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Studies and procedures of water loss reduction in the water supply system of the town of Vidin

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Abstract: This paper is assessing the current level of the losses in the water supply system of the city of Vidin based on an established methodology by the world practice. Calculations of water balance for the whole city and water balance month by month for certain pilot areas were performed. The volumes of the water losses are presented in different units, which facilitates the comparison with results obtained in other cities in Bulgaria and abroad. The infrastructure leakage index has been obtained, which describes correctly the state of the real water losses. Measurements for the minimum night flow have been carried out in the district metered areas, its component being analysed and the values of the physical night losses in the water supply system calculated.

Key Words: water balance, performance indicators, infrastructure leakage index, district metered area, minimum night flow

1. INFORMATION ON THE WATER SUPPLY SYSTEM IN VIDIN

The water supply system of Vidin is maintained and managed by the town's water utility - Water Supply and Sewerage Ltd. It provides services to 50 000 inhabitants. The water source of the town is a Ranney-type well located near the village of Slanotran. From here, water is pumped out into the system and is delivered partially to 8 small settlements before reaching the distribution system. The pressure in the system is about 3 atm. The whole length of the pipes is approx. 140 km, of which 25 km are water mains and 115 km distribution pipes. The service connections are nearly 4000. The asbestos-cement pipes represent 65% of all pipes, while 30% are cast iron and steel pipes. Almost all service connections are made of galvanized pipes with the exception of the replaced and newly-made connections.

2. MEASUREMENTS AND ANALYSES

2.1. Pressure management in the water supply system of Vidin

In April 2003 the water utility introduced a mechanism for pressure management in the water distribution system and management of the water flow at the outlet of the pumping station at Slanotran. By then, due to the reduced water consumption in the night, the pressure at the pump station's outlet had risen to 5.2 atm, which was also the approximate value of the free head in the system. In case of maximum consumption it had been reduced to approx. 2.7 atm. This situation has been changed with the help of an adjustable frequency drive (inverter) connected to the pump delivering water to the town. Through a pulse transmitter in the frequency drive, the pump receives a signal from a manometer located in the town center. The rotating speed of the pump wheel has been adjusted to maintain a constant pressure of 3 atm in the system. When receiving a signal from the town that the pressure has risen by more than 0.1 atm and that this value is being retained for more than 10 seconds the frequency drive reduces the speed of the pump and the water flow respectively so that in the center of the town the pressure will return to the set value of 3 atm. Through the application of this scheme of head regulation, the maximum pressure at the pump station outlet is slightly over 4 atm, while the pressure in the system is maintained within 2.5 – 3.5 atm.

The outcomes of the successful pressure management in the water supply system of Vidin are shown in Tables 1 and 2, and Fig. 1 and 2 below.

Table 1. Water flows of Vidin

Year		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Water	(m^3/year)	7412671	6020967	6247549	5907474	5428071	5018593	4948393	5005884	4650456	4623280
supplied	(l/sec)	235.1	190.9	198.1	187.3	172.1	159.1	156.9	158.7	147.5	146.6
Billed	(m^3/year)	2132127	2017843	2020202	1943722	1924454	1911970	1947175	1941391	1848713	1821292
consumption	(l/sec)	67.61	63.99	64.06	61.64	61.02	60.63	61.74	61.56	58.62	57.75
For	(m^3/year)	1572476	1524196	1483053	1456400	1456318	1450410	1471495	1457614	1442366	1428158
population	(l/sec)	49.86	48.33	47.03	46.18	46.18	45.99	46.66	46.22	45.74	45.29
For	(m^3/year)	559651	493647	537149	487322	468136	461560	475680	483777	406347	393134
companies	(l/sec)	17.75	15.65	17.03	15.45	14.84	14.64	15.08	15.34	12.89	12.47
Non-revenue	(m^3/year)	5280544	4003124	4227347	3963752	3503617	3106623	3001218	3064493	2801743	2801988
water	(l/sec)	167.44	126.94	134.05	125.69	111.10	98.51	95.17	97.17	88.84	88.85

Table 2. Distribution of reported bursts in Vidin

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Total number	316	331	330	294	271	243	276	270	258	232
Service pipes	112	128	156	114	115	103	91	101	116	106
Water mains	204	203	174	180	156	140	183	169	142	126
D ≤150	123	109	120	118	97	104	96	95	98	78
150<D≤300	27	22	9	26	15	13	41	23	13	12
D>300	54	72	45	36	44	23	46	51	31	36
Frequency of bursts per km	2187	2291	2284	2035	1876	1682	1897	1869	1786	1606

Fig.1 explicitly shows the volume reduction of the supplied water flows after the introduction of the pressure management system. In 2003, as much as 6 250 000 m^3 have been delivered to the town, while in 2010 the volume is 4 600 000 m^3, or 26% less. In spite of the demographic crisis in the region it is obvious that the consumption reduction rate is not proportional to the supplied water reduction rate. This means that the volume of the water loss is considerably decreased. Fig.2 illustrates the number and frequency reduction of the failures, from 330 in 2003 to 232 in 2010, or 30% less.

Table 3 shows the calculation of the exponent N according to the equation:

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

where L_0 is the water volume supplied to the town of Vidin in 2003, L_1 is the supplied water volume in 2008, P_0 is the pressure at the pump station outlet in 2003, and P_1 is the same in 2008. The calculated value of N is 0.96, provided the equation is applied for the whole water supply system. It is very close to N=1.00, which is the internationally accepted value in studies of pressure reduction benefits in systems composed by various types of pipes.

The pressure management programme adopted by the Vidin water utility is quite beneficial – besides the system's failures reduction, the annual power consumption has been reduced by approx. 76 000 kWh as a consequence of reduced water volumes in the periods of minimum intake.

2.2. Calculation of the water balance for the town of Vidin, with confidence intervals, ILI, performance indicators of the system

The water balance has been calculated on the basis of the system input volume. Each component of the balance possesses its own confidence interval (Table 4). Part of the parameters needed for balance calculation is assessed and contain uncertainty. Even the metered data are subject to errors. In order to reach better clarity of the final results used by the water utility to define priority actions for water loss reduction, it is necessary to make assessment and acceptance of standard deviation or standard error for each parameter (McKenzie and Lambert 2008). It represents the difference between the accepted and the actual value, expressed in percentage. The assessment is made by experts in the field, information supplied by technical teams of the water utility, published sources describing other similar characteristics and analyses for the ways and methods for obtaining the data used.

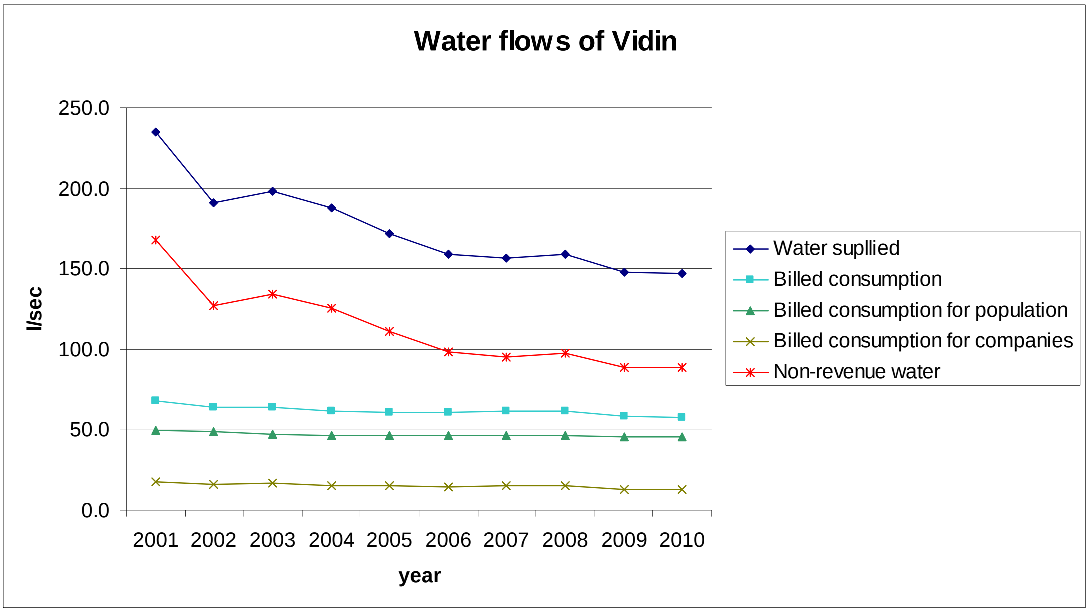

Figure1. Water flows of Vidin

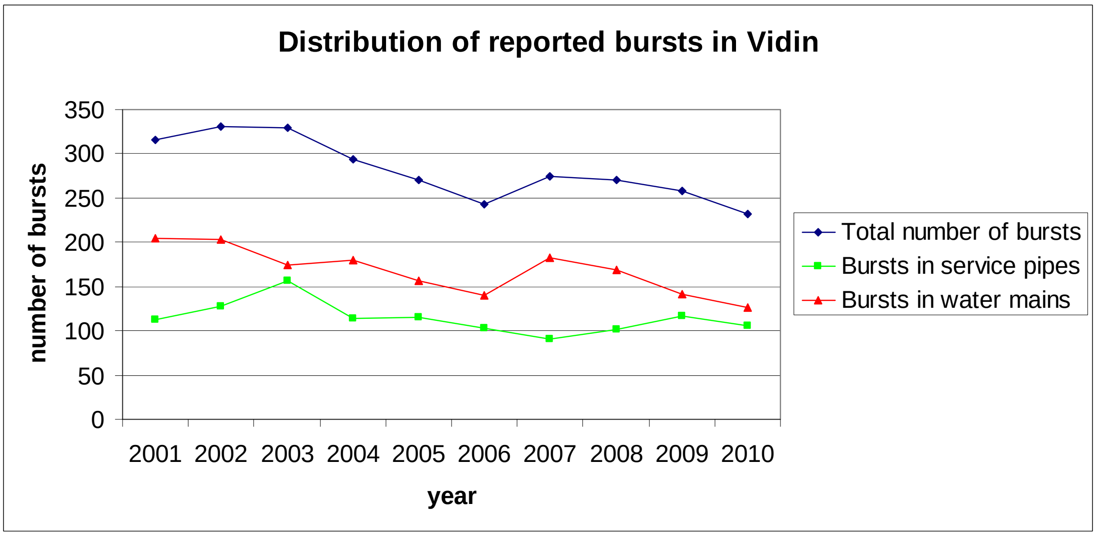

Figure 2. Distribution of reported bursts in Vidin

Table 3. Assessment of the exponent N of Vidin

2003	**2008**	
L_0 (l/sec): 204.9	L_1 (l/sec): 163.3	$L_1/L_0 = 0.80$
P_0 (m): 52.0	P_1 (m): 40.8	$P_1/P_0 = 0.78$
		$N = 0.96$

For calculation of a confidence interval which includes the components of the water balance, on the basis of an expert assessment, it is assumed that they follow the law of Gauss for the normal distribution of variables. It is assumed that the set values of the standard error in percentage corresponds to 95% confidence interval, which means that the parameter in question has 5% probability not to fall in the assumed interval, or it possesses 5% level of significance.

Table 4. Water balance of Vidin for 2010 with confidence limits

Name of components	m3	Conf. limits,%	Volume (+;-)	Volume^2
Pumping station "Slanotrun"	5854595	2.0%	117092	13710513046
Pumping station "Kos"	29341	2.0%	587	344358
Pumping station "Major Uzunovo"	641954	2.0%	12839	164841975
District "Nov pat"	423596	2.0%	8472	71773428
village "Slana bara"	27200	2.0%	544	295936
village "Novoseltzi"	21910	2.0%	438	192019
village "Akatzievo"	6060	2.0%	121	14689
village "Ruptzi"	15620	2.0%	312	97594
village "Inovo"	69170	2.0%	1383	1913796
village "Kapitanovtzi"	55145	2.0%	1103	1216388
Water supplied	4623281	2.6%	118115	13951203229
Own sources	4623281	2.6%	118115	13951203229
Water imported	0	0.0%	0	0
Water supplied	4623281	2.6%	118115	13951203229
Billed water exported	0	0.0%	0	0
Billed metered consumption	1821292	5.0%	91065	8292761373
Billed unmetered consumption	0	0.0%	0	0
Billed authorised consumption	1821292	5.0%	91065	8292761373
Revenue water	1821292	5.0%	91065	8292761373
Non-revenue water	2801989	5.3%	149144	22243964603
Unbilled metered authorised consumption	11352	3.0%	341	115981
Unbilled unmetered authorised consumption	8425	10.0%	843	709806
Unbilled authorised consumption	19777	4.6%	909	825787
Authorised consumption	1841069	4.9%	91069	8293587161
Water losses	2782212	5.4%	149147	22244790390
Customer metering under-registration	91065	50.0%	45532	2073190343
Unauthorised consumption	462328	50.0%	231164	53436818012
Apparent losses	553393	42.6%	235606	55510008356
Leakage on transmission mains	445764	50.0%	222882	49676354721
Leakage and overflows at reservoirs	0	50.0%	0	0
Leakage on distribution mains	1002969	50.0%	501484	251486545773
Lekage on service connections	780087	50.0%	390043	152133836332
Real losses	2228819	12.5%	278845	77754798746

Initially, the table-measured components with their assumed confidence intervals have been introduced, and afterwards, the sought components and their intervals have been calculated with the help of a mean-square error, which means to find out the root of the sum of the squares of the known parameters' deviations. The obtained value corresponds to the confidence interval of the parameter studied. After completing the calculations for the water balance, the real water losses, on the basis of which the performance indicators are determined, are approx. 2 230 000 m^3 per year, and we can assume with 95% probability that they could have values from 1 950 000 m^3 to 2 510 000 m^3. This outcome is reached after we have assumed the volume of the apparent water losses. As it is demonstrated in Table 4, they have a standard error of 42.6%, which means that the water utility has to make more efforts in the future to study and obtain more correct data leading to a reduction of the confidence interval for this component, thereby reaching higher accuracy in the analysis of the real losses.

For this volume of the real water losses obtained from the calculated water balance for Vidin for 2010, Table 5 illustrates the performance indicators of the water supply system, and the Infrastructural Leakage Index (ILI) is calculated (Kalinikov 2004; Farley and Trow 2003).

Table 5. Water loss performance indicators and ILI of Vidin

Volume of real losses per year:	2228819.30	m^3/*year*
Daily avarage real losses:	6106.35	m^3/*day*
Number of service connections:	4000	number
Real water loss performance indicators	1527	l/connection.day
	49645	l/km of mains
	46	l/connection.day.m head
Avarage network pressure:	33	m
Connection density	33	number/km mains
Unavoidable annual real losses components		
1.Total lenght of the water mains (km)		
123	2214	l/day.m.head
2.Number of service connections		
4000	3200	l/day.m.head
Unavoidable annual real water losses	5414	l/day.m.head
Unavoidable annual real water losses for the network pressure	178662	l/day
	45	l/connection.day
The Ifrastructure leakage index (ILI):	34.2	
Number of reported bursts on water network per year:	232	number/year
Frequency of bursts on mains and services:	1.89	number/km mains.year

The calculated ILI for Vidin is 34.2. This value exceeds twice the limit above which is class D of the World Bank Institute's classification of water supply systems according to their ILI, the respective text reads as follows: "bad maintenance and bad condition of the system, and there is a need of starting immediate procedures for real water loss reduction" (Farley and Trow 2003; WSA/WCA 1994a). The value of ILI for Vidin is at a medium level compared to the values for other towns in the country which are within a wide scope – from 4.3 for Smolyan and 6.8 for Ruse to 52.6 for Varna and 111.8 for Vratsa. These outcomes and analyses would have been with a greater weight after the initial realization of measures related to the assessment and reduction of the apparent (economic) water losses. Their more precise determination would have brought about right conclusions about the magnitude of ILI.

Measurements have been carried out for the monthly input water flow and the minimum nightly water volume delivered to three small pilot zones in Vidin – Boninia, Panonia, Geo Milev, as well as DMA Akdjamia (Dimitrov 2010). The results indicate a low volume of the real losses, and the value of ILI is about 10, which is 3 times less than the one for the town in general. This difference could mean that the value of the real losses is considerably less than the one calculated for the water balance of the town, which, in turn, leads to the conclusion that the assumption for the apparent losses is underestimated. This means that a more in-depth study of the incorrect measurement and the illegal use of water is needed. The related volumes may be found to be higher than the ones from leakages and failures in the system.

2.3. *Measurements of the minimum night flow in DMA Akdjamia and analysis of its components*

DMA Akdjamia has been established as a pilot zone in 2011. The total length of the pipes is

10 165 m. There are 573 service connections (SC), mainly to one-family houses with a density of 56,4 SC per kilometer of the system. The population is approx. 3100. The zone is supplied through Ø 110 mm connection from Ø 600 mm steel main. A DN 100 mechanical water meter having a mechanism for recording the water flow with attached data logger is installed. The results which represent water volumes in 15 min intervals are processed by special software, and afterwards presented in Excel format.

Each night the values of the water volumes between 00:00 and 06:00 o'clock have been studied and the measured minimum night flow (MNFmeas.) is determined as the least measured value for a 15-min period. The calculations and analyses are demonstrated in Table 7, while the adopted parameters are shown in Table 6.

Table 6. Basic parameters for analyzing MNF

Assessed household night use	0.49	l/person.hour
Background losses		
On water mains	40	l/km mains.hour (50m head)
	21.2	l/km mains.hour (30 head)
On service connections	4	l/connections.hour (50m head)
	2.1	l/connections.hour (30m head)
Median flow rate of unreported burst		
Burst on water main	2500	l/hour (50m head)
	1325	l/hour (30m head)
Burst on service connection	1600	l/hour (50m head)
	848	l/hour (30m head)

The value of the customer (useful) night usage of 0.49 l/inhabitant has been determined after studying the consumption between 02:00 and 04:00 in 12 residential houses in Vidin. The value of the hidden leakages in mains and service connections have been accepted in (WSA/WCA 1994c) Report E – Interpreting Measured Night Flows as average background losses (ICF=2). The lost water volume in case of unreported failures in mains or service connections has been defined in the same source and serves for comparison in obtaining the rate of the night losses and carrying out of assessment of the number of the assumed failures. All values are reduced to the operational pressure in the water supply system in the town – 30 m, through the application of the pressure correction factor (PCF) mentioned in Report E (WSA/WCA 1994b,c).

Table 7. Analysis of MNF during the nights 06.08.2011-18.08.2011

	MNF (measured)		SDCF	MNF (calculated)		Household night use		Background losses		Real losses	
day	l/hour	m3/hour	-	l/hour	m3/hour	l/hour	m3/hour	l/hour	m3/hour	l/hour	m3/hour
06.8.2011	8400	8.400	1.060	8902	8.902	4612	4.612	1430	1.430	2860	2.860
07.8.2011	8400	8.400	1.060	8902	8.902	4612	4.612	1430	1.430	2860	2.860
08.8.2011	5600	5.600	1.060	5935	5.935	3519	3.519	1430	1.430	985	0.985
09.8.2011	7600	7.600	1.060	8054	8.054	4612	4.612	1430	1.430	2012	2.012
10.8.2011	8800	8.800	1.060	9326	9.326	4612	4.612	1430	1.430	3283	3.283
11.8.2011	8400	8.400	1.060	8902	8.902	4612	4.612	1430	1.430	2860	2.860
12.8.2011	8400	8.400	1.060	8902	8.902	4612	4.612	1430	1.430	2860	2.860
13.8.2011	8000	8.000	1.060	8478	8.478	4612	4.612	1430	1.430	2436	2.436
14.8.2011	4800	4.800	1.060	5087	5.087	2226	2.226	1430	1.430	1430	1.430
15.8.2011	3600	3.600	1.060	3815	3.815	1519	1.519	1430	1.430	866	0.866
16.8.2011	4000	4.000	1.060	4239	4.239	1519	1.519	1430	1.430	1290	1.290
17.8.2011	4000	4.000	1.060	4239	4.239	1519	1.519	1430	1.430	1290	1.290
18.8.2011	3600	3.600	1.060	3815	3.815	1519	1.519	1430	1.430	866	0.866

For more precise calculations and and analysis of the MNF's components, a measurement duration correction factor (SDCF) has been used (WSA/WCA 1994c). With its help, the 15-min log is truly transformed to an hourly flow (MNFcalc.), with enclosed data for customer night usage and background losses. The value of the factor has been obtained after evaluation of 17 observations for the inlet minimum night flows.

After loading of all parameters to a table, the volume of the unreported leaks in the studied DMA during the night is obtained. After 14 Aug. 2011 the observations in the zone have been carried out after stopping the supply to the only big consumer, the sewer pump station, as to remove its uneven consumption influence on the analysis of the inlet MNF. There is a difference between the target night flow and the measured one of slightly over 1 m^3. According to Table 6 this value corresponds to one or two unreported failures in the service connections or one failure in a distribution main. Given the fact that the greatest part of the pipes is made of asbestos cement, we may assume that the failures are in the service connections made predominately of galvanized and steel pipes. The detection of these failures is realized with the help of the available equipment in the water utility. After the repair works, the MNF values and the hourly consumption are determined in several consecutive days. The steady consumption level in the DMA is analysed, and any subsequent rise of this level shall be considered as a problem in the water supply system. This continuous monitoring of the inlet water flow is a very accurate means for active leakage control of the particular sector, which helps for reducing the awareness time of a failure, which leads to a reduction of the leak duration and real water loss.

3. CONCLUSION

The paper considers part of the procedures applied in fighting the water losses in the water supply system of Vidin, which have their own specificity. Widely accepted methods have been used but suited to the local environment.

The water utility has used the pressure management in the system as the main and the most useful approach for real losses reduction. The tables and graphs facilitate the understanding the advantages and efficiency of the executed project. The system input volume has been diminished by 26%, and the number of new failures – by 30%.

An annual water balance for the town has been prepared and the volume of the real water losses with a confidence interval has been obtained, thus providing better clarity how this parameter could vary. Depending on the calculated standard errors for each of the balance's components, the water utility may prioritise its activities related to their measurement and analysis.

The water loss levels have been compared using various performance indicators and ILI has been determined for the whole town; it gives the most authentic information for the system's condition.

A DMA has been established which is subject to constant monitoring through the installation of an inlet water meter with a logger for recording the results. The measured MNF is analysed on the basis of concrete measurements and assumptions for part of its components. After obtaining the MNF value the water utility is able to assess the availability of unreported leaks and failures. The comparison of the obtained nightly real losses with the difference between the supplied and the billed water for certain sector allows a correction to be made in the assumed values of the apparent water losses.

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