Water Supply System Performance Improvement in the Town of Pirot Using Water Balance IWA Methodology and Numerical Simulations

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Abstract: The methods for performance measuring and benchmarking proposed by IWA Water Loss Task Force has been adopted worldwide during the last two decades. This methodology and active water loss management is still poorly applied in Serbian water supply systems. This research presents application of hydraulic modelling to estimate water supply network performance in the town of Pirot in Eastern Serbia and evaluate potential effects of active leakage management for water saving using IWA best practice. In the hydraulic model, diurnal demand multipliers for total and registered consumption and leakage exponent are calibrated for the extended period simulation. Calibrated model is then used for hydraulic analysis to estimate system water loss reduction, improvement of the technical performance indicator values and financial savings for the system subdivided in seven pressure management zones. The system pressure control with ten pressure reduction valves was simulated, for two different scenarios: a) using pressure reducing valves with fixed outlet pressure and b) with pressure sustaining valves to maintain the minimum pressure in the zone reference node. Both the resulting water balance and system technical performance indicators are significantly improved in both simulated pressure management scenarios.

Keywords: IWA best practice; pressure management; technical performance indicators; water loss reduction; water supply network

1 INTRODUCTION

The level of water losses, both real and apparent, is one of the most important efficiency issues for water supply systems around the world. When it has become obvious that integral approach for water supply system management and benchmarking was of primary interest for water utilities, International Water Association (IWA) Water Loss Task Force (WLTF) recommended Best Practice Water Balance (BPWB) and Technical Performance Indicators (PI) [19]. American Water Work Association (AWWA) produced manual for water supply practices for water audits and loss control programs [4]. Technical PIs recommended by IWA WLTF have been calculated for thousands of water supply systems in the world during the last two decades. Many countries have achieved significant results in water leakage management following IWA Performance Indicators and Best Practices including Denmark, Malta, USA, Austria, and Australia [5].

The first steps in water supply system benchmarking in Serbia have been performed over a decade ago [12]. No further significant advancement in water supply systems performance was achieved in the meantime [13]. The infrastructural condition of water supply systems in Serbia is similar to the ones in developing countries [10].

Hydraulic modelling is an initial and important step to forecast the effects of planned leakage management schemes, before any intervention is done in the system [7]. Calibration of hydraulic model requires determination of water demand multipliers and pressure-leakage relationship in a water supply system [6, 20], because pressure management is one of the most convenient and efficient measures for water loss reduction.

In this paper, the town of Pirot water supply system (PWSS) has been used as the case study to check potential for IWA BPWB and PI improvement. This system is considered representative for Serbia, because it has PI values close to the average ones for the data set in Serbian water supply systems [12]. Systematic site measurement and data collection during 2016 is followed by mathematical modelling. The research goal is to design representative hydraulic model as a forecasting tool for assessment of both hydraulic and financial effects of potential water leakage reduction and PI values improvement in PWSS even in case of scarce system data. Calibration of water demand multipliers, pressure-leakage relationship and "Unit Loss" is performed for real conditions in PWWS through original multiple iterative process.

2 MATERIALS AND METHODS
2.1 Methods to Estimate Water Supply System PI Values

IWA "Best Practice" [2] involves standard approach for Water Balance calculations. The methodology for PI calculation is regularly updated, including long and short term action planning, measuring, equipment installation, permanent data acquisition and creating data bases, leakage monitoring, and water loss reduction. Its consistent application brings a need for organizational and systematic changes [3].

For this research, principal components of the IWA Water Balance are used in its original form: System Input Volume (SIV), Authorized Consumption (AC), Non-Revenue Water (NRW), Water Losses (WL), Apparent Losses (AL), Unauthorized Consumption (UC), Metering Inaccuracies and Real Losses (RL).

The basic PI with the greatest range of applicability for RL [3, 10], are "Technical Indicator Real Losses" (TIRL) and "Unavoidable Annual Real Losses" (UARL). The non-dimensional Infrastructure Leakage Index (ILI) evaluates infrastructural state of a single system. It is an indicator of wellness of distribution network management, appropriate for water supply systems benchmarking in different areas and countries that use different measurement units [10]. A system is rated as excellent for low ILI value close to 1, and as poorly maintained for high ILI value (close to 10 or higher), [9].

Software packages (like Epanet and Aquanet) are standard tools to simulate many different consumption scenarios and water loss (WL) in water supply system. Extended period simulation is used for forecasting a system behaviour and WL value. An appropriate tool to

simulate WL volume distributed over the water supply network is "Unit Loss" and it presents WL volume per kilometre of the water supply network per 1 bar pressure. Total measured WL volume in the system is used here to calibrate Unit Loss and $N1$ leakage exponent, both at the design stage and as the first step of investigating or comparing existing networks [17]. Namely, in the equation for the Leakage Rate:

$$L = C_d A \times (2gP)^{N1} \tag{1}$$

where L is leakage, P is pressure, g is gravitational constant, C_dA is the effective area and $N1$ is leakage exponent [8]. The most appropriate general equation for simple analysis and prediction of leak rate change due to pressure change is:

$$L_1/L_0 = (P_1/P_0)^{N1} \tag{2}$$

where existing L_0 corresponds to P_0 and changed L_1 to P_1 in a node of a distribution system. It was proven worldwide both in laboratory and in the field, that exponent $N1$ depends on percentage of rigid (non-elastic) pipes in the system [16] and has values from 0,5 for leaks with fixed area up to 1,5 for leaks where area varies with pressure.

Water balance in a real water supply system generated by numerical simulations for extended period is used to estimate water supply system performance and technical performance indicators. Numerical simulations in the calibrated model are used to test the effectiveness on system performance and benefits of two management schemes in a real water supply system before their implementation on site.

2.2 The State of Water Supply Systems in Serbia

Traditional four system efficiency PI and IWA Best Practice PI have been estimated for 36 water supply systems in Serbia upon data collected during 2004 - 2005 [12]. The estimated average ILI value for the investigated Serbian water supply systems was about 11 (Fig. 1).
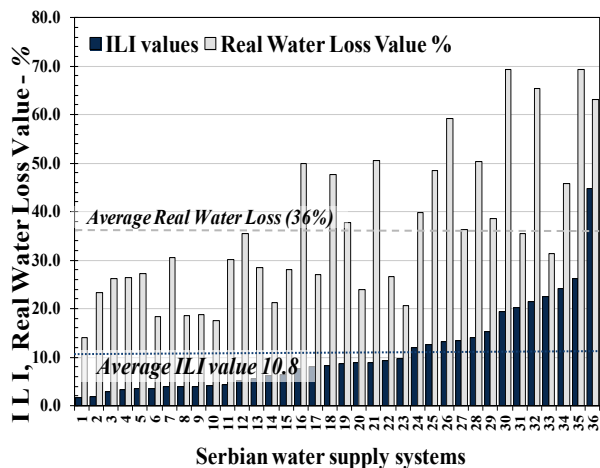

Figure 1 ILI and Water Loss (%) in 36 water supply systems in Serbia [14]

Average RL, expressed in the "outdated" percentage of SIV was 36%. Recent data from Serbian water supply systems show that the state of supplying networks remained the same [13].

2.3 Pirot Water Supply System Description

The town of Pirot is situated in the Eastern part of Serbia (Fig. 2). There are about 46 000 consumers supplied by the PWSS (Fig. 3). Two karst water springs are being used for water supply (Kavak and Krupac), while the third spring (Gradište), is occasionally used during summer months. The system is pressurized during the whole year. Two pumping stations are installed in the PWSS: Kavak, on the Kavak spring, and buster pumping station Berilovac on the pipeline from Krupac toward the town central area. Two storage tanks store water for the town: Sarlah (2000 m^3), and Pirot (5000 m^3).

Figure 2 The location of the town of Pirot in Serbia (Source: GoogleMaps)

The water supply network is mostly composed of steel and asbestos cement pipes, many of them over 50 years old. Recently constructed parts are composed of polyethylene and ductile iron pipes. Total length of the water supply network is about 120 km.

Table 1 Pipe material in Pirot water supply system

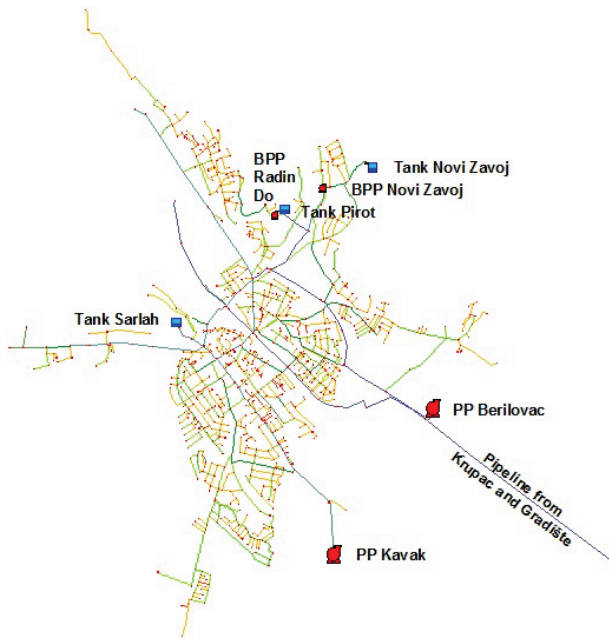| Pipeline length and material in Pirot water supply system					
≤ Ø50	Steel & Iron	5436	Ø65-100	PE	17 826
	AC	9260		AC	17 715
	PVC	16 102		Cast Iron	5000
	Total / m	30 798		Total / m	17 826
Ø150-250	LG	2665	Ø250-400	Steel	135
	AC	580		Cast Iron	3325
	PE	630		AC	1890
	Total / m	3875		Total / m	5350
Ø250-400	Steel	135	Ø400-600	AC 500	7030
	Cast Iron	3325		AC 600	8800
	AC	1890		AC 400	2755
	Total / m	5350		Steel	881
				Total / m	19 466
				Total length / m	120 390

Figure 3 The layout of the Pirot Water Supply System

The main and the largest PWSS zone is situated in the central town area, supplying over 90% of consumers. The central town area is rather flat, with an average elevation of 365 m a.s.l. The pressure varies in the range 4,5-5,5 bar in the distribution network. Water consumption is metered by volumetric service meters.

The industrial area is gravitationally supplied through the separate pipeline from the Krupac - Gradište springs. This pipeline has a separate measuring system and there is no interaction with the communal water supply system, thus not considered in the paper.

During the year 2005 electromagnetic flow meters have been installed in the pumping stations Kavak and Berilovac and fixed level meters in the storage tanks Sarlah and Pirot. System input discharge and water levels in the tanks have been permanently measured since then. All metering equipment is connected to the operational centre; real time data on water level in the tanks are used by the automatic/operator action for switching pumps on/off or to maintain constant flow in the pumping stations. All discharge and tank level data are being recorded and stored in daily data bases.

System input discharge in PWSS typically varies in the range 120-270 l/s during a day.

2.4 Water Consumption in Pirot Water Supply System

Average daily SIV in the residential area, calculated upon data registered on the flow and level meters during the year 2016 are shown in the Tab. 2.

AC for residential area, public institutions and small business is estimated from the data metered on the service meters. The unmetered AC is estimated to 1% of the SIV. WL consists of Apparent Losses (Unauthorized Consumption and Metering Inaccuracies) and Real Loss (leakage on transmission and distribution mains, leakage and overflows at storage tanks and leakage on service connections up to the customer meters). Average WL amount is about 44% in the residential area.

Table 2 Water balance in Pirot water supply system during 2016

Water Balance	System Input	Authorized	Water Loss	Water Loss
Month	m³/day	m³/day	m³/day	%
January	17 219	8 124	8904	52
February	19 538	10 637	8874	45
March	17 792	8 886	8775	49
April	16 930	9 587	7368	44
May	17 262	10 668	6739	39
June	16 930	10 213	6826	40
July	19 865	10 997	8864	45
August	19 980	10 843	9105	46
September	19 640	11 875	7895	40
October	**18 924**	**10 684**	**8264**	**44**
November	19 621	10 344	9205	47
December	16 283	9 230	7079	43
Average	**18 332**	**10 174**	**8158**	**45**

2.5 Pirot WSS - Input Data Preparation, Model Parameter Calibration and Hydraulic Analysis

Mathematical model of the PWSS is generated in the professional software package AquanetS [17]. All pipes in the network are included, following the PWSS technical documentation and database on pipe material, age and diameter. In the research preparatory stage, asset of site tests was performed using geodesy instruments, 6 pressure data loggers (SEBA), 1 mobile ultrasound flow meter (SEBA) beside the PWSS flow and tank level meters, to check performance and parameters of the main pipelines in the network (joint altitude, pipe diameter and roughness coefficient).

Available data on water consumption were analysed for the year 2016 in order to estimate PWSS water balance and performance. Daily variation in water consumption was estimated from recorded data on system input discharge measured by flowmeters and level change in the storage tanks at 15 min intervals.

Hourly demand multipliers of average daily consumption rate are calculated for every single day during the year 2016 upon recorded water consumption. The multipliers are analysed in the categories: average day, working and weekend day. Then, representative demand multipliers are estimated for each month, as average value in the same hour for all days in the month.
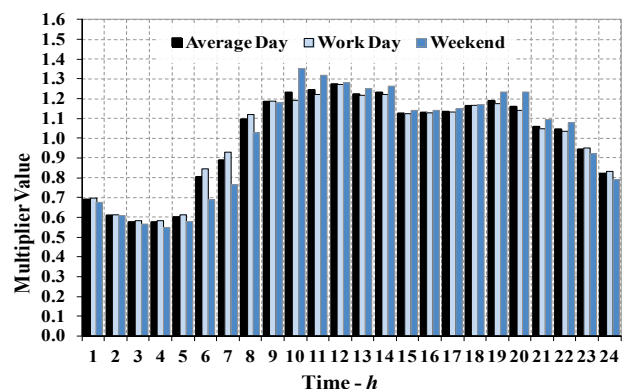

Figure 4 Diurnal demand multipliers for SIV in Pirot water supply system during work and weekend days, year 2016

The values of the generated demand multiplier are rather similar for all three categories, for all months in the study period. Because the most reliable and closest to the average annual data were recorded in October 2016, this

demand pattern was adopted for further analysis and simulation in the mathematical model (Fig. 4). Therefore, generated demand multipliers are considered representative for the SIV, i.e. for the sum of AC and WL.

For conducting water supply network hydraulic analysis aimed at estimating IWA BP Water Balance, PWSS demand multipliers are calibrated for the Authorized Consumption plus Apparent Loss (Unmetered Consumption and Metering Inaccuracies) and marked as AC+). SIV in that way becomes a sum of the AC+ and Real Loss (RL).

The nodal demands in the mathematical model are generated upon geographical position, street and address of service meters. Registered consumption for October 2016 on the service meters is accumulated in the nearest node and enlarged proportionally for the estimated Unmetered Consumption, Apparent Loss and Metering Inaccuracies (1% of SIV each), and the sum of these water balance components is AC+. The purpose of this approach was to separate SIV into AC+ and RL and to test potential of the two leakage management schemes (scenarios) to reduce RL volume, while Apparent and Metering Losses should be reduced using more precise metering equipment i.e. service and flow meters.

Hydraulic analyses on the mathematical model were done for the extended time simulation, with the discrete calculation step of 15 min.

Demand multipliers for AC+ and parameters for Real Loss (RL) are simultaneously calibrated in the iterative process on the mathematical model. The initial demand multipliers for the AC+ are assumed the same as hourly demand multipliers for the total SIV for October 2016.

RL is considered dependent on water pressure in the supply network. RL is modelled by using Unit Loss and distributed spatially in the water network nodes, depending on the relevant pressure in the node. Initial Unit Loss value was 17,55 m^3/km/day per 1 bar pressure, matching the volume of average daily RL. During the calibration process (Fig. 5), pressure driven water losses concentrated in nodes are calculated by exponential Eq. (2) using calculated pressures and predefined exponent $N1$ in corresponding nodes. The software [17] allows $N1$ value setting in each network node.

After RL daily variation is calculated in the mathematical model for the initial demand patterns matching daily RL volume, it is subtracted from the total SIV to calculate the AC+ for every hour during a day. In that way, new AC+ demand patterns are generated, and the next iteration starts with new AC+ demand patterns to calculate daily pressure variation again. RL is dependent on pressure value, so Unit Loss value has to be corrected for the next iteration. A couple of iterations is needed for AC+ demand patterns and Unit Loss values to converge for the predefined $N1$ value.

During the model calibration process, predefined value for exponent $N1$ is varied in the range 0,8 to 1,15 with an increment of 0,01. This range is recommended in the case of unknown pipe material and leakage level [16]. For each $N1$ value, corresponding Unit Loss value is determined, and function $F(N1)$, which is difference between assumed and calculated RL volume.

$N1$, AC+ demand patterns and Unit Loss value which gives minimum $F(N1)$ value are considered representative values at the end of calibration process.

Through this convergent calibration process for PWWS, mathematical model gave the best fit for the $N1$ value of 0,95 and Unit Loss 16,88 m^3/km/day per 1 bar pressure, matching multiple validation criteria: recorded and calculated values of daily RL volume, SIV, recorded and calculated tanks water level variations.
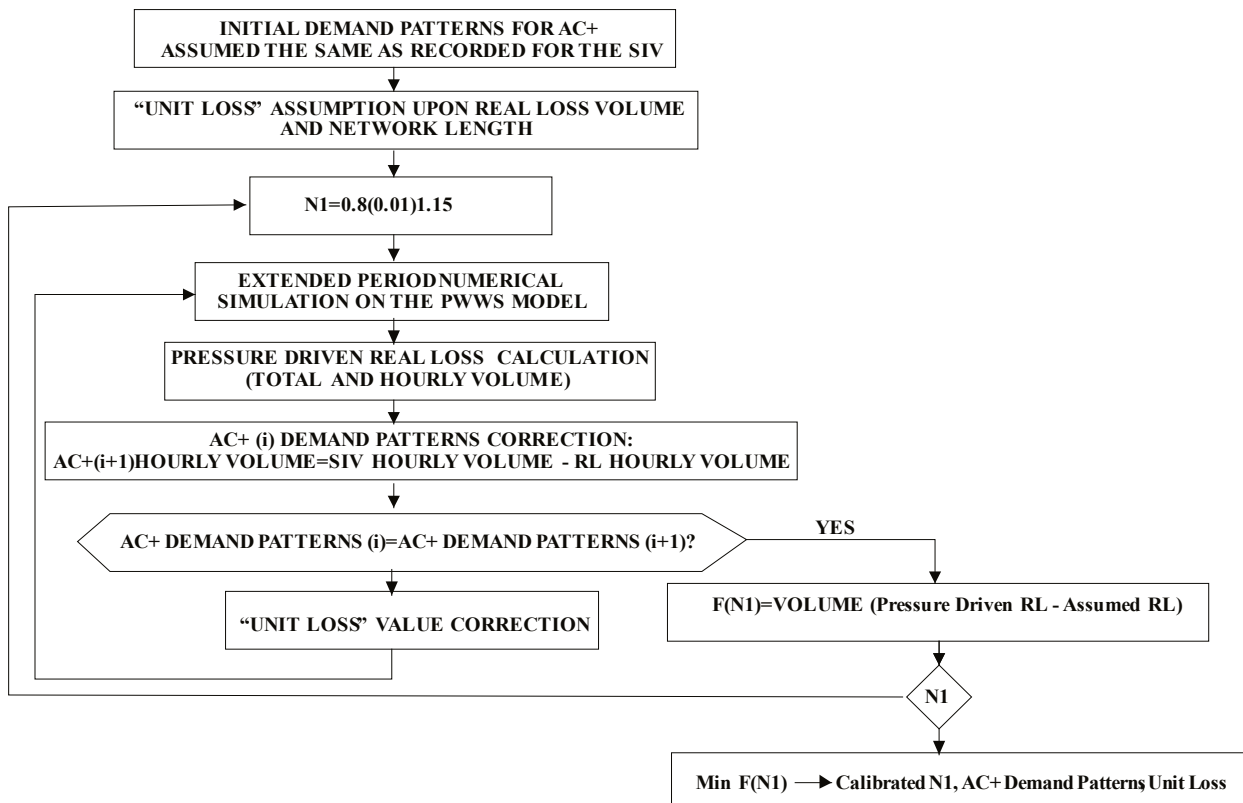

Figure 5 Numerical model parameters calibration - flowchart

As the result of the described calibration process, estimated AC+ daily demand multipliers are shown in Fig. 6, together with SIV daily demand multipliers.

There is a higher variation of the AC+ during the day compared to variation of the SIV. In the former case, maximum to minimum value is 8 times higher, in the latter case this ratio is 2, indicating high leakage levels pronounced during the night hours. On the other side, RL value has small daily variation: it is slightly higher during a night.

Using these AC+ daily demand multipliers, $N1$ exponent and Unit Loss value in the mathematical model of PWSS, water balance components at the annual level were obtained (Tab. 3). The WB components: SIV, AC+, and RL are equal to the ones measured for the year 2016. Therefore, the model was verified and could be used to simulate system response at the present and similar system conditions. IWA BMP WB in PWSS, based on the metered data and numerical simulations is shown in Tab. 3.

WL (45%) consists of the AL (estimated 2%) and RL (43%). Leakage and overflows at storage tanks are

estimated to 1% of SIV. The rest of RL is divided in the categories Leakage on transmission and distribution mains (19%) and Leakage on service connections (23%). Estimations are based on pipe lengths on mains and service connections.
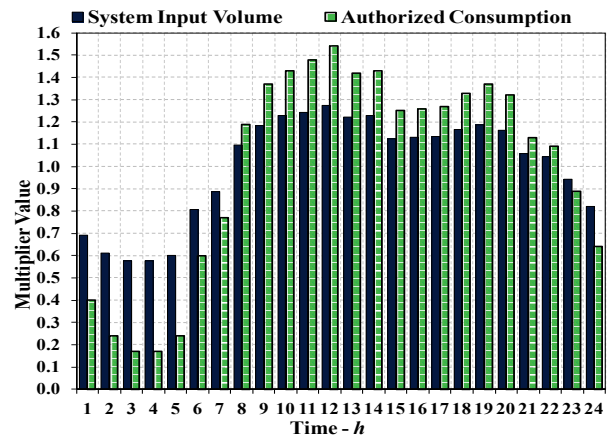

Figure 6 Diurnal demand multipliers in Pirot water supply system in Oct 2016

Table 3 IWA Best Management Practice Water Balance in Pirot water supply system

System Input Volume (corrected for known errors) 6 687 717 m³ (100%)	Authorized Consumption 3 710 793 m³ (55%)	Billed Authorized Consumption 3 309 530 m³ (49%)	Billed Metered Consumption 3 309 530 m³ (49%)	Revenue Water 3 309 530 m³ (49%)
			Billed Unmetered Consumption 0	
		Unbilled Authorized Consumption 401 263 m³ (6%)	Unbilled Metered Consumption 334 386 m³ (5%)	Non-Revenue Water (NRW) 3 323 737m³ (51%)
			Unbilled Unmetered Consumption 66 877 m³ (1%)	
	Water Losses 2 976 923 m³ (45%)	Apparent Losses 133 754 m³ (2%)	Unauthorised Consumption 66 877 m³ (1%)	
			Metering Inaccuracies 66 877 m³ (1%)	
		Real Losses 2 843 169 m³ (43%)	Leakage on Transmission and/or Distribution Mains 1 247 480m³ (19%)	
			Leakage and Overflows at Utility's Storage Tanks 66 877m³ (1%)	
			Leakage on Service Connections up to the point of Customer metering 1 528 812 m³ (23%)	

2.6 Active Leakage Control Effects in PWSS - Simulation on the Mathematical Model

One of the most convenient measures to reduce water loss in the water supply system is pressure control. Dividing a system in pressure management zones, with pressure controlled by an optimal number of pressure control valves [11], improves system operation results: lowers water loss rate, reduces burst number, prolongs pipe and device life. Reduced pressure in water supply system management zones should be verified by numerical models [15, 16] before introducing control devices on the site. For this research, PWSS mathematical model is reconfigured in 7 pressure management zones (industrial zone is not analyzed as it has own independent system). Conceptual design for introducing pressure control zones is shown in Fig. 7.

To estimate potential for water saving and impact of pressure reduction on the system PI, results from the hydraulic simulations are used.

In the first case, pressure is controlled by 10 pressure reducing valves (PRV), installed with fixed outlet pressure values which stop pressure in the downstream reference node from rising above the given limit during the whole

day. The adopted criterion for the given pressure limit is that pressure in any network node in the pressure management zone has to be higher than 20 m during all 24 hrs to provide normal network functionality.

In the second case, pressure is controlled by 10 pressure sustaining valves (PSV) to maintain the minimum pressure of 20 m in the reference pressure management zone node during 24 hrs, to provide normal network functionality. The second scheme allows more active pressure control, especially during the night hours.

3 RESULTS AND DISCUSSION

Numerical simulations on the PWWS "as is" model have shown that RL has very small daily variation, 87-97 l/s, while AC+ has significant variation, 24-185 l/s. The lowest AC+ is between 2 and 3 a.m., matching the SIV lowest value.

Assuming AC+ remains the same in the pressure reduction work scheme, results from simulated two leakage management schemes are compared to the current management scheme. RL with simulated reduced pressure control in the first case (10 PRV), varies in the range 69-86 l/s during a day.

Reduction in RL volume estimated by numerical simulations is about 16%, and reduction of the total SIV is about 7%. This leakage management scheme could potentially save 457 865 m³ of potable water per year, or 228 932 € for water supply utility, taking unit water production cost of 0,5 €/m³ (Tab. 4).

Figure 7 Pirot water supply system reshaped - 7 pressure management zones with 10 pressure regulating valves and independently supplied industrial zone No 8

Table 4 Water consumption and Real Water Loss in Pirot water supply system during a day

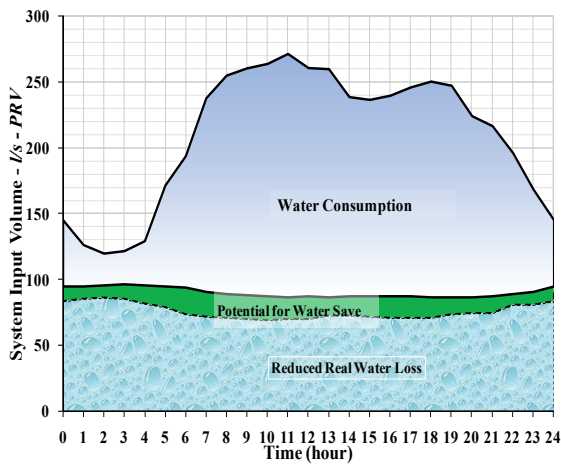|	Without pressure management			PRV-constant outlet Pressure			PSV Pressure Sustaining Value		
	AC+	RL	SIV	RL	SIV	Water Save	RL	SIV	Water Save
Hour	l/s	l/s	l/s	l/s	l/s	l/s	Loss	l/s	l/s
0	50	95	146	84	134	11	64	114	31
1	32	95	127	86	117	10	62	94	33
2	24	96	120	86	111	9	63	87	33
3	25	97	122	86	111	11	61	86	36
4	34	96	130	82	116	14	63	97	33
5	77	95	172	79	156	16	65	142	30
6	100	94	194	74	174	20	69	169	25
7	147	91	238	72	219	19	73	220	18
8	166	89	255	71	237	18	75	241	14
9	172	88	261	70	243	18	77	249	11
10	177	88	264	69	246	18	77	254	11
11	185	87	272	70	255	17	78	263	9
12	174	88	261	70	244	17	78	252	10
13	174	87	260	73	246	14	78	252	9
14	151	88	239	73	224	15	73	224	15
15	149	88	237	72	221	16	73	222	15
16	152	88	240	71	224	17	73	225	15
17	159	88	246	71	230	17	75	234	13
18	164	87	251	71	235	16	75	239	12
19	161	87	248	74	235	13	75	236	12
20	138	87	225	75	212	12	69	207	18
21	129	88	217	75	204	13	68	197	20
22	107	89	197	81	188	8	65	172	24
23	78	91	169	81	159	10	64	142	27
Average	122	90	212	76	198	15	64	186	20
	m³/year	m³/year	m³/year	m³/year	m³/year	m³/year	m³/year	m³/year	m³/year
	3 844 548	2 843 169	6 687 717	2 385 304	6 229 852	**457 865**	2 018 304	5 862 852	**618 567**
	57% SIV	43% SIV	100% SIV	84% RL	93% SIV	228 932 €	71% RL	88% SIV	309 284 €

Figure 8 Daily potential for water save after introducing pressure reduction with 10 outlet pressure fixed reduced value (PRV) valves
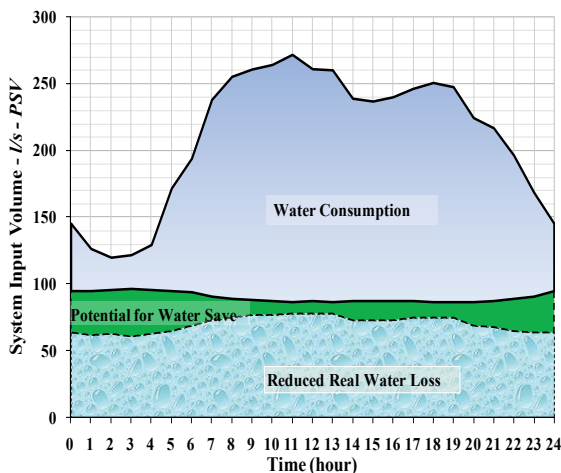

Figure 9 Daily potential for water save after introducing pressure reduction with 10 pressure sustaining value (PSV) valves

All three components of average daily consumption for management scheme with 10 PRV are shown in Fig. 8. AC+ and RL are separated by the bold line. The dashed line delimits potential water savings from the reduced RL.

In the second case (10 PSV) with simulated reduced pressure control, RL varies between 61 and 78 l/s during a day. Reduction in RL volume estimated by numerical simulations is about 29% (Tab. 4), and reduction of the total SIV is about 12%. This leakage management scheme has potential to save 618 567 m³ of potable water per year, or 309 284 € for water supply utility (Tab. 4). Three components of Average Daily Consumption for management scheme with 10 PSV are shown in Fig. 9 using the same symbols (lines) to separate its components as in Fig. 8. Water savings come from the reduced RL.

The first pro-active leakage management scheme with 10 PRV is one of the simplest schemes for pressure level maintenance. Fixed outlet pressure, downstream of the PRV has the same value during the whole day. During the night hours, when AC+ has the lowest value, average pressure in the pressure management zone is higher than during the day, so the leakage reduction level is higher during the day than during the night. Consequently, a separate night/day PRV settings scheme has potential to achieve higher WL reduction.

It can be seen from Fig. 9 that 10 PSV provide more active WL management by keeping pressure level fixed in the pressure management zone representative node. In this way, during the night hours, this management scheme keeps pressure at lower level in the pressure management zone compared to the first management scheme.

Calculated RL volume has very low variation during the 24 hrs in all three simulated scenarios - without pressure reduction, and two schemes with pressure reduction. The extreme RL volume is four times higher than AC+ volume during the night hours (Figs. 8 and 9).

Tab. 5 shows that ILI value remains in the same range despite the PWSS potential to achieve notable water savings and better UARL value by the pressure control. The ILI indicator robustness is therefore verified. Its values point out to poor infrastructural state of the distribution network and a need for the system rehabilitation.

Table 5 Benchmarking Criteria for Real and Simulated System PI Values

ITEM	Real	Simul. 10 PRV	Simul. 10 PSV
Number of consumers	46 873	46 873	46 873
Numb. of reg. serv. conn.	14 412	14 412	14 412
Distr. netw. length / km	120	120	120
Service conn. length / km	144	144	144
Avr. Netw. pressure / m	45	38	33
Real Loss Volume / m³	2 847 440	2 385 304	2 018 304
Real Loss of SIV / %	43	38	34
TIRL	541	453	384
UARL	259 719	219318	190 460
ILI	11,0	10,9	10,6

4 CONCLUSION

BPWB and Technical PI recommended by IWA WLTF have proven their usability as objective benchmarking tools in Pirot WSS [12].

A systematic data collection and measurements organized in PWSS targeted to meet IWA WLTF recommendations would lead to better system understanding, action planning and overall long term benefits.

The PWSS has representative infrastructural state for the set of Serbian water supply systems. Real data have been collected on the PWWS performance during the preparatory period. Continuous flow input and recorded tank levels have been used to estimate daily, monthly and yearly consumption and to estimate representative diurnal demand patterns.

PWSS hydraulic model has been calibrated on AC+ (as sum of Authorized Consumption and Apparent Loss) hourly demand patterns and Real Loss parameters, Unit Loss and N1 exponent value. This specific approach created hydraulic model capable of estimating daily variation of the AC+ and Real Loss volume as SIV components.

During the simulation period, calibrated PWSS mathematical model has shown AC+ had significant daily variation (24-185 l/s), while RL had very small daily variation (87-97 l/s).

It is shown in the paper that there is high leakage level in the PWSS due to current system infrastructural condition. Nevertheless, numerical experiments on modified PWSS network scheme (reshaped in 7 pressure management zones with 10 PRV and 10 PSV) indicate significant water and financial savings potential. Estimated water saving for the system operation with 10 PRV is

457865 m³/year (about 228 932 €). SIV could be reduced by 7% and volume of RL by 16%. These savings would be higher if night/day PRV operation scheme is applied.

For the simulated system operation with 10 PSV, saving is 618 567 m³/year (about 309 284 €), SIV could be reduced by 12% and volume of RL 29%. Therefore, pressure or flow modulation (either time programmed or proactive) has potential for higher water savings in PWSS.

An additional investigation of the PWSS infrastructure state is needed to detect the most prone to leak system parts. This is a starting point for an "Asset Management Plan" for the system systematic rehabilitation. Permanent leakage monitoring [18] in PWSS is strongly recommended, in order to keep control on the system operation and achieve improvement in its performance and effectiveness.

Acknowledgment

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