Reducing Water Losses for Sustainable Urban Development

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Abstract. From the point of view of water supply systems, and in particular of distribution networks, the environmental, social and economic criteria have had a significant role in the selection of urban water development decisions. In this respect, the article addresses the issue of reducing water losses in drinking water supply systems. Thus, there are presented the methods and technologies used and studied, currently, for the detection of damages on the pipes of the distribution networks. Continuous monitoring of the pipeline network has become an integral part of drinking water supply systems. Remote data transmission and the use of professional software allows for accurate loss detection in places where the probability of loss is maximum. The relocation method has the benefit of economies of time and money. In most developed countries, the percentage of water loss is significant. The article makes a theoretical analysis on the application of non-revenue water loss solutions (NRW) in Timisoara, Romania. At various points in the drinking water distribution network, measuring points are installed to measure the pressure, residual chlorine concentration, flow rate and flow direction. Measurement panels installed in underground fireplaces and sensors mounted directly on pipes transmit the measured data from sensors directly to the dispatcher via the GPRS data service. In addition to this information, the measurement point also generates alarms in the event of a home flood, unauthorized access, or lack of power from the grid. The results of the analysis highlight the fact that the loss reduction is quantified in water savings with positive effects on the reduction of pressure on the existing networks.

1. Introduction

It is estimated that by 2020 population growth and living standards will increase demand for water by up to 30%. In Figure 1 is represented the water withdrawals would increase by about 35% over 1995 values by 2025, with low and high estimates of 23 and 49%, respectively and are presented “Conventional Development Scenario” (CDS), with best-guess estimates of future population growth, economic development, and water-use intensity. [1].

Climate change and environmental pollution increasingly affect the availability of water resources that will have to respond to increasing demand for water [2-3].

Decreasing water resources (surface and underground), associated with inefficient use of water consumption, is increasingly threatening the safety of urban, agricultural and environmental water needs. For this reason, in order to respond to the future demand for water, special attention is needed for efficient water management, optimal water system operation and, last but not least, water loss reduction.

Sustainable use of water resources is a subject approached by researchers in various fields, since mismanagement can lead to serious financial, environmental and social problems. Various studies address issues in the fields of hydrology, hydrogeology, climate science, environmental engineering,
and optimization of municipal water supply infrastructure [1] [4-9]. This context highlights the need to introduce alternative water sources and demand management and, in particular, to take into account the sustainability of all these water sources [10].

Water distribution networks play an important role in modern societies, the functioning of which is directly related to the welfare of the population. However, water supply activities tend to be natural monopolies that guarantee a good level of these services in a sustainable way. For this reason it is necessary to evaluate the performance of water supply systems.

The huge amount of leakage water leaked into water distribution systems (physical or real water losses) and the volume of water distributed without billing (apparent losses of water) can complicate the water supply situation, especially in countries in and in transition countries [11]. The framework for managing and reducing water losses is complex and involves many components. Efficient and sustainable water management requires not only to find and implement technical solutions, but also to take political, financial and managerial aspects into account.

2. Operational performance of distribution networks
Assessing the performance of a system is the key to sustainability. From the point of view of the water supply system, performance assessment can be defined as an approach that allows assessment of the efficiency or effectiveness of a system or service by producing performance measures [12]. Currently, performance assessment is a well-known practice in the public water services sector (water supply, waste water collection and transport) [13]. Generally, two main types of performance assessment tools are available, tools available to water and sewerage managers (performance indicators) and performance assessment tools.

In many cases, the implementation of water supply development projects is based only on economic criteria, so environmental and social criteria do not have significant roles in decision-making. In this way, most of these projects will not be able to meet the main sustainable development objectives in the urban water sector.

3. Loss of water: causes and detection methods
Water losses are undesirable but inherent phenomena occurring during the operation of water supply systems, a clear obstacle to sustainability. Actual and apparent losses, along with unrecognized authorized consumption (eg sewerage or fire-fighting) are a non-revenue water (NRW) in a water supply system [11]. It can be said that water loss affects all aspects of the sustainable operation of a water supply system. Thus, efforts need to be made to analyze, quantify, combat and reduce physical and apparent water losses in water supply systems.

Water loss in the system has three major causes [14]:
- Pressure operation of water supply systems;
- Non-leaking joints of the building elements;
- Operating control is complicated and laborious.
In order to identify and remedy the damage in a short time it is necessary to go through the following steps:

- **The existence of measurement areas for monitoring debits and pressures:**
  At this stage, it is important to have a Geographic Information System (GIS) database with accurate information about the pipeline network and its components. The division of the network into District Metered Area (DMA) allows for an analysis of transit flows, in particular by following the minimum nocturnal flows that indicate the maximum loss value in the monitored area. Thus, the areas with the greatest losses can be identified and interventions can be made where there is an urgent need to reduce the largest losses. On the other hand, if there is no division of the network into DMA areas, it is necessary to measure flows in different areas with the help of portable ultrasonic flow meters or electromagnetic flowmeters with insertion.

- **Pre-locating defects**
  If water flow rates are recorded in the flow and pressure monitoring stage in a given sector then the pre-localization of the faults (Figure 2) will be carried out by mounting the noise loggers to narrow the search area. Noise loggers have the ability to collect network noise information recording network noise in the quietest interval (1 to 4 o'clock), on the basis of which thorough investigations are carried out in the verified area. Prelocalization can also be done with listening devices (contact microphones or metallic rods), but requires a longer time to narrow the search area.

- **Location of the fault**
  For the defect localization stage (Figure 3), equipment can be used to identify the location where the water loss is located, followed by a precise localization of the fault with the ground microphone, which identifies where the loudest noise is generated.

Components of Real Losses on different parts of the infrastructure (mains, service connections, etc.) are considered to consist of Background leakage at joints and fittings, unreported leaks, and Reported leaks and each have different characteristic frequencies, flow rates and duration (Figure 4).
Thus, it can be concluded that the most important factors for reducing water loss remain the time span from the occurrence of a defect, awareness, location and remedy of the defect.

4. Methods of analysis and evaluation of water losses

4.1. The NRW indicator (non-revenue water)

The NRW indicator method uses the quantification of unfeated water. This method is the expression of non-revenue water as a percentage of the water entering the system and is calculated with relation (1) [15]:

\[
\frac{V_{WS} - V_{Wi}}{V_{WS}} \times 100
\]  

Where:
- \(V_{WS}\) - Water volume supplied in the distribution network
- \(V_{Wi}\) - Water volume invoiced to all consumers

Using this method there will be seasonal differences, but it is important that delivery periods and billing periods coincide. The accuracy of determining NRW values depends on the accuracy or accuracy of the data used. Errors of some of the meters at the source or from the consumers can lead to the use of estimated values, which may lead to erroneous results. The use of the NRW performance indicator expressed as a percentage of the water produced and delivered in the distribution network has some limitations. For example, the NRW indicator can not indicate which losses are mainly "real" or "apparent" because it takes into account the technical characteristics of the network (pressure, bundle density, etc.). Once the NRW volume has been established, it must be divided into apparent losses and actual losses. NRW is therefore a more useful indicator for operators to consistently monitor and report internally on changes in water loss over time. For this reason, performance indicators have been developed that can be linked to infrastructure and network performance criteria as well as economic criteria, indicators that can provide information on the need to rehabilitate the network.
4.2. **ILI Indicator Method (Infrastructure Loss)**

The ILI Infrastructure Loss Index is developed by IWA (International Water Association), which, in purely technical terms, is a measure of how network management is used to control actual losses at current working pressure.

The ILI index is calculated by relation (2) [15] and represents the ratio between Actual Annual Actual Losses (CARL) and Unrealized Annual Real Losses (UARL):

$$ILI = \frac{CARL}{UARL}$$  \hspace{1cm} (2)

For establishing the CARL and UARL and then the ILI index, it is necessary to have the following system data:

- $QB$ - Consumed billed consumption [m$^3$/year];
- $Q_{NB}$ - Consumed non-invoiced consumption [m$^3$/year];
- $QL$ - Volume of water losses [m$^3$/year];

The volume of water loss is calculated by the relationship (3) [15]:

$$QL = Q_{RL} + Q_{AL}$$  \hspace{1cm} (3)

- $Q_{RL}$ - Real losses [m$^3$/year];
- $Q_{AL}$ - Apparent losses [m$^3$/year];
- $Q_{SIV}$ - Volume entered into the system [m$^3$/year];
- $QR$ - Registered debit [m$^3$/year]

The QR flow is calculated with the relationship (4) [15]:

$$QR = QB + Q_{NB}$$  \hspace{1cm} (4)

- $Cn$ - Number of connections;
- $Ln$ - Total network length [km];
- $Lc$ - Total network length [km];
- $Pm$ - Average network pressure [yards of pumping height];
- $QS$ - Flow provided [m$^3$/year];

The recorded QS flow is calculated with the relationship (5) [15]:

$$QS = QR + Q_{AL}$$  \hspace{1cm} (5)

- $T$ - Number of hours of daytime power [hours/day];

Actual Actual Annual Losses CARA [m$^3$/year/branch] are calculated with relation (6) [15], and the Actual Annual Losses UARL [liters/day], with relation (7) [15]:

$$CARL = \frac{Q_{RL}}{Cn}$$  \hspace{1cm} (6)

$$UARL = \frac{(A \times Ln) + (B \times Cn) + (C \times Lc)}{Pm}$$  \hspace{1cm} (7)

For a correct calculation of the ILI value, CARL and UARL must be expressed in comparable units of measurement (liters/day per line). A, B and C - are International constants (A = 18, B = 0.8 and C = 25). In the case of non-24 hours URL water supply is reduced in proportion to the hours of supply. The ILI value is influenced by local conditions, pipeline dimensions and network pressure. For example, an over-sized network operating at low pressure will generate a high ILI.

4.3. **LKM Indicator Method (Network Losses/km)**

The calculation of the LKM [m$^3$/an/km] indicator is determined on the basis of actual $Q_{RL}$ losses, but also takes into account the technical state of the network, expressed in losses per km of network length and established by relation (8) [15]:

$$LKM = \frac{Q_{RL}}{Ln}$$  \hspace{1cm} (8)
\[ LKN = \frac{QRL}{Ln} \quad (8) \]

4.4. ELI indicator method (Economic Loss Index)

For the operator of a network, the assessment of the economic value of acceptable water losses is essential and is based on the relationship between the Economic Index (EI) and the Loss Index (LI) with relation (9) [15]:

\[ ELI = EI \times LI \quad (9) \]

For EI the values are considered:

- 1.5 - the water is treated in two stages and pumped into the grid at a minimum of 5 bar;
- 1.0 - the water is treated in two steps and in the grid is distributed gravitationally, or requires only disinfection and is pumped into the system.
- 0.5 - water requires only disinfection and is distributed in the grid gravitationally.

The value LI is determined by the relation (10) [15]:

\[ LI = \frac{LKN}{3600} \quad (10) \]

To use the ELI value, you can use the classification:

- ELI > 3.5 a network with significant economic losses and where the operator should focus on reducing losses.
- 2.5 ≤ ELI ≤ 3.5 a network where losses do not generate significant operating costs.
- ELI < 2.5 a network where the level of loss is acceptable and where other loss-reducing investments are not cost-effective.

5. Estimation of water losses through performance indicators for a water distribution small system

In Romania, they are currently using two models according to which the state of the distribution networks is assessed:

- The World Bank model (WB) - which includes distribution networks of category A (good condition), ILI = 1-2 to category D (weakness) for ILI greater than 8.
- The model recommended by the National Manual of Water and Sewer Operators in Romania (MNOACR) - which encompasses distribution networks of category C1 (very good condition) for ILI = 0-10 to category C5 (unacceptable state) for higher ILI of 40.

The study was conducted for a 3.5 km water distribution network that supplies water to a locality with about 250 households and commercial agents. Estimation of water losses has taken into account a 30% metering rate. Loss indicators were also considered: the NRW indicator expressed in m\(^3\) / day and in percent, actual network losses in m\(^3\) / day and percent, actual losses per line / lane / day and ILI indicator.

The analysis was carried out in the following hypotheses:

- the losses due to the errors of water meters were considered 0% of the authorized consumption invoiced;
- For unauthorized consumption, four possible scenarios were considered: 0%, 25%, 50% to 100% of the authorized consumption;
- The ILI indicator was calculated at a 2.5 bar pressure (pumping station discharge pressure).

The resulting performance indicators are presented for 2017 in Table 1.

Obviously, NRW has a constant value irrespective of the variation in apparent loss, but all indicators that relate to physical loss are diminishing accordingly. From the unauthorized consumption analysis ranging from 0% to 100% of the authorized consumption, it is noticed that the ILI indicator has decreased about 15 times. In the case of a 100% authorized consumption (ILI = 2), according to the
MNOACR model, the state of the network is very good with an acceptable loss level and no investment is needed to reduce it, and according to the BM model, the state of the network is in the category of good or potential improvement networks (premanagement management, improved active control of failures and better system maintenance).

Table 1. Performance indicators

| Indicators                                      | UM Scenarios | 0% | 25% | 50% | 75% | 100% |
|------------------------------------------------|--------------|----|-----|-----|-----|------|
| NRW m³/day                                     |              | 260| 260 | 260 | 260 | 260  |
| %                                              |              | 51 | 51  | 51  | 51  | 51   |
| Real Losses on the Water Network m³/day         |              | 257| 195 | 139 | 77  | 16   |
| %                                              |              | 50 | 38  | 27  | 15  | 3    |
| Real Losses on the Pipe Branching l/b a/day    |              | 1009|779 |550 |323 |92  |
| ILI                                            |              | 29 |22  |15  | 7   | 2    |

* a b – pipe branching to the water network.

If for 100% authorized consumption, the two models are not subject to major differences, in the case of unauthorized use of 50%, the ILI = 15 indicates, according to the MNOACR model, a low risk level for which no special measures are needed to improve of this indicator, and the BM model evaluation indicates poor network performance due to inefficient use of resources and NRW reduction programs are imperative.

On the basis of the study and comparison of NRW and ILI performance indicators, the most eloquent example is that associated with the ILI indicator. It can be noticed that the NRW indicator can not lead to making correct losses reduction decisions, but the ILI indicator can provide real information. Undevelopment of apparent losses may lead to sets of measures to reduce non-economic losses, with an unjustified emphasis on reducing physical losses.

6. Conclusions

Water losses in water supply systems are an essential issue for the sustainability of their operation, generating the following effects:
- Economic - for system users;
- Fundamental - for freshwater and environmental resources;
- Important - for the energy lost in the environment.

Losses of water loss make the link between water loss indicators and asset wear rates resulting in rehabilitation programs.

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In Romania the importance and impact of the measures differ according to the chosen evaluation model, which means that the under-assessment of the apparent losses can lead to unspent loss reduction measures, placing unjustified emphasis on reducing physical losses. In conclusion, a top-down and bottom-up combined and realistic approach to water balance assessment is needed to assess the state of the networks and to establish measures to reduce water losses.

Another important conclusion is to highlight the effect of unauthorized metering and consumption on the ILI performance indicator.

Effective approach and problem solving is required to protect the water resource. It is generally considered that NRW reduction solutions are too costly and, therefore, there is often not a careful assessment of the efficiency of investment in pipelines, water meters or new fittings. An effective approach involves performing analyzes of the cost of long-term loss as a result of the use of defective...
or high-wear assets and comparing them with the cost of operating a rehabilitated / upgraded system. Loss recovery can be transformed into a new source of revenue by reducing operating costs.

Based on water performance indicators, a methodology can be established to assess the performance of the infrastructure and therefore the network rehabilitation needs can be prioritized.

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