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CONSIDERATIONS REGARDING WATER LOSS FROM DISTRIBUTION NETWORK ANALYSIS

BY

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Abstract. The paper presents the analysis of water loss occurrence and evolution from urban and rural distribution networks. Water losses from pipes are an important issue in the management of water supply systems. Water losses come to consume approximately 35,...,45 % of the water entered into the water supply system. This issue is addresses with great interest at national and international levels. The paper presents the mechanism of the losses, how they occur and the method of analysis and interpretation of the effects. The paper comprehensively analyses the methods of identifying the network’s defects and damages, which can lead to the loss of water. Limiting water loss requires spending significant amounts of money and increases the specific price of drinking water.

Keywords: pipes; pipe failure; defects; analysis parameters.

1. Introduction

Water distribution companies are constantly faced with the issue of meeting the consumer’s water demand and with the delivery of services that fit the standards of operational quality and safety. Water losses come to consume approximately 35,...,45 % of the water entered into the water supply system. This issue is addresses with great interest at national and international levels.

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The water loss issue has become particularly important due to the shrinkage of potable water sources and the degradation of their quality.

The losses are reflected in the additional charges demanded by the catchment, treatment, pumping and distribution of larger water quantities which are required to cover the consumer demand. Additional costs are required to develop environmental procedures where they are imposed by the pipe exfiltrations which have an negative impact on the environment. The continuous decreasing of water sources requires water loss reduction in the adduction and distribution networks.

Given that the issue of water loss puts pressure on the water supply system's proper functioning, often leading to significant economic damage, it is necessary to study the phenomenon's occurrence ways and the factors contributing to the system's degradation.

2. Water Loss Management

Physical water loss may occur among all components of the water supply system. The majority of water losses do not manifest at the surface, and become visible after a long period of time (period in which great water volumes are lost). The water losses occurring at the surface are immediately fixed, therefore the lost water volume is reduced. The size of the losses depends on the infrastructure conditions, along with the internal water companies politics in terms of management and loss detection. In most cases, the damage caused by the loss of small volumes of water that go unnoticed for years are significantly higher than the spectacular bursts manifested on the ground surface.

Water loss can be found in the following forms: physical loss, unauthorised consumption (theft), metering errors, faulty administrative procedures and handling of data. Physical losses are responsible for the biggest problems in the operational activity because they can be found in a variety of forms and sizes and are often difficult to identify. Physical water loss occur due to the network's defects and damages. The leaks can be classified according to the size of the failure as follows (GIZ, 2011):

1. Visible or reported leaks, caused by main bursts or joints failure in the distribution and adduction pipes. They appear towards the ground surface and at the ground surface and are easy to locate on site.

2. Hidden or unreported leaks, which do not appear at the surface and require special leak detection equipment. The leakage flows generated by them are greater than 250 l/h at 5.0 bars pressure.

3. Backgound leakage have flows under 250 l/h at 5.0 bars pressure, appear as water drops and can't be detected by using acoustic methods.

Physical water loss can be classified in the following categories, according to their emergence location:

a) distribution and transmission networks leakage; they occur at pipes, valves and joints and have high and medium flow rates at medium and short runtimes;

b) service connections leakage; due to their construction and materials used, service connections are considered weak spots; the leaks generated on service connections are challenging to detect due to their low flow rates and very long runtimes;

c) water supply sistem structural components leakage (storage tanks, pumping stations, water treatment plants, water overpasses and underpasses) due to water exfiltration, evaporation, run tests etc.

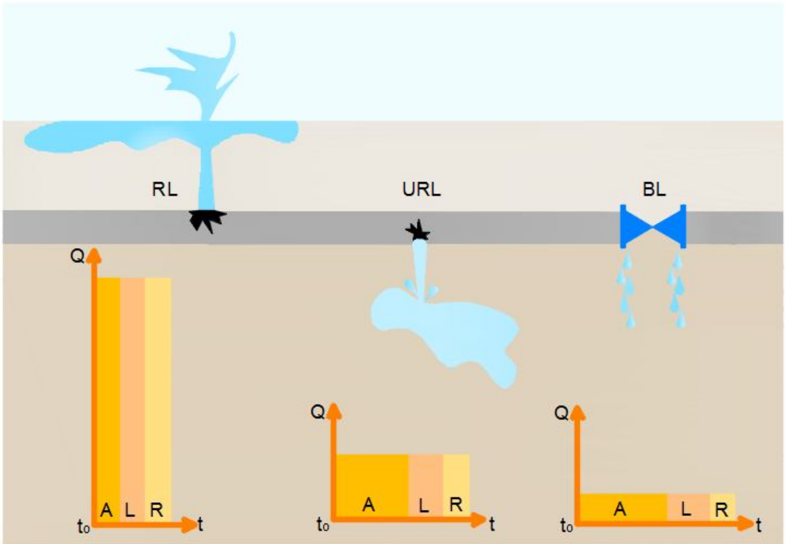

Fig. 1 – Pipe leakage classification and the relation between leakage flow and runtime: RL – reported leakage; URL – unreported leakage; BL – background leakage; A – awareness; L – location; R – repair; Q – leakage flow; *t* – runtime; t_0 – occurrence of leakage (adapted from GIZ, 2011).

A large part of leakages are a result of systematic or accidental water supply network operating errors.

Physical water loss management can be schematically represented according to the factors and parameters involved in the phenomenon and the water supply network operational process (Fig. 2).

Water loss reduction can be achieved by implementing the four key factors in the following way:

a) field active leakage control should be introduced to detect the leakage occurrence and evolution;

b) repair times must be as short as possible in order to have low runtimes; it is important to correlate detection and repair activities to achieve low leakage levels;

c) it is required a continuous network assessment on the longterm, damaged pipes should be rehabilitated or replaced using materials with high quality parameters;

d) active pressure management should be used during the operational process of the supply network.

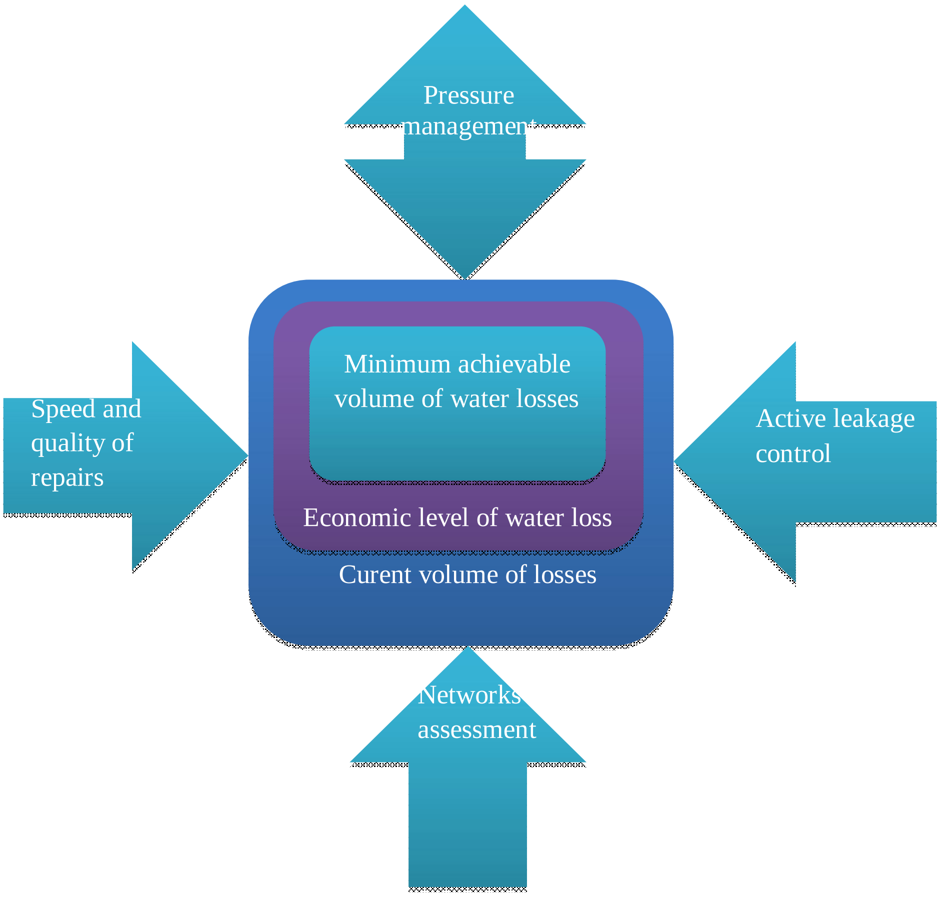

Fig. 2 – Water loss management (Lambert, 2003).

Water supply systems are complex structures, exposed to special operating conditions which do not always allow their rigorous control. The main factors which can cause water leaks to occur in the potable and industrial water supply network are: pressure, temperature, the embedding environment characteristics, the degradation of pipes and fittings, defects, damages, maintenance and repair schedule etc.

1° Pressure

High pressure can lead to higher lost water volumes and it also increases the probability of occurence of new leaks. High pressures favours the prompt discovery of leaks and therefore the water loss. However, a low pressure makes it difficult to locate the leaks and allows the flows to leak undetected for an extended period of time. Pressure management efficiency is described through the equation (Morrison *et al*., 2007):

$$L_1 = L_0\,(P_1/P_0)^{\alpha}, \tag{1}$$

where: L_0 is the initial flow rate of the leakage at P_0 pressure; L_1 – flow rate of the leakage at P_1 adjusted pressure; P_0 – average initial pressure; P_1 – average adjusted pressure; α – leakage exponent.

2º Temperature

According to studies conducted by Steven Folkman, quoted by Saadeh (Saadeh *et al*., 2013), the number of failures increases especially during winter, when temperatures drop below 10°C. Temperature variations cause tensile stress in the pipes, leading to the formation of circumferential cracks. Data collected between 2010–2013 from Fort Wayne water supply system confirms this (Table 1). The highest percentage of failures was registered in January (Saadeh *et al*., 2013).

Table 1

Failure Percentage Across Calendar Months in Fort Wayne Between 2010–2013

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
%	13.6	7.5	3.7	6.6	4.4	5.5	10.7	10.1	8.6	9.2	9.5	10.4

3º The interaction between the pipe and the embedding environment

The pipe laying conditions must satisfy and guarantee the water supply system operational safety. Gallage and collaborators have shown the earth’s movement around buried pipes (Gallage *et al*., 2009). From (Fig. 3) it can be observed how the earth’s movement becomes more pronounced as the depth of the pipe laying increases. An important factor is the terrain humidity, primarily caused by rainfall, but also by groundwater, which directly affects the ground stability.

Temperature variations, humidity, freeze – thaw process cause movement at ground level. The effects of these movements consist in joints disconnection, fittings stress or pipe failure.

The permeability of the rocks from the embedding environment is the factor which determines the velocity and how the exfiltration from the pipe will manifest. If the ground has a high permeability (the case of weak and non cohesive rocks), under the effect of the pressure gradient, the water movement will rapidly develop towards the ground surface. For cohesive rocks, with low permeability, the water movement will be slower, mainly towards the depth of the ground, and the phenomenon will remain hidden.

Chemical and electrical aggression of the embedding environment can amplify the external corrosion of the pipes.

The pipe network design process must take into account traffic conditions on the surface area of the site, especially heavy traffic loads. The pipe laying in heavily travelled areas must be managed with great care to prevent additional failure.

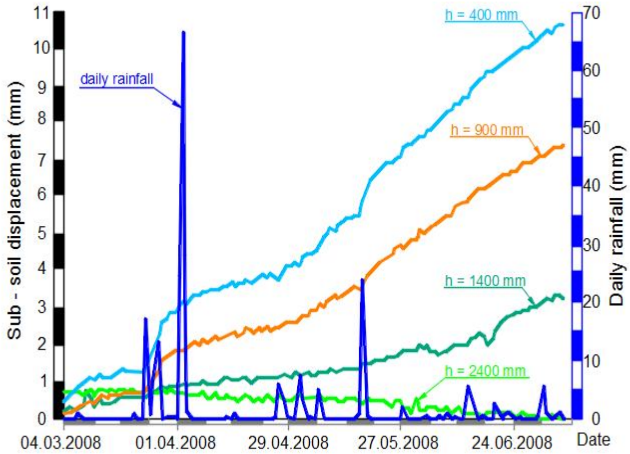

Fig. 3 – Terrain movement in accordance to the pipe laying depth (Gallage *et al.*, 2009).

4º Pipe degradation

The pipes used in water supply systems are made of different materials, each possessing different properties. The network's components degradation may occur under the following circumstances:

- pipe aging due to the operational process or due to the exceedance of the standard operational life;
- the existence of hidden manufacturing defects;
- incorect use of technological execution procedures;
- poor quality of the network design process that did not take into account the characteristics of the embedding environment;
- lack of repair and maintenance work.

Table 2
Main Failure Modes (Rajeev *et al.*, 2013)

Type of failure	Failure mode
Pin holes	Corrosion
Longitudinal split	Corrosion and internal pressure
Circumferential split	Ground movement and external loads
Pieces blown out	Corrosion and internal pressure
Joints leakage	External or internal loads, thermal loads and construction defects

A study conducted on large diameter pipes operated by five companies in Australia indicates the failure rates for each type of material found in the water supply network (Rajeev *et al.*, 2013) (Table 3). The materials studied were: cast iron, cement mortar lined cast iron, steel, cement mortar lined steel, cement mortar lined ductile iron, asbestos cement – AC. Data recorded in the analysed pipe networks shows that the most reliable material is ductile iron, which was rehabilitated with the use of cement mortar.

Table 3
Pipe Failure Rates Recorded in Australia Differentiated on the Type of Material Used for the Water Distribution Network (no. failure/km/year (Rajeev *et al*., 2013))

Company	Period (number of years)	Cast iron	Cast iron cement mortar lined	Steel	Steel cement mortar lined	Ductile iron cement mortar lined	Asbestos cement
A	2000–2012 (13)	–	7.20	–	4.20	–	2.8
B	1973–2010 (38)	34.50	–	–	3.10	0.10	2.2
D	1998–2012 (15)	–	14.00	–	5.10	0.80	–
E	1996–2009 (14)	7.80	8.90	6	2.40	1.85	4.2
F	1997–2012 (16)	29.50	21.50	42	8.00	8.00	–

U.S.A. University of Utah has conducted a study on the frequency of water distribution networks failure in a number of areas from the U.S. and Canada. The study data revealed the way in which pipe made from different materials degrade (Folkman, 2012).

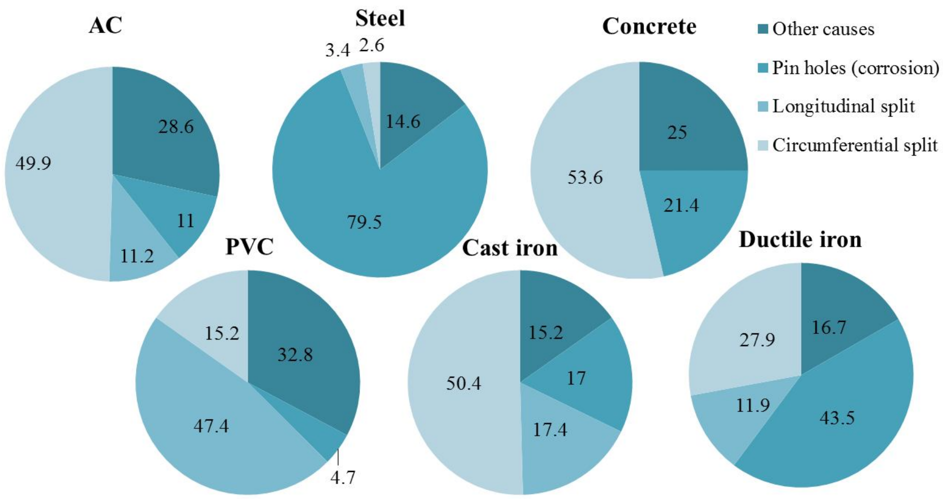

Fig. 4 – Degradation mode of pipes in accordance to their type of material (expressed as percentage (Folkman, 2012)).

Data analysis (Fig. 4) shows that mechanical action and chemical corrosion are the main factors leading to pipe degradation. The water's mechanical action combined with the embedding environment leads to the damage of the steel pipes due to the emergence of circumferential cracks. This type of degradation can also be found in pipes made of asbestos, cement and cast iron. Degradation due to longitudinal cracks occurs mainly in PVC pipes. Other causes leading to pipe degradation could be: standard operational life, pieces of material blown out, leakage from fittings and valves, joints disconnection or other defects.

5º Defective valves, fittings and fire hydrants.

Water losses appear around valves, fittings, joints, street fountains or fire hydrants. Due to the small volumes of water lost, they are difficult to detect and repair. The damages often occur for extended periods of time and lead to significant water losses. The failure is caused by: advanced degradation due to the operating lifetime, hidden defects or inadequate working procedures. Preventing and remedying this type of failure requires the existence of continuous network monitoring programs within water companies.

3. Conclusions

1. Water loss management must become a priority for water distribution companies. It must include continuous specialised network assessment, monitoring and control programs.

2. Limiting water loss activities must be carried out from design and pipe network execution phases by providing high quality and efficient materials, and modern execution processes.

3. Water companies must comply with the standard operational life of the pipes, valves and fittings that make up the network and include those approaching or exceeding this period in rehabilitation or replacement programs.

4. Operational activities should include water loss monitoring programs throughout the supply and distribution network and the staff should be specialised in this field.

REFERENCES

Folkman S., *Water Main Break Rates in the USA and Canada: A Comprehensive Study*, Buried Structures Laboratory, Utah State University, 2012.

Gallage C., Chan D., Gould S., Kodikara J., *Behaviour of an In-Service Cast Iron Water Reticulation Pipe Buried in Expansive Soil,* Ozwater '09: Australia’s National Water Conf. a. Exhibition, Melbourne, Australia, 2009.

Lambert A.O., *Assessing Non-Revenue Water and its Components - a Practical Approach*, Water 21 - Magazine of the Internat. Water Association, Vol. August 2003, 50-51.

Luca M., Toma D., Bălan A., Luca Al.L., Apetroi I.V., *The Adduction Pipes Management on Limiting Water Loss*, Rev. Rom-Aqua, An XXI, nr. *8*, Bucureşti, Romania, vol. **106**, 19-30 (2015).

Mănescu Al., Sandu M., Ianculescu O., *Alimentări cu apă*, Edit. Did. şi Pedag., Bucureşti, 1994.

Morrison J., Tooms S., Rogers D., *District Metered Areas Guidance Notes*, IWA Publishing, London, United Kingdom, 2007.

Rajeev P., Kodikara J., Robert D., Zeman P., Rajani B., *Factors Contributing to Large Diameter Water Pipe Failure as Evident from Failure Inspection*, Proc. of LESAM 2013 Strategic Asset Manag. of Water and Wastewater Infrastructure, Sydney, Australia, 2013.

Saadeh M., Beck S., Ngwenya K., *Optimal Design of Water Distribution System to Minimize Risk of Water Main Breaks in Western Fort Wayne*, Civil Engng. Program, Dept. of Engineering, Indiana University - Purdue University, Fort Wayne, USA, 2013.

* * * *Manualul naţional al operatorilor de apă şi canalizare*, Ministerul Mediului şi Pădurilor, 2010.

* * * *Normativ privind proiectarea, execuţia şi exploatarea sistemelor de alimentare cu apă şi canalizare a localităţilor*, NP 133-2013, Vol. **1**, Edit. Matrix, Bucureşti.

CONSIDERAŢII PRIVIND ANALIZA PIERDERILOR DE APĂ DIN REŢELELE DE DISTRIBUŢIE

(Rezumat)

Lucrarea prezintă analiza modului de apariţie şi evoluţie a pierderilor de apă din reţelele de distribuţie amplasate în localităţi. Pierderile de apă din conducte reprezintă o problemă importantă în managementul sistemelor de alimentare cu apă. Pierderile de apă ajung să consume circa 35,...,45 % din apa intrată în sistemul de alimentare cu apă. Această problemă este tratată în mod deosebit pe plan naţional şi internaţional. Lucrarea prezintă mecanismul apariţiei pierderilor, modul în care acestea se manifestă şi modul de analiză şi interpretare a efectelor. Lucrarea analizează în complex modul de identificare a defectelor şi avariilor ce apar în reţeaua de conducte şi care pot determina pierderi de apă. Limitarea pierderilor de apă impune cheltuirea unor fonduri importante şi determină creşterea preţului specific al apei potabile.