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Water loss reduction in Razgrad demonstrative project through active leakage control, pressure management and the relationship between pressure management and leakage: The case of Kooperative Pazar DMA

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Abstract: This demonstrative project comprises four of the 24 districted metered areas (DMA) of the town of Razgrad connected to SCADA system - Kooperativen Pazar, Largo 1, Largo 2 and Parkova zones respectively. The first phase of the project was implemented for three months. This was possible not only because of the high level of completeness of the SCADA system but also due to the realized in the period between September 2006 and September 2007 project under a Dutch governmental initiative managed by Aquapartner Ltd, Bulgaria and Aquanet Ltd, the Netherlands. The aim then was a twinning project between Water Company PWN, the Netherlands and Vodosnabdyavane Dunav, Razgrad for improvement of the water supply management in Water Company Razgrad, Bulgaria. The project was financed under programme LOGO East of the Association of Netherlands Municipalities (VNG) for strengthening of the regional and local government through partnership and by PWN, the Netherlands. The report gives a summary of the Demonstrative project. The project observes the water supply network of the four zones by using the IWA approach and the achieved savings for this short period are demonstrated – for Kooperativen Pazar zone– 3.8 l/s, Largo 1 zone – 1.1 l/s, Largo 2 zone – 1.0 l/s and Parkova zone – 0.8 l/s.

Keywords: water loss, DMA, SCADA system, leakage

1. INTRODUCTION

This project has been implemented by the Aquapartner Ltd team and the team of Vodosnabdyavane EOOD, Razgrad, the water company, headed by the main engineer Stoyan Ivanov. The projects demonstrates the possibilities for delivering real and positive results in water loss reduction by water companies in Bulgaria with relatively few resources and the professionalism of the operating team.

The report addresses the various stages of analysis, preparation and application of an appropriate water loss reduction programme in 4 purposely pre-selected districted metered areas (DMA) and, in particular, the application of Active Leakage Control (ALC) and Pressure Management (PM) in DMA Kooperativen Pazar.

A prerequisite for the outcome obtained was the implementation of a joint project, which took place between September 2006 and September 2007, between two water companies - PWN, the Netherlands and “Vodosnabdyavane Dunav”, Razgrad, aiming to improve the water supply management of the water company of Razgrad, Bulgaria. The project was initiated by Aquapartner Ltd, Bulgaria, and Aquanet Ltd, the Netherlands, and funded under the LOGO East Programme of the Association of Netherlands Municipalities (VNG) with the purpose of strengthening regional and local governments through partnership with PWN, the Netherlands. Under this joint project, the water supply system was surveyed throughout the town, a model of the water supply network was made and a pilot zone was selected to analyze water losses in it and prepare an investment programme.

2. OVERVIEW

The town of Razgrad is situated in the north-eastern part of Bulgaria (Figure 1) in an area with specific land relief and hydro-geological characteristics and ground level variations up to 110 m.

Figure 1. Location of Razgrad

The town's population counts 38,725 residents. It is supplied with water mainly by means of pumps. The water supply network is 251 km long, of which: 135 km transmission and 116 km distribution mains. There are five pressure tanks of a total volume of 45,740 m^3; 5,251 service connections of a total length of 47 km. The quantity of water supplied is 7.1 million m^3, of which around 2.8 million m^3 comes from the Dunav water supply system.

- The town of Razgrad receives water from five water supply sources: Pumping station "Vodna Tsentrala" operates 24 hours a day with a max capacity of 25 l/s.
- Water supply system "Getsovo" operates 24 hours a day with a max capacity of 88 l/s.
- Pumping station "Yuri Gagarin" operates 24 hours a day with a max capacity of 38 l/s.
- Pumping station "Cherkovna" operates 24 hours a day with a max capacity of 28 l/s.
- Water supply system "Dunav". The system operates nights only supplying an average of 7,500 m^3 per night, i.e. an hourly average of 86 l/s over a 24-hour period. The operating time of the system "Dunav" is set according to the levels of the pressure tanks, which feed water to the town. (Figure 2).

The street water-mains in Razgrad are made of asbestos cement and steel pipes, water-supply service pipes – of zinc galvanized steel pipes. All these were built in the 1935-1980 period. A small portion (less than 1%) of the street water-mains and service pipes has been replaced with PEHD pipes. The old and worn-out water transmission network, the characteristics of the relief and the lack of booster sets in the high-rise buildings contribute directly for the high rate of real water losses.

All pumping stations, pressure tanks and part of the district areas chambers are under the control of an automated water supply management system – SCADA. This system allows a certain operating independence of the facilities following a certain algorithm. The SCADA operator on duty gets visual information for the current state of the facilities and the relevant sound alarm signals in case of departure from the pre-set parameters (Figures 3 and 4).

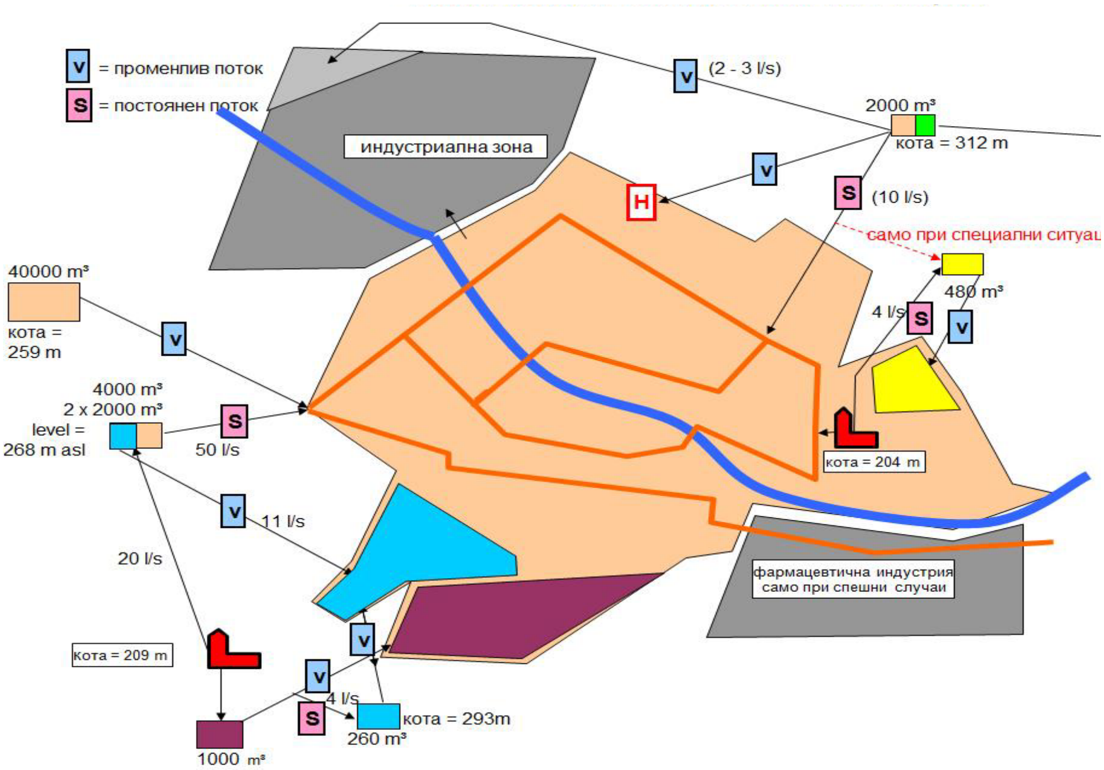
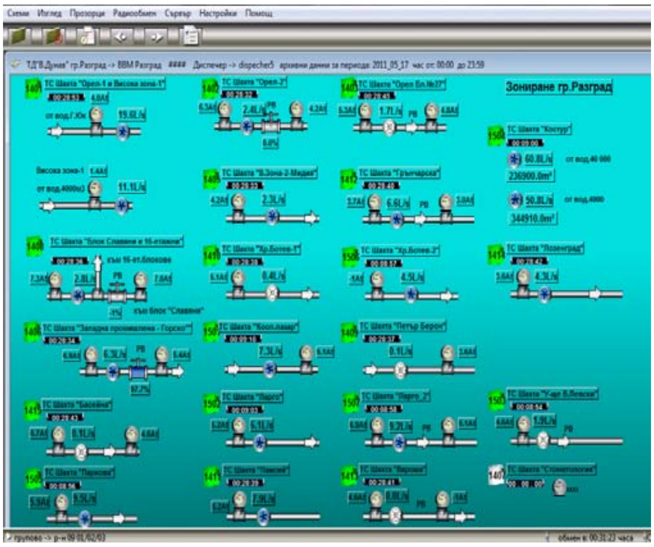


Figure 2. Diagram of Water Supply in Razgrad



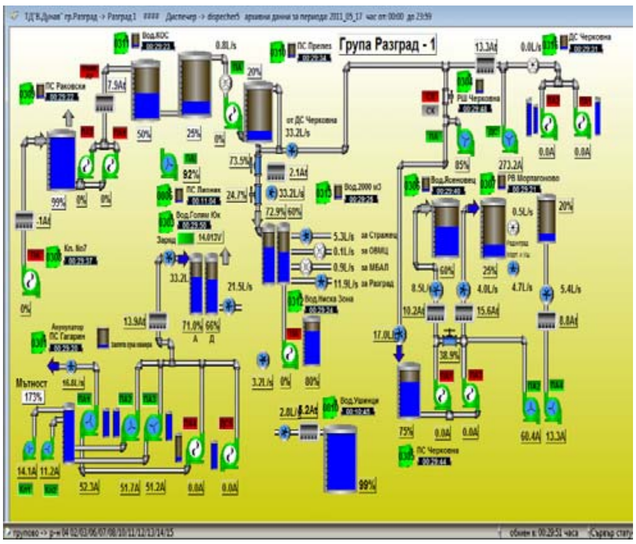


Figure 3. SCADA management of DMA's

Figure 4. SCADA management of pressure tanks and PS's

3. WATER LOSS REDUCTION IN RAZGRAD DEMONSTRATIVE PROJECT

The project comprises four DMA's of the water-supply system (marked in red in Figure 5) Kooperativen Pazar area, Largo 1 area, Largo 2 area and Parkova area with a total minimum night flow of 32.4 l/s in the small hours of the night, when water consumption is supposed to be at its minimum. The areas are concentrated in the central parts of the town with a total length of the water supply pipes of around 13 km and serviced population of 5,928 people. A great deal of the required data – 24-hour data on water input volumes, pressures downstream and upstream of the DMA chambers – were obtained through SCADA (Graph 1).

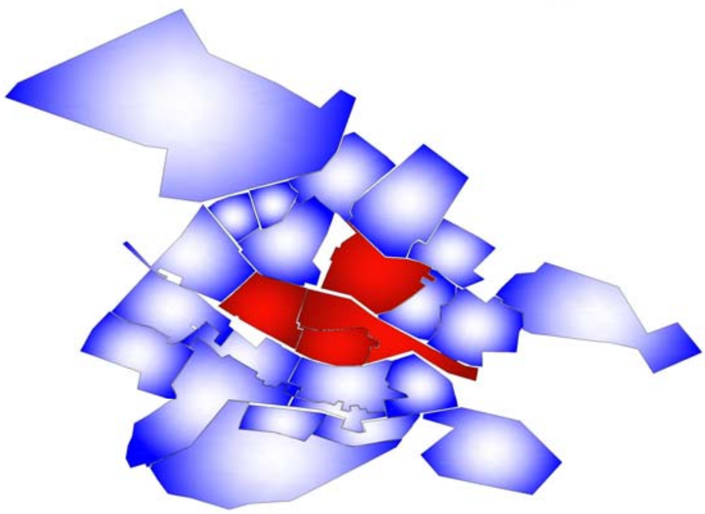
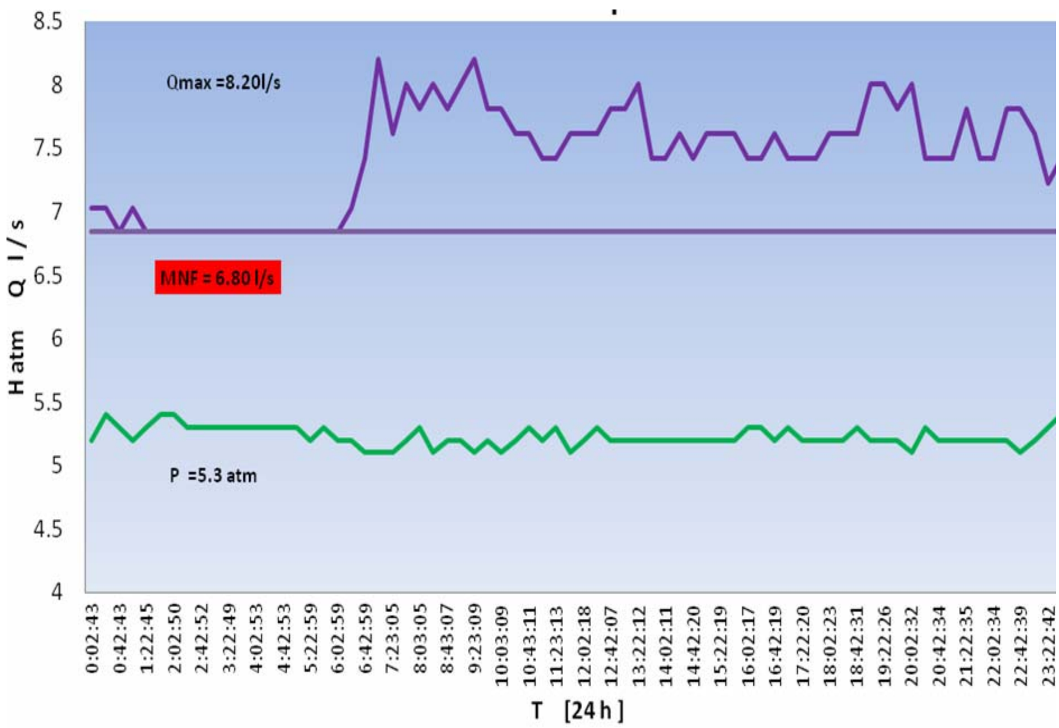


Figure 5. DMA's in Razgrad



Graph 1. Minimum night flow and pressures in a DMA chamber

The methods of the International Water Association (IWA) were applied, to a great degree, in the respective areas for a period of 3 months:

- DMA monitoring;
- Preparing a water balance and calculating ILI;
- Applying Active Leakage Control (ALC);
- Pressure Management (PM).

3.1 DMA monitoring

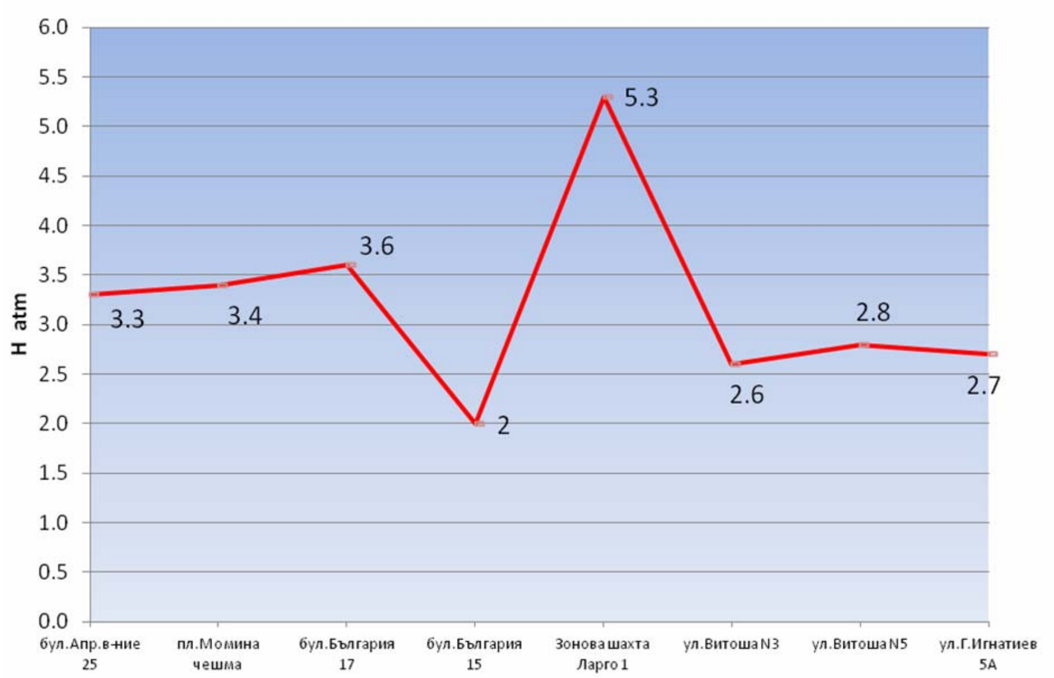
Together with qualified specialists of the water operator, the Aquapartner's team surveyed the water supply network and its accessories: state of network, working stop valves, location of water pipelines, number of service connections, fire hydrants and other accessories. MNF (minimum night flow) and network pressure data was obtained by means of SCADA.

In order to rule out an error in the readings of bulk meters, those were tested in a licensed metrological laboratory.

The DMA's monitoring included 24-hour monitoring of the amount of water input into the DMA areas and pressures downstream and upstream of DMA's chambers.

Critical points were set for each DMA (Figure 6), where measurements were made (Graph 2) of pressures before and after each significant project step.

Figure 6. Control points where pressure is measured



Graph 2. Control points

3.2 Preparing a water balance and calculating ILI

Based on data provided by the water operator for the past reporting period 03.2010 - 03.2011 regarding the amounts of water input into the DMA and the volumes of water billed, we prepared a water balance for each DMA observing the rules and steps described in the Bulgarian Regulation 06/1 of 5 May 2006 on the Methodology for setting acceptable water losses from the water supply systems. We also calculated ILI (the Infrastructure Leakage Index), analyzed the data from the water balance data the ILI and undertook the necessary steps to reduce water losses (Tables 1 and 2).

Table 1. Water Balance – town of Razgrad

No.	DMA	Period of Monitoring and measurement: one year
1	Determining the amount of water input into the respective DMA during the period	Q_4 = 7 114 193 m³/yr.
2	Determining the quantity of water supplied and billed during the period	Q_3 = 1 781 684 m³/yr.
3	Determining the quantity of water supplied but not billed	Q_{3A} = 0 m³/yr.
4	Determining the total authorized consumption	Q_5 = 1 781 684 m³/yr.
5	Water losses	Q_6 = 5 332 509 m³/yr.
6	Apparent losses 10%	Q_8 = 711 419.3 m³/yr.
7	Real losses	Q_7 = 4 621 089.7 m³/yr.
8	Specific real water losses	q = 4.54 m³/h x km
9	Water supply network length	L = 116 km

Table 2 ILI – Town of Razgrad

	Data entry	Calculated Values	Default Values	Data from another worksheet	
Vod. Dunav	Town of Razgrad	45 conn./km	01/01/2010	Up to	31/12/2010
Type of PI	Purpose of Performance Indicator	Comments	NRW and its components	PI	Unit
Operational management of NRW (Treated water)	Metric: comparison between water companies	Infrastructure Leakage Index ILI = CARL/UARL	Real losses	41.5	Non-dimensional
	Process: monitoring the progress towards targets for the water operator	Use m^3/km of mains/day, if connection density is less than 20/km; for 20/km or more, use liters/service connection/day	Non Revenue Water (NRW)	2782	litres/service conn./day
			Unbilled authorized consumption	0	litres/service conn./day
			Apparent losses	311	litres/service conn./day
			Real losses	2471	litres/service conn./day
Financial management of NRW (Treated water)	Traditional: with significant interpretation problems	% of System Input Volume	Non Revenue Water (NRW)	75.0%	%
		% by volume of water supplied		75.0%	%
	Metric: comparisons between water companies	% of billed metered consumption (except for exported water)	Apparent losses	33.5%	%

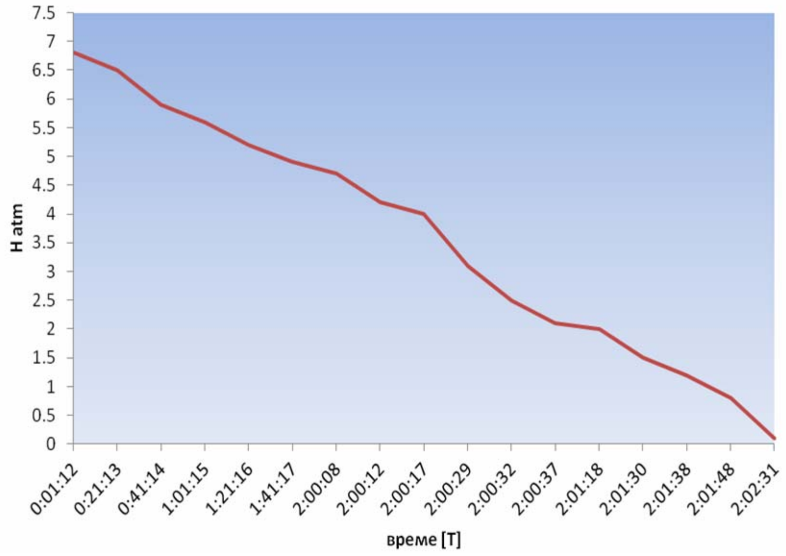
Determining the percentage of water losses:

$$Q_{loss} = [(Q_4 - Q_3)/Q_4] \times 100 = [(7\,114\,193 - 1\,781\,684) / 7\,114\,193] \times 100 = 74.95\% \quad (1)$$

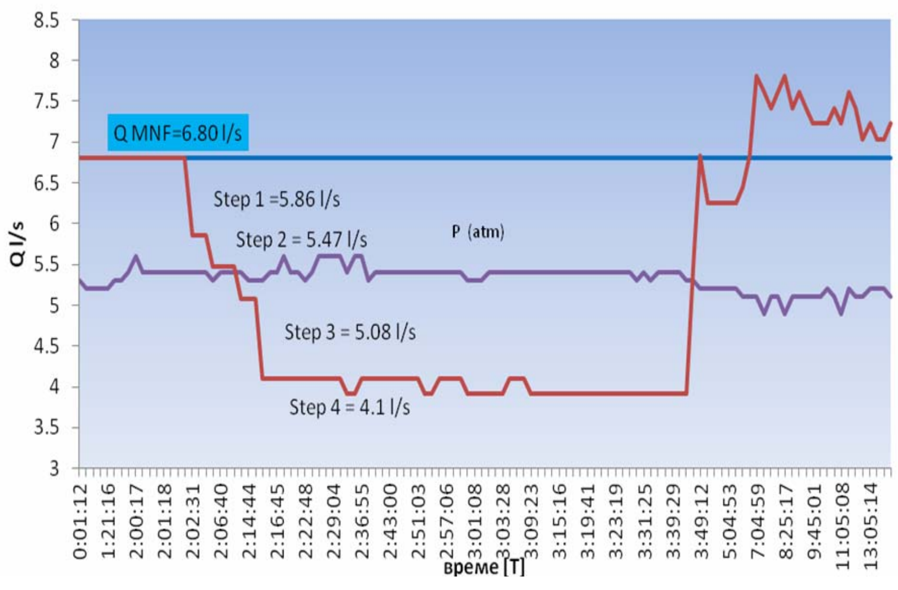
74.95 % : high level of total water losses.

3.3 Conduction of Active Leakage Control (ALC)

Within the scope of the performed Active Leakage Control, we conducted a zero test, a step test, searching with specialized equipment for detecting hidden leaks and their timely and quality repair.



Graph 3. Zero Test Graph



Graph 4. Step Test Graph

As a first step we conducted a Zero Test (Graph 3), whereby, stopping the water supply into the area and monitoring the pressure in the critical point in the basement, we checked the isolation of the area, i.e. if there were any hidden connections with other areas. The tests carried out showed that the DMA's are accurately and well isolated from each other and there was no water flowing from one area into another.

We established the working stop valves for each area and with the help of those and additionally installed ones, we were able to isolate sub-areas to be monitored. A step test was carried out in those sub-areas (Graph 4). By means of SCADA we managed to establish the sub-areas with the biggest losses of l/s in the small hours of the night.

Together with teams trained to search the water supply network for hidden leaks, we localized 6 leaks (Pictures 1 and 2) in four areas, the repair of which led to reduction of the minimum night flow in the areas with a total of 5,9 l/s.

The repair of the leaks (Picture 3 and 4) in the DMA's was reflected in the increase of the minimum free pressure in the critical points. Another very common water loss reduction approach was put in place – Pressure Management (Graph 5).

Picture 1. Hidden leaks detection (a)

Picture 2. Picture 1. Hidden leaks detection (b)

Picture 3. Repair of leaks (a)

Picture 4. Repair of leaks (b)

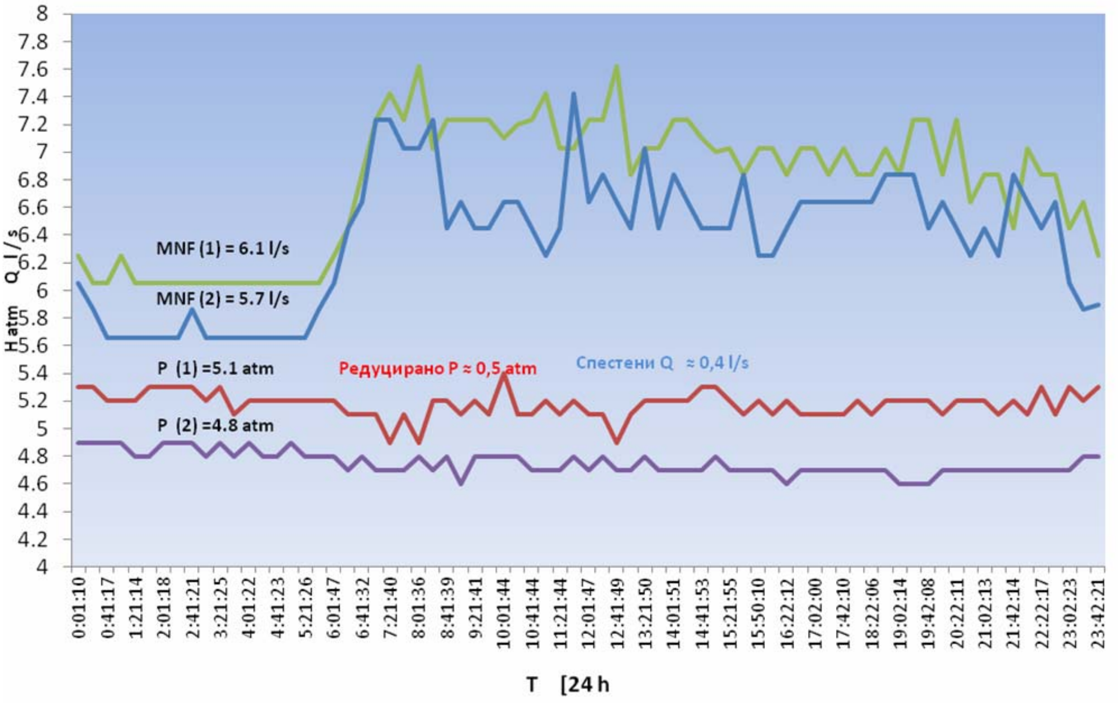
3.4 Pressure Management (PM)

Analyzing the rise in the free pressure, which we had monitored systematically before and after the leaks repair, we resorted to reducing the free downstream pressure of the DMA's chambers of Kooperativen Pazar DMA with 0.5 atm and Largo DMA 1 with 0.3 atm.

Controlling pressure down to the minimum acceptable for the DMA's resulted in further decrease in the night flow of the DMA's with 0.8 l/s.

4. THE CASE OF THE KOOPERATIVEN PAZAR DMA

The Kooperative Pazar DMA is situated in the central part of the town of Razgrad (Figure 7), isolated from the adjacent areas be means of boundary valves. The population serviced by the DMA is 1 105 people, the total length of the distribution mains being 3 076 m. 16% the water supply mains in the area are made of modern materials (PEHD), and the rest 84 % - of steel, eternit and zinc galvanized pipes. The average DMA's water supply rate is 98 l/resident/day.



Graph 5. Pressure reduction

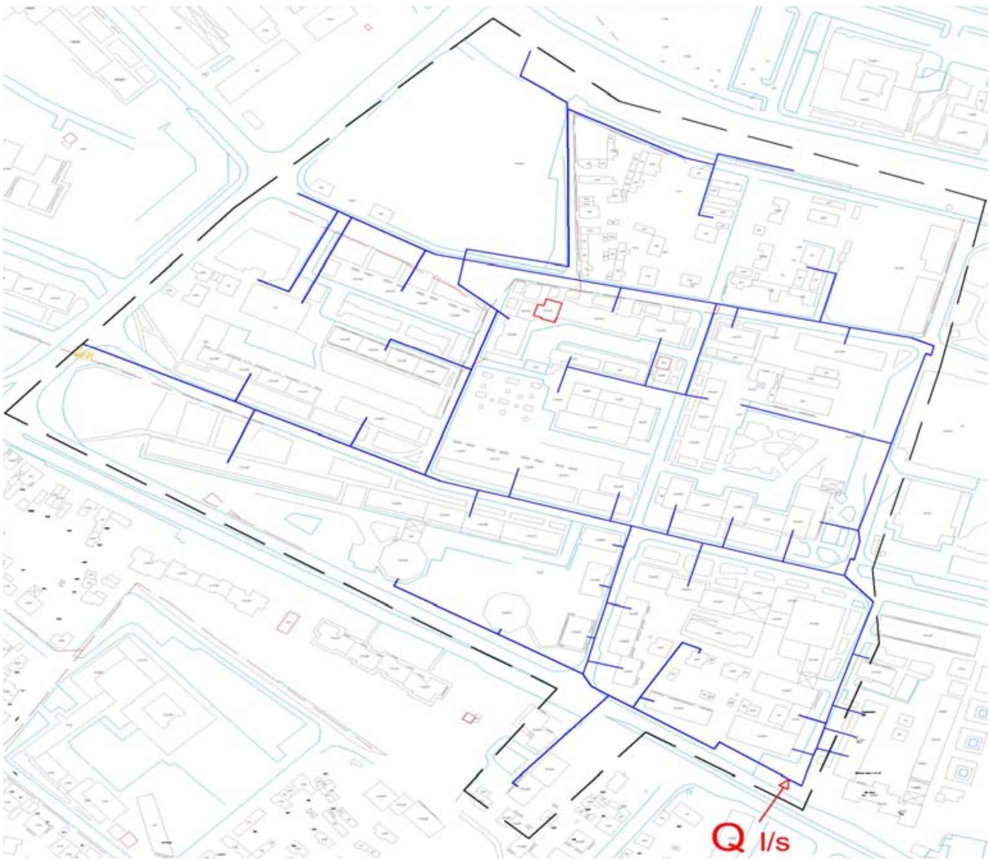


Figure 7. The water-supply mains of Kooperativen Pazar DMA

The DMA is supplied by a single point from the main branches. A DMA chamber (Picture 5 and 6) houses a downstream pressure regulator regulating pressure to 5,1 atm and a digital night flow water meter - MNF = 10,6 l/s, which could be monitored in real time through SCADA. The variation in the DMA levels is small, within 5.0 m, the average buildings height is around 6 floors. The average network pressure was maintained between 3.5 atm and 4,8 atm due to the existence of a 9-floor block of flats (the critical point) in the middle of the DMA, setting the downstream pressure of the pressure regulating valve (PRV).

Picture 5. The Kooperativen Pazar DMA's chamber – Water meter

Picture 6. The Kooperativen Pazar DMA's chamber – PRV

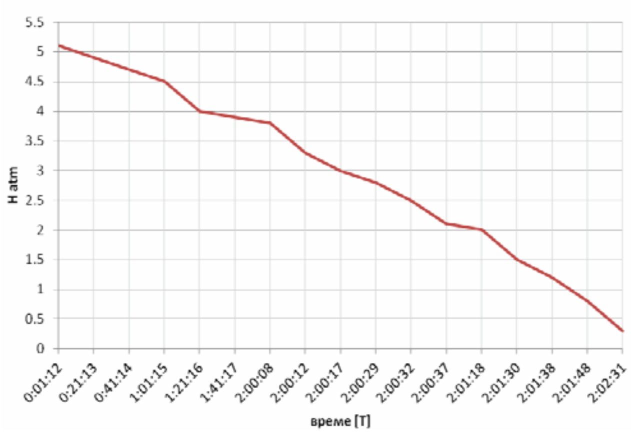
The high pressure and the old infrastructure predetermined the high level of losses - 88% in the DMA, which clearly indicated a high level of real losses, which in turn lent the possibility of applying the methods and principles of the International Water Association (IWA) and the preparation of water loss reduction programme.

4.1 Water loss reduction strategy in Kooperativen Pazar DMA

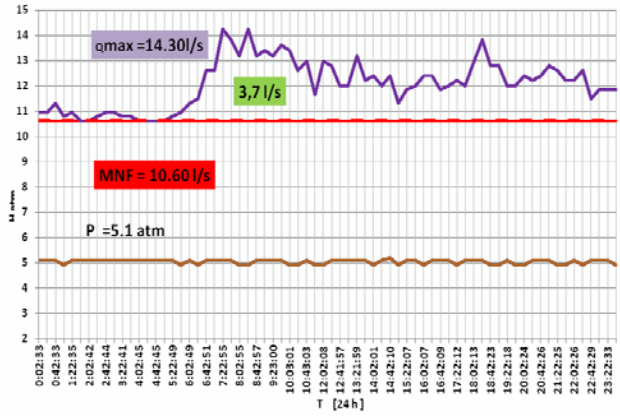
A water loss reduction programme undertaken in the project entails applying internationally practiced methods: monitoring, active leakage control and pressure regulation.

4.1.1 STEP1 - Detailed survey and collection of information

1) To start with, we dismantled the DMA's water meter DN 100 for a metrological inspection and sent it to a licensed laboratory to make sure that it metered the volumes of water supplied to the area within the acceptable measurement error. The inspection showed that the water meter was in good repair.
2) Together with teams of the water company, we went around the DMA and checked if the existing stop valves were in good condition, we also checked the location of the service connections. Based on historical data and field inspections, we established the diameters and the materials, of which the distribution mains and the service connections were made. The data was copied to a digital media to facilitate its analysis.
3) We conducted a ZERO TEST, to establish if the DMA was isolated from the other areas, through stopping the supply of the DMA and monitoring pressure the DMA's lowest point (Graph 6). The results in the above graph showed that the Kooperativen Pazar DMA was isolated from the other areas and water was not flowing from one area into another.
4) Through SCADA we obtained the necessary information from the 24-hour DMA monitoring, namely data about the water volumes supplied to the DMA and the pressure downstream of the DMA's regulating valve, both as graphs and tables (Graph 7).



Graph 6. Zero Test Underway



Graph 7. SCADA graph of MNF = 10,6 l/s and pressure in DMA's chamber

The above graph illustrates that the maximum DMA's consumption was 14.26 l/s, and the minimum night flow in the small hours of the night was 10.6 l/s (the water losses). The difference between these, namely 3.7 l/s, was the real consumption. The DMA pressure was almost constant and was dictated by the DMA's critical point, namely the 9-floor block of flats in Maritsa St.

5) Using the annual reports provided to us on the DMA's input volumes and billed water volumes, we developed a balance of the water flows in compliance with Regulation 06/1 of 5 May 2006 on the Methodology for setting acceptable water losses from the water supply systems for the 2010 report year (Table 3).

Table 3. 2010 Water balance table of Kooperativen Pazar DMA.

No.	Kooperativen Pazar DMA	Monitoring period
1	Determining the amount of water input into the DMA at issue during the period.	Q4 = 357 824 m³ annually
2	Determining the amount of water supplied and billed during the period	Q3 = 44 667 m³ annually
3	Determining the amount of water supplied but not billed	Q3A = 0 m³ annually
4	Determining the total authorized consumption	Q5 = 44 667 m³ annually
5	Water losses	Q6 = 313 157 m³ annually
6	Apparent losses 10%	Q8 = 35 782,4 m³ annually
7	Real losses	Q7 = 277 374,6 m³
8	Specific real water losses	q = 10.28 m³/h x km
9	Water supply network length	L = 3,08 km

The water balance shows a high level of total water losses from the DMA.

4.1.2 STEP 2 - Active Leakage Control

1) The active control for the DMA meant a periodical and regular reporting of the values of the minimum night flow (MNF), as well as the pressure in the distribution network. To monitor pressure, we determined beforehand the location of 12 control points, predetermined by means of EPANET (Figures 8 and 9). For each point, manual pressure measurements were made and the values were recorded both in a table and a graphical format, before and after each significant event. (Graph 11; Table 5)

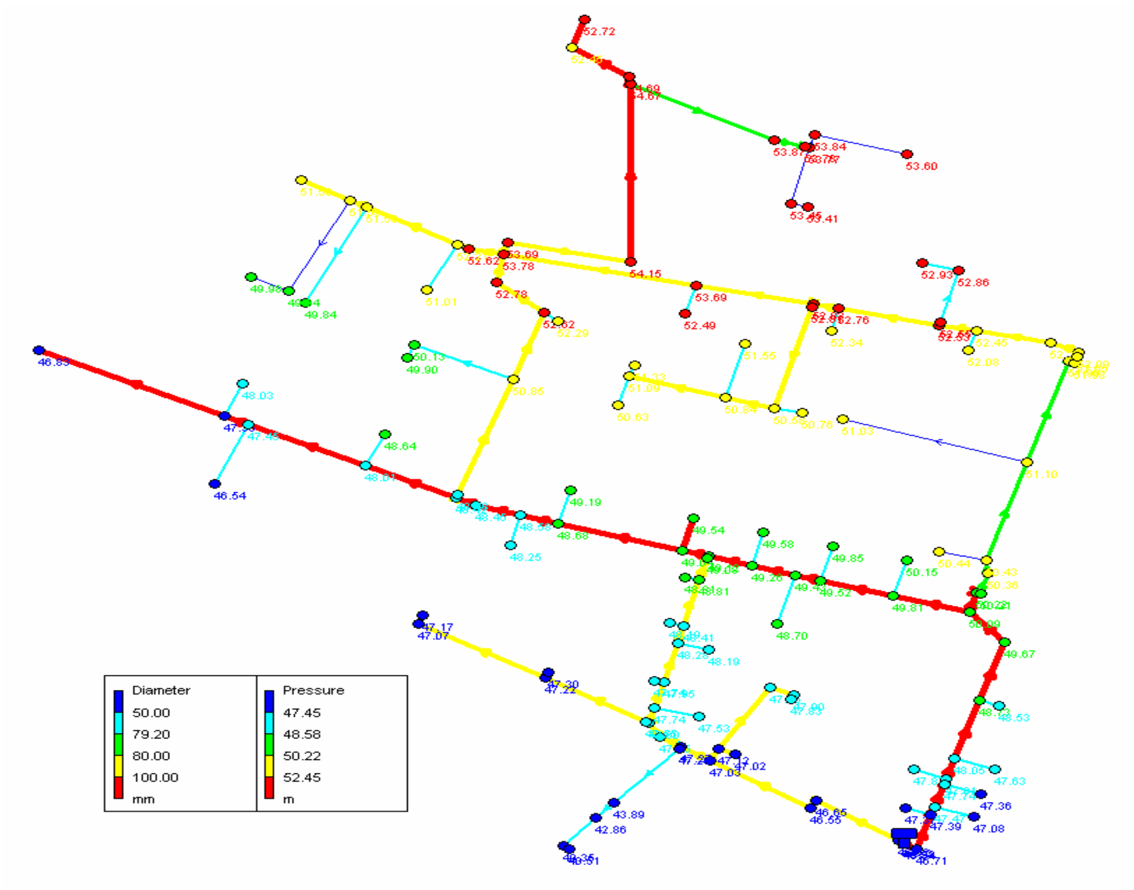


Figure 8. Kooperativen Pazar DMA – EPANET

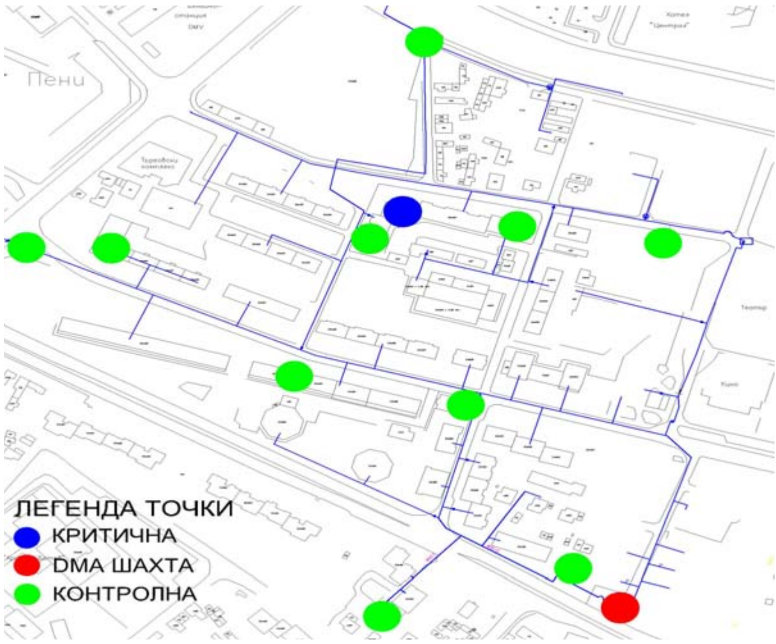


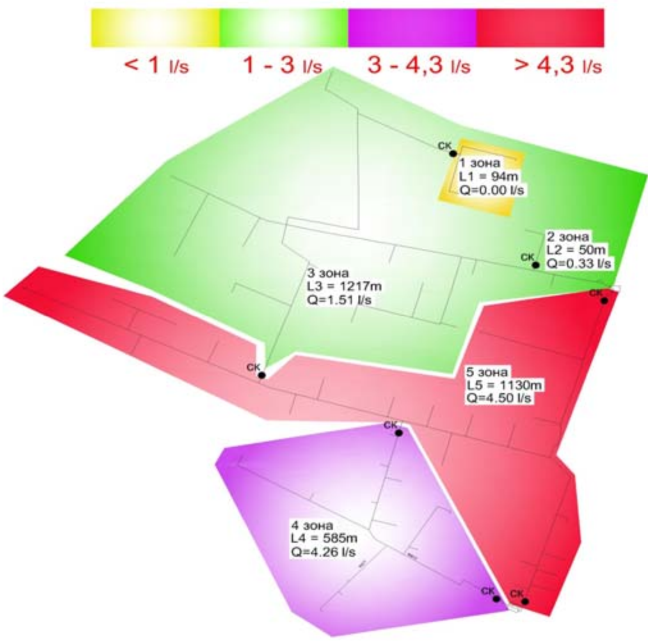
Figure 9. Control points for Kooperativen Pazar DMA

2) The conduction of a STEP TEST aimed the localization of possible failures (leaks). Using the existing working stop valves, we subdivided the DMA into 5 sub-DMA's for the purpose of monitoring. We determined in advance for each area the length and the materials, of which the water-supply mains were made. The test revealed, through the step-by-step shutting-off of the sub-DMA's during the small hours of the night 1:00 – 4:00h (Pictures 7 and 8) and SCADA monitoring, how many l/s from the minimum night flow were owning to

failures in each sub-DMA. (Figure 10; Table 4; Graph 8). The test carried out, it was established that there were 2 sub-areas with high water losses. Table 4 exemplifies the allocation of losses in %. Based on the step test data, it was found out that 4.26 l/s were being lost in sub-area 4, in only 585 m, which indicated there was a huge leak (pipe failure). During the preparation ahead of the above mentioned test, we determined the pipe materials, which also provided a clue in finding possible failures. The water supply mains are mainly built of steel, zinc galvanized and asbestos cement pipes.

Picture 7 Step test in Kooperativen Pazar DMA

Picture 8 Step test in Kooperativen Pazar DMA



SUB-AREAS

Area 1 - 0,00 l/s
L_1=94m

Area 2 - 0,33 l/s
L_2=50m

Area 3 - 1,51 l/s
L_3=1217m

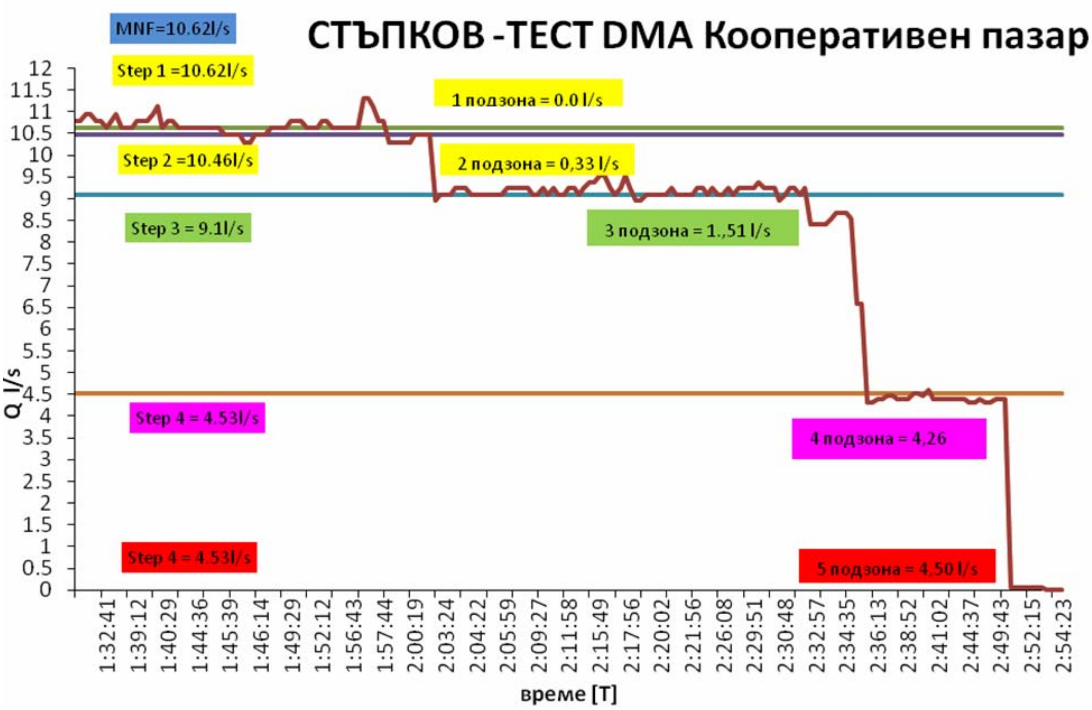
Area 4 - 4,26 l/s
L_4=1130m

Area 5 - 4,50 l/s
L_5=585m

Figure 10. Step test in Kooperativen Pazar DMA

Table 4. Water losses by sub-areas – Zero test results

Sub-area	Water losses (l/s)	L of sub-area(m)	Losses (%)
1	0.00	94	0
2	0.33	50	3
3	1.51	1217	14
4	4.26	585	40
5	4.50	1130	42
∑	10.60	3076	100



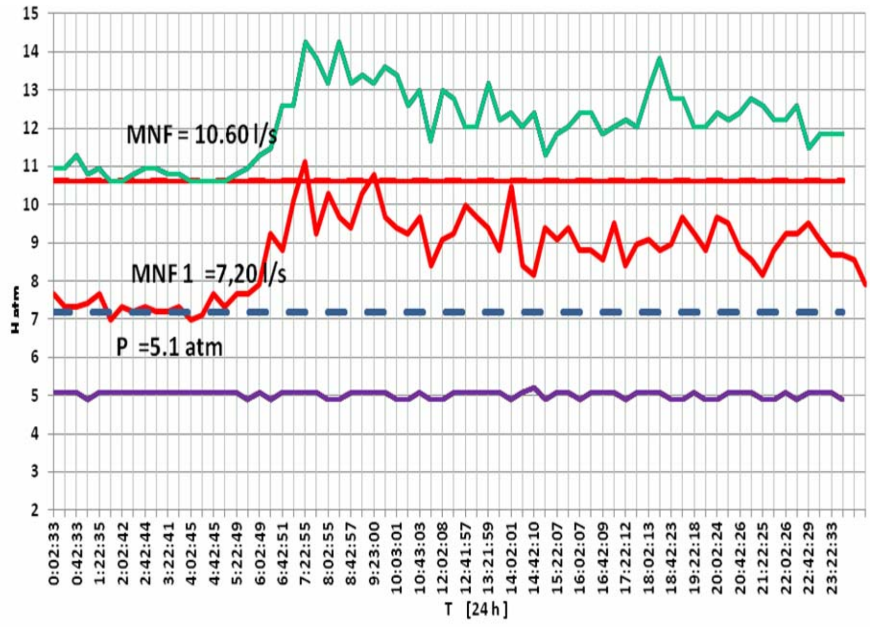
Graph 8. Step test in Kooperativen Pazar DMA

3) The next step in applying the water loss reduction programme was searching the area for hidden leaks with an electrical acoustic listening stick and a correlator. Together with a team of the Razgrad water company, specially trained and equipped for the purpose, we searched sub-areas 4 and 5, making our way along the water main branches made of steel and their associated service connections (Pictures 9 and 10).

Picture 9. Searching in sub-areas 4 and 5 of Kooperativen Pazar DMA

Picture 10. Searching in sub-areas 4 and 5 of Kooperativen Pazar DMA

4) Following the interventions in the two areas, we discovered 1 significant leak in sub-area 5. The leak from the steel pipe was due to massive corrosion on the external side. We replaced a 3.0 m long pipe section with a PEHD Φ 90 PN 10. The effect of the repair of the leak was significant. The minimum night flow fell with 3.40 l/s – down to MNF 1 = 7.20 l/s, which in terms of percentages makes 32 % of MNF (Graph 9).



Graph 9. Kooperativen Pazar DMA MNF 1 = 7,20 l/s (SCADA)

Picture 11. Kooperativen Pazar DMA – Repair of a leak in a sub-area - 3,4 l/s

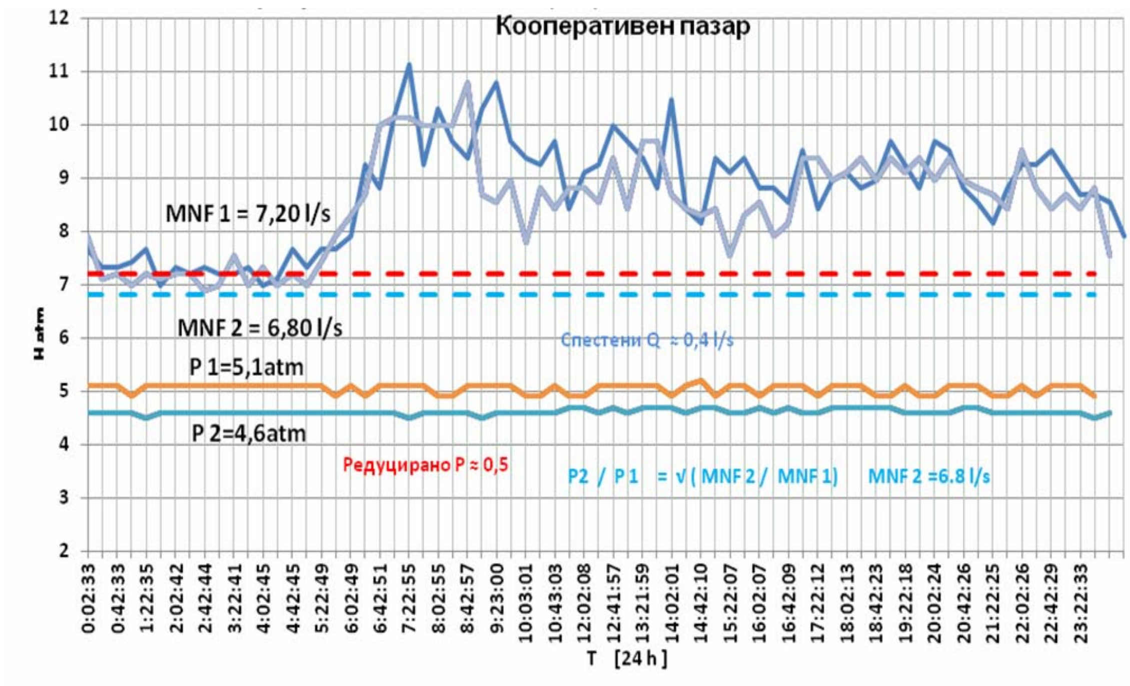
4.1.3 STEP 3 - Pressure management

After the repair of the leak was done (Picture 11), network pressure was expected to rise and therefore we conducted a second pressure measurement in the above mentioned control points (Table 5; Graph 11). It showed a rise in the free pressure in the critical point with 0.20 atm, which meant that pressure management could be applied (PM).

Pressure management is widely used in international practice as a means for reducing mains leakage. It is a quick and effective method, which allows – through minimal interventions in the distribution mains (pressure regulation) – the achievement of relatively good results.

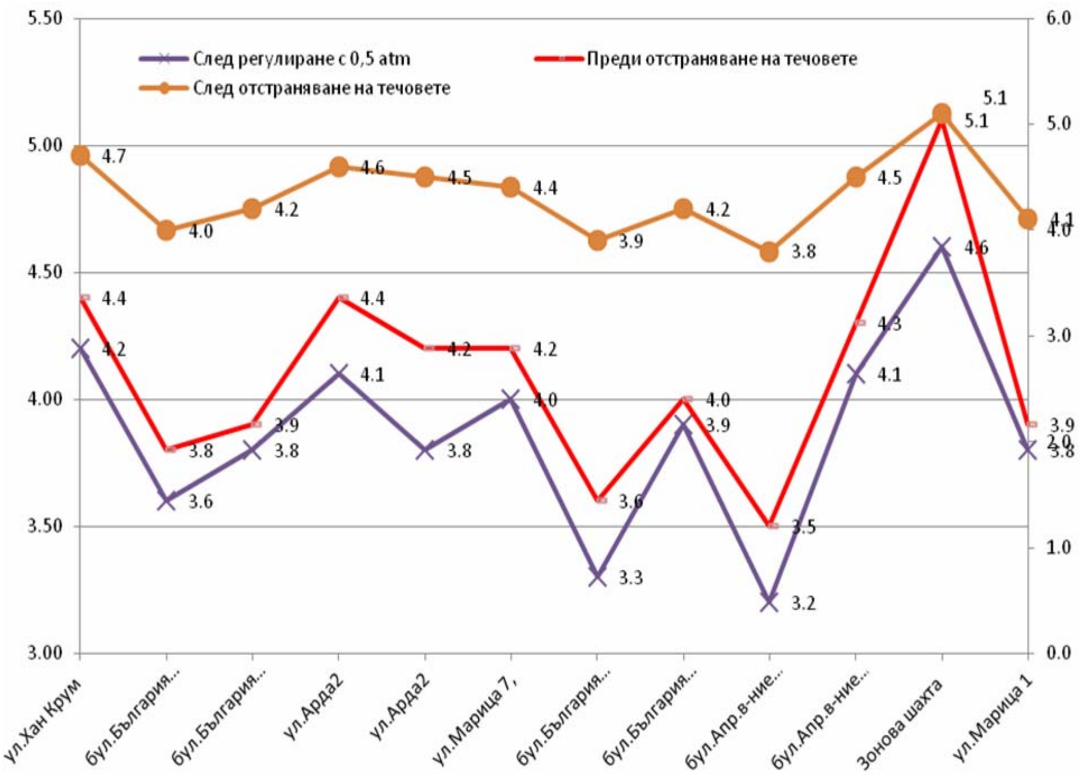
In this respect, we undertook Pressure Management in the Kooperativen Pazar DMA, where the pressure was reduced in the DMA's chamber with 0.5 atm, which was the maximum reduction possible in order to maintain the required pressure in the critical point. The supposed pressure, which we may maintain in the critical point in the basement of 2 Arda St, was 4,1 atm. (Graph 11).

Following the reduction of pressure, as expected, we achieved reduction of the night flow, too, with 0.4 l/s or, in other words, the minimum night flow fell to MNF 2 = 6.80 l/s (Graph 10).



Graph 10. Pressure reduction with 0,50 atm in the DMA's chamber

As we have already mentioned earlier, the monitoring we did before and after each significant event, along with the information gathered, helped us make a table and a graph showing the variation of the DMA pressure curve. It was monitoring that allowed us to analyze and start the current pressure management programme (PM) (Graph 11; Table 5).



Graph 11. Pressure monitoring graph in Kooperativen Pazar DMA

Table 5. Pressure monitoring table in Kooperativen Pazar DMA

No.	Location where data was obtained	P at DMA's chamber	MNF	Pressure Readings, atm	P at DMA's chamber	MNF 1	Pressure Readings, atm	P at DMA's chamber	MNF 2	Pressure Readings, atm
	As shown in Figure 5	5.1 atm	10.6 l/s	Before leaks repair	5.1 atm	7.2 l/s	After leaks repair	4.6 atm	6.8 l/s	After regulation of 0,5 atm
1	Han Krum St.			4.4			4.7			4.2
2	54 Bulgaria Blvd.			3.8			4.0			3.6
3	52 Bulgaria Blvd.			3.9			4.2			3.8
4	2 Arda St			4.4			4.6			**4.1**
5	2 Arda St			4.2			4.5			3.8
6	7 Maritsa St,			4.2			4.4			4.0
7	27 Bulgaria Blvd.			3.6			3.9			3.3
8	25 Bulgaria Blvd.			4.0			4.2			3.9
9	62 Aprilsko Vastanie Blvd, Entrance A			3.5			3.8			3.2
10	23 Aprilsko Vastanie Blvd			4.3			4.5			4.1
11	DMA chamber			5.1			5.1			4.6
12	1 Maritsa St			3.9			4.1			3.8

4.1.4 Analysis of results

The water loss reduction programme implemented in the DMA with its 3 steps resulted in decrease of MNF with 3.8 l/s.

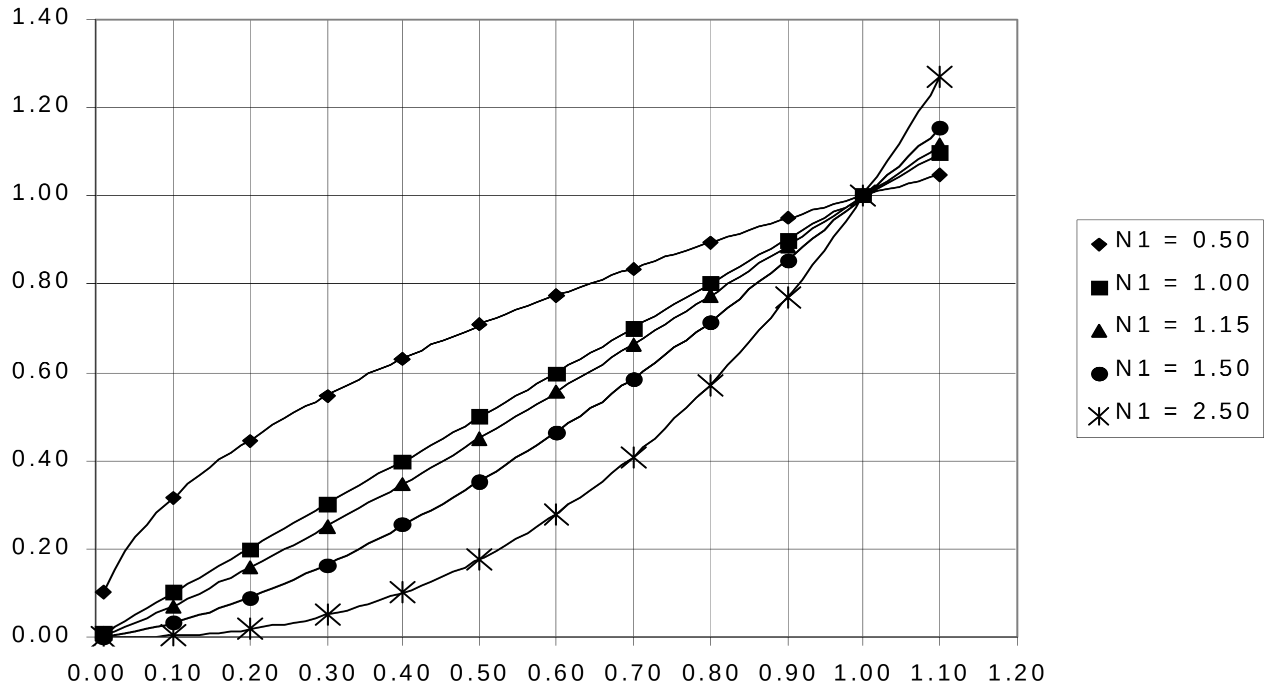
Allan Lambert and Julian Thornton, in their article on pressure management "The relationship between pressure and bursts – 'a state-of-the-art' update" in the April 2011 issue of Water 21, speak of a graphical and analytical relationship between pressure and leakage (Graph 12). In practice, for the purpose of forecasting the pressure-leakage ratio, they offer the best equation available in practice, which is based not on the difference but on the ratio of the pressure values (P1/P2) (Eq. 2).

$$L_1 / L_0 = (P_1 / P_0)^{N_1} \tag{2}$$

where:
N_1 – depends on pipe material and type of leak
L_0 – initial leakage rate, l/s
L_1 – leakage rate after pressure reduction, l/s
P_0 – pressure at initial leakage rate, atm
P_1 – pressure after pressure reduction, atm

Graph 12 clearly shows that the average pressure/leakage ratio in heterogeneous systems made of mixed pipe material usually tends to (N1 = 1,0), but in case of huge leaks from metal pipes pressure/leakage ratio is (N1 = 0,5).

Based on the above relationship, we performed an analytical calculation of the amount, by which leakage rate could be reduced if pressure was reduced with 0.5 atm in the Kooperativen Pazar DMA with the assumption that N = 0.5 bearing in mind that the leak discovered was huge and was localized at a steel pipe.



Graph 12. Ratio of pressure to leakage rate

5. EXAMPLE PROVING THE RELATIONSHIP BETWEEN PRESSURE AND LEAKAGE FROM THE KOOPERATIVEN PAZAR DMA

$$P_2 / P_1 = \sqrt{(MNF_2 / MNF_1)} \rightarrow$$

$$MNF_2 = MNF_1 \sqrt{\frac{P_2}{P_1}} = 7,2x\sqrt{\frac{4,6}{5,1}} = \qquad (3)$$

$$MNF_2 = 6,8 l/s$$

Values from Graph 10:

P_1 – pressure before reduction – (5,1 atm)
P_2 – pressure after reduction с 0,5 atm – (4,6 atm)
MNF_1 – minimum night flow before reduction – (7,2 l/s)
MNF_2 – expected minimum night flow after reduction with 0,5 atm

The expected rate of the minimum night flow after pressure reduction (MNF 2) was 6.8 l/s, analytically calculated, and was a 99 % approximation of the graphical value in **Σφάλμα! Το αρχείο προέλευσης της αναφοράς δεν βρέθηκε.**, which visualizes the SCADA data.

The example showed a confirmation of the pressure/leakage relationship (N1 = 0,5) in Kooperativen Pazar DMA, which Lambert and Thornton discussed in Water 21 of April 2011.

The measures put in place for reduction of water losses in Kooperativen Pazar DMA, such as approaches developed by the International Water Association, brought about significant results – savings of 9 850 m^3/month or, in financial terms – 4 925 BGN (≈ 2 462 €) per month, with the cost of water being around 0.5 BGN/m^3 (0.25 €/m^3). The initial investment of 6 200 BGN (3 100 €) will be paid back by the revenues from the savings for just over a month. We demonstrated that the analytical relationship between pressure and leakage held true for the DMA in our experiment and this is likely to be so for the water-supply networks in Bulgaria.

6. CONCLUSION

The Active Leakage Control and the Pressure Management applied in the four DMA's ultimately resulted in savings of 6.7 l/s, or the total minimum night flow fell to 25.7 l/s, which is a 5% decrease in the amount of water input into the DMA's.

Environmentally, following the interventions performed, a total of 579 m^3 of water per day is being saved, which is reflected in saving 286 BGN/day. The costs incurred for the whole project (27 200 BGN) are expected to be returned in 95 days from the moment of bringing the real losses down with 6.7 l/s and maintaining this level. In other words, as of now, the initial investment has been returned.

REFERENCES

Lambert, A. and Thornton, J. (2011). The relationship between pressure and bursts – 'a state-of-the-art' update, Water21.