How can IWA Water Balance calculation using "bottom-up" approach (based on result of hydraulic measurement) can become cheaper and faster

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Abstract

In accordance with the recommendations of the International Water Association (IWA), water losses in the water supply systems in Bosnia and Herzegovina and Montenegro have been lately calculated by using the water balance method and presented through financial and technical performance indicators.
In order to determine the value of water balance elements, IWA Task Force Group has recommended the two following approaches:

1. *Top-down approach, and*
2. *Bottom-up approach.*

Although the top-down approach is much cheaper and faster – reasons why it is significantly preferred in Bosnia and Herzegovina and Montenegro, this approach however is still based on the number of estimates obtained from water utility companies, so results obtained are usually unacceptable and incorrect.
Water Loss measurements, which are carried out in DMA[1]s are based on the Minimum Night Flow measured values. It would be perfect if these measurements could be performed continuously for a period of one year. However, most of water utilities in SEE[2] are not able to perform measurements continuously, but only occasionally, Due to that reason, it is of particular importance to define the exact day when this measurement will be performed, in order to ensure that the flow contains the most of the real water losses. Taking into account that such results, obtained during measuring performed within the short period are usually incorrect, utilities as well consultants, choose cheaper and easier option as "top - down" approach is.
The author has elaborated results obtained by continuous flow measurements in DMAs in 27 water supplying systems in Bosnia and Herzegovina and Montenegro (251 DMAs). Depending on geographical positions and climate, results are sorted in three groups: Water Supply systems in Continental part (16 Water supply systems), Water Supply systems in Mediterranean part (6 Water supply systems) and Water Supply systems in the hinterland (5 Water supply systems). Furthermore, each group of results is divided in dependence of whether the DMA lies in urban or rural part of municipality.
In order to facilitate the calculation, author has prepared tables and software named RecalcuLEAKator programmed in popular MS Excel as tool for easier and more accurate recalculation flow data obtained by short period measurement. Tables and software are set up on the author's web site www.waterloss.com.ba, for free download. Tables and software will be continuously complemented and updated with new results in the future.
The aim of that work is to enable cheaper and faster Water Balance analysis, based on results obtained by Hydraulic measurement in DMA, with satisfactory accuracy which will enable further activities, in order to be reduced amount of NRW.

[1] District Metered Area
[2] Southeastern Europe

Taking into account the similar behaviour and climate conditions, this model can be used in other countries in SEE as well, It can be supplemented with new data which will enable its improvement, over period of time.

Introduction

Water loss measurements that are carried out in the DMAs are based on measured values of minimum night flow and it would be ideal if these measurements are carried out continuously for a period of one year. As Water Utilities in the region of South East Europe are generally not able to carry out measurements continuously, but only occasionally, it is particularly important to determinate more precisely the period when the measurements will be carried out, in order to thus ensure that the measured flow contains the highest amount of real losses. Due to the different consumer behaviour during the day, week or season, appearance of the minimum night flow (MNF) directly depends on the unevenness of consumption. Bosnia and Herzegovina and Montenegro are two independent countries that have much in common when it comes to climate, relief and geographic location. Most water systems in both countries are in very poor condition and according to the Federal Bureau of Statistics (Figure 1), in FB&H the amount of non-revenue water is increasing from year to year. The exception was 2012, when there was a slight decrease in losses that timely coincides with the implementation of a major loss reduction project in five Water Utilities in Central Bosnia [2].

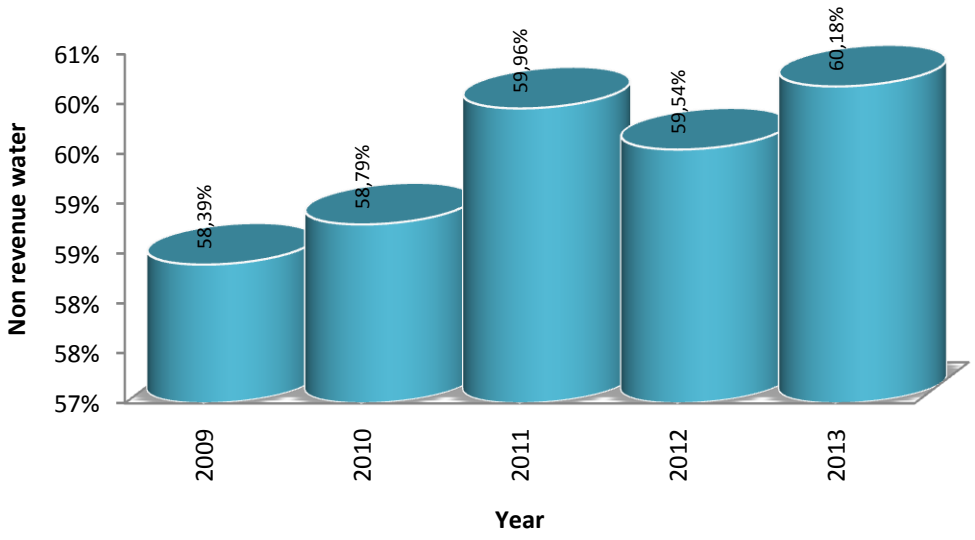

Figure 1: Percentage values of non-revenue water in water utilities in FBiH

There are 23 municipal water supply systems in Montenegro. The situation is very similar to the situation in Bosnia and Herzegovina. According to the Bureau of Statistics of Montenegro- Monstat (Figure 2) which relate to period of 12 years (from 1999 to 2011), a large increase in non-revenue water can be seen in the period between 2002 and 2005 in the amount of 16.36%.
This large increase in NRW refers to the period before the independence of Montenegro in 2006. In the period from 2008 to 2011, this big trend of loss increase started dropping, which coincides with the establishment of the Coordination Company for Water and Wastewater Services for the Montenegrin Coast - Vodacom. This institution has implemented a large number of loss reduction projects in the previous period in water utilities that are members of this company: Herceg Novi, Budva, Bar, Kotor, Tivat and Ulcinj.

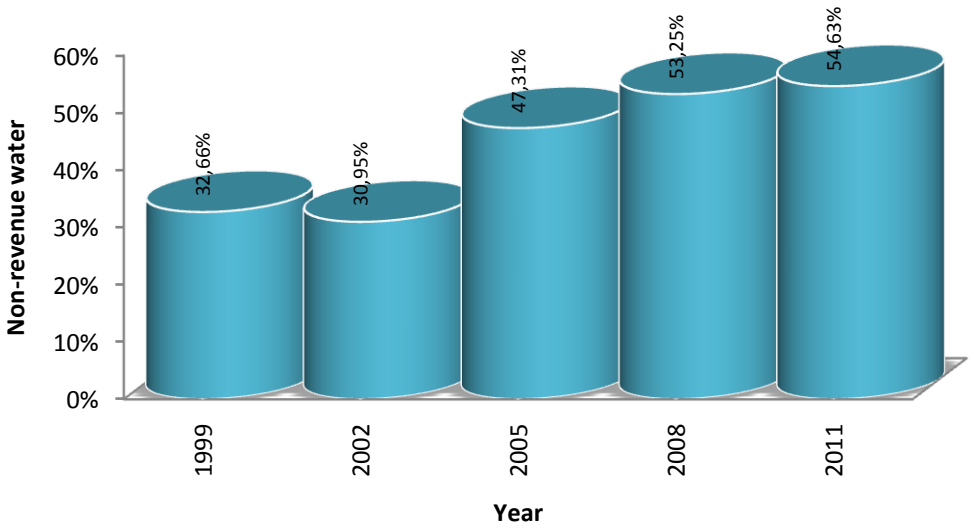

Figure 2: Percentage values of non-revenue water in water utilities in MNE

Besides mentioned projects, after the proclamation of independence, loss reduction projects are implemented in Montenegro in water utilities Podgorica and Cetinje, but due to lack of funding repair of the 334 detected leakages was never carried out. By the construction of the Regional Water Supply system in 2010, water from sources located in the Skadar Lake is transported to all coastal municipalities by powerful pumping system.
This way the lack of water in the coastal municipalities of Montenegro is mitigated to some extent, but due to the high cost of water production in the regional system, coastal water utilities are forced to continue or even intensify reduction activities and active monitoring of losses in their systems [2].
A particular problem in both countries is a tendency to display almost complete value of NRW as a real loss, or to constantly minimize presence of apparent losses. This problem comes to the fore when trying to calculate the water balance with approach from the top down, in which the value of real losses is based on the analysis and value estimation of apparent losses. The results of the water balance analyse calculated using top down approach are unacceptably inaccurate which can be clearly seen from the following chart which shows the difference in the defined values of real and apparent losses in five water companies (3 in B&H and 2 in Montenegro) which is balance calculation initially done by top down approach and subsequently with bottom up approach which is based on the results of hydraulic measurements.

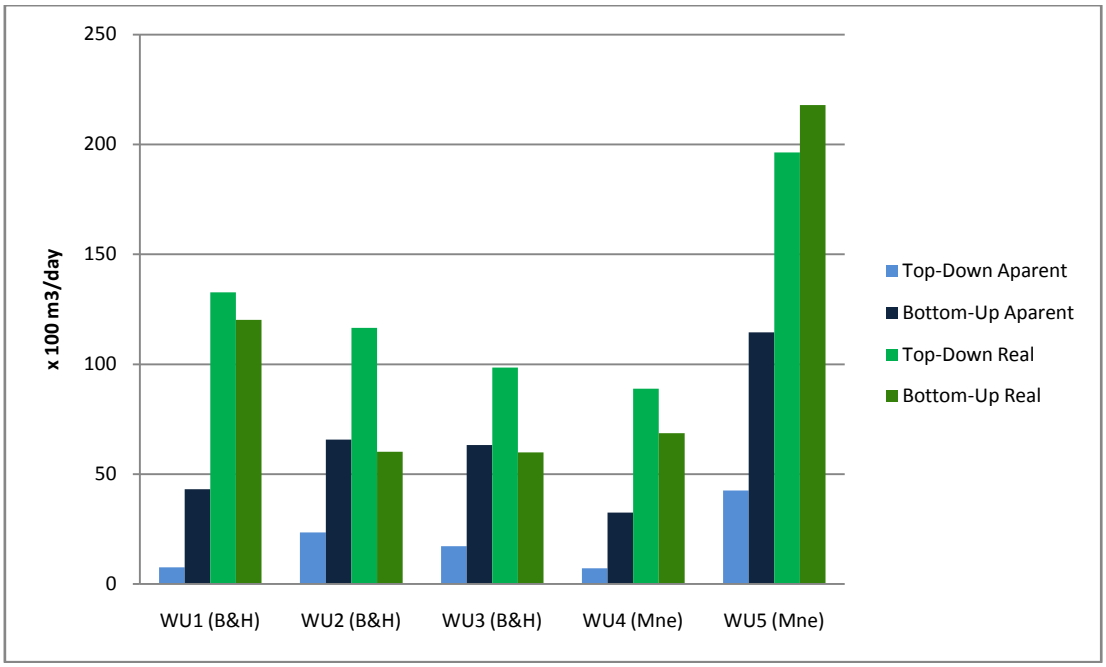

Figure 3: The differences in the values of real and apparent losses - the application of different approaches

Methodology for the "bottom-up" approach simplification

It is difficult to compare the results of measured flow of two or more water utilities, because this information depends on the value of losses in each system, and also on many other subjective factors.

However it is possible to compare the results that are measured on a certain day of the week and year with data measured in "similar" DMAs. This can be done based on increase and decrease flow tendencies during a specific interval of time, which gives the possibility of defining the trend of water consumption. Using the intermediate trend of water consumption in larger numbers of similar water utilities as the basis, the percentage of flow increase or decrease can be relatively accurately estimated by horizontal synchronization. Synchronization is carried out separately for each one-hour interval (Figure 4). This processing can be further extended to the assessment of the daily flow rate on an average annual basis. The assessment of MNF values is defined in the same way as the day and interval in which it will appear.

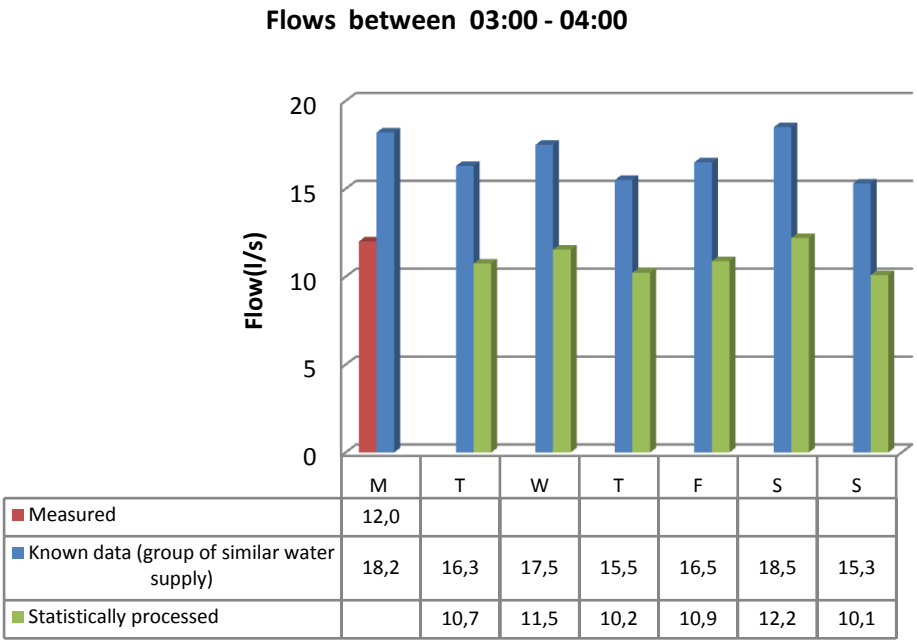

Figure 4: Defining the hourly consumption based on well-known trend

Classification of water utilities and DMA zones

Bosnia and Herzegovina and Montenegro share similar influence factors which form the appearance and size of the minimum night flows.
However it is not possible to classify all water utilities in B&H and Montenegro in the same group. Based on the geographical position which is to some extent related to climate conditions, a division can be made to:

Water utilities on the Adriatic coast (Mediterranean water utilities)

The Mediterranean climate brings hot summers and mild winters. Water utilities in these areas have a pretty evident seasonal unevenness of water consumption, and therefore large differences in the values of minimum night flows.

Water utilities in the Adriatic hinterland

Although in this area climate is also Mediterranean, these water utilities are different when comparing to coastal ones as they are not to such an extent subject to the appearances of seasonal unevenness, considering that there is no well-known tourist destinations in general, therefore there is minor deviation in the number of water consumers.

Water utilities in the continental area

These water utilities exist in an area where climate is continental, with hot summers and cold winters and they are less responsive to seasonal unevenness.
In each of mentioned groups it is necessary to make division into zones belonging to:

The urban area

In which most of the population lives and where there is a larger number of small enterprise facilities (non-resident customers). In these areas, unevenness daily consumption during the week is usually more expressed, i.e. the difference in consumption during working days and weekend days is more expressed.

The rural area

Although it is common that people from rural areas are employed in the urban part of town, still in these areas, due to exposure to rural way of life, daily unevenness during the week is less expressed.
Each defined category needs to be considered separately in summer and winter period.

Water utilities that are subject of research

For research purposes flow measurement the data are analyzed in a period of one year or in different times of the year over a longer time intervals in 27 water supply systems in Bosnia and Herzegovina and Montenegro, i.e. 251 measurement areas (DMA).
Only the data for days and weeks in which the supply and consumption of water occurred in the "usual" way were statistically analyzed. Data for days and weeks in which extraordinary events have occurred, such as religious holidays, national football team matches, big concerts, interruptions in water supply etc. were not considered because they could create a wrong picture of water balance.
The best example of such data is illustrated in Figure 5. On the date 15 June 2014 Bosnia and Herzegovina was playing their first match at the Football World Cup in Brazil against Argentina. Measurements that are performed that day in one water supply system in B&H with one minute records interval show how the TV broadcast of this game affected the decrease in consumption. Flow rate measured in the last minutes of the game is one of the lowest recorded flow rates throughout the year.

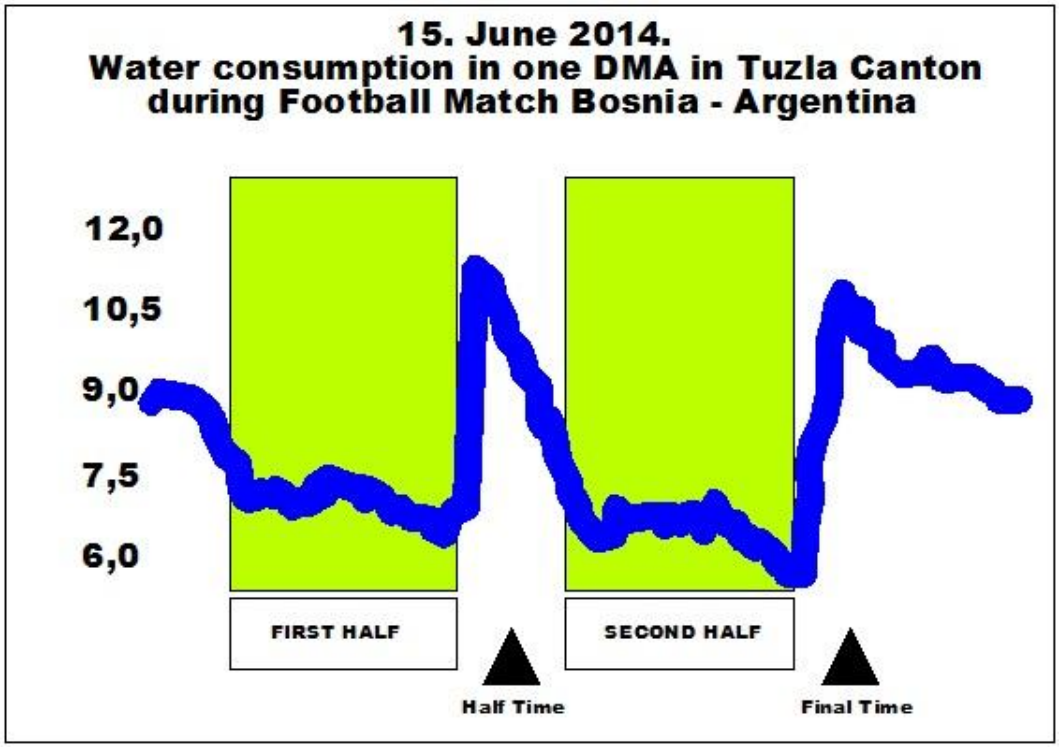

Figure 5: Influence of f football match on water consumption

For research purposes flow measurement the results in 27 water supply systems (17 in B&H and 10 in Montenegro, with a total of 251 zones) are analyzed.

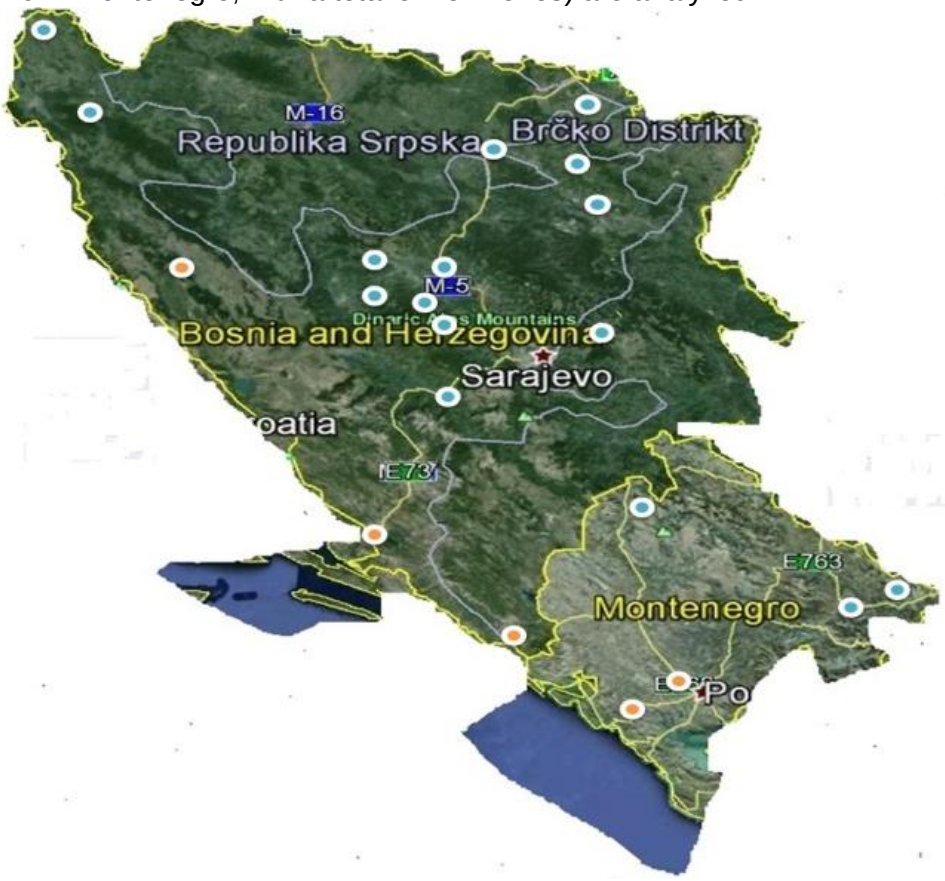

Figure 6: The position of water supply systems in B&H and MNE, in which the research was conducted

The results were statistically analyzed and divided into three groups, depending on the geographical location and climate of each water utility separately. Total of 9493 weekly samples is processed. In further research the results were considered, depending on whether the associated measuring zone are in an urban or rural area, as well as whether the measurement was conducted in the summer or winter period. The position and the list of mentioned water utilities is illustrated in Figure 6 and Table I.

Continental Area			Mediterranean Area			Mediterranean hinterland		
nb	Municipality	Country	nb	Municipality	Country	nb	Municipality	Country
1	Tuzla	B&H	1	Neum	B&H	1	Trebinje	B&H
2	Bihać	B&H	2	Bar	B&H	2	Čapljina	B&H
3	Orašje	B&H	3	Herceg Novi	Mne	3	Livno	B&H
4	Velika Kladuša	B&H	4	Kotor	Mne	4	Cetinje	Mne
5	Doboj	B&H	5	Ulcinj	Mne	5	Danilovgrad	Mne
6	Konjic	B&H				6	Podgorica	Mne
7	Sokolac	B&H						
8	Travnik	B&H						
9	Zenica	B&H						
10	Novi Travnik	B&H						
11	Busovaća	B&H						
12	Vitez	B&H						
13	Gradačac	B&H						
14	Pljevlja	Mne						
15	Rožaje	Mne						
16	Plav	Mne						

Table I: Groups of water supply systems in which research was conducted

Characteristic unevenness of consumption

By statistical analysis of data of water utilities that were the subject of research the trends of following unevenness and appearances in water consumption are defined.

Defining the hourly minimum flow rates during one day ($MNF^{n/7}$)

The minimum value of the hourly flow for each day of the week is calculated according to the formula (1)

$$\mathrm{MNF}^{\,n/7} = \min\left(\mathrm{Q}^{n/7}_{00-01}; \mathrm{Q}^{n/7}_{01-02}; \mathrm{Q}^{n/7}_{02-03}; \ldots; \mathrm{Q}^{n/7}_{23-00}\right) \qquad (1)$$

wherein:

$\mathrm{MNF}^{\,n/7}$ - Minimum night flow (l/s), which appeared in the interval of one hour in a certain day of the week,

Q - Average flow measured at an interval of one hour on certain days of the week (l/s),

n - The day of the week, whereby 1≤n≤7,

Defining the minimum flow rates on a weekly basis (MNF_7)

The value of the minimum night flow on a weekly basis is the lowest value from the group of minimum hourly flow rates of each day in the monitored week, ie (formula (2))

$$MNF_7 = min\left(MNF^{\,1/7}; MNF^{\,2/7}; \ldots; MNF^{\,7/7}\right) \qquad (2)$$

wherein:

MNF_7 - The lowest recorded value of the IMF in 7 days (l/s),

$\mathrm{MNF}^{\,n/7}$ - The minimum night flow (l/s) for a particular day of the week (Monday to Sunday)

All individual values $\mathrm{MNF}^{\,n/7}$, which are part of the same group in terms of geographical origin, urbanization and climate, and depending on time of year when it made the measurement, are summed and divided by the number of weeks (samples) in which the measurement is made, giving the average value $AVMNF^{N/7}$for the entire group of water utilities for each day of the week individually (equation (3)).

$$AVMNF^{n/7} = \sum_1^k MNF^{n/7} / k \qquad (3)$$

wherein:
$AVMNF^{n/7}$- average value of minimum night flow in a certain day of the week in analysed areas (group of water utilities)
k - number of weeks in which the measurement was performed.

Defining the number of MNF occurrences for a certain day in the observed period

Number of $D^{n/7}$ occurrences where a certain day of the week had the lowest weekly MNF value is calculated by simple summing $MNF^{n/7}$ for the certain day. As these values are shown as the ratio of the minimum daily flow compared to minimum weekly flow, a minimum value of the coefficient will be 1.

$$D^{n/7} = \sum MNF^{n/7} \qquad (4)$$

wherein the condition is as follows: $MNF_{n/7}$=1 and 1≤n≤7
$D^{n/7}$ - Number of occurrences when in the certain day of the week the lowest minimum flow of the week was recorded.

Software for statistical elaboration of flow measured by a 24h measurement – RecalcuLEAKator

All researches conducted in 251 MZ in 27 water supply systems are processed in the form of tables, that allow the user to quickly recalculate measured flow value in relation to the expected values that include hourly, daily and weekly unevenness.
With the aim of even faster and safer recalculation, software tool called RecalcuLEAKator 2015 was made. Using the program, which is available in Bosnian and English language, the user is able to, based on results of flow measurement that lasted only 24 hours, obtain high quality assessment of the daily flow line on a weekly and annual basis, then the estimated value of the minimum night flow, as well as the assessment of the day and hour when the minimum night flow of the week in which the measurement is conducted will appear. [3] This software is programmed in Visual Basic (VBA) and operates within MS Excel program. Software can be downloaded free of charge at the website of the author www.waterloss.com.ba.

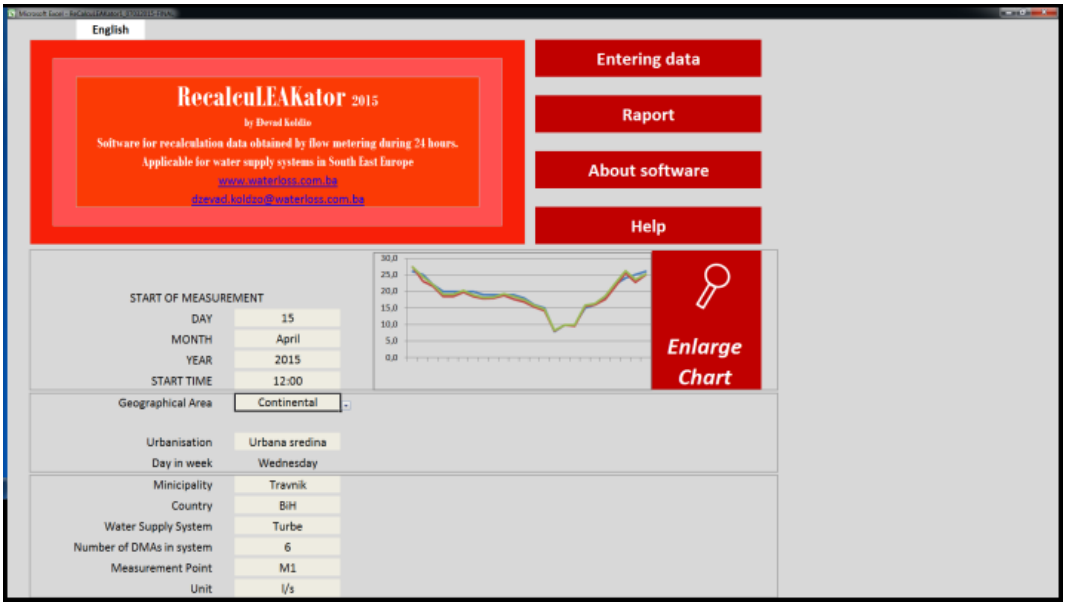

Figure 1: Software tool RecalcuLEAKator

Summary

Described methodology will allow application of bottom up approach (based on hydraulic measurements results) to become accessible for water utilities in Bosnia and Herzegovina and Montenegro. The same methodology can be applied anywhere in the world, it being understood that to carry out the collection of appropriate data based on which the analysis can be carried out. It is very important that the collected data are reliable and accurate, because the incorrect input will produce even less accurate result. Just one wrong data can create a completely wrong picture. Finding and removing such data from the analysis is laborious but inevitable job as each extreme change caused by any event is reflected badly on the results of the analysis.
IWA methodology of Water Balance is still the best methodology for the analysis of non-revenue water, but it is especially important it to be based on the results of hydraulic measurements and to avoid any kind of assessment that due to subjective and objective circumstances will always remain imprecise, sometimes even to such an extend to leads us to wonder what was the purpose of its implementation, at least when it comes to water supply systems in South Eastern Europe. Therefore, the introduction of the illustrated method using the software tool RecalcuLEAKator is an incentive for all the people aspiring to perform more precise analysis of losses in their water supply systems, and also the basis for the unified analysis of NRW elements which processed this way can be included in IBNET and DANUBIS benchmarking database and thereby to make sure that provided data in these bases are indeed comparable, which so far has not always been the case.

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