

WATER DISTRIBUTION SYSTEM PERFORMANCE ASSESSMENT: BENCHMARKING THREE GREEK CASES USING A MODIFIED WATER BALANCE METHODOLOGY

Stavroula TSITSIFLI¹ & Vasilis KANAKOUDIS¹

(1) Department of Civil Engineering, University of Thessaly, Greece, e-mail: tsitsifli@civ.uth.gr
& bkanakoud@civ.uth.gr

ABSTRACT

The present paper deals with a benchmarking process of three water supply systems performance evaluation in Greece. The goals of the study are: (a) to evaluate the water distribution system performance; and (b) to compare the results taking into account the local factors influencing them. The proposed modified IWA Water Balance (WB) and Performance Indicators (PIs) methodology is used for the performance evaluation of the distribution systems. Basic performance indicators such as Water Losses (WL), Real Losses (RL), Non-Revenue Water (NRW), Unavoidable Annual Real Losses (UARL) and the Infrastructure Leakage Index (ILI) are being estimated. The present paper uses the results of the water distribution systems for three different Greek cities (Larisa, Kos and Veria). Each system has its own characteristics and its operation is being influenced by different local factors/conditions. These differences make the whole benchmarking process worth attempting. The study revealed that, although all three water utilities experience high water losses levels, they do not actually implement any kind of water losses reduction strategies. Therefore their water systems are categorised in the “worst” category regarding the ILI performance Indicator. Although this “attitude” seems strange and illogical, it has a quite easy explanation. In Greece, the predominant water pricing policy, water utilities apply, includes a minimum fixed charge linked to a minimum water use. This means that when the actual water use of a consumer lays below a certain level (threshold), he is being charged with a minimum amount of water use, even if he never consumes it. This is a clever but not socially just way for the water utility to recover a significant part of the system’s real losses revenues. Finally suggestions are given in the form of a multi steps methodology for the reduction of the water losses.

1 INTRODUCTION

Today water utilities are experiencing a global problem: huge amounts of water are being lost in their distribution networks. This problem needs to be solved as the whole planet is experiencing water scarcity problems. A solid and effective (global) management strategy is required, based on a better understanding of the causes of water losses and the factors influencing them. The volume of water lost depends on the characteristics of the pipe network, the operational practices applied by the water utility

and the level of technology and expertise utilised (Farley & Trow, 2003).

Recent studies show that one third of the water abstracted for urban uses is lost due to leaks and brakes occurring in the water distribution networks (Liemberger et. al, 2007). This means that not only significant amounts of water are being lost, but also revenues for the water utilities. This is forcing water utilities to consider developing effective water loss and Non-Revenue Water (NRW) reduction strategies. Additionally, the Water Framework Directive 2000/60/EC (WFD) requires that all water utilities operating in EU countries should develop and implement appropriate water pricing policies that will guarantee the recovery of the full cost of the water being used (full water cost recovery principle). This strict obligation makes the reduction of water losses an even more urgent goal for water utilities to achieve. International Water Association (IWA) trying to establish a “common language” for the water distribution networks performance assessment developed an international best practice standard methodology. This methodology consists of the IWA standard international WB and a set of 170 PIs utilizing the best out of best (BoBs) practices from many countries around the world (Lambert et al., 1999; Alegre et al., 2006).

During the IWA methodology implementation in Greece, the handicap of poor and unreliable data sets kept by water utilities arose. Therefore a modified WB was proposed by the authors (Kanakoudis & Tsitsifli, 2010b). The implementation of this modified WB to Greek water distribution systems showed the way water utilities recover a significant part of the system’s real losses revenues. This is accomplished by charging a minimum fixed charge linked to a minimum water use. In the present paper a comparative analysis and a benchmarking process takes place regarding the performance evaluation of three water supply systems in Greece.

2 ANALYSIS OF THE IWA METHODOLOGY

IWA methodology regarding the performance evaluation of water losses in water distribution networks includes the International Standard WB (Fig.1) and a set of 170 PIs regarding the utility’s all operational aspects (Lambert et al., 1999; Alegre et al., 2006). WB is a tool widely used to assess the system water losses by taking into consideration the water amount produced, imported, exported, consumed and lost. The PIs evaluate the efficiency and effectiveness of the water services provision process by combining several variables. The IWA PIs range from simple ones offering a general management overview of the network’s operation in terms of efficiency/effectiveness, to detailed ones that deal with specific elements of operational practices. Although the PIs have been highly acknowledged as a very efficient tool, discussions on their appropriateness have recently emerged (Liemberger et al., 2007).

2.1 The modified WB

McKenzie et al. (2007) introduced the first IWA modification to include the water volume being charged but not paid for (Non-Recovered) (Fig.1). This endeavour introduced for the first time the economic dimension of the volumetric IWA WB. When both versions were applied in Greek cases they drive to misleading results. In Greece the water tariffs used are not the usual ones (e.g. inclining; declining; flat rates), but include a fixed charge (called minimum charge), related to water volumes being charged but not actually used. Thus, the calculated level of the Real Losses (RL) is underestimated by the Minimum Charge Difference (MCD), which, although producing

revenues (falsely decreasing the NRW level), it remains to be a part of the RL. This is the predominant water charging practice adopted almost by all water utilities in Greece, where, as a significant portion of the RL (up to 43%) produces revenues, the necessity to plan any water loss reduction strategy is diminished (Kanakoudis & Tsitsifli, 2010b). A further modification of the IWA WB is proposed by the authors to include the MCD (Kanakoudis & Tsitsifli, 2010b) (Figure 2).

International Standard IWA WB					1 st modif.
Annual System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue Water (RW)	RW
			Billed Unmetered Consumption		Non Recovered
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non - Revenue Water (NRW)	NRW
		Unbilled Unmetered Consumption			
	Water Losses	Apparent Losses	Unauthorised Consumption		
			Customer Meter Inaccuracies and Data Handling Errors		
			Real Losses		

Figure 1. IWA International Standard WB and its 1st modification.

System Input Volume (SIV)	Authorized Consumption (AC)	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water (RW)	Revenue Recovered Water (RRW)
			Billed Unmetered Consumption		Non Recovered
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non Revenue Water (NRW)	Accounted for Non Revenue Water
	Unbilled Unmetered Consumption				
	Water Losses (WL)	Apparent Losses (AL)	Unauthorized Consumption		
			Customer Meter Inaccuracies & Data Handling Errors		
		Real Losses (RL)			

Figure 2. Proposed modified IWA WB (Kanakoudis & Tsitsifli, 2010b)

2.2 Literature review

Lambert et al. (1999) presented the IWA WB (fig.1) being a very useful tool used to assess water distribution systems performance in terms of NRW and Water Losses (WL). Since then both the IWA WB and the IWA PIs have been used in many cases all around the world. NRW consists of Unbilled Authorised Consumption being water use authorised but not paid for; Apparent Losses (AL) consisting of water theft, illegal connections and meter/metering errors (Rizzo and Cilia, 2005); and RL consisting of tank overflows and pipes leaks and breaks. Studies about AL showed that water metering errors consist of the biggest part of the AL (Criminisi et al., 2009; Arregui et al. 2006). Factors such as water use pattern, meters specifications and flow rates affect water metering errors (Male et al., 1985; Arregui et al., 2006; Ferreol, 2005). Surveys showed that meters economic life cycle lays between 5 and 10 years (Lambert, 2002; Stakiadis & Papanikolaou, 2007). Criminisi et al. (2009) proved that AL rapidly increase as the meter ages and when private water tanks exist. Rizzo et al. (2007) suggested an integrated strategy consisting of several measures to tackle AL.

RL can be assessed by: (a) figuring the network's WB; (b) performing Component Analysis; and (c) performing Night Flow Analysis (NFA) (Lambert, 2002). The joint use of WB, NFA and network hydraulic simulation model could result in locating the leaks (Tabesh et al., 2009). One of the most important problems reported in assessing the network performance by evaluating its WB is the unreliable or even non-existing data (Paracampos & Thornton, 2002; Kolbl et al., 2007; Pearson, 2009).

3 PROBLEMS IDENTIFIED, ADDRESSED AND TACKLED - KEY LOCAL FACTORS

Several local factors were addressed during the water system performance evaluation methodology in Greece. The most common problem was the lack of data from the water utilities. Even if some data existed they were unreliable as the variables were not kept on a regular basis (Kanakoudis & Tsitsifli, 2010a). Tips and tricks are used by the authors to tackle the problems faced (Kanakoudis & Tsitsifli, 2010a).

The first key local factor that needed to be assessed was the water volume actually consumed and the water volume finally charged. As mentioned before the modified WB is used for the NRW estimation taking into account the MCD factor. Billed metered consumption is the real consumption taken from the meters readings.

Another obstacle to be tackled was the fact that almost all Greek water utilities do not keep any records regarding: a) the unbilled un-metered use; b) the unauthorized use, the illegal connections, bypasses, theft, etc.; c) the WL due to meter errors, under-registration etc., d) the actual number of customer connections; and e) the average length of customer connection pipe. The way to tackle this problem is to use data from the literature (international and national) and the empirical knowledge from the utilities technical personnel. After a thorough and extended field study, the research team reached to the point to consider the unbilled un-metered use a negligible part of the WB. Thus, it was excluded from further analysis. The unauthorized use was assumed to be 1% of System Input Volume (SIV) according to relative data found in the international literature (Farley & Trow, 2003; Kanakoudis & Tolikas, 2001). WL due to meter errors, under-registration etc. are also not being registered by water utilities. This amount was assumed to be 5% of SIV based on an acceptable metering error level (3%) provided by the manufacturer and found in the literature (Kanakoudis & Tolikas, 2001; Georgiadis & Kanellopoulou, 2008). The actual number of customer connections is also not registered by the water utilities. Since each city is built in a different way the density of connections vary a lot not only from one city to another but also from one area to another in the same city. To give an example, there are areas where each building is being served by more than 15 water meters and other areas where it is served only by one or two water meters. Sometimes one connection serves two or even three buildings at the same time. Therefore the number of connections is estimated based on the specific case study. Finally the connection pipes length is another not registered data. This length differs a lot across the city depending on the water meters location, either in front or in the back of the buildings. To safely estimate the WB and the PIs a sensitivity analysis takes place for each assumption made regarding the variables values.

4 CASE STUDIES

Three case studies are being presented in this paper. They refer to the water distribution networks of three Greek cities, namely Larisa, Kos and Veria. The performance assessment of each water distribution system was affected by local factors. The methodology used is the modified IWA WB and a set of selected PIs (Table 1).

Table 1. : Performance indicators calculated and their mathematical formulas

Indicators			Formula		
Op23	Water Losses (WL) per connection		$(A15*365/H1)/C24$		
	Apparent Losses (AL) per connection				
Op27	Real Losses (RL) per connection		$(A19*1000)/(C24*H2/24)$		
	UARL		$(18*(C8/C24)+0,8+0,025*C25)*(D34/10)$		
Op29	Infrastructure leakage index (ILI)		$Op27/(18*(C8/C24)+0,8+0,025*C25)/(D34/10)$		
Fi46	NRW by Volume (%)		$(A21/A3)*100$		
	NRW in lt/connection/day		$A21*1000/C24/H1$		
Indicator	Variable	Units	Indicator	Variable	Units
A3	System input volume	m ³	C24	Number of service connections	-
A15	Water losses	m ³	C25	Average service connection length	M
A19	Real losses	m ³	D34	Average operating pressure	KPa
A21	Non-revenue water	m ³	H1	The assessment period	Days
C8	Mains length	Km	H2	The time system is pressurized	Hours

4.1 Larisa case study

Larisa is a city located in the eastern part of the Greek mainland. Its water distribution network serves almost 192,000 people through 72,000 water meters (2006 data) and 628 km of cast iron, asbestos cement, steel, PVC and PE pipes. In order to check whether the PRVs installed in the pre-selected network nodes, forming four pressure zones, actually resulted in decreased NRW levels or not, the above mentioned methodology is used. A near-by-aquifer is used to supply water to the city. Three groups of water boreholes are used pumping water continuously. Water is stored in two water tanks and from there it flows, by gravity, to the city. The local water utility (DEYAL), since 2001, keeps detailed data regarding the water supplied, consumed and metered. Figure 3 presents water supplied and consumed in Larisa, Kos and Veria. The average operating pressure is 3.6 atm.

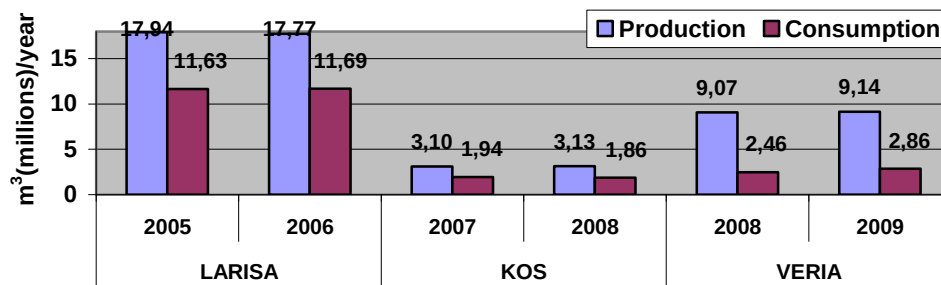


Figure 3: Water supply and water use for Larisa (2005-6), Kos (2007-8) and Veria (2008-9)

Based on DEYAL data records, the modified IWA WB was calculated for six consecutive years (2001-2006). The assumptions made for the specific case can be

summed up as follows:

- Billed metered consumption represents the meters' readings (water volume actually used, not including the in-house leaks lying below the meter's threshold). MCD represents the difference between the water volume being charged and the water volume being actually metered.
- As there were no data available regarding the unbilled unmetered use, the unbilled authorised use was considered to be equal to the unbilled metered use.
- The unauthorised use was calculated assuming that the water losses due to illegal connections and meter bypasses represent 1% of SIV, based on national data (Kanakoudis & Tolikas, 2001). Similarly, metering errors were estimated to be 5% of the SIV based on national and international literature (Kanakoudis & Tolikas, 2001; Georgiadis & Kanellopoulou, 2008).
- The number of customer connections assumed to range from 13,000 to 24,000 (1/6 to 1/3 of the total water meters respectively). The average customer connection pipe length differs a lot across the city. Having in mind that the water meters are located in the back of the new buildings (apart from the old buildings where they are located near the pavement), this length was assumed to be 7 meters. A sensitivity analysis took place to check how this assumption affects the calculations.

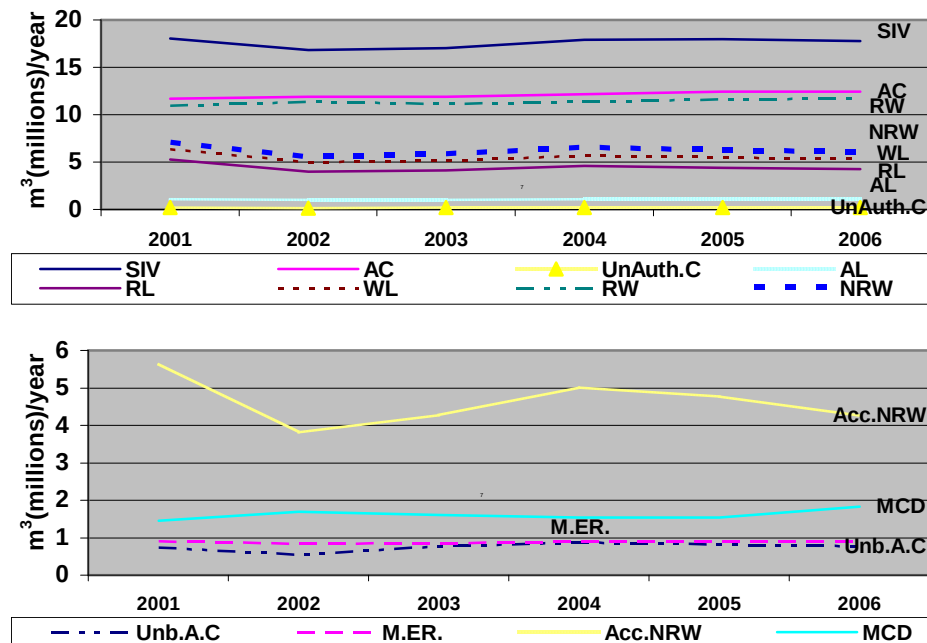


Figure 4. The IWA WB components for Larisa case (2001-2006) (a) SIV, AC, UnAuth.C, AL, RL, WL, RW, NRW; (b) Unb.A.C., M.E.R., Acc.NRW, MCD

The modified IWA WB was estimated for Larisa case for six consecutive years 2001-2006. Figures 4a and 4b present the modified IWA WB components for the years 2001 and 2006. Figure 7a presents the levels of RW, NRW, RL, AL and MCD calculated in

% SIV for 2001-2006.

4.2 Kos case study

Kos Island in Aegean Sea is situated in the south-east part of Greece, being a famous tourist destination (4th in Greece). The particularity of this case is that Kos town population gets more than double during summer. The winter population is 18,000 inhabitants (2001 census) while during summer it exceeds 40,000 people. Kos water network consists of 122 km pipes, serving the customers through 13,000 meters (2008 data). The local water utility (DEYAK), keeps detailed data records regarding the water supplied, consumed and metered since 1999 (Fig.3). The modified WB and the related PIs are calculated in a bimonthly basis to include the impacts of water demand peaks. The network's operating pressure ranges from 0 up to 5.5 atm (average: 3.0 atm). Many problems had to be tackled trying to form the modified IWA WB for Kos town case, mainly due to the insufficient data records kept by DEYAK. The assumptions made for Larisa case (sub-section 4.1.) hold for Kos case as well. The number of water meters is 13,000 in Kos town. Thus, the number of customer connections assumed to range from 3,000 to 7,000 connections (1/4 to 1/2 of the total water meters respectively). As the length of any service pipe is also not known, it was assumed to be 7 meters. Based on DEYAK records, the network's bimonthly modified WB was figured out from 1999 to 2008. Figures 5a&b present the modified WB components for 2007 on a bimonthly basis. Figure 8 presents data regarding the RW, NRW, RL, AL and MCD for the years 1999 to 2008 as % SIV.

4.3 Veria case study

Veria is a city situated in the north-west part of the Greek mainland. The city population is 47,411 inhabitants (2001 census). The water distribution network serves several municipal departments as well. The final population approaches 55,000 people served by 29,000 water meters. The case study refers only to the municipal department of Veria (47,000 people served by 26,000 meters). Veria water network consists of 270 km pipes, most of them made of PVC. The city abstracts water from two main surface water sources. Water is stored in two water tanks and from there it flows to the city by gravity. The big altitude difference is the city's particularity. The local water utility (DEYAV), keeps data records regarding the water supplied and metered since 2008 (Fig. 3). There are no data kept by the utility regarding the real consumption. Therefore the MCD is assumed to be negligible. DEYAV records data such as chlorine level, water level in the water tanks and operating pressures using a SCADA system. As water from the water sources is abundant, the utility has never implemented a water losses reduction strategy. However the city geomorphology demands the distribution network to operate at high pressures. The average network's operating pressure is 6.5 atm.

Veria case is a typical Greek water utility case, not recording data. The assumptions made for Larisa case (sub-section 4.1.) hold for Veria case as well. Moreover the unbilled authorised consumption is not recorded and therefore it is assumed to be 1% of SIV based on international literature (Farley & Trow, 2003). There are 29,000 water meters. Thus, the number of customer connections assumed to range from 6,000 to 9,000 connections (1/5 to 1/3 of the total water meters respectively). This assumption was based on the city urban structure. As the length of any service pipe is also not known, it was assumed to be 2.5 meters based on the utility technical staff experience.

Based on DEYAV records, the network's annual modified WB was figured out for two years, 2008 and 2009 (Fig.6). Figure 7b present data regarding RW, NRW, RL and AL for 2008 and 2009 as % SIV.

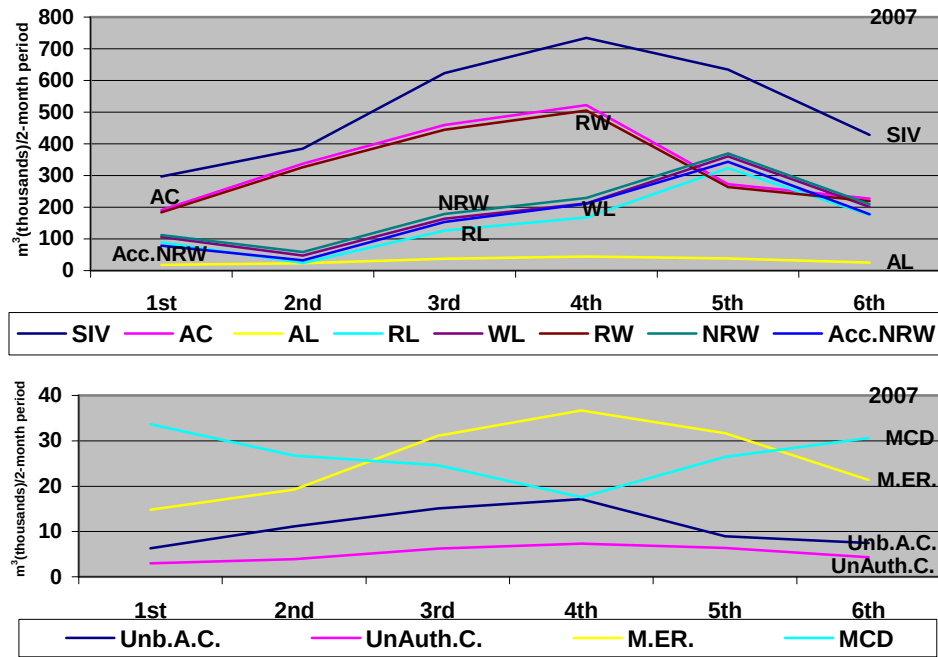


Figure 5. The bimonthly modified IWA WB components for Kos case for 2007

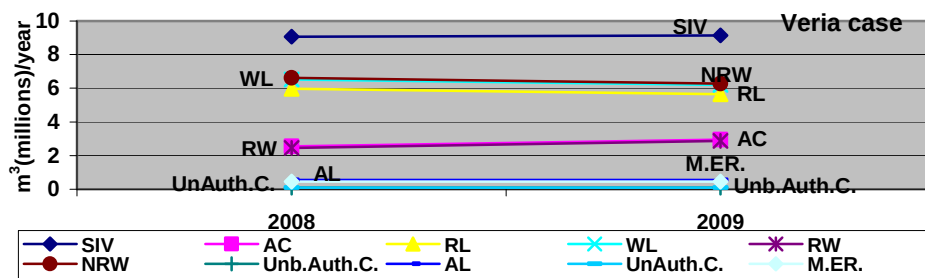


Figure 6. The annual modified IWA WB components for Veria case (2008; 2009)

5 RESULTS AND DISCUSSION

5.1 Calculating the modified WB

The modified IWA WB is performed for each case study. Figures 4a and 4b present the Larisa case annual modified WB components for 2001-2006. Figures 5a and 5b present

the Kos modified WB components from 2007 on a bimonthly basis. The modified WB has been estimated from 1999 to 2007 on a bimonthly basis. Figure 6 presents the annual modified WB components for Veria case for 2008 and 2009. Specifically the figures show the values of SIV, Authorised Consumption (AC), Unauthorised Consumption (UnAuth.C.), AL, RL, RW, NRW, Unbilled Authorised Consumption (Unb.A.C.), meter/metering errors (M.E.R.), Accounted for NRW (Acc.NRW) and MCD. It is worth noting that billed metered consumption equals to billed authorised consumption and to RW values. Billed unmetered consumption is considered to be zero. The graphical representation of the consumption values showed that DEYAK registered falsely the consumption levels of the third 2-month periods of 1999 and 2002 and the second 2-month periods of 2004 and 2006. Therefore although presented, these periods will not be taken into consideration in the analysis. Figure 7b shows that NRW and RL values are higher than RW values in Veria case. This is not happening in Larisa and Kos case.

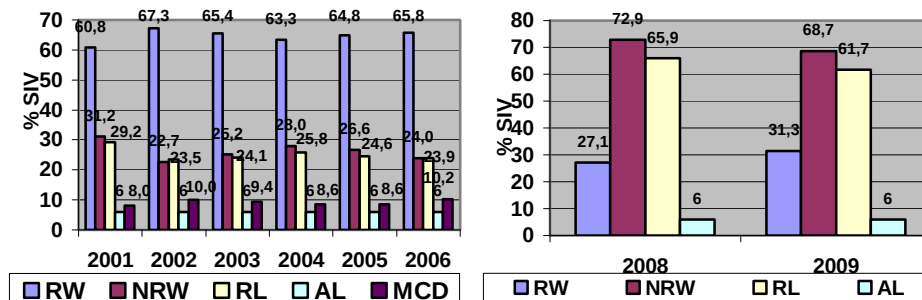


Figure 7. RW, NRW, RL, AL and MCD as % SIV for: (a) Larisa; (b) Veria

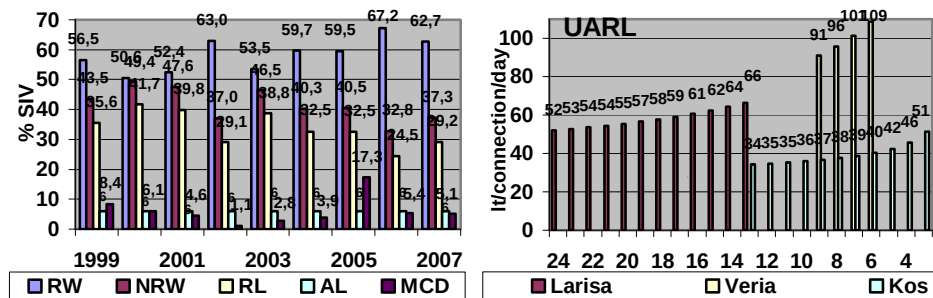


Figure 8. (a) RW, NRW, RL, AL and MCD as % SIV for Kos ; (b) UARL for all cases

5.2 Calculating the PIs

Several PIs are being estimated to assess the performance of a water distribution system concerning water losses. Table 1 shows the PIs being estimated for the three case studies. As previously mentioned for the cases of Larisa and Veria the PIs are being estimated on an annual basis, while for the Kos case they are being estimated on a bimonthly basis. Table 2 presents the minimum and maximum values of the following PIs: WL per connection, RL per connection, AL per connection, NRW in

lt/connection/day and ILI for Larisa and Kos cases. The results showed that PIs values increase as the number of connections decrease. For Veria case RL per connection values range from 1,717.16 to 2,729.62 lt/connection/day. RL account a lot in Veria case as shown in figure 6. WL per connection values range from 687.73 to 1,087.06 lt/connection/day in Veria case. NRW values range from 1,912.03 to 3,019.68 lt/connection/day. UARL level is also high in Veria mainly because of the high operating pressure values due to the geomorphology of the city (fig.8b). Another result is that NRW values are higher in the 4th and the 5th 2-month periods in Kos case (fig.5a). Their lowest values appear in the 2nd 2-month period. The maximum annual ILI value for Larisa is 16,7 (2001), for Veria is 25,1 (2008) and for Kos is 28,6 (2000). The minimum annual ILI value for Larisa is 8,7 (2002), for Veria is 18,8 (2009) and for Kos is 7,03 (2006) (Fig. 9b). ILI values for the three cases (excluding only two ILI values for Kos) are greater than 8 being the upper limit for a water distribution network to belong in the C category of the Physical Loss Assessment Matrix (Liemberger et al., 2007). Therefore all three water distribution networks belong to the category D according to the physical losses assessment matrix. The bimonthly analysis of ILI in the Kos case show the ILI values fluctuations among the 2-month periods verifying that the analysis should be made for smaller time periods when demand peaks are met.

Table 2. : Calculated PIs MIN and MAX values for 3000-7000 connections (Kos & Larisa case)

PI		MAX values		MIN values			MAX values		MIN values	
		3000 conn	7000 conn	3000 conn	7000 conn		13000 conn	24000 conn	13000 conn	24000 conn
WL/connection	Kos case	1,220.88	523.23	53.63	22.98	Larisa case	488.80	264.77	382.14	206.99
RL/connection		3,003.30	1,287.13	15.91	6.82		1,110.82	601.69	451.77	834.04
AL(lt/conn/day)		359.21	153.95	97.55	41.81		329.01	178.21	228.36	123.70
NRW(lt/conn/day)		3,417.02	1,464.44	214.27	91.83		1,187.34	643.14	804.26	435.64
ILI		58.51	33.25	0.13	0.17		16.73	11.56	12.56	8.68

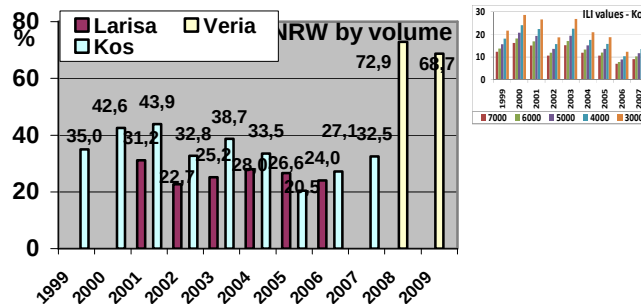


Figure 9. (a) NRW by volume for all cases; (b) ILI - Kos

6 CONCLUSIONS

The present paper aims at performing a benchmarking process regarding the water distribution network WL among three Greek case studies. The methodology used includes the proposed IWA WB modification (Kanakoudis & Tsitsifli, 2010b) and the

IWA PIs. Three Greek urban distribution networks are analysed namely Larisa, Veria and Kos. Each case presents its own characteristics. The common local factor is that water utilities do not keep detailed data records. This results in providing unreliable data if not no data at all. To overcome this problem tips and tricks used in similar cases were used (Kanakoudis & Tsitsifli, 2010a).

DEYAL implemented since 2004 a pressure management program using pressure reduction valves (PRVs) at certain points of the network. The results showed that this program attributed in reducing RL and NRW values (fig. 4a;4b;7a). Veria is a city with high altitude differences resulting in high operating pressure values and higher UARL values than the other cases (fig.8b). DEYAV does not implement any water losses reduction strategy mainly because of the rich aquifer in the area. Its network experiences high NRW and RL values (fig. 6;7b). The results showed that there is a crucial need for a water losses reduction strategy since ILI values are extremely high. Kos presents big differences in water supply and demand within the year since it is a famous tourists' destination. In the summer the city population becomes more than double. Therefore the analysis is performed in a bimonthly basis being the utility billing period. DEYAK does not implement any water losses reduction strategy. The results showed that during the 4th and the 5th 2-month periods (July until October) RL and NRW get their highest values (fig.5;8a). As there is no pressure management in the network, RL per connection get their highest value during the 5th period while the highest consumption occurs in the 4th period. This happens because the network still operates at high pressure during the 5th period although the water consumption is decreasing. Because of the high ILI values (fig.9b) a water losses reduction strategy is imperative, especially in Kos case since the system is operating under large pressure variances.

The basic reason for the water utilities not implementing any WL reduction strategy is the minimum charge they bill to their customers. As shown in fig. 4b and 5b the accounted for NRW is less than the real NRW. Therefore water utility managers falsely believe that their RW is greater. This pricing policy is not socially just as it transfers the RL costs to the consumers. The consumers should only pay for the minimum acceptable RL level being 5% of SIV.

The authors taking into consideration the full water cost recovery principle propose a methodology for water losses reduction. This methodology includes 12 successive steps forming an integrated management approach: 1) Monitor the network; 2) Develop a hydraulic simulation model; 3) Assess the initial UARL and NRW levels based on the system's operating pressure; 4) Assess the Full Water Cost (FWC) level based on the initial SIV level; 5) Determine the water price levels based on the FWC to guarantee the recovery of the full cost of the water used (new water tariffs); 6) Assess the new levels of the water demand (considering the water price-related water demand elasticity index) and the Economic Annual Real Losses (EARL) based on the water prices; 7) Pinpoint the crucial network points for pressure management (apply the most cost-effective water loss reduction strategy); 8) Estimate the new UARL, NRW levels due to the lower operating pressure levels; 9) Assess the new (lower) FWC level (due to the reduced water demand); 10) Set the water price levels adjustment period based on the FWC calculation cycle; 11) Determine the new water demand, EARL levels (new water prices); and 12) Repeat steps 7-11 (after some loops the system will balance at its "sustainability level").

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