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Applying an integrated methodology toward non-revenue water reduction: the case of Nicosia, Cyprus

V. Kanakoudis[a], S. Tsitsifli[a,*], G. Demetriou[b]

[a]*Laboratory of Hydromechanics and Environmental Engineering, Department of Civil Engineering, University of Thessaly, GR38334 Volos, Greece, email: bkanakoud@civ.uth.gr (V. Kanakoudis), Tel. +30 2421074182; Fax: +30 2421074135; email: tsitsifli@civ.uth.gr (S. Tsitsifli)*
[b]*Water Board of Nicosia, 1515 Nicosia, Cyprus, email: gdemetriou@wbn.org.cy*

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ABSTRACT

Non-Revenue Water (NRW) is one of the major issues water utilities are facing today, especially in areas with severe water scarcity conditions. The WATERLOSS-DSS, a user friendly decision support system (DSS), was developed to help water operators decide which NRW reduction measure(s) to apply in their water networks. The DSS evaluates the water network performance level and finally proposes a list of prioritized NRW reduction measures. This DSS was checked for Nicosia's (capital of Cyprus) urban water network. Three problematic District Metered Areas (DMAs) were chosen. The DSS provided a list of prioritized NRW reduction measures targeting at various NRW causes for each DMA. Nicosia's water utility officials decided to apply some of the short-listed measures in those DMAs, resulting in significant NRW reduction and additional benefits. The annual water savings came up to 1 million m^3, equal to 4.8% of the water entering the network. Economic benefits of more than 700,000 € are noted. Additional benefits are important energy savings, reduced overtime, and better knowledge of the network. These were incredibly important for Nicosia, as Cyprus is facing severe water scarcity conditions.

Keywords: Water losses; Non-Revenue Water; NRW reduction measures; Pressure management; Active leakage control

1. Introduction

Non-Revenue Water (NRW) is one of the primary problems water utilities are facing today. Water resources are stressed and the increasing water demand and the climate change conditions jeopardize their sustainability. The situation becomes even worse in countries facing water scarcity conditions, such as the Mediterranean basin countries, where NRW levels are high enough exceeding in some cases 50% of the water entering the water distribution networks (WDSs). NRW's consequences are both environmental and economic. The first ones involve water volume lost, energy lost, and increased carbon footprint, while the latter involve revenues lost for the water utilities.

*Corresponding author.

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Globally, one-third of the total water volume abstracted from the water resources and used as drinking water is lost in the distribution networks due to pipe leaks and breaks [1]. A World Bank study [1] revealed that each year more than 32 billion m^3 of treated water are lost through leakage in WDS. An additional 16 billion m^3 per year are delivered to customers but not invoiced due to theft, poor metering, or corruption. A conservative estimate of the total annual cost to water utilities worldwide is US $14 billion. Saving just half of this amount would supply water to an additional 100 million people without further investment [1]. It is commonly accepted that water utilities should face the NRW problem applying all the necessary measures. The way to address NRW problem follows Deming's cycle: (a) plan—estimate the WDS's performance level; (b) do—assessment of the distribution network's performance level (ex-ante evaluation) and determination of the NRW reduction measures; (c) check—evaluation of the measures (ongoing evaluation); and (d) act—implementation and evaluation of the results (ex-post evaluation). Up to now, there is not an integrated approach to confront NRW but only individual water audit tools estimating the WB or/and some or all the Performance Indicators (PIs). Although these tools are helpful for the performance level assessment, they provide the user with results without connecting them to the real causes of the problem. Additionally, these tools do not provide the necessary measures to address the specific problems. Thus, an integrated approach is missing to confront NRW. The WATERLOSS project aiming at helping water utility operators design and apply NRW reduction strategies developed a decision support system (WATERLOSS-DSS) in 2013 [2]. The DSS evaluates the performance level of the WDSs and then depending on their performance evaluation proposes a list of prioritized NRW reduction measures obtained from the literature and the water utilities participating in the project input. The whole idea is directed toward the Mediterranean area utilities to face specific local conditions. The present paper aims at presenting the results of a strategy the water utility of Nicosia (Cyprus) designed to apply. The results are astonishing as big amounts of water, energy, and money are saved.

2. Assessing and managing the NRW

2.1. NRW: the basic components and the reduction measures

The first step of the methodology applied to assess the performance level of a WDS is the estimation of the NRW and its components. The well-acknowledged methodology used monitors the progress of the WDS performance level and checks the impact of the measures taken using the International Standard Water Balance (WB) along with a set of 170 PIs [3,4]. The WB determines the Revenue Water, the Water Losses, and the NRW (Table 1). Two modifications followed to make the WB useful in cases characterized by specific conditions (i.e. South Africa and South Europe). The first WB modification proposed by McKenzie et al. [5], introduced the water volume that although being charged was not paid for (Non-Recovered) (Fig. 1). This endeavor introduced for the first time the economic dimension of the volumetric IWA WB. In 2010, Kanakoudis and Tsitsifli [6] introduced the second

Table 1
The IWA Standard International WB and its modifications

<table>
<tr><th colspan="5">IWA Standard International WB [3]</th><th>First modification [5]</th><th>Second modification [6]</th></tr>
<tr><td rowspan="8">System Input Volume</td><td rowspan="5">Authorized Use</td><td rowspan="3">Billed Authorized Use</td><td>Billed Metered Use</td><td rowspan="3">Revenue Water</td><td rowspan="2">Water billed and paid for (Free Basic)</td><td rowspan="2">Revenue Water</td></tr>
<tr><td rowspan="2">Billed Unmetered Use</td></tr>
<tr><td>Water billed but NOT PAID for (apparent NRW)</td><td>Water billed but NOT PAID for (apparent NRW)</td></tr>
<tr><td rowspan="2">Unbilled Authorized Use</td><td>Unbilled Metered Use</td><td rowspan="5">Non Revenue Water (NRW)</td><td rowspan="5">Water not being sold (Non-Revenue Water/real NRW)</td><td rowspan="4">Accounted for Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Use</td></tr>
<tr><td rowspan="3">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Use</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td colspan="2">Real Losses</td><td>Water generating revenues although not consumed (Minimum Charge Difference)</td></tr>
</table>

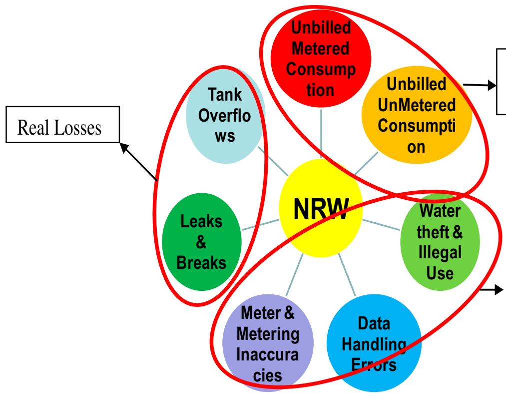

Fig. 1. The NRW causes and sub-causes.

modification (Table 1), emphasizing a common pricing policy adopted in the Mediterranean countries.

NRW (water not bringing in revenues to the water utility) consists of physical (real) losses, commercial (apparent) losses, and not billed authorized consumption (metered and unmetered) (Fig. 1). Apparent losses (AL) of main components are the illegal use (water theft), the billing and data handling errors, and the metering errors [7]. Field studies proved that AL may range from 1–3% (Australia) to 9% (Korea and Malaysia) of the system input volume (SIV) [8]. According to Arregui et al. [9], the key factors that may affect metering errors, include the choice of the appropriate meters type (volumetric vs. flow meters); their correct size and proper installation; and how frequently they are being replaced by the water utility. In addition, Arregui et al. [9] 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. Real losses (RL) are water losses due to leak, breaks, and tanks' overflows. Their size can be assessed through (a) the system's WB; (b) component analysis; and (c) night flow analysis [8]. According to "Background and Bursts Estimates (BABE)" water losses practice [8], RL consist of (a) background leakage (flow rate <0.5 m^3/h) and (b) reported and unreported leaks/bursts. Farley and Trow [10] and Thornton [11] stated that leakage in a WDS can be determined using field studies concepts of yearly WB and Minimum Night Flow (MNF) assessment, possibly in combination with BABE. Since NRW components cannot take zero values, there are values that can be accepted as minimum ones. Unbilled authorized consumption values up to 1% of the SIV can be accepted and no measures are taken. AL values up to 2% and RL ones up to 5% are considered within acceptable limits [12].

2.2. NRW: the reduction measures—literature review

Many techniques and methodologies are developed to reduce water losses [13,14]. Rizzo et al. [15] suggested that several measures forming an integrated strategy should be applied to tackle AL. Actions and approaches that define a water utility's apparent water loss control strategy are [15] (1) actions taken to adapt to changing environmental, legislative, and economic conditions; (2) moves to relate the organization's general strategic direction to the more specific and functional AL strategy; (3) actions to develop, purchase, and standardize upon quality instrumentation, information systems, tools, and techniques; (4) efforts to complete and sustain a holistic WB by integrating real and AL; (5) actions to strengthen the relative human resource structure and capabilities; (6) direct efforts and institutional links to research innovative AL concepts and techniques; (7) actions to control local workload by outsourcing specific task; and (8) efforts to develop and sustain the chosen AL control methodology (zoning criteria, GIS, metering policy, technical/economic targets, theft control policy, and AMR). A toolbox approach has been developed to help water utility managers understand how to control AL [16] (Fig. 2). According to the AL toolbox [16], the first very important step is to understand the water supply network by performing site audits. Technological tools can help toward this direction, but the most important part is the actual knowledge of the network. A metering strategy comes next to develop the consumer profiles, select the correct class and size of water meters, monitor the meter performance with time, and finally develop an economic meter replacement/maintenance strategy. The use of valves will help modify the inlet flow pattern (e.g. unmeasured flow reducer—UFR). On-site meter reading can verify that meter readings are within the limits; the correct

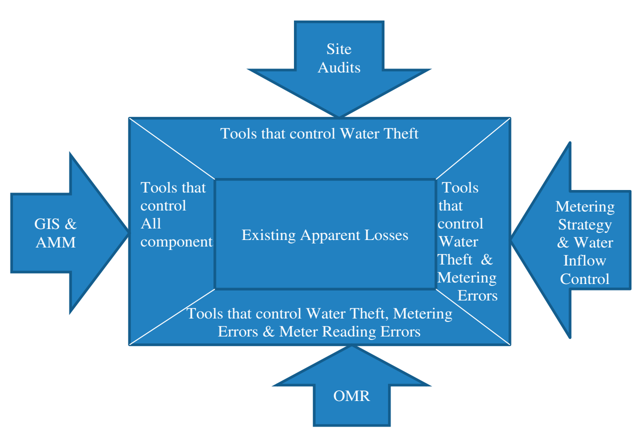

Fig. 2. AL toolbox approach [16].

meter is being read; and the meter performs within expected operating parameters [16]. Data will be uploaded into the billing system electronically. The last step is the automatic meter management (AMM) supported by a GIS system. AMM is an integrated business system allowing the utility to relate the water volume entering the zone with the water volume billed in this zone [16].

RL management is based on four pillars: pressure management; active leakage control (ALC); speed and quality of repairs; and pipeline and assets management [10] (Fig. 3). Pressure management is considered as the most important and well-known elements of a leakage reduction strategy. Since the rate of leakage is a function of pressure, it is evident that the higher the pressure, the higher the leakage. Pressure management can be obtained by dividing the open network into smaller, more manageable areas, the District Metered Areas (DMAs). DMAs enable network operators to manage the WDS more effectively in terms of pressure management [17]. Pressure-reducing valves (PRVs) are also used to reduce or maintain pressure at the same level, installed at strategic points [18]. Leakage detection methods include the awareness methods, the localization ones, and the pinpointing methods [13]. Leakage control methods can be reactive or/and active (ALC) [13]. In the reactive leakage control methods, the utility responds only to the reported leaks and breaks by the public and are used for low leakage levels (10–15%) [13]. On the contrary, ALC refers to methods detecting and locating leaks. Flow metering and leak localizing, locating, and pinpointing are the main activities for ALC. Techniques used for the detection of leaks are noise loggers, leak noise correlators, ground microphones, and sounding sticks [17]. Other methods to detect the leaks include (a) acoustic correlation where cross-correlation method is used to define the average interrelation between the signals at two (or more) points, identifying the difference in time taken for the leak noise to arrive at each sensor; (b) the Sahara method, where the Sahara leak location system is able to detect and pinpoint the location of very small leaks in mains of all materials; (c) aerial surveys—thermal imaging: a technique that does not rely on the acoustic detection of a leak but is based on the detection of soil temperature anomalies produced by the presence of a leak; (d) helium tracing: the distributed water is mixed with the helium gas and when the water escapes through a leak, the helium gas raises to the surface. The location of the leak is identified by surveying the area using a helium gas detector [18,19]. In most WDSs, leakage control involves the combination of hydraulic modeling software with GIS and SCADA systems [20]. The total leak repair time consists of the awareness time, the localization time, and the repair time. The soonest the leaks are located and repaired the less water will be lost. Leaks should also be repaired properly, avoiding the chance to occur again [18]. Maintenance strategies need to be identified based on proactive actions to increase the reliability of the water system's pipes and assets. The dilemma "replace or repair" needs to be answered based on technical-economic criteria. Models estimating the pipes optimum replacement times have already been developed [21]. The developed techniques and methodologies to reduce real and AL are taken into consideration during the development of the DSS tool. A list of strategic and operational measures to tackle each NRW component was developed including not only the measures indicated in the literature and in best practices but also measures that partner water utilities applied in the past.

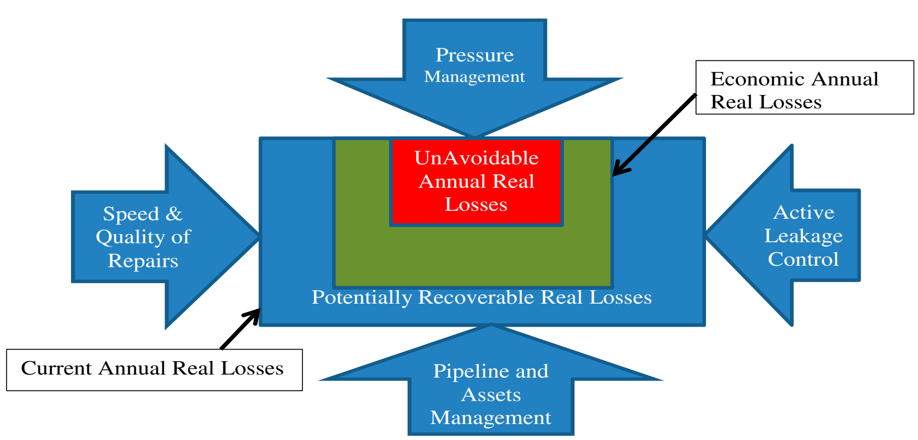

Fig. 3. The ways to manage RL [10].

2.3. The integrated methodology

There are many water audit software tools existing to assess the performance level of WDSs estimating the WB and calculating some or all the PIs. Such water audit tools are Sigma Lite [22]; Benchleak/Benchloss [23,24]; AquaLite [25] and Aqualibre [26]; LeaksSuite [27]; WB-EasyCalc [28]; and AWWA WLCC [29]. The inputs needed and the outputs provided differ among the water audit tools. None of the existing water audit tools estimates the second modified WB though. Therefore, Tsitsifli and Kanakoudis [30] developed a water audit tool called WB/PI Calc-UTH to estimate the initial and the two modifications of the WB and all the 170 PIs [2,30]. This tool was the basis for the development of the WATERLOSS-DSS.

3. The DSS toward NRW reduction

WATERLOSS project developed a DSS to (a) help water utility managers estimate the NRW level of their system; and (b) propose a prioritized list of NRW reduction measures based on the NRW actual cause [2]. The DSS evaluates the WDSs performance based on the estimation of the second modification of the IWA WB and a list of PIs developed during WATERLOSS project [2]. These PIs include 75 of the existing 170 PIs proposed by Alegre et al. [4] and 41 new PIs developed during the project [31]. Eleven of them derived from the existing IWA ones by modifying them to address special issues, mainly including operational PIs regarding RL, AL, water losses, and NRW and 30 new PIs. The remaining 30 new PIs cover issues, such as social, environmental and health factors, energy use, and conservation. To estimate the total 116 PIs, 137 existing and new variables need to be measured in the field. The actual inputs to the DSS are variables used to estimate the WB and the PIs and threshold values for the PIs calculated. A list of strategic and operational NRW measures has been also developed based on the literature (as presented in detail in Section 2.2.) and the partners' experiences. All measures were classified according to the NRW sub-component targeted (Table 2). The DSS is able to classify and evaluate the NRW control methods initially suggested, based on the results of the system's WB assessment. This can be achieved using a hierarchical tree developed guiding toward the measures and trying to identify the NRW causes (Figs. 4 and 5). It was formed by successive steps through a path from the impact (NRW) to its cause (Figs. 4 and 5). The DSS flowchart moves from the NRW components evaluation to its sub-components and finally ends up with a list of proposed strategic/operational measures. The DSS guides the user through a path where PIs are estimated and compared to the threshold values set by the user. The DSS indicates the points where the estimated PI value is worse than the threshold value showing the actual cause of the problem. After successive stages comparing the PIs values to the threshold ones, the user is finally guided to the proposed NRW reduction measures.

The prioritized measures list is based on six semi-qualitative criteria, namely (a) importance (low/medium/high); (b) time needed for the measure's application (short/medium/long); (c) duration of its effect (short/medium/long); (d) institutional complexity (low/medium/high); (e) additional construction works needed (low/medium/high); and (f) cost effectiveness (low/medium/high). The DSS covers the whole water supply process from the point the water enters the system (water resources) up to the customer's water meter. The DSS specifications include (1) forming the second modified WB and assessment of PIs values (for any time period chosen); (2) selection of the most appropriate PIs to tackle the case-specific problem(s); (3) PIs classification/prioritization; (4) define the critical mass of PIs; (5) system's evaluation based on these PIs; (6) NRW reduction measures listing (depending on the NRW cause); (7) connection of the measures to PIs values resulting in proposed actions based on benchmarking; and (8) dynamic monitoring and evaluation (ex-ante, ongoing, and ex-post) [30,32]. The DSS was validated using real data from the WATERLOSS partners including the case of Nicosia, the capital of Cyprus.

4. The case of Nicosia

4.1. Presentation of the case study: the problems

As Cyprus faces severe water shortage problems, the local water utilities are very advanced in applying NRW strategies. In 2008–2009, the water utilities in Cyprus decided to supply water to their customers for 12 h every 48 h (intermittent supply—water availability 21.4%). Nicosia is the capital city of Cyprus. Nicosia's WDS supplies with water many municipalities, including the municipality of Nicosia (almost one-third of the total population). The water is distributed by a network of 1,406 km of pipes and 111,700 water meters. The WDS is divided into 24 zones and 51 DMAs. A SCADA system monitors the whole network through 49 monitoring stations. The average operating pressure ranges from 17 to 42 m depending on the DMA. Before implementing intermittent supply measures, NRW level in Nicosia network was 16.6% of the SIV during the first

Table 2
Strategic measures targeting NRW components and sub-components [2]

NRW component	NRW sub-component	Strategic measures	Measures applied in WBN
Unbilled authorized use	Unbilled unmetered use	Review the estimation practice (volumes, discharges) applied	
	Unbilled unmetered and unbilled metered	Improve knowledge on unbilled authorized use	
		Review the pricing policy applied (consider altering the tariff's structure/levels)	
		Reconsider the need for such uses—volume reduction=water use restrictions	
AL	Water theft/illegal use	Improve internal processes for water theft/illegal use research	
		Preliminary: knowledge on volume of water theft/illegal use	
		Improve research methods toward water theft tracing and protection from illegal use	
		Stricter legislation on water theft/illegal use	
	Customer meter under-registration	Evaluate volumes under-registered and where they occur	DMA15;
		Improve internal processes toward solving customer meters under-registration	
		Methods to reduce under-registered volumes	DMAs15;20
		Impose stricter legislation on faulty metering devices	
	Data handling errors	Evaluate volumes related to data handling errors	
		Improve internal processes toward solving data handling errors	
		Introduce methods to reduce volumes related to data handling errors	
RL	Active leakage control (ALC)	Improve internal processes regarding ALC	DMA20
		Preliminary methods/techniques for ALC and detection	DMAs15;20
		Implement permanent methods/techniques for ALC and detection	DMAs20;17
		Implement punctual methods/techniques for leakage detection	
	Speed and quality of repairs	Improve internal processes regarding repairs	
		Improve quality of repairs	
		Improve speed of repairs	
	Pressure management	Preliminary: pressure measurement and analysis	
			DMA15;20;17

(Continued)

Table 2 (*Continued*)

NRW component	NRW sub-component	Strategic measures	Measures applied in WBN
		Preliminary: install equipment having an impact on pressure	
		Pressure modulation to reduce losses' level (leaks or breaks)	
		Pressure reduction to reduce losses' level (leaks or breaks)	DMAs15;14A;14B;16A;20;17
	Pipeline and assets management: selection, installation, maintenance, rehabilitation, and replacement	Improve internal processes for asset management	
		Preliminary for asset management: knowledge of pipes	
		Preliminary for asset management: knowledge of the surrounding environment	
		Improve pipe protection/rehabilitation	
		Improve service connections replacement	
		Improve joints replacement	
		Improve valves management and replacement	
		Improve pipes replacement techniques	
General for ALL components	Improve internal processes on NRW	Implement standards and procedures	
		Introduce software and new technologies to facilitate work	
		Education of staff	
	Improve knowledge and accuracy on NRW volumes	Improve bulk meter accuracy	
		Improve customer meter accuracy	
	Economic resource availability	Review the pricing policy	
	Comparison with other services or with reference indicators	Auditing	
		Networking	

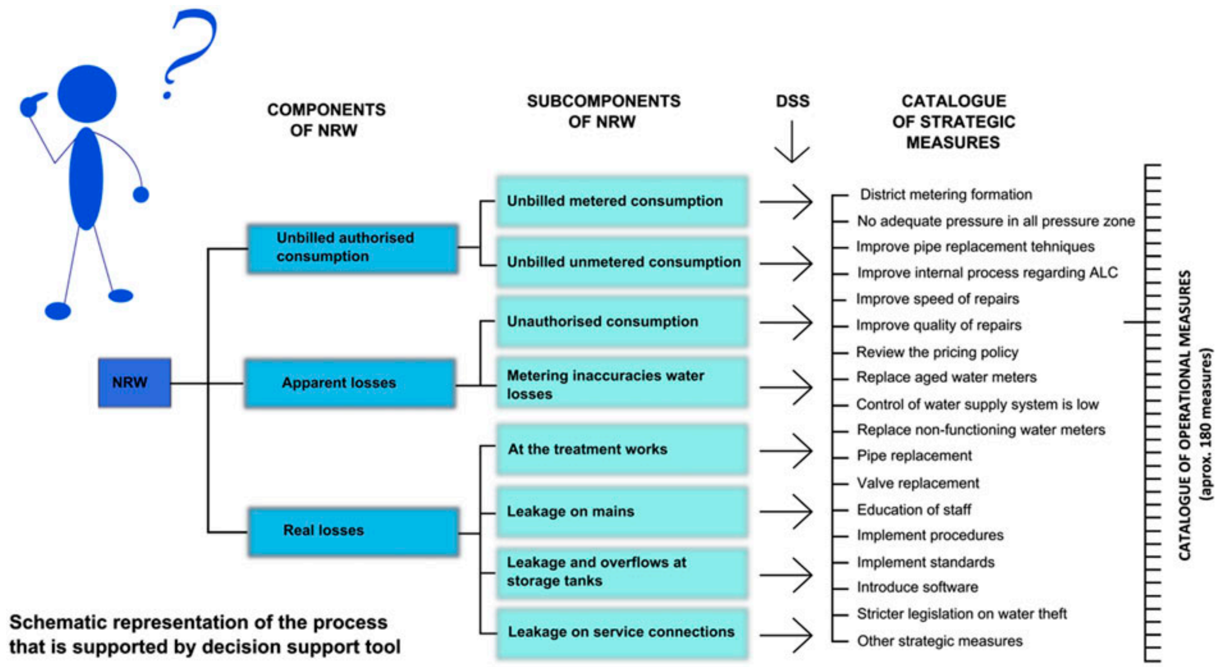

Fig. 4. The DSS core [2].

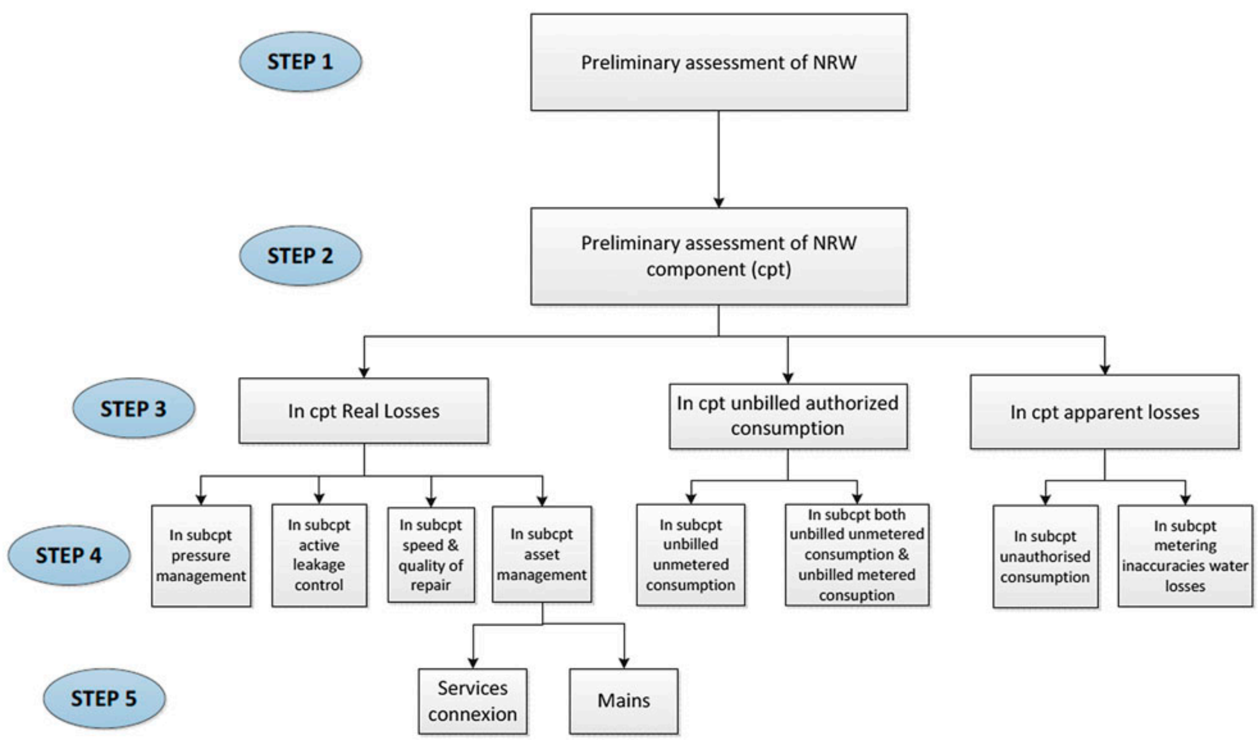

Fig. 5. The DSS hierarchical tree in brief [2].

two-month period in 2008. After returning to normal conditions (water supply 24hrs 7 d per week), NRW values increased significantly, ranging from 21.1% of SIV (fourth period in 2011) to 29.4% (second period in

2010). NRW values show a decreasing trend from 2010 and onward (Fig. 6).

The water utility identified three DMAs suffering from high NRW values, namely DMAs 15, 17, and 20 (Fig. 7; Table 3). Each DMA faces different problems. DMAs 15 and 17 face high NRW and MNF values indicating high leakage levels. DMA 20 is a particular case as the zone is located in Nicosia's historical center, enclosed in the Venetian walls. Although NRW levels are not high, DMA 20 faces leakage events not obvious to the surface, causing ground subsidence

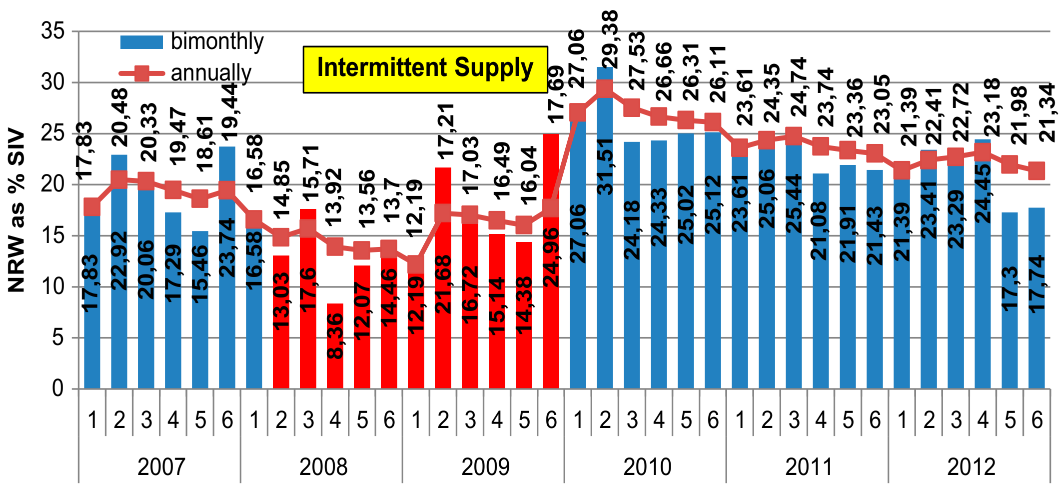

Fig. 6. NRW (% SIV) bimonthly and annually 2007–2012.

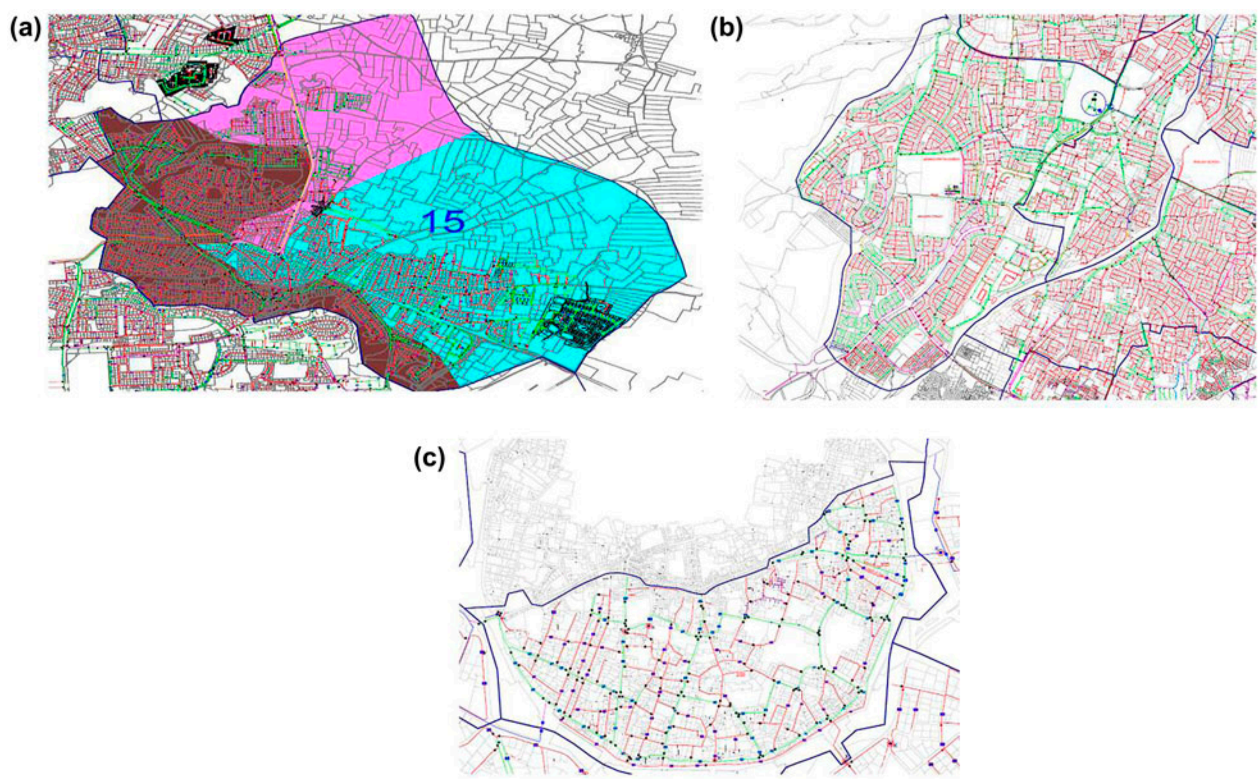

Fig. 7. (a) DMA 15; (b) DMA 17; and (c) DMA 20 (source: WBN).

Table 3
Characteristics of DMAs 15; 17; and 20 (source: WBN)

	DMA 15	DMA 17	DMA 20
Area (Km^2)	7.84	10.47	0.84
Population served (inh)	23,000	31,000	8,800
Pipes' length	83.63	187.26	20.76
No. of service connections	4,215	6,968	1,699
Mean operating pressure (m)	53	32.6–37.8	25
NRW (% SIV) 2010	41.7	31.8	16.0
RL (% SIV) 2010	35.9	25.4	8.4
AL (% SIV) 2010	5.2	6.0	7.1

and damages to old buildings. The main causes are the water mains age and the type of soil.

4.2. Applying the DSS and the NRW reduction measures

The water utility applied the WATERLOSS DSS to the three DMAs to determine the measures it should apply to reduce NRW values. The DSS provided the WB assessment for each DMA (Fig. 8) verifying that NRW values are high (Fig. 9). In all cases, as AL values were found high enough, the DSS proposed specific measures since there is no water meters' replacement strategy and every property is obliged to have a roof tank, resulting in greater values of under-registration (Fig. 10).

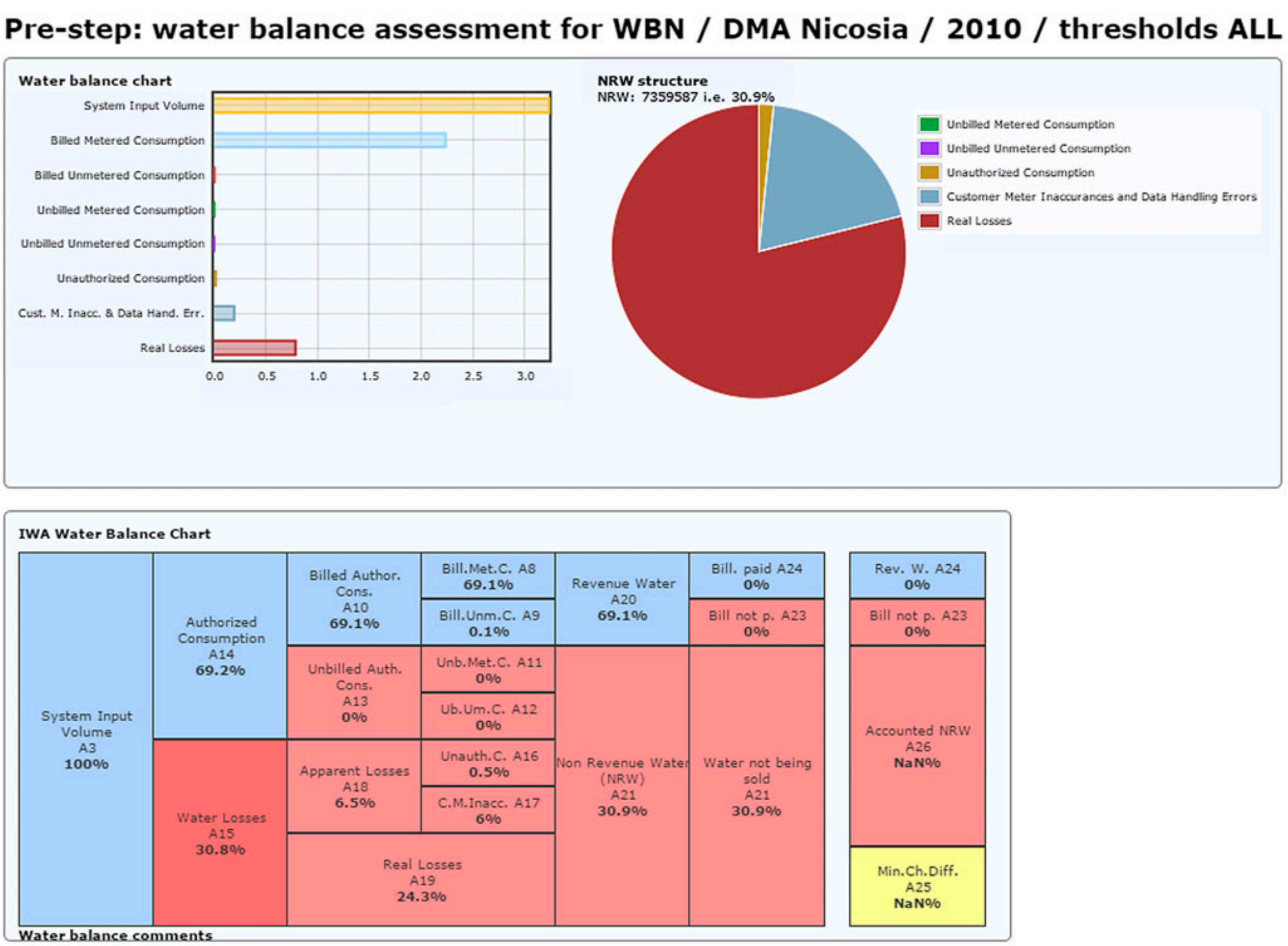

Fig. 8. WB assessment using the DSS (print screen).

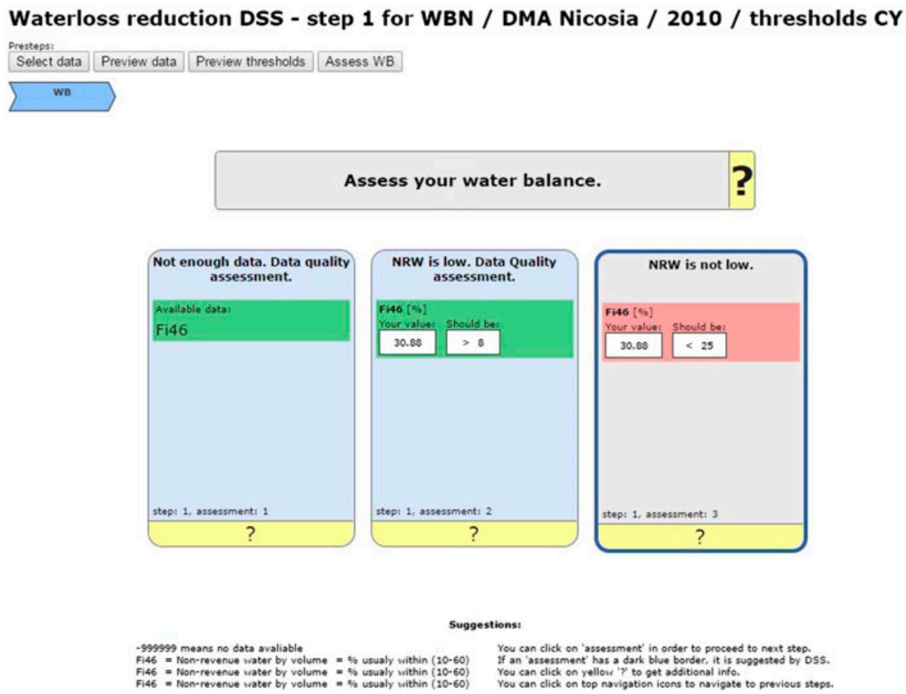

Fig. 9. NRW values indicating whether they are considered low or not (print screen).

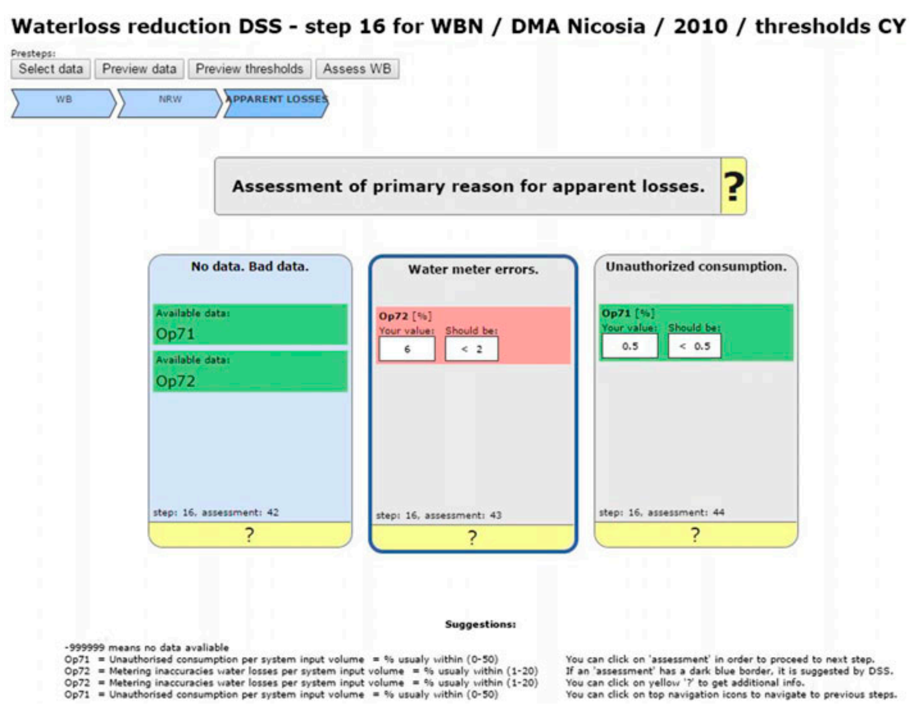

Fig. 10. AL assessment (print screen).

DMA 15: from the proposed list of measures, the water utility decided to include pilot projects to define the exact meter under-registration, replace the old water meters aged more than 10 years, and impose strict penalties in cases of water theft (Table 2). Specifically, 411 water meters (5.3%) aged more than 10 years were replaced during the year 2012, in DMA 15. One of the DMAs presenting high NRW and MNF levels is DMA 15. The utility redesigned the limits and the division of the zone in three smaller sub-DMAs following the implementation of various scenarios using a hydraulic simulation software. A part of the former DMA 15B merged in DMA 15C. The latter was expanded to include part of the DMA 15A. A PRV was installed in the entry node of DMA 15B. The average pressure at DMA15B prior of the installation of PRV was 53.4 m. The initial setup of the PRV was 44.5 m and the final pressure adjustment in the PRV is 36.2 m. Additionally, portable pressure data loggers were installed in DMAs 15B and C at five points (Table 2).

DMAs 14A; 14B; 16A: to back up the redesign of DMA 15, PRVs are also installed in neighboring DMAs 14B, 14A, and 16A (Table 2).

DMA 20: in DMA 20, water meters aged above 10 years were also replaced (168 meters—6% of the total meters in DMA 20). The DSS indicated the causes of the RL being high operating pressure and not adequate ALC practices. To tackle the RL, the general measures applied include PRVs installation; permanent noise loggers' installation where needed; personnel increase for ALC; and establishment of an emergency unit for leaks and breaks (24 h/d operation). As DMA 20 is sensitive to leakage, it is continuously monitored while pressure management and ALC are both applied to avoid damage to old buildings due to ground subsidence. The water utility established constant noise loggers to perform ALC on a constant basis (Table 2).

DMA 17: as pressure exceeds 50 m in some parts of the DMA, the water utility modified the zone's supply nodes and two PRVs are established (Table 2). The total cost was 20,000 € for both PRVs and 22,000 € for all necessary works. The utility also established constant noise loggers during May, June, and December 2012.

5. Results and discussion

DMA 15: the redesign of the DMAs and the pressure management resulted in pressure reduction up to 32.1% in DMAs 15B and 15C (Fig. 11(a)). Water losses were reduced saving water volume up to 76,953 m^3/year resulting in money saving of 59,254 €/year (Tables 4 and 5). The value of the water saved through water loss reduction results in the depreciation of the cost of PRV installment (total cost 4,600 EURO) within 28 d only. The amount of water saved due to the 32% pressure reduction could provide water supply to a population of 1,800 persons (allowing 115 l/person/d). Additionally, the total number of leak incidents in DMA 15 reduced based on results only for one-month period (Fig. 11(b)). The campaign for detecting unreported leaks in DMA 15 was conducted installing 170 acoustic noise loggers, before applying pressure management during September to December 2011. The detection of hidden leaks (54 incidents) resulted in reducing the minimum night consumption by 37 m^3/h and water supply by 26,230 m^3/month. The reduction of the level of losses resulted in reducing water losses by 730 m^3/d, saving 560 €/d (from value of water conserved) and serving a potential population of 6,300 persons, by reducing water losses (Table 5).

DMAs 14A;14B;16A: pressure management measures were also applied in DMAs 14A, 14B, and 16A. The reduction in pressure by 37.9% in the DMAs resulted in the reduction in DMA supply by 21%, reduction in the amount of NRW by 1,097 m^3/d (potential water supply for 9,500 persons), and monetary savings of 844 €/d (Fig. 12; Table 5).

DMA20: leakage is being continuously monitored in DMA 20 using the existing PRV (pressure set at 25 m and reducing pressure by 37%) and permanent installment of 200 acoustic noise loggers. During 2012,

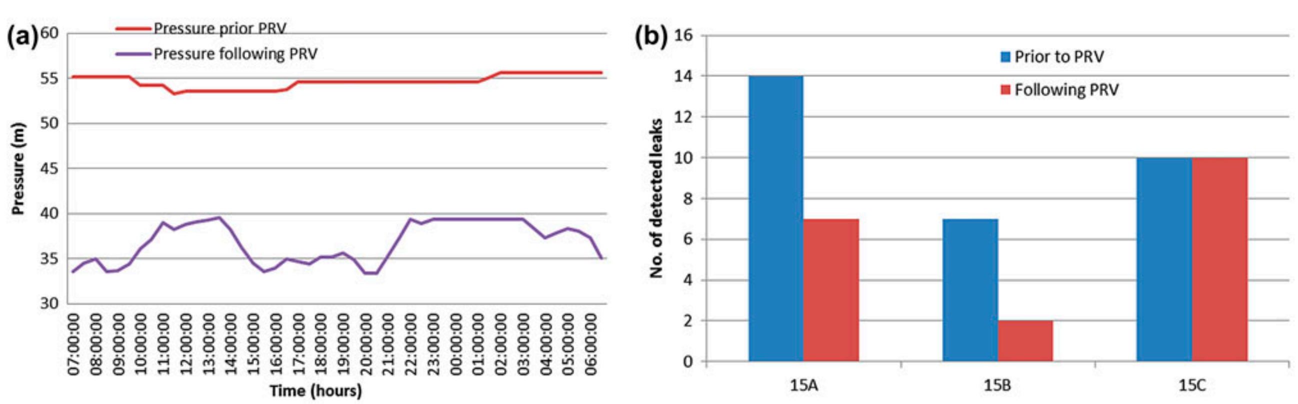

Fig. 11. (a) Pressure reduction in DMA 15B and (b) no. of leak incidents before and after the PRV[32].

Table 4
Pressure reduction resulting in water and money saving in DMAs 15B and 15C [32]

	Average pressure (m)	Pressure reduction (%)	MNF (m^3/h)	Water leakage rate (m^3/d)	Reduced leakage rate (m^3/d)	Annual water savings (m^3/year)	Annual money savings (€/year)
Prior to PRV installation	53.4		46.6	820			
Initial pressure setting in PRV	44.5	−16.6	38.4	647	−173	62,952	48,473
Final pressure setting in PRV	36.2	−32.1	36.8	609	−211	76,953	59,254

Table 5
Applied measures and benefits in all DMAs

DMA	Measures applied	Water volume saved (m^3/year)	Money saved (€/year)	Additional population supplied	Additional benefits
15	Pressure management	77,000	59,254	1,800	Leakage incidents reduction
15	ALC	266,450	205,166	6,300	
14A; 14B; 16A	Pressure management	400,000	308,000	9,500	
20	Pressure management	93,000	71,610	2,200	
20	ALC	43,000	32,850	1,040	
17	Pressure management	21,883	16,850	521	Energy saving

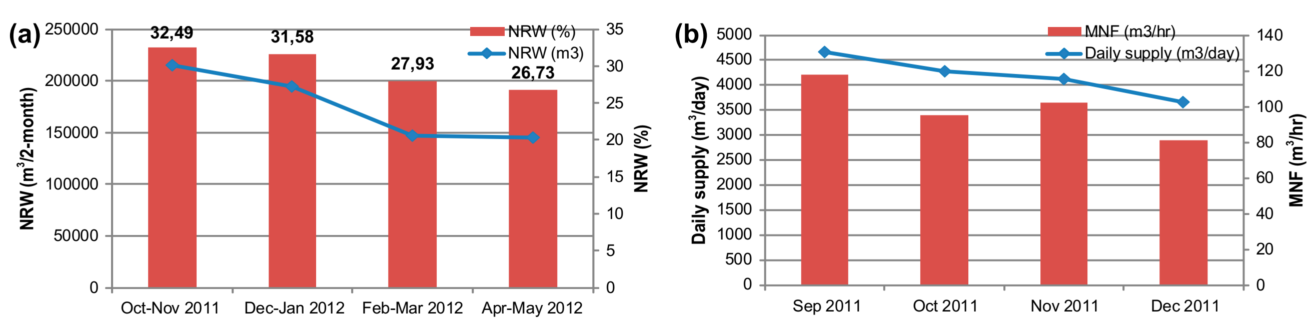

Fig. 12. (a) NRW reduction before and after pressure management measures in DMAs 13, 14, 15, and 16 and (b) daily supply and MNF as a result of ALC in DMA 15 [32].

27 leaks incidents were detected through ALC and limited the amount of water losses to 19.5% or 213 m^3/d (water losses 20.97% or 254 m^3/d at the end of 2011) (Table 5). The observation of DMA supply in telemetry system provides an early warning of leakage incidents and with the installed acoustic noise loggers, the position of system leakages are detected, limiting the water loss and damage to buildings due to subsidence. During February 2012, an increase in MNF observed in DMA 20 resulted in the detection of three leaks in the system (two in supply connections and one in distribution main) through ALC, resulting in reduction of MNF by 23 m^3/h, in total savings in supplied water of 390 m^3/d, and monetary savings of 300 €/d. From January to April 2013, in DMA 20, a detection of 24 leak incidents through ALC resulted in the

reduction of water losses by 120 m^3/d (reducing the peak MNF of 19.7–13.5 m^3/h). The benefits of ALC in DMA 20 include savings of 90 €/d and the potential water supply of 1,040 persons (Table 5). Additionally, 168 customer water meters (6%) aged more than 10 years were replaced during 2012.

DMA17: the pressure management measures applied in zone 17 resulted in pressure reduction and consequently to MNF reduction of 2.5 m^3/h meaning that the economic benefits are 16,850 € per year (Table 5). The ALC measures resulted in detecting 13 leaks in the zone during May, June, and December 2012. Additionally, 35% of energy is saved in the pumping station supplying zone 17 with water (yearly energy consumption for 2012 was 101,430KWh compared to 158,361KWh for 2011). The total cost saving was 14,000 € only for 2012.

Totally, the results obtained from the application of NRW reduction measures include the operating pressure drop up to 38% and the reduced leak incidents and the MNF. Totally, almost 1 million m^3 per year representing 4.8% of the SIV and 16% of the total NRW and more than 700.000 €/year are saved only from the measures confronting RL. The meters replacement provided additional savings increasing the water volume charged and reducing AL. Additional benefits also include the reduction of energy consumption.

6. Conclusions

NRW is one of the major problems water utilities are facing today, especially in areas facing water scarcity conditions. The water operators have recently realized the magnitude of the problem and try to find ways to confront it. Until now, only individual water audit tools exist to assess the WDSs' performance, including the methodology of WB and PIs. The water operators are then obliged to look for measures to tackle high NRW levels in their networks. They were used to address to their colleagues from more advanced (in terms of applying NRW reduction strategies) water utilities or to just follow the guidelines provided by suppliers of infrastructure. It is well known though that each WDS is unique and it has to be treated as such. During WATERLOSS project, the first attempt to develop a DSS to finally suggest NRW reduction measures took place. The DSS tool provides to the user a list of prioritized NRW reduction measures addressing the actual causes of NRW and based on semi-qualitative criteria. This integrated user friendly tool is used in the case of Nicosia, Cyprus. The application of the DSS in three problematic DMAs assisted the water utility operators to design a NRW reduction strategy through targeted and prioritized measures. The water utility specified its strategy in DMAs 14, 15, 16, 17, and 20 as they are operating in high pressures and/or have high MNF levels. The measures taken tackled both Real and AL. Specifically, the measures included PRVs' installation; DMAs' redesign and water supply through alternative nodes; ALC installing permanent noise loggers; and replacement of water meters aged more than 10 years. The results were obvious right away including water saving (4.8% of the SIV or 16% of the total NRW), money saving (more than 700,000 €/year), and energy saving. The results are extremely important for Cyprus facing extremely severe water scarcity conditions. The measures are too effective that their cost depreciation is estimated in a couple of months only. Collateral benefits include the better knowledge of the network and the reduced overtime. The water utility of Nicosia tries to reduce NRW to its levels prior the intermittent supply. These conditions (2008–09) resulted in many leak incidents and high NRW values when the system returned to normal operating conditions. WBN's target for NRW is now 18% of SIV.

The application of the DSS tool to the Nicosia water utility showed that an integrated tool should be used to indicate to the water operators the measures to be applied to tackle the NRW causes. Water meters under-registration is a significant part of water losses in WDSs, especially when no strategy is applied to replace the old water meters (aged more than 10 years). The design of a water meters replacement strategy eliminates water losses due to under-registration, especially in cases where roof tanks are used (as the Nicosia case). The present case study verified that pressure management through the installation of PRVs is one of the best practices to reduce RL. DMAs design should be optimized using a hydraulic simulation software and applying different scenarios. The installation of noise loggers provides to the water operators an early warning system to locate leakage events. The application of such measures reduces NRW levels and additionally provides collateral benefits to the water utility (increased revenues, reduced costs, water saving, and energy saving).

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