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Defining the level of the Non-Revenue Water in Kozani, Greece: is it a typical case?

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ABSTRACT

Water Losses in pipe networks usually represent the biggest "water use" due to the high leakage occurring. Water utilities are forced to apply effective Non-Revenue Water (NRW) reduction strategies, as climate change conditions put an enormous stress on the water resources reserves. WATERLOSS project attempts to assist towards NRW reduction through developing a decision support system (DSS) that will provide water utility managers with a prioritized list of NRW management/reduction measures. Kozani city water distribution network was one of the pilot cases where the integrated methodology developed within WATERLOSS was applied to. The results revealed that although the specific network experiences high NRW values, the local water utility has not implemented any integrated NRW reduction strategy so far. The reason for that could be the use of the fixed charge in the water bills, rising up to 70% of the NRW when expressed in equivalent water volume. Similar studies in Greece and the results of WATERLOSS project verified that water utilities' common practice involve the fixed charge in water bills as a means to keep costs and revenues balanced. The fixed charge should represent the opportunity cost consumers have to pay for water services in a socially fair billing practice.

Keywords: Urban water network; Water balance; Water losses; NRW; Fixed charge

1. Introduction

The need for a conservative water use is today more pressing than ever, due to the climate change conditions the whole planet is facing. Non-Revenue water (NRW) is identified as a major problem in urban water distribution networks and water utilities must take all the appropriate actions towards its reduction. NRW results not only to water, but also revenues and energy being lost. Additionally, the consumers are being "forced" to pay for these losses, although they are not fully responsible for them. As water utilities have to reach to an economic break-even point (where the total revenues will equal the necessary expenses) they charge their customers with these losses. Therefore, water utilities are trying to plan and apply effective water losses and NRW

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reduction strategies. The NRW problem is quite serious, as recent studies revealed that more than one third of the total water volume abstracted from the water resources to meet urban water needs is being lost along the pipe networks, due to leaks and breaks occurring [1]. Additionally the Water Framework Directive 2000/60/EC demands from the water utilities to design and apply appropriate water pricing policies, towards the recovery of the full water services cost (direct; environmental; and natural resource costs). WATERLOSS project (2G-MED09-445) trying to offer something valuable to the battle against the NRW reduction, developed an integrated approach and a Decision Support System (DSS) which provides the water utility manager, using it, a list of prioritized NRW reduction measures focused on the problems his own network faces. The integrated approach consists of several modules: (a) the performance evaluation of any water distribution system (WDS) using the water balance (WB) and a list of performance indicators (PIs); (b) the development of NRW reduction measures by NRW component; and finally (c) the DSS platform, which prioritizes the specific measures shortlisted for the specific network studied.

The present paper analyses the performance assessment of a specific pilot case, the city of Kozani. The methodology used is the well acknowledged one developed by the International Water Association (IWA) consisting of the Standard International WB [2] and the list of the 170 PIs suggested [3].

2. The methodology

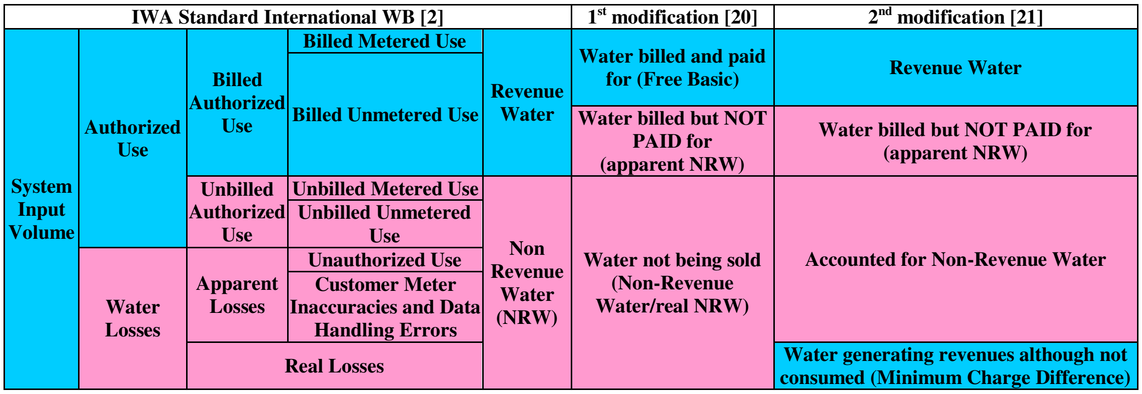
2.1. Literature review

To establish a common language and terminology for the evaluation assessment of WDSs, IWA developed the concept of a WB, being able to estimate where the water entering the system (System Input Volume—SIV) was actually being "used". The IWA Standard International WB [2] splits the SIV into the revenue water (consisting of the water bringing revenues to the utility) and the NRW. The latter represents the water used by authorized users but not billed and the water losses (Fig. 1). A network's operating status can be well assessed using the WB template that can be applied using either a top-down or a bottom-up approach. The entire process should be backed up by the appropriate PIs, picked up from the respective IWA list, applying the super-market concept, where the "customer" chooses those PIs that suit his needs best [4].

Water losses in a water distribution system represent the apparent (or commercial) losses (AL) and the real (or physical) losses (RL). The apparent losses consist of the illegal use (theft); the billing and data handling errors; and the metering errors [5]. AL are difficult to be measured. Field studies proved that AL value may range from 1 to 3% (Australia) to 9% (Korea and Malaysia) of the SIV [6]. According to Criminisi et al. [7] water metering errors should be blamed for the biggest part of the AL. An extra reason for this is the fact that water metering errors are very difficult to quantify. Arregui et al. [8] identified the following key factors for meter under-registration: water consumption pattern; water quality; environment conditions; mounting position; velocity profile; seasonal water use; and tampering. Water metering errors are not constant but depend on the flow rate. Thus, it is important to know the water use pattern and the specifications of the meter (e.g. metering threshold; sensitivity) at different flow rates [8–10]. Rizzo et al. [11] suggested that several measures forming an integrated strategy should be applied to tackle AL.

RL consist of the water being lost due to leaks, breaks, and tanks' overflows. According to "Background and Bursts Estimates—BABE" [6] RL consist of: (a) background leakage (flow rate less than $0.5\,\mathrm{m}^3/\mathrm{h}$); (b) reported leaks and bursts; and (c) unreported leaks and bursts. The size of the RL can be assessed through: (a) figuring the network's WB; (b) component analysis—CA; and (c) night flow analysis—NFA [6]. Component analysis proved that in well operated systems the RL main part occurs in the service connection pipes rather than in supply mains. This is also the feeling most water practitioners have [12]. Farley and Trow [4] and Thornton [13] stated that leakage in a water pipe network can be determined through extended (in terms of consecutive years) field studies of WB and minimum night flow (MNF) assessment, possibly in combination with BABE. Tabesh et al. [14] determined the NRW components (including RL) using real and estimated data, presenting a new methodology for leak detection in pipes and nodes, utilizing the system's hydraulic simulation model and dividing the total water-use in a pressure dependent part and a pressure independent one. Almandoz et al. [15] developed a methodology for RL evaluation. They considered AL as the non-metered use (called "uncontrolled water") that depends on the water use patterns (domestic, industrial, institutional, etc.). RL were considered to be pressure dependent in certain parts of the system.

To safely calculate the PIs, concluding our effort by reliably determining the infrastructure leakage index (ILI) levels, the quality of the necessary data and their collection techniques adopted, are both crucial, as stated in a Sao Paolo case [16].



IWA Standard International WB [2]					1^{st} modification [20]	2^{nd} modification [21]
System Input Volume	Authorized Use	Billed Authorized Use	Billed Metered Use	Revenue Water	Water billed and paid for (Free Basic)	Revenue Water
			Billed Unmetered Use		Water billed but NOT PAID for (apparent NRW)	Water billed but NOT PAID for (apparent NRW)
		Unbilled Authorized Use	Unbilled Metered Use	Non Revenue Water (NRW)	Water not being sold (Non-Revenue Water/real NRW)	Accounted for Non-Revenue Water
			Unbilled Unmetered Use			
	Water Losses	Apparent Losses	Unauthorized Use			
			Customer Meter Inaccuracies and Data Handling Errors			
		Real Losses				Water generating revenues although not consumed (Minimum Charge Difference)

Fig. 1. The IWA standard international water balance and its modifications [2,20,21].

Additionally, a benchmarking project in Austria [17] raised the issue of data reliability and accuracy, describing the “weaknesses” of the data kept by the local water utilities. Finally, rural, urban, and metropolitan networks were examined resulting in different leakage values. Pearson [18] recommends that necessary data, adequate availability, and quality safeguarding is a precondition when a NRW reduction strategy is being developed. Therefore, confidence levels are used to check the sensitivity of the results. Water Utilities do not always keep appropriate data records. Another case study from Geneva city concerning the calculation of the WB, highlighted that a previous good knowledge of the WB components is necessary in order for the WB to be reliably figured and that the utility staff involved should have full access to the information needed [19].

2.2. The WB and PIs methodology

The WB and PIs methodology is widely used by water utilities worldwide to assess the performance of a WDS and check the impact of the measures taken [2,3]. The PIs evaluate the efficiency and effectiveness of the water services provision process, combining several variables. A detailed list of 170 PIs needs 232 variables values to be metered in the field and recorded [3]. Implementing the WB methodology for WDS auditing in different countries and systems, local conditions are met, raising the need for IWA WB modifications. McKenzie et al. [20] introduced in the IWA WB, the water volume being charged but not paid for (Non-Recovered) (Fig. 1), proposing the IWA WB first modification. This was the first time that the economic dimension of the volumetric IWA WB was introduced. During the performance assessment of WDS across the Mediterranean EU countries, Kanakoudis and Tsitsifli [21] faced a challenge. The water utilities trying to balance their costs and revenues have included a fixed charge in their water bills. This policy would be normal, if the fixed charge corresponded to the opportunity cost that each water user has to pay, for enjoying adequate quantity and pressure of clean water in his tap. This approach led Kanakoudis and Tsitsifli to propose the IWA WB second modification [21], including the minimum charge difference (MCD) element in the IWA WB (Fig. 1). The MCD, or water losses generating revenues, represents water volume billed but not actually consumed. Such a pricing policy results in underestimating the NRW level, since the water utility recovers a part of the lost revenues related to the water losses. Thus, usually the water utility does not implement or even plan any kind of measure/strategy to reduce the water losses levels.

Kanakoudis et al. [22] developed a methodology to calculate the MCD element [22]. The fixed charge included in the water tariffs may be expressed either as a minimum water use (m^3) or as a minimum water charge (e.g. in €). When the former applies (minimum water volume), the MCD expresses the difference between the water volume charged to the customers and the respective volume actually recorded by their water meters. When the latter applies (minimum fixed -extra- money charge), then the MCD expresses the equivalent water volume, that if sold (on net water price, excluding the fixed cost) would have resulted in the same revenues (e.g. in €). To express the MCD as water volume (m^3), the mean water use charge (revenues related to water sold over water sold generating revenues) is used. The level of the mean monthly fixed charge varies from country to country and even within the same country (e.g. €2–5 in Greece; €4–7 in France; €5–9 in Spain; €6–8 in Italy). The mean water charge (revenues related to water sold, over water volume sold generating revenues) is usually applied for the estimation of MCD rates by water utilities. However, this process offers them an excuse to avoid investing in NRW reduction measures. The MCD equivalent water volume, although providing revenues, should be considered as water losses. Whenever a water utility manager forms the WB of its WDS to assess its status, he should also include the part of the MCD related revenues that concerns the water actually used. This practice, although resulting in reduced NRW-related revenues, does not reduce the actual NRW level. "Billed Metered Use" represents only water meters' recordings. The IWA WB second modification also integrates the first modification [20].

3. Kozani water distribution network

3.1. Presentation of the case study

Kozani city is the capital of Kozani Regional Unit in north-western Greece (Western Macedonia Region). DEYAK is the municipal water/sewerage utility responsible for the entire water supply system (i.e. water recourses; water pumping and transfer units; water transfer mains; water storage tanks; distribution network; and waste water treatment plant). DEYAK has 121 full time employees and its services include the operation; maintenance; construction, and administration of water and sewerage network of Kozani Municipality (71,000 people). In 1995 similar responsibilities related to the local remote heating system were added to the day-to-day operation of DEYAK [23].

The Water Distribution Network (WDN) of Kozani City (and not of the entire Municipality) is used in this paper as the case study. This WDN has a total length of 129,584.4 meters (consisting of PVC; asbestos cement; and HDPE pipes) supplying the 28,281 water meters of its customers (47,000 people, 2001 census) through 9150 service connections [23]. The average length of a service connection is 6 m. The connecting pipes consist of 60% galvanized iron with diameter of 1.5 in, 30% PE with diameter of 22 mm and 10% HDPE with diameter of 25 and 28 mm. The WDN supplies water from Ermakia natural resources (since 1992) and two groups of boreholes in Vathylakos (Fig. 2). The tanks used to collect and distribute the water into the city and the districts of Kozani are: (i) "Agia Paraskevi" tank with capacity 1000 m^3; (ii) a group of 3 tanks with capacity 1200, 1800 and 3000 m^3, respectively; and (iii) the tank "9000" with a capacity of 9000 m^3.

The total water supplied reached 5,535,078 m^3 in 2009; 5,688,642 m^3 in 2010; and 5,844,632 m^3 in 2011, slightly increasing from year to year. DEYAK applies an increasing block water tariff (the billing period is 4 months) using a fixed charge of 17€ per 4 months. The fixed charge is charged regardless of the actual consumption. Thus, it is an extra money charge. DEYAK identified high NRW values as the main problem is its WDN experiences. The main causes are the aged parts of the network; its non-registered parts; illegal connections; flow meters failures; and non-existing maintenance policy.

The WDN includes three pressure zones, namely: high zone (ground level: 750–800 m); medium zone (ground level: 710–750 m); and low zone (ground level: 610–710 m) (Fig. 2). WDN's operating pressure range is 3–5 atm. DEYAK, stated that the operating pressure down limit refers to the pressure during peak hours in all 3 zones, while its upper limit refers to the operating pressure during the night, under minimum demand conditions (Table 1). Unfortunately, these three pressure zones cannot be considered as District Metered Areas because they are not hydraulically isolated (i.e. having only one entrance and one exit point).

3.2. Assessing the WB and the PIs in Kozani city case

As DEYAK applies a four-monthly billing policy, the WB of its WDN was accordingly formed (and also annually). Like many water utilities across the Mediterranean, DEYAK did not provide full data for all necessary variables. The authors used assumptions according to the international literature and the experience of DEYAK's staff (Table 2).

There is no billed unmetered consumption since all consumers have water meters installed. The unbilled metered consumption is considered to be zero too, since DEYAK does not register any unbilled consumption. The unbilled unmetered consumption was assumed to be 2% of the SIV (based on DEYAK's staff experience). DEYAK doesn't keep any records related to the unauthorized consumption, illegal connections, theft, etc. Thus, this volume was assumed to be 1% of the SIV (Table 2). This assumption was based on the relative data met in the international literature [24,4]. The Customer Meter Inaccuracies and Data Handling Errors were assumed to reach 10% of the Billed Metered Consumption (Table 2), laying within the margins met in the literature (it is also lower compared to other regions in Greece). The assumed value seems reasonable as recently DEYAK replaced a large number of water meters. A study in EYDAP (Athens Water Utility) in 1998 revealed that meter errors account for 15% of the SIV [24]. Another pilot project implemented also by EYDAP ten years later (2008) revealed that meter errors account for 7–9% of the authorized consumption [25].

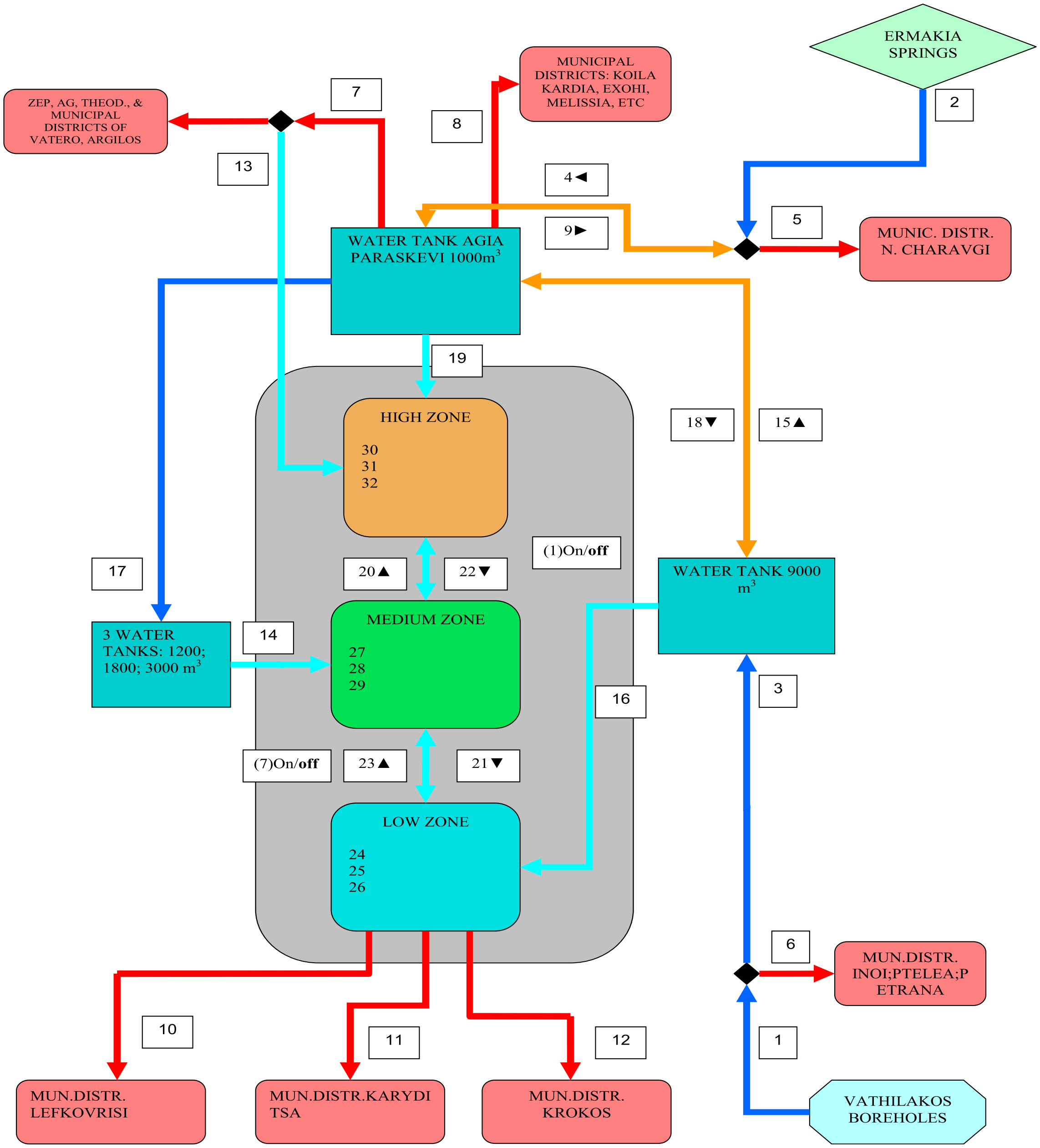


Fig. 2. Water supply system of DEYAK.

Table 1
Altitude, operating pressure, and number of connections per zone

Area	Altitude(m)	Operating pressure (atm)	Number of connections
High	750–800	1.5–5.5	1000
Middle	710–750	1.5–5.0	2500
Low	610–710	2.0–8.5	5650

Table 2
Assumptions for variables with unknown values

Variables	Values
Unbilled unmetered consumption	2% of SIV
Unauthorized consumption (mainly theft)	1% of SIV
Customer meter inaccuracies & data handling errors	10% of billed metered consumption

Table 3
Water equivalent volume calculation corresponding to the fixed charge

	R_{fc} (€)	R_{wuc} (€)	Q_{wsp} (m^3)	MCD (m^3)
2009	1,442,311	1,377,609.04	2,170,749	2,272,702
2010	1,476,268	1,412,820.11	2,215,196	2,314,678
2011	1,478,568	1,396,141.70	2,182,963	2,311,842

As already stated, DEYAK charges a fixed charge of €17.00 per 4 months. Table 3 presents the equivalent water volume corresponding to this fixed charge for the period 2009–2011. Since there was no data available on 4-month basis, the annual MCD is appropriately divided for each year. The MCD is the ratio of the revenues related to the fixed cost (R_{fc}) over the mean water use charge (revenues related to water sold R_{wuc} over the water volume generating revenues Q_{wsp}) (Table 3).

The new modified IWA WB for Kozani is figured: (a) annually for the years 2009 and 2010; and (b) every 4 months for the period 2009–2011. The water audit tool used was the WB/PI-CalcUTH [26].

4. Results and discussion

NRW values ranged from 53.2 to 61.8% of the SIV (4-months evaluation) and from 58.1 to 60.0% (annual evaluation) (Figs. 3 and 4). MCD values ranged from 37.4 to 44.5% of the SIV (4-months evaluation) and from 39.6 to 41.0% of the SIV (annual evaluation) (Figs. 3 and 4). RL represent the biggest part of NRW and their values ranged from 45.5 to 55% of the SIV (4-months evaluation) (Fig. 5). AL values ranged from 4.8 to 5.7% of the SIV (4-months evaluation) (Fig. 5).

The interesting finding is that the MCD values ranged from 60.5 to 83.8% of the NRW (4-months evaluation) and 65.9–70.7% NRW (annual evaluation) (Fig. 6). This means that DEYAK underestimated the NRW actual values by almost 40% of the water entering the system. A typical example is during the 1st 4-month period of 2009 the actual NRW value was 53.2% of the SIV, DEYAK recovered the largest part of it (83.8%) letting only the remaining NRW value (8.6% of the SIV) to "worry for" (Fig. 3). The results obtained from the WB analysis explained very well why DEYAK does not implement any NRW reduction measures, although its WDN experiences high NRW levels. Another reason explaining this attitude is that Kozani is situated in a part of the country very rich in water resources.

Although the water audit tool WB/PI CalcUTH, used to evaluate the performance of Kozani's WDN, can calculate all the IWA PIs, only the most important ones, in terms of water losses, were calculated (Table 4). ILI values verify the fact that RL are playing a major role in NRW, since ILI's values get higher than 8 (Table 4), ranking Kozani's WDN to the category D according to the World Bank RL assessment matrix [27].

The results from the WB analysis evidenced that although NRW values are too high (exceeding 50% of the SIV), DEYAK does not implement measures to reduce them. The main reason is the fixed charge included in DEYAK's water bills, resulting in recovering almost 70% of the NRW (equals to almost 40% of the SIV). Thus, DEYAK losses result only from the remaining NRW. Similar case studies in Greece showed that for example the MCD represents 25.7–44.3% of the NRW (8–10.2% of the SIV) in Larisa city (with a fixed charge expressed as minimum consumption of 20 m^3 per 2 months) (Fig. 7(a)) and 2.9–19.4% of the NRW (1.1–17.3% of the SIV) in Kos town (with a fixed charge expressed as minimum consumption of 8 m^3 per 2 months) (Fig. 7(b)) (2005 value is excluded due to wrong recordings) [28]. The WATERLOSS project findings showed that high NRW values, exceeding even 50% of the SIV, are met also in other EU cities (Fig. 8) [29]. The same also stands for the MCD levels (as % SIV) (Fig. 8) [29].

Several PIs were also calculated for Kozani's WDN. As the PIs expressions "NRW % by volume" and "Apparent Losses as % of SIV" do not properly reflect the significance of the NRW and the Apparent Losses, three different expressions were used for Kozani's WDN: (a) Apparent losses expressed in lt/connection/d; (b) NRW expressed in lt/connection/d; and (c) NRW expressed in m^3/km/d [23].

Although the PIs have been highly acknowledged as a very efficient tool, discussions on their appropriateness have recently emerged [27,30]. Some of the

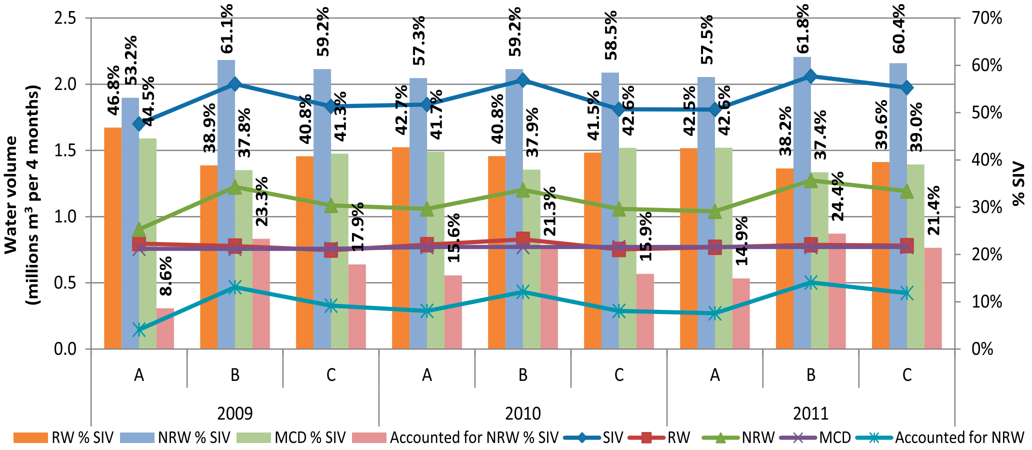


Fig. 3. SIV, RW, NRW, MCD, and accounted for NRW for 4-month period assessment.

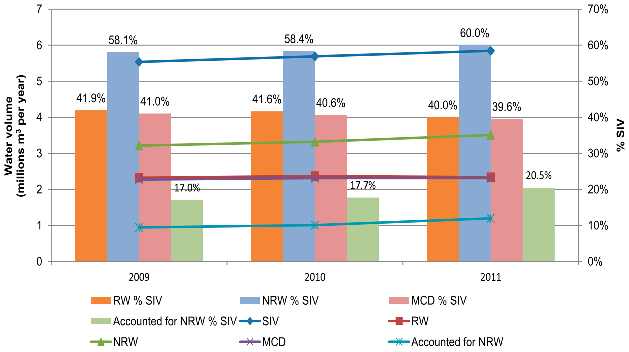


Fig. 4. SIV, RW, NRW, MCD, and accounted for NRW per year.

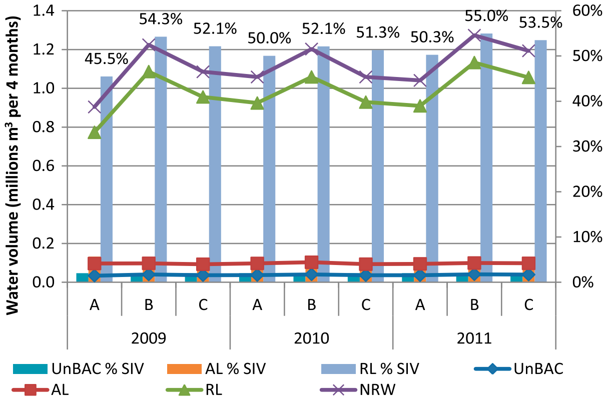


Fig. 5. NRW, RL, AL, and UnBAC per 4 months.

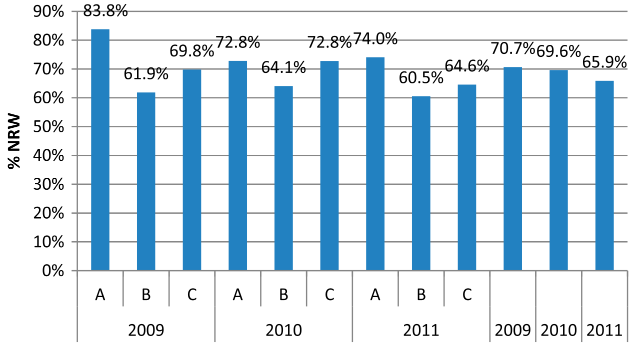


Fig. 6. MCD as % of NRW.

IWA PIs should become more detailed, highlighting specific WB components. WATERLOSS project proposed new PIs (11 derived from existing ones and 31 new ones) to cover regional conditions and current issues (energy, carbon footprint) [31]. Here two new PIs are proposed to address specific cases. The first is the ILI_{MAL} (Eq. (1)) expressing ILI's worst/biggest value when the unavoidable annual real losses (UARL) become minimum (WDN operates under the lowest possible pressure) (Fig. 9).

$$\text{ILI}_{\text{MAL}} = \frac{\text{CARL}}{\text{UARL}_{\text{OPTIMUM}}} \tag{1}$$

where CARL stands for the current annual real losses.

The second PI proposed is the LOS_{NRW} expressing how many times the current NRW level is greater than the minimum NRW level. The LOS_{NRW} concept is the same as the ILI concept: a dimensionless indicator, providing a quick evaluation of NRW.

$$\text{LOS}_{\text{NRW}} = \frac{\text{NRW}_{\text{C}}}{\text{NRW}_{\text{MIN}}} \tag{2}$$

Table 4
Performance indicators as calculated for 2009–2011 both annually and on 4-month basis

Performance Indicators		2009	2010	2011	A2009	B2009	C2009	A2010	B2010	C2010	A2011	B2011	C2011
WR1 (%)	Inefficiency of use of water resources	50.86	51.19	53.02	45.47	54.26	52.14	50.04	52.12	51.3	50.27	54.97	53.49
Op23 (m^3/connection/year)	Water losses per connection	339.09	350.33	370.58	289.19	384.03	342.87	339.57	376.78	334.25	333.92	399.63	377.34
Op24 (m^3/km/year)	Water losses per mains length	65.6	67.77	71.69	55.95	74.29	66.33	65.69	72.89	64.66	64.60	77.31	73.00
Op25 (%)	Apparent losses per connection	5.19	5.16	5.00	5.68	4.88	5.07	5.27	5.08	5.15	5.25	4.82	4.96
Op26 (%)	Apparent losses per system volume	5.19	5.16	5.00	5.68	4.88	5.07	5.27	5.08	5.15	5.25	4.82	4.96
Op27 (lt/connection/d)	Real losses per connection	842.94	871.85	927.80	704.29	965.34	856.01	841.73	940.61	832.15	828.36	1006.61	946.16
Op28 (lt/connection/d)	Real losses per mains length	59,520.14	61,561.44	65,512.42	49,730.07	68,155.85	60,443.48	59,434.62	66,416.83	58,758.27	58,490.64	71,077.07	66,808.85
Op29	Infrastructure leakage index (ILI)	17.26	17.85	19.00	14.42	19.76	17.53	17.24	19.26	17.04	16.96	20.61	19.37
Op39 (%)	Unmetered water	58.06	58.35	60.02	53.16	61.15	59.22	57.31	59.2	58.45	57.52	61.79	60.45
Fi46 (%)	Non-revenue water by volume	58.06	58.35	60.02	53.16	61.15	59.22	57.31	59.2	58.45	57.52	61.79	60.45

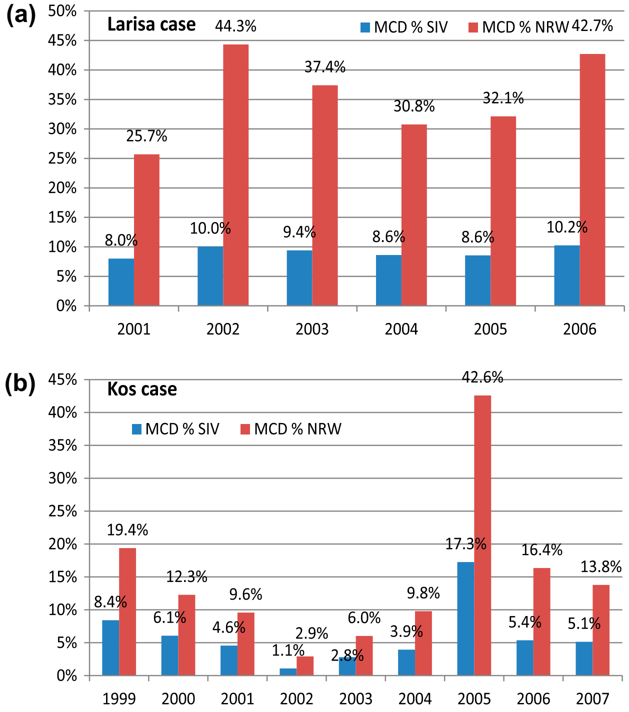


Fig. 7. MCD as % of SIV and NRW: (a) Larisa case; (b) Kos case.

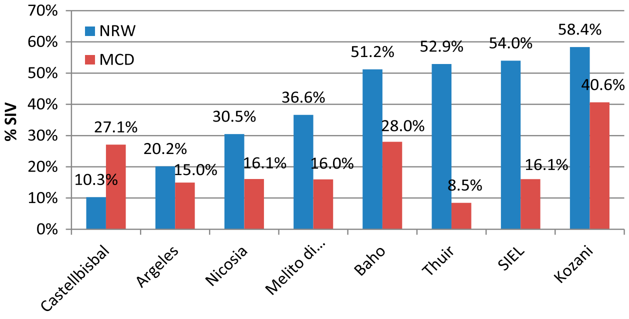


Fig. 8. NRW and MCD as % of SIV for WATERLOSS project pilot cases (data: 2010).

where NRW_C is the current value of NRW and NRW_{MIN} is its minimum value. NRW_{MIN} is achieved when the NRW components (RL; AL; UnBAC) become minimum. RL minimum value is UARL or even UARLopt (i.e. UARL for the optimal/minimum possible operating pressure). AL minimum value is achieved according to the case-specific specifications. It is commonly accepted that this value can be 2% of the SIV [32]. Unbilled Authorized Consumption minimum values are set by the water utility and its policy (where it prefers to supply water without charging it). Again, 1% of the SIV can be considered as a minimum value [32].

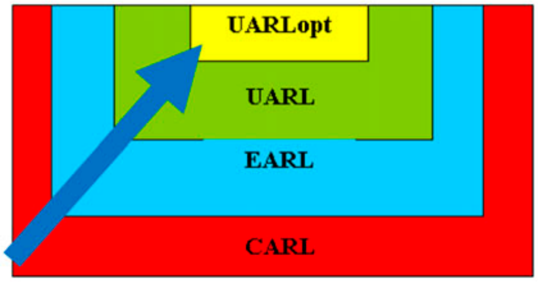


Fig. 9. The evolution of CARL to UARLopt.

5. Conclusions

The evaluation of Kozani’s WDS performance through the WATERLOSS project revealed high NRW levels. Actually the NRW, represents a large part of the SIV ranging from 53.2 to 61.8%, meaning that more than half of the water entering the WDS is not being sold. The water tariff in use includes a fixed charge of €17.00 per 4 months regardless of the actual water consumption. This amount of money translated to water volume represents almost 70% of the network’s NRW and 40% of its SIV. This means that the local water utility (DEYAK), recovers the largest part of its NRW through the fixed charge applied. This is the main reason why DEYAK hasn’t applied any NRW reduction strategies. This is a common practice met also in other cases in Greece and in the Mediterranean area in general, where the water utilities recover a large part of the lost revenues related to the NRW, through the fixed charge, underestimating the importance of the actual NRW level. The analysis of the PIs selected revealed that Kozani’s water distribution network experiences high ILI values classifying it to group D. This means that there is an urgent and imperative need to develop water losses and NRW reduction strategy. This is one of the benefits DEYAK gained from its participation in the WATERLOSS project. Another benefit was that its staff realized the importance of the NRW and was persuaded to monitor its actual value, adopting a common terminology and trained to use water audit tools and find out possible measures to reduce the NRW level. Additionally DEYAK incorporated the PIs database formed within WATERLOSS project into the quality assurance system it applies.

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