a group composed of medium and large systems and another composed of small systems (usually for localities with less than 10,000 inhabitants). The detailed representation of the small systems also illustrates a great diversity of the density of the connections, which implies additional groupings.

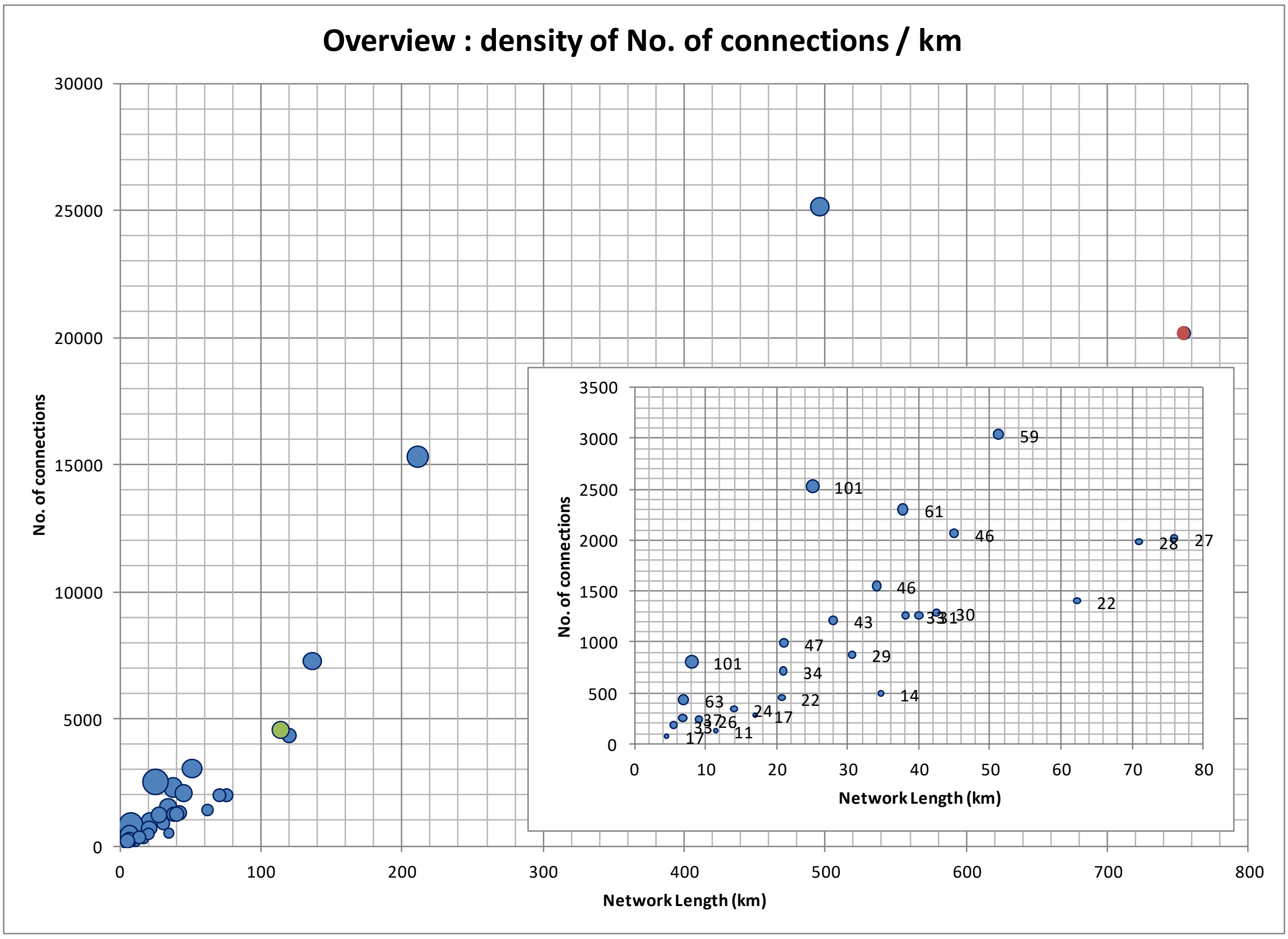

Fig. 3 Overview of the different water supply systems analyzed in this study: the colors red and green represent systems where the transport pipes were also taken into account.

The connection density criterion was calculated using only the length of the distribution network, but in two cases it was not possible to separate the values for the lengths of the transmission and distribution pipelines (in fact these systems are composed of several distribution networks).

The values obtained actually served two purposes: one was to establish small groups of systems suitable for comparing performance indicators and the other was to raise a question mark about the somewhat large difference in values. The additional investigations revealed that in some cases the data for the existing connections took into account only the active connections and in other cases the length of the transmission pipelines was included in the company's data as part of the distribution network.

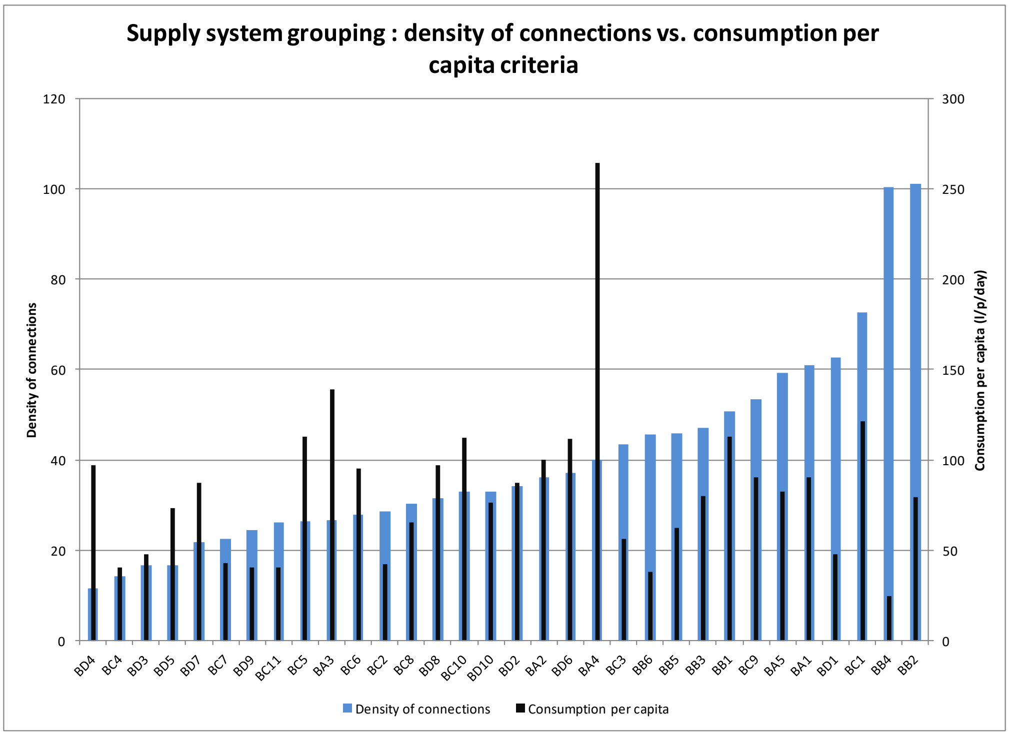

Fig. 4 The per capita consumption criterion suggests a different "cluster" of comparison

One of the relevant aspects of this analysis is the calculation of performance indicators for the analyzed systems, in particular ILI and NRW expressed as a percentage of the volume entered into the system. The results obtained confirm the opinion of water loss experts regarding the non-correlation of the two indicators and in particular the mistake of using as a performance indicator unused water expressed as a percentage of the volume entered in the system. The figure below shows these results:

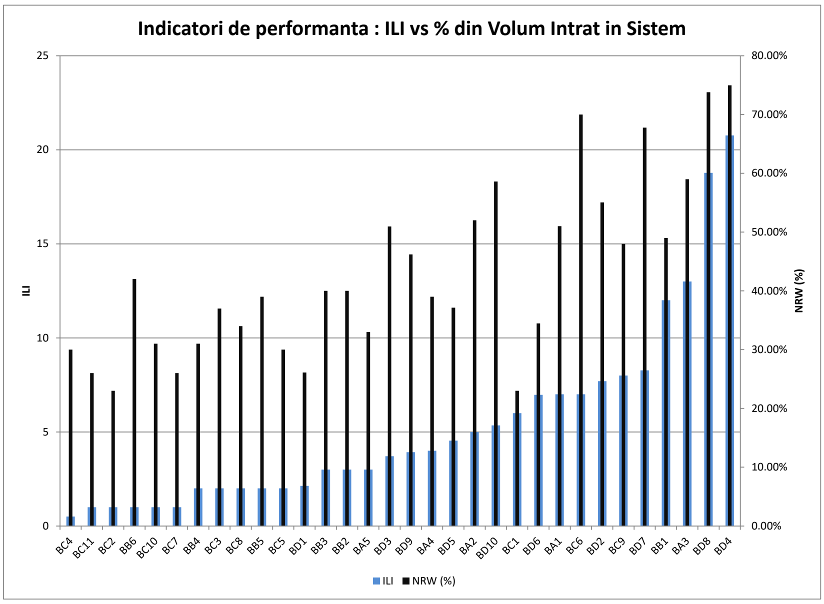

Fig. 5 Comparative analysis between the values of the ILI indicator and of the unused water expressed in% of the volume entered in the system

7 FINAL CONCLUSIONS

The analysis carried out in the previous sections highlights some aspects that need to be clarified regarding the assessment of a distribution system from the point of view of water losses, namely:

1. Set of different measures in importance and impact depending on the chosen evaluation matrix. The most eloquent example is the one associated with the ILI indicator, where the value 10 is considered very good in the National Manual matrix (and does not require special measures) but according to the World Bank matrix indicates a tolerable state of affairs only in extreme cases.

2. Underestimation of apparent losses that can lead to sets of measures to reduce uninspired losses, with undue emphasis on reducing physical losses

3. The need for a combined "top-down" and "bottom-up" approach to water balance, especially in situations where the reliability and accuracy of input data are low.

4. Flow measurements for 24 hours can provide valuable information on the state of operation of the distribution network both for quantifying physical losses and for determining the hourly variation of consumption.

5. As the physical characteristics, variations and consumption volumes of the analyzed distribution networks are different, it is necessary to establish criteria for comparing them for a relevant analysis of the performance indicators. The proposed comparison criteria are as follows:

    a. Connection density (connections / network length)

    b. The ratio between active and inactive connections

    c. The ratio between the length of the adductions and the length of the distribution network

    d. Annual profile of authorized consumption (only where data are available for several years)

    e. Per capita consumption

6. The proposed comparison criteria can also be used for the particular case of the multi-annual analysis for a given distribution network in the idea of wanting to assess the impact for changes to the distribution network.

The documents presented show discrepancies in the interpretation of performance indicators. The most eloquent example is the one associated with the ILI indicator, where the value 10 is considered very good in the National Manual matrix (and does not require special measures) but according to the World Bank matrix it indicates a tolerable state of affairs only in extreme cases.

Following the relatively brief analysis of the presented documents, the main conclusion is that it is necessary to standardize / harmonize the technical documents regarding the management of water losses, starting from the basic principles.

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