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STUDIES AND RESEARCH ON PIPE NETWORKS WATER LOSSES

Ştefania CHIRICA[1], Mihail LUCA[2]
[1] Technical University "Gheorghe Asachi" of Iasi, Romania
[2] Technical University „Gh. Asachi", Mangeron Dumitru Str. 63, 770800, Iasi, Romania,
Tel./Fax: +040 232 270804
e-mail: mluca2015@yahoo.com, stefania.chirica@gmail.com

ABSTRACT

The issue of water losses in pipe networks (transmission mains, conveyance and distribution pipelines) is one of the major problems encountered in water supply systems management. The losses have reached very high values, in some cases up to 60% of the water volumes entering the networks, and therefore they require urgent measures to reduce them. In Romania, the average non-revenue water percentage amounts to 48.3%, ranging from minimum values of 22% and maximum values of about 68%. The significance of addressing this issue properly is reflected in the concern of national and international bodies, such as ARA (Romanian Water Association) and IWA (International Water Association), which analyse the systems' status and establish appropriate directions of action to be followed. The powerful development of industry and intensive agriculture in the last decades, in conjunction with global warming, has had a major impact on water resources. In the international context of quantitative and qualitative water sources reduction, adequate water loss management must become one of the water - sewerage agencies' top priority. Solving this issue requires a long-term approach, which involves rehabilitation and modernization measures, appropriate metering for the supply system's conveying water flows, implementation of hydraulic modeling software and leakage detection equipment. Water losses can be found under commercial and physical aspects. Amongst these, the physical ones have the highest share, as they affect all the water supply system components: transmission mains and distribution networks, storage tanks etc. Water loss management must contribute to the efficient resource usage through prevention and intervention measures, adjusted to the particularities of the situation being addressed.

KEYWORDS: water scarcity, physical and apparent water losses, non-revenue water, pipe degradation

1. Introduction

Water supply systems face the issue of water loss in all the components: catchment, treatment plant, storage tanks, distribution network, etc., materializing in losses of raw and treated water, intended for domestic, commercial and industrial consumption. Distribution networks are often faced with this issue, given the vast pipeline networks, their operational and maintenance process peculiarities and the high costs required by their optimal management. In the international context of global warming phenomenon, one of the priorities regulated at national and international level ought to be to water losses reduction and viable water sources protection. Water scarcity must be fought with massive investments in the water supply systems' infrastructure, rehabilitation, modernization, monitoring and prevention works for the defects, which lead to water loss.

2. Material and method

The material analyzed consists of the water supply system: water tanks, adductions, distribution network, connections, etc. The largest water losses are recorded in the pipeline network. In this case, defects resulting from the embedding environment, operational process and maintenance conditions lead to losses that directly affect consumers. The water losses, which go undetected, cause major problems in regard to the stability of the land where the pipelines are located, whilst the visible ones, which manifest themselves in a spectacular way, visible on the surface, create major discomfort and material damages.

The research methodology seeks to analyze the methods used by water – sewerage utility companies to limit losses and repair the deficiencies which manifest themselves in the water supply systems. The variety of the methods used results from the extremely varied situations that may occur on the ground. The nature of the deficiencies which lead to the appearance of water losses requires the adoption of measures adjusted to the specifics of the problem, so that the efficiency of the damages localization and repair is maximal. The methodology used to reduce water losses should be chosen based on a number of factors such as:

- the location of the defect (distribution pipes, connections, water tanks, valves, etc.);
- the size of the deficiency;
- the volume of water loss caused;
- the characteristics of the embedding environment in the analyzed area;
- consumers' distribution, etc.

3. Results and discussion

Water loss reduction can be summed up to a series of activities, which use methods to decrease the percentage of non-revenue water and protect the available water sources. The implementation of a water loss reduction methodology should use elements adjusted to the specificity of the water supply system studied. The components in question are inspected and analyzed using both human and material resources, together with top of the range equipment and technologies in the field of water loss detection and reduction.

The main methods used to control water losses are analyzed below.

1. Pressure management is used to monitor and analyze pressure values in the network's main nodes, to correlate the pressure in the supply and consumption nodes, or to configurate the network into district monitored areas and reduce pressure by installing line valves. A constant drop in the pressure value implies the existence of water losses and an increase of the pressure value indicates faults in the valves and pipes or changes in the recorded consumption.

2. District metering allows the water flow to be recorded at the entrance and exit points of an area isolated by valves and supplied through a single node. The water loss is determined by isolating the area analyzed and by cutting off the consumers' water supply. The subsequent isolation of pipe sections in the studied area allows the accurate identification of the losses.

3. The partial metering is used for measuring the water flows conveyed through the water supply system at the catchment point, storage tanks, pumping stations, treatment plants, consumers, etc. The metered water volume must be found in the billed volumes and the ones used for the system's own consumption, otherwise, the difference between these values is quantified into water loss components.

4. Nighttime flow measurements consist of keeping track of the water level variation inside storage tanks, the use of district metering or of the water balance in the studied area. The recorded nocturnal consumption, which exceeds a minimum threshold determined according to the number of inhabitants, is considered to be one of the water losses' components.

5. Pipe network inspection involves:

- the use of water loss detection equipment (loggers, correlators, electronic ears, etc.) to identify hidden defects in the pipeline;
- visual inspections of the water supply system components to reveal noticeable flaws and damages.

The equipment and technology used is mainly based on locating the source of the noise produced by water when it exits through a defect on the pipe with pressure.

6. The water balance drawn up both for the entire water supply system coverage area and for each sub-system, illustrates the distribution of water volumes supplied into the system and shows the critical points of the water scheme, which contribute to the amplification of the water loss phenomena.

7. The rehabilitation and modernization of the water supply system involves:

- the replacement and rehabilitation of damaged pipe sections, valves and network constructions;
- the usage of state of the art high performance materials;
- the upgrading of measurement and control equipment etc.

The radical nature of this method leads to a significant decrease of water losses, however, due to the very high investment costs it implies, it is recommended only in those cases where the other methods of control and loss reduction would not be successful.

8. The SCADA (supervisory control and data acquisition) software implemented for the entire water supply system takes the data recorded from the water system components and sends them to the dispatcher where the information is analyzed, thus ensuring effective control of physical water losses.

9. Making the GIS (Geographic Information System) model by integrating and processing field collected data, which then, exported, provides

information on the existing infrastructure and the history of the maintenance and operational works carried out. The information provided is used for:

- the configuration of the network into district monitored areas;
- the implementation of the pressure management;
- the planning of the inspection, rehabilitation and modernization activities.

10. The implementation of the hydraulic model for the water supply systems should be operated by collecting field data, processing them and calibrating the initial model. The calibrated model provides information on network flows and pressures, allows simulation and identification of optimal district areas, sets the minimum night flow, illustrates the effect of pressure management and marks sensitive areas identified in the water supply system.

Water losses are categorized into apparent losses and actual losses. The category of apparent water loss is made up of the component resulting from measurement errors and from unauthorized (fraudulent) consumption. Addressing this loss category focuses primarily on:

- elements which analyze the performance of the measurement equipment;
- network inspection campaigns;
- the identification of illegal links.

The contribution of apparent water losses to the total losses in a water supply system is very small compared to the real losses. The category of real (physical) water losses consists of the volumes of water lost from storage tanks, distribution network, adductions and connections up to the point of consumption. Physical water losses fall into three broad categories:

- visible and reported;
- hidden and unreported;
- background leaks.

The last two categories, the hidden and the background losses, are the ones which sum up the highest volumes and occupy the largest share of the total water losses recorded in a water supply system. Loss reduction measures are largely focused on addressing and remedying deficiencies, which cause physical water loss.

Reducing water losses with nocturnal flow measurements is a method that allows the operator to locate and identify the size of the defect through which water leaks from the pipeline network or storage tanks. The method is based on the principle that, between 00:00-04:00, the recorded consumption is considered to be a component of water loss. However, for the method and measurements to be accurate, a minimum nocturnal flow value, corresponding to household consumption is considered. The values obtained above this threshold are quantified as water losses. The specialty literature shows some basic values of the minimum nocturnal consumption (Table 1), but these values have to be adjusted to the specificity of each area. Operators should establish the minimum night consumption for each sector analyzed, taking into account the industrial or commercial type of activities carried out in the studied area, as well as the domestic one, through the use of meters. The statistical data show that the value of the minimum night flow is influenced by the total number of connections, the length of the pipelines in the analyzed area, the age and their execution materials (Jaber M.A. Alkasseh *et al.*, 2013).

Table 1. *Estimated values for night consumption (Cheung P.B. et al., 2010)*

Number of inhabitants in the analyzed area	Minimum night flow (l/min)
< 10,000	0.01
10,000 – 50,000	0.01 – 0.02
50,000 – 150,000	0.02 – 0.025
150,000 – 500,000	0.025 – 0.05
> 500,000	0.05 – 0.1

In order to obtain real-time data that reflect the field situation with the use of nocturnal measurements, it is required increased attention from the operator as this study method is based on work procedures and carefully selected equipment for that purpose. Among the most important factors to consider are listed (Werner M. *et al.*, 2011):

- choosing the appropriate flowmeters to record the system's minimum flow rates with high precision;
- adequate district area configuration, so that flows entering and leaving the study region can be effectively monitored;
- adequate installation of the recording equipment, sensors and data transmission devices used;
- regular inspections of the equipment and its field calibration when the situation in the study area requires it.

Regional Operator S.C. APAVITAL S.A. monitors the water volumes entering and leaving the system through more than 60 district areas and transition flow meters. In the case of pumping stations, pipelines serving different areas as well as those with a different pressure regime are monitored. The values obtained are recorded in monthly summarizing tables, together with the observations made by the operator. The accuracy of the recorded data is influenced by the phenomena that may occur during a monitoring interval. The analysis of the results obtained must also take into account the observations of the operator. These refer to:

- methods of calculating the resulted flows;
- flaws in the measuring equipment and repair works;
- consumers’ information;
- data transmission errors;
- values which do not fall within the normal consumption limits, etc.

The Red Cross district metering area is located in the western part of Iaşi metropolitan area, being situated in the Păcurari storage tanks area (Fig. 1). The small size of the monitored surface (Fig. 2) allows for an analysis of recorded water consumption and flows through the water supply system, highlighting the problems encountered in this study area.

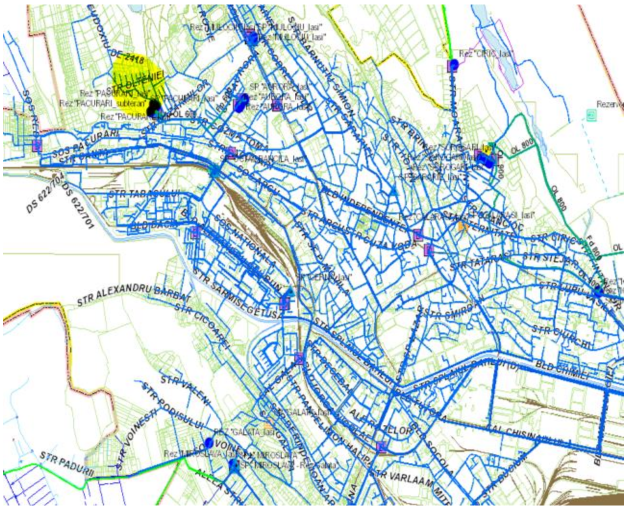

Fig. 1. *Framing of the study area in the water supply system assembly of Iaşi county*

Fig. 2. *Red Cross district metering area*

Measurements conducted in the Red Cross district area during 2009, 2012 and 2014 show the variation in the minimum and maximum hourly flow rates in the system for this particular study area. Interpretation of the obtained data has been done through:

- the reference values found in the specialty literature;
- the hydraulic characteristics of the water supply system (flows, pressures, specific consumption and consumption categories);
- the constructive characteristics of water utility networks (materials, diameters, operational span).

Measurements conducted in the Red Cross district area in 2009 (Fig. 3) show maximum flow rates exceeding 15 m^3/h. At the same time, the minimum flows range around 7.6 m^3/h. The lowest recorded values are during 22.01.2009 - 23.01.2009, between 23:00 and 05:00 time slot. On 23.01.2009, the 02:00-03:00 time slot shows maximum hourly flow rates of 9 m^3/h and a minimum hourly flow rate of about 7.5 m^3/h. The values recorded in this case far exceed the values estimated in the specialty literature. The data show that the pipeline network is damaged and records major water losses. Such values show the urgent nature of the rehabilitation and replacement measures needed by the pipeline network. In their absence, the damages will be more and more frequent, the defects will multiply, and the lost water volumes will continue to increase.

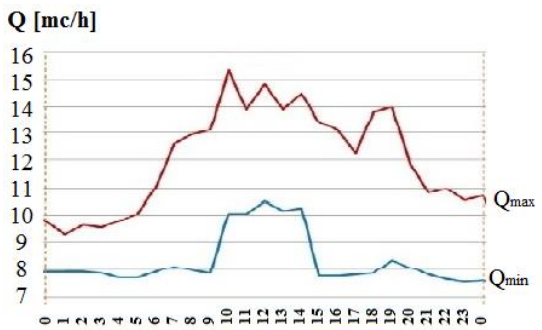

Fig. 3. *Flow rate measurements conducted in in the Red Cross district on 22.01.2009 (color code: red – Q_{max}, blue – Q_{min})*

Measurements conducted in the Red Cross district area during 2012 (Fig. 4) show an increase in the minimum recorded flows rates compared to the values from 2009. Within a three-year period, the minimum hourly rate has increased and is now situated around 12 m^3/h, slightly surpassing 13 m^3/h during peak time. The hourly time slot with the lowest recorded consumption is 03:00-04:00 when the minimum hourly flow rate is 12 m^3/h, and the maximum is around 13.4 m^3/h. Also, increases in the maximum hourly flow rate were observed, coming close to 19 m^3/h, higher than 15 m^3/h in 2009.

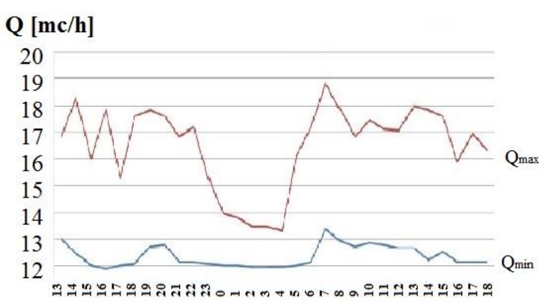

Fig. 4. *Flow rate measurements conducted in in the Red Cross district area during 13.03.2012 – 14.03.2012 (color code: red – Q_{max}, blue – Q_{min})*

Compared to 2009, there is an increase of 4.5 m^3/h of the minimum hourly flow rate. The 57% increase in nocturnal water consumption shows the magnitude of the water loss phenomenon in the pipeline network. The additional consumption as compared to 2009 suggests that during the three years no measures have been taken to replace, rehabilitate or modernize the pipeline network serving the analyzed area.

The measurement campaign conducted during 10.01.2014 - 13.01.2014 (Fig. 5) shows much lower values than those obtained in 2009 and 2012. On 11.01.2014 it was recorded the maximum hourly flow rate of about 10.3 m^3/h. The minimum hourly flow rate was obtained during 00:00-06:00 time slot, and its value is below 1 m^3/h. Compared to the data obtained in previous measurement campaigns, the values are much lower. The maximum hourly flow rate of 10.3 m^3/h is lower than the value achieved in 2012 for the minimum hourly flow rate. Such values show the actual magnitude of the losses. Replacement and rehabilitation of pipelines in the Red Cross district area led to significant decreases in water losses.

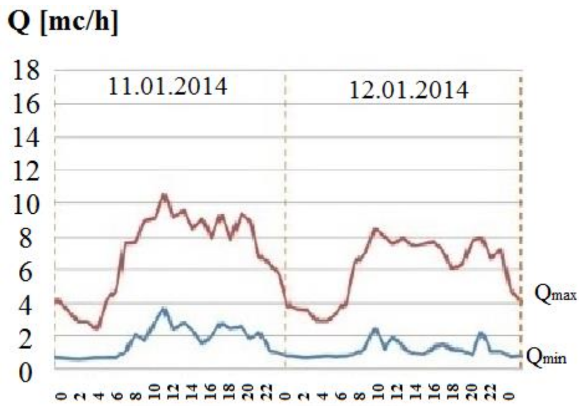

Fig. 5. *Flow rate measurements conducted in in the Red Cross district area during 11.01.2014 – 12.01.2014 (color code: red – Q_{max}, blue – Q_{min})*

The data recorded during 2009, 2012 and 2014 were analyzed and taken into account, showing the evolution of the minimum and maximum hourly flows obtained during the studied periods (Table 2).

The analysis of the data from Table 2 shows the evolution of the minimum and maximum hourly flow rates recorded during 2009 - 2014 in the Red Cross district area. The variation in the minimum and maximum hourly flow rate values from the measurements shows the significant increase in water consumption between 2009 - 2012. The value of the minimum hourly flow has increased with about 4.40 m^3/h, which represents a percentage increase of about 57.89%. The time slot in which these values were recorded, namely 23:00-05:00, is characterized by minimal levels of water consumption. Furthermore, there is no industrial activity in the Red Cross district area, and commercial businesses in this space do not require water consumption during the night. The only type of consumption in the analyzed sector is domestic, but the values obtained are well above the normal data found in the specialty literature for this time interval. Thus, the data obtained suggests water loss in the network. The analysis of the next time interval, 2012-2014, demonstrates the effectiveness of the reduction measures undertaken by the water-sewerage agency. The decrease in the minimum consumption by 11.20 m^3/h represents a reduction of 92.67% of the flows conveyed through the water supply system.

Table 2. *Analysis of the values obtained during 2009 - 2014 in the Red Cross district area*

Specific values	2009	2012	2014
Q_{min} [m^3/h]	7.60	12.00	0.80
Time slot	23:00 05:00	03:00 04:00	02:00 06:00
Variation [m^3/h]	-	+ 4.40	- 11.20
Variation [%]	-	+ 57,89	- 92.67
Q_{max} [m^3/h]	15.30	18.80	10.30
Time slot	10:00 11:00	06:00 08:00	10:00 12:00
Variation [m^3/h]	-	+ 3.50	- 8.50
Variation [%]	-	+ 22.87	- 45.21

The study of maximum hourly flow rates recorded in the Red Cross district area shows a similar evolution to the one of the minimum hourly flow rates, although the magnitude of the water loss phenomenon is not highlighted to the same extent. The period between 2009 and 2012 is characterized by increases in water consumption by up to 22.87%. The maximum values are recorded in the consumption intervals 10:00-11:00 and 06:00-08:00. As with the minimal hourly flow rate variation, peak values were significantly reduced during the 2012 - 2014 monitoring period. The consumption decrease of 8.50 m^3/h represents a decline of 45.21%. Thus, a stricter control of the volumes transported across the network is achieved. The actions and measures implemented by the operator aligns the performance of the water supply system to the European and global standards and guidelines for reducing water scarcities as well as improving water volume extraction and protecting viable water sources.

4. Conclusions

1. Water supply systems face the problem of water loss, a phenomenon which can be found at all the components (catchment, treatment plant, pumping stations, adduction, storage tank, distribution network, etc.).

2. Water - sewerage companies use specific methods to reduce water losses recorded in the system, adjusting them to field conditions correlated with data obtained from a thorough analysis of the operated networks.

3. One of the most applied methods for identifying and detecting water losses consists of using the nighttime flow rate, when the values recorded with the measuring equipment are only justified by the presence of water losses in the system analyzed.

4. The nocturnal flow measurements conducted between 2009 and 2014 in the Red Cross district area show the magnitude of the "water loss" phenomenon, evidenced both by an upward and a downward trend for the water flows conveyed through the system.

5. Values recorded between 2009 and 2012 illustrate the speed of degradation of the elements which make up water systems and the magnitude of water losses in the absence of rehabilitation and upgrading measures adjusted to the specific situation of the field.

6. The analysis data from 2014 highlights the efforts of the regional operator S.C. APAVITAL S.A. to reduce water losses through massive investments in the water supply system infrastructure, as pointed out by the very low values of the minimum hourly flows recorded.

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