CONSIDERATIONS REGARDING MAIN WATER PIPELINES MONITORING FOR THE PURPOSE OF LIMITING WATER LOSS

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Abstract
The paper deals with the issue of water losses on the main supply pipes of Iaşi County regional water supply. The case study was conducted on the Timişeşti - Iaşi main water supply pipes and highlights a series of situations regarding the mechanical failure phenomena and the behaviour of the pipes over time. The case study analyses the magnitude of the "water loss" phenomenon in the context of limited available drinking water volumes in the Moldavian Plateau and Plain. The research showed that the water loss value for the Timişeşti - Iaşi main supply pipes is around 15%, with an annual variation ranging from 11% to 20%. The case study has made a correlation between modern water loss detection technologies and the structural and hydraulic complexity of AdI Timişeşti - Iaşi adduction pipe.

Keywords
Damages, pipes, annual evaluation, network management, water loss, case study.

1. INTRODUCTION

The "water loss" phenomenon is present in pipe networks supplying urban and rural localities with a variable monthly and annual weight factor. The phenomenon is present in all networks in Romania as well as globally. The non-revenue water (NRW) percentage at national level reaches an average of 48.3%, with extreme values ranging from 22% in Buzău County to 68% in Botoşani County [1]. Globally, the lowest percentage of NRW is reached in developed countries such as Australia - 11% and the USA - 13%. The developing countries are at the opposite end, with the NRW percentage exceeding 50%, such as Albania - 65% or the Republic of Macedonia - 61% [2].

The geographical area of the Moldavian Plateau and Plain is characterised by a limited number of viable drinking water sources. Groundwater and surface water are affected by pollution phenomena. Rural areas, where sewage systems are lacking or with intensive farming activities are the most affected by the absence of uncontaminated water sources. The available water sources in the geographical area of Moldavian Plateau and Plain fail to cover the water demand regarding the standard requirements of quantity and quality. For example, in Iaşi County, the available drinking water resources amount to about 106.00 million m^3. At the same time, the water demand for all consumption categories exceeds this number by 31% [3].

Considering the degradation of viable water sources, it is necessary to limit the value of losses in the structural components of drinking water conveyance and distribution systems. A first priority is the fast discovery of defects on the pipe network and the decrease of intervention time for the repair of the damages. The detection of water losses is accomplished through modern procedures, involving the use of advanced equipment and technologies: satellite detection [4], identification and monitoring with unmanned aerial vehicles [5], [6], ground penetrating radars [7], [8] etc. Quick intervention on the ground, in order to identify damages causing water loss, is done through specialised teams and appropriate equipment. Intervention teams are aware of the technological processes required for the effective damage remediation, as well as the structural and hydraulic characteristics of damaged pipe sections.

2. IAŞI COUNTY REGIONAL WATER SUPPLY SYSTEM

By the end of 2016, S.C. APAVITAL S.A. regional operator served consumers in Iaşi County through a pipe network supplied from 12 water sources. This network uses eight drinking water treatment plants, 179 storage tanks, main water supply pipes with a length of 871 km and 2,293 km of distribution networks. The main water sources in Iaşi County regional water supply system are represented by Timişeşti groundwater source and Prut River source (Figure 1) [9].

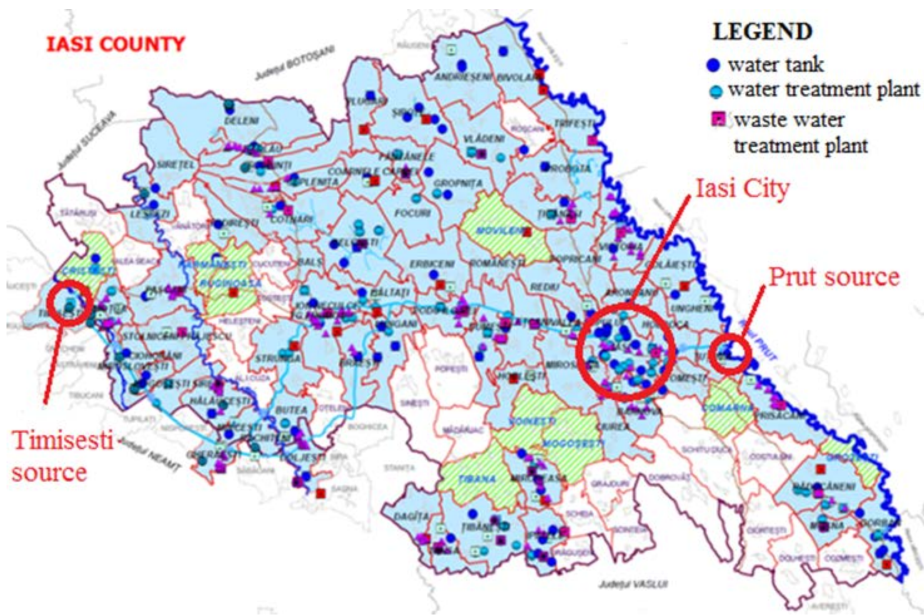


Figure 1. Operational area S.C. APAVITAL S.A. during 2016; colour code: blue – operated systems, green – systems in work, white – systems not operated

Timişeşti groundwater catchment is located in Neamţ County, about 100 km away from Iaşi, in the Siret River drainage area, at the confluence of Neamţ River (Ozana) and Moldova River. Timişeşti groundwater source partially covers the water demand of localities from Iaşi and Neamţ counties. Timişeşti – Iaşi adduction conveys a variable gravity-flow through three pipes, depending on the monthly availability of the water source. The structural and functional parameters of the Timişeşti – Iaşi main water supply pipes are differentiated by the period during which they were designed and the construction materials used (Table 1).

Table 1. Timişeşti – Iaşi main water supply pipes characteristics

Pipe		Commissioning year	Flow [l/s]	Diameter [mm]	Length [km]	Material	Lay-out route
AdI		1911	300	600 - 800	102.00	concrete, cast iron, steel	Timişeşti – Săbăoani – Brăeşti – Sârca – Iaşi
AdII	AdIIa	1975	450 - 1200	1000	56.00	PREMO, steel	Timişeşti – Strunga
	AdIIb			1000	56.00		Timişeşti – Strunga
	AdII			1000	54.00		Strunga - Iaşi
AdIII		2001	110	800	38.20	PREMO	Mirosloveşti - Strunga

The water volumes extracted from Timişeşti groundwater source are conveyed to Iaşi city storage tanks through three pipes (Figure 2). Water mains AdI and AdII, with AdIIa and AdIIb pipelines depart from the catchment located in Moldova River. The three adduction pipes undercross the Moldova River in the Soci area then their route continues near the national road DN 2 up to Săbăoani locality, at the intersection with DN 28. Adduction pipes AdI and AdII split at this point and each follows different routes. The AdI pipeline overpasses Siret River in Rotunda area and continues on the Brăeşti - Sârca route. The AdII pipe, with its two components AdIIa and AdIIb, overpasses Siret River in Scheia area, then passes under Strunga Hill through a hydrotechnical gallery. In the hydrotechnical gallery exit valve house, the two adduction pipes AdIIa and AdIIb unite in AdII, which continues its route to Sârca. In this area, the AdI and AdII adduction pipes are reunited up to Păcurari storage tanks located at the entrance of Iaşi city. The AdIII adduction pipe conveys water flows extracted from the Mirosloveşti wells, located alongside the Moldova River, up to Strunga area, along the same route as the AdII main pipe.

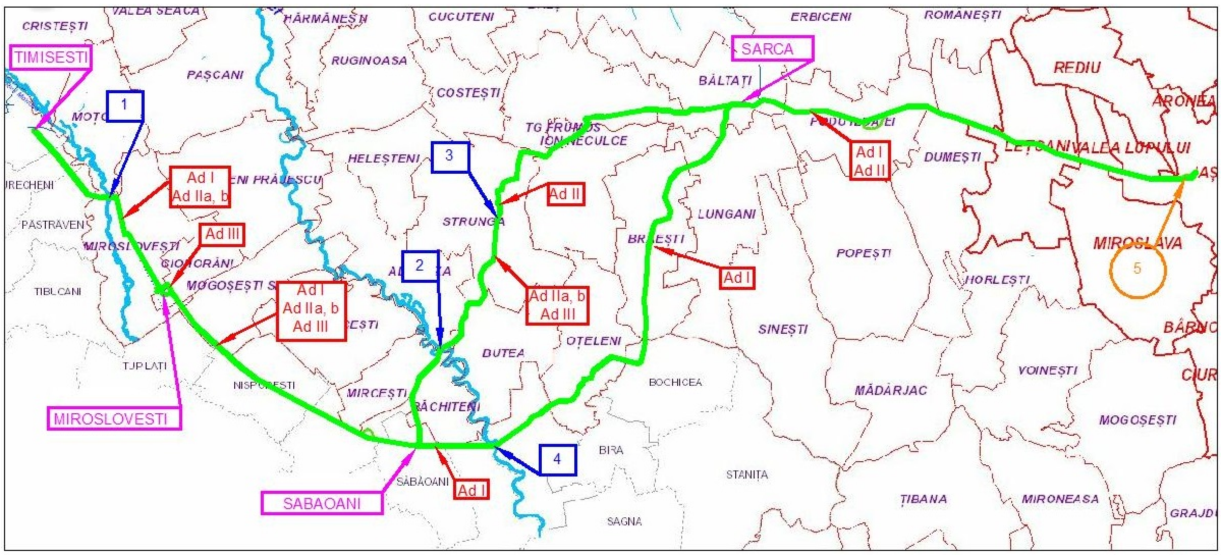


Figure 2. Timişeşti – Iaşi adduction pipes lay-out; 1 – Soci area Moldova River undercrossing; 2 – Scheia area Siret River overpassing; 3 – Strunga hydrotechnical gallery; 4 – Rotunda area Siret River overpassing; 5 – Păcurari storage tanks situated at the Iaşi city entrance point

Iaşi city surface water source is represented by the Prut River. It is located 15 km away at the eastern city border, in Ţuţora area. The water volumes extracted are pumped through five steel main pipes with diameters D = 1200 - 600 mm. Part of the water flow from Prut River is pumped into Chiriţa Lake, located on the Iaşi eastern boundary. Chiriţa Lake has the role of decanter for raw water extracted from the river. The decanted water from Chiriţa Lake is gravitationally transferred to Chiriţa treatment plant. An adduction pipeline directly conveys water from Prut River to Chiriţa water treatment plant. The water treatment plant operates in two ways depending on the quality of the raw water:

- when the silt charge of Prut River water is high, the plant is supplied from Chiriţa Lake through a 1200 mm diameter steel pipe;
- when the silt charge of Prut River water is low, the treatment plant draws the raw water directly from Prut River.

The comparative analysis of the water quality taken from the two sources demonstrates the superior characteristics of the Timişeşti groundwater source. This source distinguished itself through the presence of optimal quality parameters. Thus, the water drawn from the catchment requires only a chlorination before being distributed to consumers. However, lately, this groundwater source began to be contaminated through the pollutant waves transported by Moldova River and by the sources of contamination formed in the area of the groundwater drainage surface [3]. The main sources of contamination consist of the dumps on the Moldova River tributaries, the Târgu Neamţ City Wastewater Treatment Plant, zootechnical complexes in the area, unorganized waste dumps, etc. A source of pollution consists of the numerous gravel plants on the Moldova River located in the groundwater catchment area [10].

3. ADDUCTION PIPE BEHAVIOUR ANALYSIS FOR THE ACTIONS GENERATED BY THE EMBEDDING ENVIRONMENT AND THE OPERATIONAL PROCESS

The unique nature of the main supply pipes consists of the structural design and the operational process parameters. Water mains are made up of pipes and tubes with various diameters, lengths and materials with different lifetime. The adduction pipes have an extremely varied route, which crosses complex topographical areas (rivers, hills, railways, roads, etc.), requiring different design parameters on pipe sections [11]. The great number of factors structurally defining the main supply pipes is an issue in the operational activity. Such a case is represented by the drinking water supply pipe Timişeşti - Iaşi. In this case, the safe conveyance of water flows to consumers, at the designed quality parameters, is hindered by a number of different types of factors. The most important factors are the exceeding of the service life of the pipes, fittings and valves, the frequency of the damages, the corrosive action of the embedding environment, the seismic activity, etc.

Timişeşti – Iaşi adduction pipe AdI (Figure 2) operates since 1911. The pipe conveys the raw water extracted from Timişeşti catchment to Păcurari storage tanks, located at the entrance of Iaşi city (two tanks of 10,000 m^3). The long service life of the AdI pipeline, about 107 years, causes complex and severe operational problems. The frequency and magnitude of the water losses recorded on the main supply pipe are amplified by the high repair times. The diversity of locations where AdI and AdII adduction pipes are placed implies the presence of routes that run through unpopulated areas, hard to reach by intervention teams, where the highlighting and reporting of water losses (observed due to the presence of water on ground surface) is done after a long time. In the particular case of AdI pipe, the route and the pipeline operational characteristics, draws in a series of additional problems. The long service time of the adduction pipe, the changes over time in the pipe's management, the limited technical documentation sources, the frequent interventions, etc., caused the existence of areas where the exact position of the pipeline is not known, and also its structural and hydraulic characteristics (pipe material, diameter, laying depth, etc.).

The "water loss" phenomenon recorded on the Timişeşti - Iaşi main water supply pipe from Iaşi County regional water supply system highlights significant aspects regarding the mechanisms of failure and the behaviour of the pipes over time. Water losses have been highlighted mainly by the presence of damage, but also through flow measurements. The case study conducted on the AdI main water supply pipe revealed an average of 27 major damages per year (Table 2). Data analysis shows that most network failures were recorded in January, February and March (Table 2). The values obtained are supported by Folkman's studies, which established that during winter months, when temperatures below 10°C are frequently recorded, water supply pipes are prone to damage [12].

Table 2. Number of major interventions per year on AdI adduction pipe

Month/ Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total year
2013	3	3	1	4	1	6	2	2	2	1	1	1	27
2014	1	7	7	1	0	1	1	0	0	0	2	0	20
2015	4	1	2	0	4	3	1	3	1	4	8	4	35
2016	6	7	4	3	2	1	0	1	0	2	1	0	27
Total month	**14**	**18**	**14**	8	7	**11**	4	6	3	7	**12**	5	-

The data obtained from the research indicated the main failure mechanisms of the adduction pipes considered in the study. Based on the analysis of the obtained data, the following observations and conclusions (Figure 3) resulted:

- the main factor that leads to water loss is the degradation of the pipes or tubes joints (uncoupling of the cast iron and concrete tubes, cracking of the sockets, expulsion of the sealing rings from the socket, failure of the welds on the steel sections); the research highlighted 97 events of this type out of the total of 109 analysed;

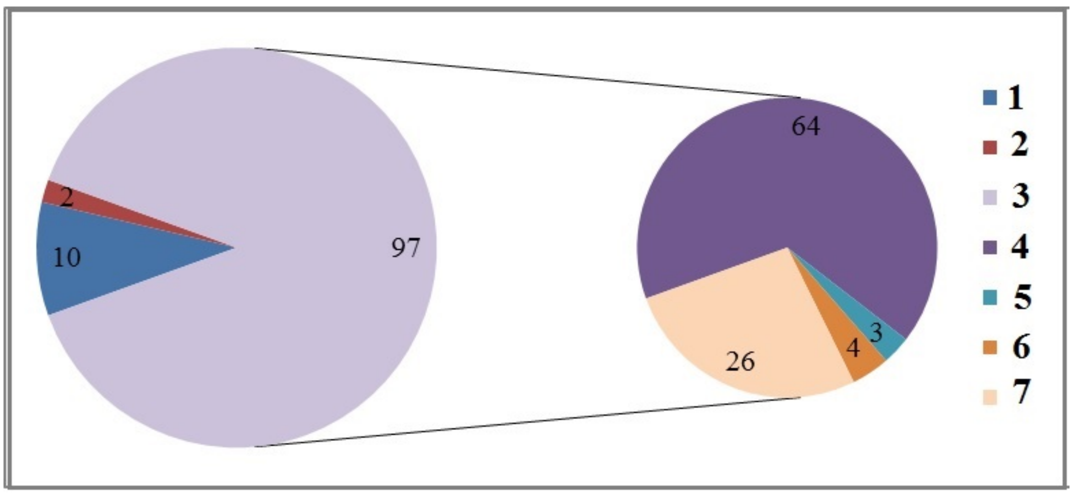


Figure 3. Main failure types registered on Timişeşti – Iaşi AdI adduction pipe; 1 – material expulsion; 2 – valves failure; 3 – damaged joints; 4 – damaged couplings on cast iron pipes; 5 – damaged couplings on PREMO pipes; 6 - failure of steel pipes welds; 7 – failure of joints in concrete pipes [13]

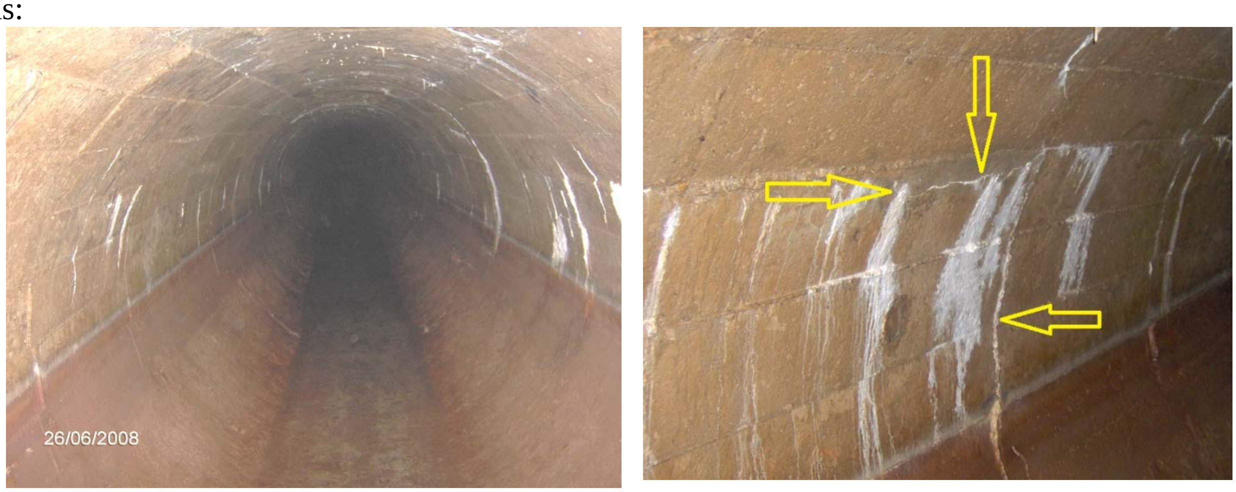
- ductile cast iron tubes are the most exposed to degradation factors through uncoupling and degradation of sealing rings in sloping embedding environments with drift potential and frequent seismic activity (Figure 4b); the analysis has highlighted that about 65% of the cases studied are ductile cast iron joints failures, amounting to 58% of the total damage recorded;
- the steel sections of the main water supply pipe are exposed to chemical corrosion caused by the external environment but also internally; the analysis revealed phenomena of structural failure of pipes and welds (4 cases out of 109, representing 3%);
- concrete tubes with sockets, fitted in the main water supply pipe (Figure 4a), show frequent cracks and breaks of the socket area (23% of cases), and their remediation is difficult due the embedding conditions of the adduction pipe;

a b

Figure 4. AdI main water supply pipe failure mechanisms; a – cracks on reinforced concrete pipe with 800 mm diameter [13]; b – damaged socket on cast iron tubes with 600 mm diameter [14]

- failure of PREMO tube pipes results due to the deformations generated by mechanical actions on site (3 cases out of 109, representing 2%);
- the expulsion of material from the pipe, especially for those made of plain concrete and reinforced concrete, represents a medium risk factor; the analysis carried out showed that only 9% of the total defects identified fall within this category;
- valves failure is not a high risk situation in the management of water losses on the main water supply pipe; the analysis carried out identified only two exceptional situations in the four years covered during the study period; they have a share of about 2% of the total number of registered cases.

Water losses have manifested themselves on this pipe, but also on the components of the transport and distribution system since the 1930s to present day. The events were recorded and analysed by the water - sewer operator. The annual water volume lost consists of 11 - 20% of the water volume entering the system, with an annual average of about 15% [9]. Currently, significant amounts of lost water volumes are recorded at the critical points on the AdI and AdII route, such as:



a b

Figure 5. Failure types on Strunga hydro technical gallery located on Timişeşti - Iaşi AdII adduction pipe; a – general view of the flow section made of reinforced concrete; b – details on the existence of horizontal and vertical micro-cracks in the concrete wall [16]

- Moldova River undercrossing area, due to the continuous action of the hydrodynamic phenomena generated by the variation of hydrological and hydraulic parameters in the river bed;
- the hydrotechnical gallery passing under Strunga Hill, where infiltration and seepage processes through the concrete wall of the gallery are present (Figure 5) [15];
- the main water supply pipe located between Sârca and Iaşi, where the high value of overpressure causes frequent damages on some pipe sections.

4. LIMITATION OF WATER LOSS THROUGH MODERN INVESTIGATION AND MONITORING METHODS AND TECHNOLOGIES

The upgrading of water supply systems is also done on the segment of water loss reduction. Knowing as quickly and accurately as possible the exact location, position and factors which caused water loss is an important system management requirement. An important contribution to the knowledge of the phenomenon is represented by modern technologies and equipment for data investigation and interpretation. The centralisation of field and study data into a monitoring program is a water supply system upgrading requirement [17].

One of the equipment commonly used in recent years to monitor and investigate underground pipe networks is the ground penetrating radar. The quick results obtained with this equipment allow real-time identification of risk situations on the ground. The detection equipment is used to investigate underground pipe networks [13]. The underground pipe components are investigated by electromagnetic radio waves. One of the ground penetrating radar's features is the ability to locate water losses from underground pipes. Water losses are identified using the density difference which occurs in the field's structure and the identified water content [7]. The main factor that determines the quality of the results provided is the field conductivity. Fields characterised by high conductivity, with elevated water content, or made of very fine particles do not provide valid results [8]. Thus, the usability of the ground penetrating radar depends on the atmospheric conditions, requiring the surface of the investigated area to be dry (Table 3). The data analysis in Table 3 shows that the ground penetrating radar can also identify the illegal connections that contribute to the total water loss value.

The U.A.V. (unmanned aerial vehicle) equipment is increasingly being used by water - sewer companies to monitor remote water supply systems. The U.A.V. features most commonly used are photogrammetry, thermal investigation and spectrometry [5]. Photogrammetry uses images to investigate objects in terms of their shape and position, with its main function being the inspection of buildings and installations placed above ground (overhead pipes, pipes overpassing rivers and geographical depressions, hydraulic chambers, etc.). Spectrometry is frequently used to identify water losses in pipes which are present on the ground surface. Georeferenced images obtained by periodic passage over the pipeline can reveal structural changes at the ground surface. The thermal investigation procedure has the highest rate of usage for water loss detection. The thermal cameras identify the water discharge area on the pipe based on the temperature difference that is recorded between the embedding environment and the water leaking from the pipe. The interpretation of the data presented in Table 3 shows that the technology can be used to identify water losses regardless of the emission flow and in any site type. The results obtained are conditioned by the density of the vegetation in the research area, the daily hour of data acquisition and the investigation day, as the solar radiation is reflected and registered by the thermal sensors, which influences the outcome of the research.

Satellite water loss detection technology uses the spectral footprint of potable water. The satellite-mounted sensors transmit raw data that is laid over the pipeline GIS model and interpreted by a complex algorithm. The technology is appreciated by water - sewer companies as it covers large areas of land, indicates the affected areas in an area of 6.00 m in diameter and is suitable for any type of material, diameter and embedding environment [4].

Table 3. Conditional factors in choosing the water loss detection equipment

Factors	Specific analysis components	Georadar	U.A.V.	Satellite detection
Water loss type	Visible / on ground surface water loss		x	x
	Unreported water loss	x	x	x
	Background water loss	x	x	x
	Unauthorised consumption	x		
	Connections water loss	x	x	x
Pipe location	Under streets / sidewalks / pavements	x	x	x
	Under green areas	x	x	x
	On private property		x	x
Special constructions monitoring	Rivers undercrossing		x	
	Rivers / railways / roads overpassing		x	
Embedding environment conductivity	High conductivity			x
	Low conductivity	x		x
Investigations time slot	Measurements without sun / nocturnal	x	x [1]	x
	Daytime measurements	x	x [2]	x
Ground surface humidity	Wet surface measurements	x	x	x
	Dry surface measurements		x	x
Vegetation density	High	x		x
	Low	x	x	x

1 – Nocturnal measurements are recommended in the investigation of elements by thermal imaging, since the thermal signature picked up by sensors can be influenced by the incident solar radiation which is reflected during daytime and changes the results of the measurements [6].
2 – U.A.V. features (photogrammetry, spectrometry) are used during daytime in order to obtain optimal results.

The analysis of data from Table 3, in relation to the characteristics of AdI Timişeşti - Iaşi main water supply pipe, reveals a number of aspects which can contribute to the identification of water loss areas from pipe sections, such as:

- the investigation of the main pipe in unpopulated areas, difficult to reach, without effective travel routes, can be done with satellite detection and U.A.V.;
- the ground penetrating radar equipment is recommended to identify fraudulent consumers using minimal excavations;
- the detection of pipe water losses which do not manifest themselves at ground surface can be done by covering the network layout with the georadar or remotely with U.A.V. and satellite sensors;
- if the adduction pipe is located on private property, where the access of the operational personnel is restricted, situation found in the Săbăoani - Răchiteni area, the remote monitoring equipment is the most suitable;
- the undercrossing construction of the Moldova River requires special monitoring because the water surface makes it impossible to identify the water losses; in this case the method of thermal investigation is indicated, since the water transported from the groundwater source may have different temperatures from that of the Moldova River (the groundwater temperature is lower than the river temperature, except for the winter season);

- Siret River overpass construction can be analysed in terms of water loss with both spectrometry techniques and thermal imaging.

From the structural and functional analysis process of Timişeşti - Iaşi adduction a series of important data was issued, which influence the development and evolution of water losses in time. The safe transport of extracted water flows to consumers, at designed quality and quantity parameters, is primarily conditioned by the advanced age of the pipes made mostly of cast iron. The relatively high frequency of damages is influenced by the action of the mechanical factors generated by the embedding environment and the operational process, which favours water losses. The analysis carried out on the AdI Timişeşti - Iaşi adduction pipe shows the necessity to approach a modern strategy for monitoring the structural and functional parameters in order to limit water losses and mainly their occurrence rate.

5. CONCLUSIONS

1. Main water supply pipes have special structural and functional features, including location areas and the nature of the construction materials, situation which has a negative impact on the process of water loss detection and on the intervention works in order to limit them.

2. The structural and functional characteristics of the AdI Timişeşti – Iaşi adduction pipe, the extended lifetime (over 100 years) and the geotechnical diversity of the embedding environments, together with the behaviour of the construction materials in time, lead to the multiplication of the damages and involve a series of difficult problems in the activity of water loss limitation.

3. The management of water losses on the AdI adduction pipe must be achieved through complex use of high-performance detection equipment, which should be adaptable to the topographic, geotechnical and hydrogeological features in the location of pipe sections.

4. The analysis of the structural failure of the AdI main water supply pipe indicates that the joints between the tubes are the most exposed to the external and internal risk factors, which influence the occurrence and the evolution over time of the water losses, also evidenced by the number of annual damages (around 97 events from the total of 109 analysed).

5. The investigation and monitoring of adduction pipes using non-invasive methods can be achieved through the use of modern technologies such as the ground penetrating radar, satellite detection, U.A.V. (spectrometry, thermal imaging and photogrammetry) etc., methods that can be used depending on the features of the pipes in relation to the characteristics of the embedding environment.

6. The structural complexity of the AdI Timişeşti – Iaşi adduction pipe implies that the georadar is the most efficient solution to monitor and investigate the underground pipe networks, while the particularities of the special river overpassing and undercrossing structures designate the thermal imaging, photogrammetry and spectrometry technologies as the best solutions in water loss management.

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