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A new set of water losses-related performance indicators focused on areas facing water scarcivty conditions

V. Kanakoudis[a], S. Tsitsifli[a,*], P. Samaras[b], A. Zouboulis[c], P. Banovec[d]

[a]*Department of Civil Engineering, University of Thessaly, GR-38334 Volos, Greece*
Tel./Fax: +30 24210 74156; email: tsitsif@otenet.gr
[b]*Department of Food Technology, Technological Education Institute of Thessaloniki, GR-57400 Thessaloniki, Greece*
[c]*Department of Chemistry, Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece*
[d]*Faculty of Civil Engineering and Geodesy, University of Ljubljana, SI-1000 Ljubljana, Slovenia*

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ABSTRACT

As almost all Mediterranean countries are facing water scarcity problems today, water losses in drinking water supply networks have grown to an urgent problem, needing immediate confrontation, representing a too valuable to be neglected water potential. The first step towards water losses reduction is the water supply network performance assessment process. The most commonly used methodology is the one introduced by the International Water Association (IWA), including the International Standard Water Balance and a list of Performance Indicators (PIs). Five years after the second PIs handbook edition was launched increasing the PIs included to 170 from 133 of the first edition, there is a need to re-evaluate them, including also new PIs adapted/focused to regional conditions and addressing other important topics such as environmental issues. The paper presents a new set of water losses-related PIs, focused on areas facing water scarcity conditions met in the Mediterranean countries, forming a solid basis for an integrated Decision Support System (DSS) to evaluate water supply networks and prioritize alternative water losses reduction strategies. The new set includes 75 out of the 170 IWA PIs and 42 new proposed PIs. The new PIs set is formed, selecting the most appropriate existing PIs and suggesting new ones. An integrated approach using a survey among local stakeholders in each partner's country is used. The platform and the basic components of this user-friendly DSS tool are also being presented here.

Keywords: Water supply systems; Nonrevenue water; Decision support system; Performance indicators

1. Introduction

Today, water resources are increasingly stressed due to climate change conditions and growing population's increasing needs [1]. Especially in the Mediterranean area, water scarcity is identified as a major threat, jeopardizing the sustainability of local ecosystems. Within the specific geographic and climatic context of the Mediterranean area, particular

*Corresponding author.

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attention needs to be paid to water resources, aiming to safeguard a sustainable water supply in a period of climate change [1,2]. Thus, water utilities must become highly efficient throughout the entire water supply process/chain to guarantee sufficient quantities of good quality water [3]. Since water is one of the most valuable natural goods, water losses in the water supply systems (WSS) represent an urgent problem that needs to be tackled, representing a too valuable to be neglected water potential. Water losses (Physical/Real and Apparent/Commercial) represent the biggest part of the so-called Non-Revenue Water (NRW), thus water not bringing in revenues to the water utility [4]. A World Bank study showed that approx. 45 billion m^3 of water is annually being lost through leakage corresponding to 35% of the total water supplied [3]. If half of this water was saved, 200 million people would have access to safe water without any further investment. The NRW has negative environmental (lost water and energy) and economic (lost revenues) impacts. Water losses imply green house gas (GHG) emissions since the water volume being lost has been pumped, treated, and distributed using energy. Water losses-related GHG emissions are even bigger when desalination is used as the main or an alternative water supply process.

Water utilities can reduce the large volumes of treated water being lost by applying improved methods for water auditing and water losses control. Associations, such as the International Water Association (IWA) and the American Water Works Association (AWWA), have suggested water audit tools and methodologies to assess the performance level of a WSS. These methodologies include Water Balance (WB) assessments and databases of Performance Indicators (PIs). Specifically, the IWA has proposed the Standard International WB Assessment and a database of 170 PIs based on 232 variables that have to be regularly measured/monitored [4,5]. Although the core idea of the methodology is based on the typical super-market concept (buy only what you really need and fits best), it neglects practical problems arising during its application (e.g. unreliable or even lacking data; local conditions) [6]. Till now, an integrated approach is lacking that will utilize quantified and balanced PIs to account for regional specific conditions and an optimization routine to rank the actions that could be applied by water utilities. This prioritized list of measures should be adapted to local conditions pointing out benefits and revenues from the implementation of the approach, balancing the required investments, considering the income return to end-users and water utilities, due to water losses reduction. Here, a new set of water losses-related PIs, focused on areas facing water scarcity conditions met in the Mediterranean countries, is being presented, forming a solid basis for an integrated Decision Support System (DSS) to evaluate water supply networks and prioritize alternative water losses reduction strategies.

2. Water supply systems performance evaluation

As already mentioned, the IWA developed a methodology to assess the WB of a WSS (Fig. 1) and a set of 170 PIs [4,5]. Water losses include both real and apparent losses. Real losses represent the physical losses, due to leaks on supply/distribution mains; treatment plants; storage tanks (and overflows); and service connections up to the water meter. Apparent losses, on the other hand, represent the unauthorized use, due to water theft and illegal use; meter/metering inaccuracies (misread meters; incorrect estimates for stopped meters; adjustments to initial meter readings; improper calculations; computer programming errors; and systematic errors due to under/over-registration of meters); and the on-site leakage (occurring after the customer's meter, but not being registered). The NRW index is considered a crucial indicator for WSS performance evaluation, as it indicates water being either used or lost, but not being paid for, thus not providing revenues. It consists of the Unbilled Metered/Un-Metered consumption; water theft/illegal use; meter inaccuracies; data handling errors; losses due to leaks/breaks; and tank overflows.

The whole idea of IWA methodology is based on the above mentioned super-market concept. Each water utility should study and prioritize its needs regarding the WSS evaluation process. The first PIs manual published by IWA in 2000 [9] included 133 indicators, from which, 26 have been rated as of top priority. Three levels of PIs are considered as a guide for the definition priorities, according to their importance as management tools: (a) LEVEL 1 (L1): a first layer of indicators that provide a general management overview of the efficiency and effectiveness of the water undertaking; (b) LEVEL 2 (L2): additional indicators, which provide a better insight than the Level 1 indicators for users who need to go further in depth; and (c) LEVEL 3 (L3): indicators that provide the greatest amount of specific detail, but are still relevant at the top management level. The second PIs manual published by IWA in 2006 [5] included 170 more detailed PIs, covering more case-specific problems, thus improving the reliability of the performance assessment process.

<table>
<tr><th colspan="5">IWA International Standard Water Balance</th><th>McKenzie et al modification</th><th>Kanakoudis & Tsitsifli modification</th></tr>
<tr><td rowspan="7">System Input Volume (A3)</td><td rowspan="4">Authorized Use (A14=A10+A13)</td><td rowspan="2">Billed Authorized Use (A10=A8+A9)</td><td>Billed Metered Use (A8)</td><td rowspan="2">Revenue Water (A20=A8+A9)</td><td>Water billed and paid for (Free Basic) (A24=A8+A9-A23)</td><td>Revenue Water (A24=A8+A9-A23)</td></tr>
<tr><td>Billed Unmetered Use (A9)</td><td>Water billed but NOT PAID for (apparent NRW) A23</td><td>Water billed but NOT PAID for (apparent NRW) A23</td></tr>
<tr><td rowspan="2">Unbilled Authorized Use (A13=A11+A12)</td><td>Unbilled Metered Use (A11)</td><td rowspan="5">Non Revenue Water (NRW) (A21=A3-A20)</td><td rowspan="5">Water not being sold (Non-Revenue Water/real NRW) (A21=A3-A24-A23)</td><td rowspan="4">Accounted for Non Revenue Water (A26=A3-A24-A23-A25)</td></tr>
<tr><td>Unbilled Unmetered Use (A12)</td></tr>
<tr><td rowspan="3">Water Losses (A15=A3-A14)</td><td rowspan="2">Apparent Losses (A18=A16+A17)</td><td>Unauthorized Use (A16)</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors (A17)</td></tr>
<tr><td colspan="2">Real Losses (A19=A15-A18)</td><td>Water Losses generating revenues (Minimum Charge Difference) A25</td></tr>
</table>

Fig. 1. The proposed 2nd modified WB including the McKenzie et al. [7,8] 1st modification.

During the last five years, although PIs have been highly acknowledged as a very efficient tool, discussions on their appropriateness emerged (Table 1) [8,10]. Table 1 presents four basic IWA PIs, namely, NRW, Apparent, Real, and Water Losses. Unavoidable Annual Real Losses (UARL) is also presented, although it is not considered an IWA PI. The UARL is used to calculate IWA PIs and specifically, Infrastructure Leakage Index (ILI) PI. Alternative expressions of these PIs have been presented over the years. During their implementation in evaluating water supply systems, problems are met and, therefore, changes in the PIs expressions have been introduced. Such PIs expressions are discussed in Table 1, indicating the more appropriate PI expression and the conditions under which each PI should be used. Some of the IWA PIs should become more detailed highlighting specific WB components, such as the apparent losses. The respective task force of IWA proposed a new PI called Apparent Losses Index (ALI), showing how much more the apparent losses are compared to their minimum value (5% of water sales).

Another obstacle faced during a WSS evaluation process is the data reliability and availability. This is a common problem faced by water utilities. The quality of the necessary data and their collection techniques adopted are both crucial, for the calculation of the PIs levels, as has been stated in the Sao Paolo case [11]. During a benchmarking project in Austria [12,13], the reliability and accuracy of data were raised as an issue, describing the weaknesses of data kept by local water utilities. Pearson [14] recommends that data availability and quality becomes an initial imperative when a strategy is being developed. Therefore, confidence levels are used in order to check the sensitivity of results. Water utilities do not always keep the appropriate data records. Morrison [15,16] faced this problem during the water distribution system assessment process in Thessaloniki (Greece), where data were missing. Guibentif et al. [17] proposed that the utility's staff involved in the WB estimation process should have access to this information. The problem of missing data was also faced during the WSS evaluation process in the case studies of Larisa, Kos, and Veria cities (Greece) [6,18,19]. The main problems were associated to the lack of data, regarding (a) unbilled un-metered use; (b) unauthorized use, illegal connections, bypasses, and theft; (c) water losses due to meter errors, under-registration, and data handling errors; (d) actual number of customers' connections; and (e) length of service pipes. This problem was faced through assumptions made, based on the available relative literature and performing sensitivity analysis to check the impact of these assumptions on the PIs levels. Tips and tricks were used to overcome low reliability and availability of data [19]. The sensitivity analysis results showed that most of PIs (ILI, UARL, etc.) are sensitive to variables used for their estimation. Therefore, although the WB and PIs methodology is a diagnostic approach, assisting the Utility to correctly evaluate its system and develop an effective water losses reduction strategy, data reliability and availability is crucial.

Table 1
Comments on the appropriateness of the different PI expressions [6,8,10]

PI	Group	Measure	Condition	Comment
Non-revenue water	Financial	Volume of NRW as% of SIV		Influenced by non-fixed parameters, such as the SIV, the differences in consumption levels, the existence of storage tanks, the average supply time and the average pressure
		NRW% by cost		More appropriate expression
		NRW in liters/connection/day		
		NRW in m^3/km mains/year		
Apparent losses	Operational	Volume of AL as% SIV		Poor indicator
		Volume of AL as% water billed		Poor indicator
		m^3/service connection/day		More appropriate expression
		Liters/service connection/day		More appropriate expression
		Liters/metered property/day		More appropriate expression
		% of water supplied		More appropriate expression
		% of authorized consumption		More appropriate expression
Real losses	Operational	Volume of real losses as% SIV		Influenced by consumption
		Per billed account or per property		Multiple properties
		Liters/service connection/day	Service connections>20/km mains	More appropriate expression
		m^3/km mains/day	Service connections<20/km mains	More appropriate expression
		Liters/service connection/day when pressurized	Intermittent supply	Intermittent supply
Water losses	Operational	m^3/service connection / year		
UARL		m^3/km of mains/day/meter of pressure		Depends on service connections
		In liters/service connection/day/meter of pressure	Service connections>20/km mains	More appropriate expression

Local conditions and practices applied by water utilities are obstacles during a WSS evaluation process. A common issue for most water utilities in Greece is the water billing policy [6,18,19]. Most Greek water utilities apply inclining water rates that also include a fixed rate. That means that there is a minimum water volume being charged to the users even if they have not actually consumed this water. This minimum water volume threshold is called minimum charge. Other water utilities charge their customers a fixed price in return for offering them the possibility to have access to water (they consider it as the opportunity cost). The utilities add the cost of the water consumed by each customer to the fixed price. Both policies have to do with the minimum charge. The water meters recording must be considered to estimate the metered and billed water volume. The extra water volume charged but not consumed (Minimum Charge Difference—MCD) should be considered as real losses, providing revenues to the water utility. This practice met in Greece made Kanakoudis & Tsitsifli propose a 2nd modification of the IWA WB [20] (Fig. 1). This one integrates also the 1st IWA WB modification proposed by McKenzie et al. [7,8], who suggested that Revenue Water should split in three components: the free basic water that can be considered as billed and paid for at a zero tariff; the recovered revenue water, which is billed and paid for; and the nonrecovered water, which is water billed, but there is no possibility of payment. Such local conditions and characteristics could be met during the WSS evaluation process in different regions. A full PIs database used to evaluate the performance of Mediterranean WSS must include more PIs related to specific conditions met in this area. Currently, an integrated approach is lacking that will utilize quantified and balanced PIs to account for regional specific conditions and an optimization routine to create a ranked rational list of actions widely applicable.

3. Forming the PIs database

3.1. Methodology

Nine partners from six Mediterranean countries (Table 2) form the partnership scheme of a EU co-financed MED project called WATERLOSS-Management of water losses in a drinking water supply system (2G-MED09-445), aiming at developing a DSS that will result in prioritized NRW reduction measures. The whole attempt is based on the evaluation of selected WSS and the development of a database formed by critical PIs, including existing and new ones based on specific conditions met in the Mediterranean area, such as social, health, and environmental factors, water quality problems, etc. These PIs, regarding the way they are being formed, are distinguished in: (a) existing ones widely used by the water utilities in the partners' areas; (b) derived by existing ones, properly modified to address special issues, as water losses per pipe material or diameter; and (c) new ones based on the IWA concept, covering the above mentioned specific conditions met in the Mediterranean area.

3.2. Existing PIs being widely used by the water utilities in the Mediterranean area

The critical PIs database formed is part of a wider methodology developed within the project for the reduction of the NRW values. An integrated approach has been used to form the PIs database, selecting the most appropriate existing PIs and suggesting new ones. The base was a survey among local stakeholders at each partner's area, using a detailed questionnaire (acting as a well-structured Public Consultation process), regarding the use of existing PIs, topics not being addressed by them, future needs expected to become a day-to-day reality that water utility managers will have to deal with, etc. The questionnaire, distributed to water managers and other employees within water utilities associated to the 9 WATERLOSS partners, was structured in five sections. The key question to be answered was: "the following indicators or parameters offer a valuable tool to manage water losses in a drinking water supply system." The people who answered these questions used a ranking system of a 6-point scale from strong disagreement to strong agreement. Section A included the 170 IWA PIs and Section B included proposed social, operational, safety, and environmental indicators. Section C

Table 2
The WATERLOSS partnership scheme

Partner's no.	Partner's full name	Partner's city	Partner's country
LP = PP1	Aristotle University of Thessaloniki	Thessaloniki	Greece
PP2	Conseil Général des Pyrénées Orientales	Perpignan	France
PP3	Water Board of Nicosia	Nicosia	Cyprus
PP4	Regional Development Center	Zagorje ob Savi	Slovenia
PP5	Metropolitan Area of Barcelona	Barcelona	Spain
PP6	Kozani Municipal Water & Sewerage Utility	Kozani	Greece
PP7	Autorità di Bacino dei Fiumi Liri-Garigliano-Volturno	Caserta	Italy
PP8	University of Ljubljana-Faculty for Civil & Geodetic Engineering	Ljubljana	Slovenia
PP9	Department of Montepellier	Montepellier	France

Table 3
The 75 out of the 170 IWA PIs selected and their appointed priority

IWA PIs Existing	Selected				21	9	6	IWA PIs Existing	Selected				27	7	5
89	36	Group	Performance indicators		Priority 1	Priority 2	Priority 3	81	39	Group	Performance indicators		Priority 1	Priority 2	Priority 3
4	3	Water resources performance	WR1	Inefficiency of use or water resources	1			34	23	Quality of service performance	QS1	Households and businesses supply coverage		1	
			WR2	Water resources availability	1						QS2	Buildings supply coverage		1	
			WR3	Own water resources availability	1						QS3	Population coverage	1		
15	2	Personnel performance	Pe1	Employees per connection			1				QS4	Population coverage with service connections	1		
			Pe2	Employees per water produced			1				QS10	Pressure of supply adequacy	1		
26	6	Physical performance	Ph2	Raw water storage capacity		1					QS12	Continuity of supply	1		
			Ph3	Transmission and distribution storage capacity		1					QS13	Water interruptions	1		
			Ph5	Standardized energy consumption			1				QS14	Interruptions per connection	1		
			Ph7	Energy recovery			1				QS17	Days with restrictions to water service	1		
			Ph11	Customer meter density							QS20	Microbiological tests compliance	1		
			Ph12	Metered customers							QS21	Physical-chemical tests compliance	1		
44	25	Operational performance	Op3	Network inspection	1						QS23	New connection efficiency		1	
			Op4	Leakage control	1						QS24	Time to install a customer meter		1	
			Op5	Active leakage control repairs		1	1				QS25	Connection repair time	1		
			Op7	System flow meters calibration							QS26	Service complaints per connection	1		
			Op8	Meter replacement	1						QS27	Service complaints per customer	1		
			Op15	Vehicle availability			1				QS28	Pressure complaints			
			Op16	Mains rehabilitation	1						QS29	Continuity complaints	1		
			Op17	Mains renovation		1	1				QS30	Water quality complaints	1		
			Op18	Mains replacement	1						QS31	Interruption complaints	1		
			Op19	Replaced valves	1						QS32	Billing complaints and queries		1	
			Op20	Service connection rehabilitation	1						QS33	Other complaints and queries			1
			Op23	Water losses per connection	1						QS34	Response to written complaints			1
			Op24	Water losses per mains length	1			47	16	Economic & financial performance	Fi1	Unit revenue	1		
			Op25	Apparent losses	1						Fi2	Sales revenues	1		
			Op26	Apparent losses per SIV		1					Fi4	Unit total costs	1		
			Op27	Real losses per connection	1						Fi5	Unit running costs	1		
			Op28	Real losses per mains length	1						Fi9	Imported (raw and treated) water costs	1		
			Op29	ILI	1						Fi10	Electrical energy costs	1		
			Op30	Pump failures	1						Fi25	Unit investment			1
			Op31	Mains failures	1						Fi26	Investments for new assets and reinforcement of existing assets			1
			Op32	Service connection failures	1						Fi27	Investments for asset replacement and renovation			1
			Op36	Customer reading efficiency		1					Fi28	Average water charges for direct consumption	1		
			Op37	Residential customer reading efficiency		1					Fi29	Average water charges for exported water		1	
			Op38	Operational meters		1					Fi30	Total cost coverage ratio	1		
			Op39	Unmetered water		1					Fi31	Operating cost coverage ratio	1		
											Fi32	Delay in accounts receivable		1	
											Fi46	Non-revenue water by volume	1		
											Fi47	Non-revenue water by cost	1		

Table 4
The formulas and units of the 75 IWA PIs selected

PI	Formula	Units	PI	Formula	Units
WR1	WR1 = (A19/A3) × 100	%	QS3	QS3 = (F1/E5) × 100	%
WR2	WR2 = ((A3 × 365/H1)/(A1 + A2)) × 100	%	QS4	QS4 = (F2/E5) × × 100	%
WR3	WR3 = ((A3 × 365/H1)/A1) × 100	%	QS10	QS10 = (D33/C24) × 100	%
Pe1	Pe1 = (B1/C24) × 1,000	No./1,000 connections	QS12	QS12 = [(H2/24)/H1] × 100	%
Pe2	Pe2 = [B1/(A6 × 365/H1)] × 10^6	No./(10^6 m^3/year)	QS13	QS13 = [D35/(F1 × 24 × H1)] × 100	%
Ph2	Ph2 = (C1/A3) × H1	Days	QS14	QS14 = {[(D36 × 365)/H1]/C24} × 1,000	No./1,000 connections/year
Ph3	Ph3 = (C2/A3) × H1	Days	QS17	QS17 = (D38/H1) × 100	%
Ph5	Ph5 = D1/D3	kWh/m^3/100 m	QS20	QS20 = (D63/D54) × 100	%
Ph7	Ph7 = (D5/D1) × 100	%	QS21	QS21 = (D64/D55) × 100	%
Ph11	Ph11 = E6/C24	No./service connections	QS23	QS23 = F9/F10	Days
Ph12	Ph12 = (E6 + E9)/E10	No./customer	QS24	QS24 = F11/F12	Days
Op3	Op3 = [(D8 × 365)/H1/C8] × 100	%/year	QS25	QS25 = F13/F14	Days
Op4	Op4 = [(D9 × 365)/H1/C8] × 100	%/year	QS26	QS26 = [(F15 × 365)/H1/C24] × 1,000	No. complaints/1,000 connections/year
Op5	Op5 = [(D10 × 365)/H1/C8] × 100	No./100 km/year	QS27	QS27 = [(F15 × 365)/H1]/E10	No. complaints/customer/year
Op7	Op7 = [(D12 × 365)/H1]/C10	/year	QS28	QS28 = (F16/F15) × 100	%
Op8	Op8 = [(D45 × 365)/H1]/E6	/year	QS29	QS29 = (F17/F15) × 100	%
Op15	Op15 = (D19/C8) × 100	No./100 km	QS30	QS30 = (F18/F15) × 100	%
Op16	Op16 = [(D20 × 365)/H1/C8] × 100	%/year	QS31	QS31 = (F19/F15) × 100	%
Op17	Op17 = [(D21 × 365)/H1/C8] × 100	%/year	QS32	QS32 = [(F20 × 365)/H1]/E10	No./customer/year
Op18	Op18 = [(D22 × 365)/H1/C8] × 100	%/year	QS33	QS33 = [(F21 × 365)/H1]/E10	No./customer/year
Op19	Op19 = [(D23 × 365)/H1/C21] × 100	%/year	QS34	QS34 = (F22/F23) × 100	%
Op20	Op20 = [(D24 × 365)/H1/C24] × 100	%/year	Fi1	Fi1 = (G2−G35)/A14	EUR/m^3
Op23	Op23 = [(A15 × 365)/H1]/C24	m^3/connection/year	Fi2	Fi2 = (G3/G1) × 100	%
Op24	Op24 = (A15/H1)/C8	m^3/km/year	Fi4	Fi4 = G4/A14	EUR/m^3
Op25	Op25 = [A18/(A3−A5−A7)] × 100	%	Fi5	Fi5 = G5/A14	EUR/m^3
Op26	Op26 = (A18/A3) × 100	%	Fi9	Fi9 = (G10/G5) × 100	%
Op27	Op27 = A19 × 1,000)/[(C24 × H2)/24]	lt/connection/day (system pressurized)	Fi10	Fi10 = (G11/G5) × 100	%
Op28	Op28 = (A19 × 1,000)/[(C8 × H2)/24]	lt/km/day (system pressurized)	Fi25	Fi25 = G32/A14	EUR/m^3
Op29	Op29 = Op27/(18 × C8/C24 + 0,8 + 0,025 × C25)/(D34/10)		Fi26	Fi26 = (G33/G32) × 100	%
Op30	Op30 = [(D27 × 365)/H1]/C4	Days/pump/year	Fi27	Fi27 = (G34/G32) × 100	%
Op31	Op31 = [(D28 × 365)/H1/C8] × 100	No./km/year	Fi28	Fi28 = G36/(A14−A7)	EUR/m^3

(*Continued*)

Table 4 (*continued*)

PI	Formula	Units	PI	Formula	Units
Op32	Op32 = [(D29 × 365)/H1/ C24] × 1,000	No./1,000 connectiion/year	Fi29	Fi29 = G37/(A5 + A7)	EUR/m^3
Op36	Op36 = [(D42 × 365)/H1]/ (E7 × D39 + E8 × D40 + E9 × D41)		Fi30	Fi30 = G1/G4	
Op37	Op37 = [(D43 × 365)/H1]/ (E7 × D39)		Fi31	Fi31 = G1/G5	
Op38	Op38 = (D44/E6) × 100	%	Fi32	Fi32 = (G38/G3) × H1	Days equivalent
Op39	Op39 = [(A3−A8−A11)/A3] × 100	%	Fi46	Fi46 = (A21/A3) × 100	%
QS1	QS1 = (E1/E3) × 100	%	Fi47	Fi47 = {[(A13 + A18) × G57 +(A19 × G58)]/G5} × 100	%
QS2	QS2 = (E2/E4) × 100	%			

included indicators regarding the organization performance, Section D included suggestions to be made by the respondents, and Section E included some general information regarding the respondent's position, experience, education, and age. The answers collected were then evaluated by a task group within the project formed by experts. The first output of this methodology is a critical mass, containing 75 out of 170 IWA PIs (Table 3). According to the frequency, for each PI appeared in the sample, a prioritization process took place. The PIs of priority 1 are the ones that appear more than 80% (5 times) in the sample. The PIs that appear more than 50% (3 times) are of priority 2. The PIs that appear more than 25% (2 times) are of priority 3. Table 4 shows the formulas and the units of the 75 IWA PIs selected. To calculate these 75 IWA PIs, 98 IWA variables have to be measured (Table 5).

3.3. *Derived PIs by existing ones properly modified to address special issues*

It is obvious that the 170 IWA PIs do not cover all issues faced by a water utility. There are certain parameters that are not addressed by the existing IWA PIs referring to water losses. International literature [21] clearly states that pipe breaks and leaks are affected by several parameters like pipe characteristics (pipe material; diameter; age; pipe operational state; etc.), operational and maintenance factors (operating pressure; last break event characteristics; maintenance characteristics; water quality; etc.), and environmental/climate conditions (soil type; soil temperature; rainfall; traffic and loads; etc.). Therefore, such parameters as pipe material and pipe diameter are used to form new PIs derived from the existing ones. Also, apparent losses are affected by the existence and the volume of roof tanks. The second output of the above mentioned integrated methodology is a list of 11 new PIs (Table 6), derived from the IWA ones properly modified to address special issues, mainly including operational PIs regarding real losses, apparent losses, water losses, and NRW. The evolution of certain IWA PIs, already discussed by the IWA Task Force, [8,10] (Table 1) was also considered while forming the new PIs.

The denominators are different since the task group wished to check the impact of certain variables to the values of real, apparent, and total water losses. Specifically, the first three proposed PIs (Op45; Op46; Op47) investigate the impact of pipe material and/or diameter in the real losses values. The next two PIs (Op51; Op52) investigate the impact of roof tanks and their volume in the apparent losses values. Apparent losses per water meter index (Op53) are also proposed to check the water volume lost per water meter. The next PI proposed (ALI; Op54) has already been proposed by IWA Apparent Loss Team [22], but it is not one of the 170 IWA PIs yet. The task group also adopted this PI. The Op55 PI shows how much water is lost compared to the volume abstracted from the water resources. This is an important PI since water losses represent up to 50% of the System Input Volume (SIV) in many WSS. The next two PIs (Op58; Op59) refer to NRW. The NRW is being investigated on the basis of number of connections or length of mains. Finally, the last PI (Op60) estimates the mains' failures per type of main, as studies showed that the pipe material affects mains' failures [21].

Table 5
The 98 IWA variables needed to estimate the 75 IWA PIs selected

A/A	Variable	Units	A/A	Variable	Units
A1	Annual yield capacity of own resources	m^3/year	D45	Meter replacement	No.
A2	Annual imported water allowance	m^3/year	D54	Microbiological tests carried out	No.
A3	SIV	m^3	D55	Physical-chemical tests carried out	No.
A5	Exporter raw water	m^3	D63	Compliance of microbiological tests	No.
A6	Water produced	m^3	D64	Compliance of physical-chemical tests	No.
A7	Exported treated water	m^3	E1	Households and businesses supplied	No.
A8	Billed metered consumption	m^3	E2	Building supplies	No.
A11	Unbilled metered consumption	m^3	E3	Households and businesses	No.
A13	Unbilled authorized consumption	m^3	E4	Buildings	No.
A14	Authorized consumption	m^3	E5	Resident population	Persons
A15	Water losses	m^3	E6	Direct customer meters	No.
A18	Apparent losses	m^3	E7	Residential customer meters	No.
A19	Real losses	m^3	E8	Industrial customer meters	No.
A21	Non-revenue water	m^3	E9	Bulk customer meters	No.
B1	Total personnel	No.	E10	Registered customers	Customers
C1	Raw water storage capacity	m^3	F1	Population supplied	Persons
C2	Treated water storage capacity	m^3	F2	Population supplied with service pipes	Persons
C8	Mains length	km	F9	New connections establishment time	Days
C10	System flow meters	No.	F10	New connections established	No.
C21	Mains valves	No.	F11	Customer meter installation time	Days
C24	Service connections	No.	F12	New customer meters installed	No.
C25	Average service connection length	M	F13	Connections repair time	Days
D1	Pumping energy consumption	kWh	F14	Connections repaired	No.
D3	Standardization factor	$m^3 \times 100\,m$	F15	Service complaints	No.
D5	Energy recovery	Wh	F16	Pressure complaints	No.
D8	Network inspection	km	F17	Continuity complaints	No.
D9	Leakage control	km	F18	Water quality complaints	No.
D10	Leaks repaired due to active leakage control	No.	F19	Complaints on interruptions	No.
D12	System flow meter calibrations	No.	F20	Billing complaints and queries	No.
D19	Permanent vehicles	No.	F21	Other complaints and queries	No.
D20	Mains rehabilitation	km	F22	Written responses	No.
D21	Mains renovation	km	F23	Written complaints	No.
D22	Mains replacement	km	G1	Total revenues	EUR
D23	Replaced valves	No.	G2	Operating revenues	EUR
D24	Service connection rehabilitation	No.	G3	Sales revenues	EUR
D27	Pump failures	Days	G4	Total costs	EUR
D28	Mains failures	No.	G5	Running costs	EUR
D29	Service connection failures	No.	G10	Imported (raw and treated) water costs	EUR

(*Continued*)

Table 5 (*continued*)

A/A	Variable	Units	A/A	Variable	Units
D33	Delivery points with adequate pressure	No.	G11	Electrical energy costs	EUR
D34	Average operating pressure	kPa	G32	Investment in tangible assets	EUR
D35	Water interruptions	Persons × hr	G33	Investments for new assets and reinforcement of existing assets	EUR
D36	Service interruptions	No.	G34	Investments for asset replacement and renovation	EUR
D38	Days with restrictions to water service	Days	G35	Capitalized cost of self-constructed assets	EUR
D39	Residential customer meter reading frequency	No./meter/year	G36	Water sales revenue for direct consumption	EUR
D40	Industrial customer meter reading frequency	No./meter/year	G38	Accounts receivable	EUR
D41	Bulk customer meter reading frequency	No./meter/year	G57	Average water charges for direct consumption	EUR/m^3
D42	Customer meter readings	No.	G58	Attributed unit cost for real losses	EUR/m^3
D43	Residential customer meter readings	No.	H1	Assessment period	Days
D44	Operational meters	No.	H2	Time system is pressurized	hr

Table 6
The proposed PIs derived from the existing IWA ones

Existing PIs (different denominator)				
Symbol	Performance indicator	PI explanation	Formula	Units
Op45 (a−*i*)	Real losses per pipe material	Real losses/pipes length of the same material (a−*i*)	A19/$C32_{(a-i)}$	m^3/km
Op46 (a−*i*)	Real losses per pipe diameter	Real losses/pipes length of the same diameter (a−*i*)	A19/$C33_{(a-i)}$	m^3/km
Op47 (a−*i*)	Real losses per pipe material & diameter	Real losses/pipes length of same diameter & material (a−*i*)	A19/$C34_{(a-i)}$	m^3/km
Op51	Apparent losses per roof tank	Apparent losses/number of roof tanks	A18/C26	m^3
Op52	Apparent losses per roof tank volume	(Apparent losses/roof tanks volume) × 100	(A18/C30) × 100	%
Op53	Apparent losses per water meter	(Apparent losses)/(number of water meters)	A18/E6	m^3/water meter
Op54	ALI	Apparent losses/5% of water sales	A18/(0.05 × G3)	
Op55	Water losses per water resources	(Water losses/water taken from the resources) × 100	{A15/($\Sigma A27_{(a-i)}$)} × 100	%
Op58	NRW per connection	(NRW × 1,000)/(number of service connections × assessment period)	(A21 × 1,000)/C24/H1	lt/connection/day
Op59	NRW per mains length	NRW/mains length	A21/C8	m^3/km mains/year
Op60	Mains failures per type of main	[(Number of failures of the same material of mains during the assessment period × 365)/assessment period]/mains length of the same material] × 100	[($D79_{(a-i)}$ × 365)/H1/$C32_{(a-i)}$]	No./km/year

Table 7
The 31 new PIs proposed

Symbol	Performance indicator	PI explanation	Formula	Units
Op48 (a−*i*)	Real losses per pipe age	Real losses/pipe length with the same age (a−*i*)	$A19/C35_{(a-i)}$	m^3/km
Op49 (a−*i*)	Real losses per roughness coefficient	Real losses/roughness coefficient (a−*i*)	$A19/C36_{(a-i)}$	
Op50	Real losses—pressure	Real losses/average operating pressure	A19/D34	m^3/m
Op56	Water losses% water use (domestic, industrial, commercial)	(Water losses/water use (a−*i*)) × 100	$(A15/E14_{(a-i)}) \times 100$	%
Op57	Water losses per buildings height	Water losses/average buildings height	A15/C27	m^3/m
Fi48	MCD per real losses	(MCD/Real Losses) × 100	(A25/A19) × 100	%
Fi49	MCD per connection	MCD/number of connections/ assessment period (days)	A25/C24/H1	m^3/connection/day
Fi50	Accounted for NRW per NRW	(Accounted for NRW/NRW) × 100	(A26/A21) × 100	%
Ph16	Inhabitants per water meter	Number of inhabitants/number of water meters	E5/E6	Inh/wm
Ph17	Energy per volume	Energy used (kWh)/SIV (m^3)	D68/A3	kWh/m^3
Fi51	Energy costs per volume	Energy cost (€)/SIV (m^3)	G11/A3	€/m^3
Op61	Leakage energy or energy loss due to leakage (sum of the leaks-related energy loss and additional energy required to overcome leakage)	The sum of energy loss through leaked water and the additional energy required to overcome friction with the increased flow rate needed to overcome leakage (difference between the actual energy dissipated in friction losses and the value of friction losses in a leak-free network)	(D77 + D73−D74)/ D78	
Op62	Standards compliance	(Energy delivered to users/ minimum required useful energy) × 100	(D75/D76) × 100	%
Op63	Carbon footprint per SIV	Carbon footprint produced during WS process/SIV	D72/A3	TNS CO_2/m^3
Op64	Meter replacement	(Flow meters replaced/total number of flow meters) × 100	(D69/C10) × 100	%
QS35	Residential consumption size	(Residential Consumption/total consumption) × 100	(E12/A14) × 100	%
QS36	Commercial consumption size	(Commercial consumption/total consumption) × 100	(E13/A14) × 100	%
Fi52	Willingness to pay index (consumer's sensitivity to issues of water shortage and drought)	Cost to safeguard water supply/ authorized consumption during the assessment period	G59/A14	EUR/m^3
QS37	Low pressure-related complaints rate	(No of water low pressure-related complaints/total no. of complaints) × 100	(F27/F15) × 100	%
QS38	Low pressure-related complaints per service	No. of water pressure-related complaints/no. of water meters	F16/E6	
QS39	Grade of consumer's satisfaction	(Satisfied customers/total population served) × 100	(F24/F1) × 100	%

(*Continued*)

Table 7 (*continued*)

Symbol	Performance indicator	PI explanation	Formula	Units
QS40	Tap water grade of satisfaction	(Satisfied customers drinking tap water/total population served) × 100	(F25/F1) × 100	%
QS41	Water taste grade of satisfaction	(Customers affected by the taste and chlorination of potable water/total population served) × 100	(F26/F1) × 100	%
QS42	Grade of employees valuation of customer's satisfaction	Grade of employees valuation of customer's satisfaction	(F28/B1) × 100	%
Op65 (a−*i*)	Assessment of failures according to type of material and fittings in mains and service connections	Failure rates (for each type of failure) in No of failures/total No of devices	$D80_{(a-i)}$/C31	
Ph18	Under 5 years old domestic water meters rate	(Domestic water meters aged less than 5 years old/total water meters) × 100	(C28/E6) × 100	%
Ph19	5–10 years old domestic water meters rate	(domestic water meters aged between 5 and 10 years old/ total water meters) × 100	(C29/E6) × 100	%
Ph20	Over 10 years old domestic water meters rate	(domestic water meters aged over 10 years old/total water meters) × 100	(C37/E6) × 100	%
Op66	Elasticity of losses related to operating pressure	Elasticity of real losses related to pressure differences	(ΔA19/A19)/(ΔD34/D34)	m^3/m
Op67	Elasticity of failures occurrence rate related to the operating pressure	Elasticity of mains and service connections failures related to pressure differences	[Δ(D28 + D29)/(D28 + D29)]/(ΔD34/D34)	failures/m
Op68	Number of days to respond to repair leakage events	Total no. of days to respond to repair leakage events/total number of repairs occurred	D70/D71	days/repairs

3.4. *New PIs developed based on the IWA concept covering additional topics*

Additional PIs covering issues, such as social, environmental, and health factors, energy use, and conservation, have also been proposed by the task group, based on the answers given to the questionnaires and the needs of the water utilities in the Mediterranean area, facing severe water shortage problems. There, water demand in the summer months is very big due to tourism and climate conditions, causing high demand peaks. When the water utility does not apply any pressure management strategy, its network suffers from high leakage rates during its transition to normal operating conditions (during winter). Topics such as carbon footprint and energy losses are also being addressed. The MCD is used to form new PIs. The third integrated methodology output is a list of 31 new PIs, covering additional topics (Table 7). The first three PIs (Op48; Op49; Op50) aim at showing the impact of pipe age, roughness coefficient, and operating pressure to the real losses values. Pipe age, operating pressure, and pipe aging affect the pipe's operational state [21]. Thus, roughness coefficient has been used to inter-relate real losses to each pipe roughness coefficient. The Op56 and Op57 PIs do relate water losses with water use and buildings' height. The latter is connected to the operational pressure and affects water losses in the system. The MCD has been used to create new PIs (Fi48; Fi49) regarding real losses and number of connections. The MCD is part of real losses recovered by the water utility. The Fi48 PI shows the part of the real losses recovered through the MCD. The Fi49 PI counts the MCD per service connection. This PI can then be benchmarked with Op27 IWA PI, being the real losses per connection index. Fi50 PI shows how much NRW is considered to be accounted for by the water utility, compared to the total NRW. Ph16 PI shows how many people use the same water meter.

The following five PIs (Ph17; Fi51; Op61–63) refer to energy losses and carbon footprint. PIs Op61 and Op62 have already been suggested by Cabrera et al. [23] during their effort to estimate energy losses in the water distribution networks, addressing for the first time the water losses-related energy loss. The PI Op64

Table 8
The new variables needed to calculate the 42 new proposed PIs

Variable	No.	New suggested variables	Units	Variable	No.	New suggested variables	Units
ΔA19	1	Initial real losses minus final real losses (related to pressure change)	m^3	D69	1	Flow meters replaced	No.
A25	1	Minimum charge difference	m^3	D70	1	Time to respond to repair leakage events	hr
A26	1	Accounted for NRW	m^3	D71	1	Total number of repairs occurred	No.
A27(a−*i*)	*i*	Water volume abstract from the same water resource (a−*i*)	m^3	D72	1	Carbon footprint produced during the WS process	Tons of CO_2
C26	1	Roof tanks number	No.	D73	1	Actual energy dissipated in friction losses	kWh
C27	1	Average building height	m	D74	1	Value of friction losses in a leak-free network	kWh
C28	1	Domestic water meters aged less than 5 years	No.	D75	1	Energy delivered to users	kWh
C29	1	Domestic water meters aged between 5 and 10 years old	No.	D76	1	Minimum required useful energy	kWh
C30	1	Roof tanks volume	m^3	D77	1	Outgoing energy through leaks	kWh
C31	1	Total number of devices	No.	D78	1	Input energy supplied by the reservoir	kWh
C32(a−*i*)	*i*	Pipes length of the same material (a−*i*)	km	D79 (a−*i*)	*i*	Number of failures of mains of the same material (a−*i*)	No.
C33(a−*i*)	*i*	Pipes length of the same diameter (a−*i*)	km	D80 (a−*i*)	*i*	Number of same type of failure in mains and fittings (a−*i*)	No.
C34(a−*i*)	*i*	Pipes length of the same material and diameter (a−*i*)	km	E12	1	Residential consumption	m^3
C35(a−*i*)	*i*	Pipes length with the same age (a−*i*)	km	E13	1	Commercial consumption	m^3
C36(a−*i*)	*i*	Pipes roughness coefficient (a−*i*)		E14 (a−*i*)	*i*	Water use (a−i)	m^3
C37	1	Domestic water meters aged more than 10 years	No.	F24	1	Number of satisfied customers	No.
Δ(D28 + D29)	1	Initial mains and service connections failures minus final mains and service connections failures (due to pressure change)	No.	F25	1	Number of satisfied customers drinking tap water	No.
ΔD34	1	Initial average operating pressure minus final average operating pressure	Kpa	F26	1	Number of customers affected by the taste and chlorination of potable water	No.
D66	1	Minimum operating network pressure	m	F27	1	Number of water low pressure—related complaints	No.
D67	1	Maximum operating network pressure	m	F28	1	Number of employees considering that customers are satisfied	No.
D68	1	Energy used	kWh	G59	1	Cost to safeguard water supply	€

refers to flow meters replacement rate. PIs QS35 and QS36 show the residential and commercial consumption size, respectively. Fi 52 PI shows the willingness to pay index and can be assessed after a survey to the utility's customers. The following six PIs (QS37–42) express the customers' satisfaction, regarding adequate pressure, tap water, water taste, and general services customer satisfaction. Op65 PI assesses failures, according to type of material and fittings in mains and service connections. The following three PIs (Ph18–20) refer to the water meters age, dividing them in three groups: water meters aged less than 5 years, water meters aged from 5 to 10 years, and water meters aged over 10 years. These PIs aim at investigating apparent losses due to under-registration which is closely linked to meters age. PIs Op66 and Op67 measure the elasticity of losses and failures occurrence to operating pressure. The last new proposed PI (Op68) measures the efficiency of the utility during the occurrence of leakage events. This PI has to do with the leak or break location and repair time.

3.5. Variables needed to calculate existing and new PIs

To calculate the 75 selected IWA PIs, 98 existing variables are needed (Table 6). At least 42 new variables (Table 8) are needed for the estimation of all 42 new PIs (11 derived from existing ones and 31 new ones).

4. An integrated approach

The final task is the development of a user-friendly DSS tool (Figs. 2 and 3). This is currently being developed to tackle the NRW reduction strategies prioritization for WSS, focused on the Mediterranean area. The development of a DSS tool with internal (water system) and external (River Basin Management-RBM) factors is a key point, as WSS managers are not usually invited to participate in the formation of RBM Plans. Through a thorough benchmarking process, additional PIs are included, depending upon the reliability and availability of respective data, best adapted to local conditions. Among others, the DSS searches the variables needed to calculate the selected PIs (Fig. 2). The DSS evaluates the WSS according to each PI value compared to the other WSS included in the DSS (Fig. 3). It also provides an overall score according to the PIs values calculated for the specific WSS.

The DSS tool is used to classify and evaluate NRW control methods, by introducing PIs' weighting factors. Its goal is to define the most cost-effective NRW meth-

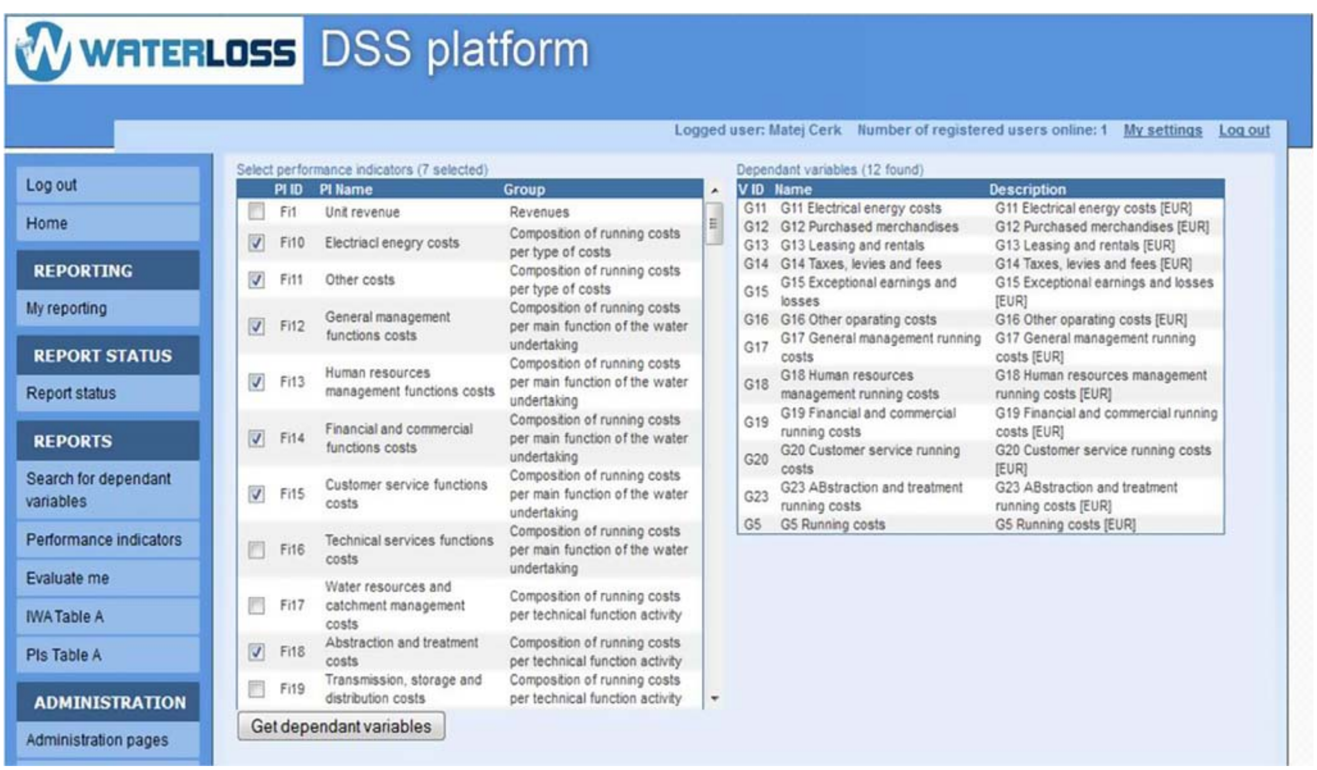

Fig. 2. PIs dependency search.

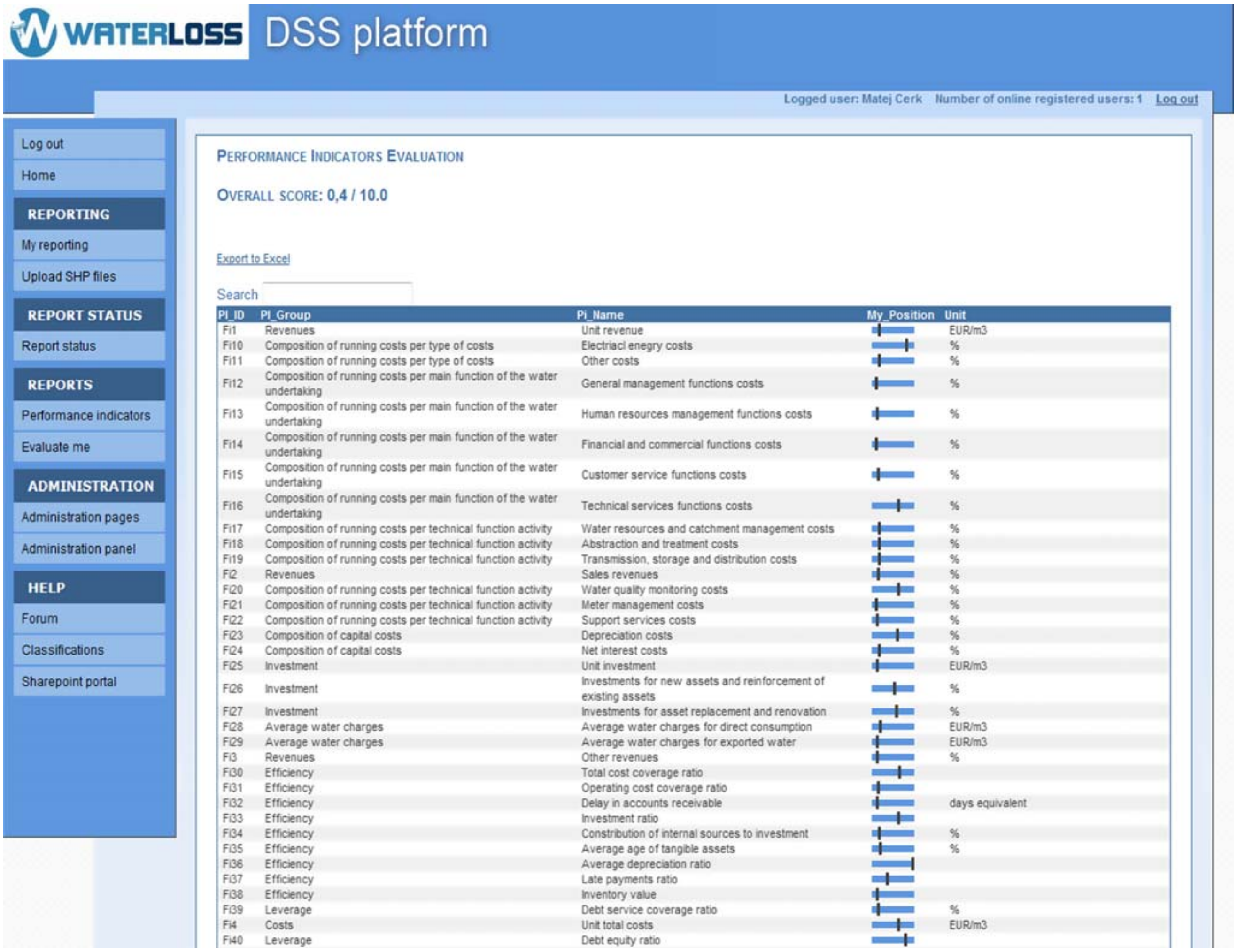

Fig. 3. Evaluation process.

ods, considering also their environmental impact. This DSS tool will cover the whole water supply process from water entering the system up to the customer's meter, considering all potential NRW parameters. Thus, it needs to be validated and readjusted after its implementation in water distribution systems in different areas, and under different conditions, to best examine water loss reduction strategies that could be applied in areas of different characteristics. WATERLOSS project implementation process follows successive steps: (a) monitoring the performance of WSS and evaluation of their water losses and NRW using the IWA methodology and the new modified WB proposed by Kanakoudis and Tsitsifli [20]; (b) establishment of a PIs database (critical mass), including not only existing PIs but also new proposed ones, emphasizing to local characteristics and health, social, and other factors; (c) collection and critical evaluation of existing and innovative methods for controlling NRW; (d) development of a DSS for the selection of appropriate measures for tackling the NRW problem; (e) establishment of a ranked list of measures for NRW reduction, considering environmental parameters and cost efficiency; and (f) implementation of the DSS in pilot cases and DSS validation and certification.

The components of the DSS are:

(1) A detailed database including all IWA variables and PIs. The user can fill in the values of the available variables and the value of the related PIs will be automatically estimated. This database will incorporate new WSS PIs with particular emphasis to regional characteristics, based on data regularly recorded by water utilities. The new developed PIs will consider issues, such as society participation, effect of media, human health impacts, and environmental and financial parameters. This tool will evaluate the WSS per-

formance and classify the WSS, according to its performance;

(2) A Dynamic DataBase of WSS PIs weighted by factors considering the regional characteristics of the target area. The WSS will be totally evaluated, regarding water losses and NRW;

(3) A user-friendly water audit tool (e.g. WB/PI Calc-UTH (UTH stands for University of Thessaly)) for WB and PIs assessment, designed to assess the 2nd proposed modification of the IWA WB;

(4) A Dynamic DataBase of conventional and new methods for NRW control, including a detailed cost–benefit analysis based on the EARL level assessment;

(5) The DSS will be dynamic, giving the chance to a water utility to check, if the NRW target has been met and reassess the methods to meet the new NRW goals.

The main aim of the developed DSS tool is to identify, collect, and critically evaluate methods and processes for monitoring and controlling NRW based on preventive approaches. The water utilities will set their desired NRW targets. The NRW reduction methods will be selected based on a prioritized list of activities on the NRW reduction goal set by the water utility and methods for their cost-effective achievement. The prepared tool will represent a comprehensive system taking into account pipe failures, water interruption, customer complaints, water demand, water quality, etc. The DSS specifications include:

- The 2nd modified WB and PIs estimation on annual, biannual, quarterly, etc. basis;
- Monitoring through historic data;
- Selection of the most appropriate PIs to tackle the right problem;
- PIs classification and prioritization;
- Critical PIs set—use of weighting factors;
- Water networks evaluation based on the critical PIs set;
- NRW reduction measures (depending on the NRW cause);
- NRW reduction measures cost calculation routine;
- Connection of measures to PIs values resulting in proposed actions using benchmarking; and
- Dynamic monitoring and evaluation (Ex-ante, ongoing, and Ex-post).

5. Conclusions

The present paper demonstrates an integrated approach aiming at developing a methodology for the WSS performance evaluation, regarding NRW and the suggested NRW reduction strategies. The paper presents the development process of the appropriate PIs, used to evaluate the performance of WSS. The whole process of developing PIs is part of an ongoing EU co-financed MED project named WATERLOSS. The basis for the PIs development has been the International WB and the PIs proposed by IWA. The IWA International WB has been modified [20] to fit in the Mediterranean cases. The use of the MCD has been proposed. Based on this proposed modified IWA WB, a task group is formed within the partners of the WATERLOSS project to use existing PIs and develop new ones. The whole attempt was based on a survey performed within water utilities related to the WATERLOSS project. The respondents evaluated the use of the 170 existing IWA PIs and proposed new PIs to address specific local problems, faced in the their water networks. The final outcome includes 75 out of the 170 existing IWA PIs, prioritized in three categories, according to their significance. A group of 11 PIs has been set up, including PIs derived from existing ones with different denominators. Finally, a group of 31 new PIs has been proposed by the partners and the task group. A group of new variables needed to estimate these PIs has been set up. A total database of 117 existing and new PIs will be used in the DSS tool, being concluded within the project. The DSS will use the PIs database and weighting factors to choose the most cost-effective NRW reduction measures. The DSS tool currently being developed integrate the following: (a) A critical set of PIs including both known PIs and suggested ones; this system will also incorporate weighting factors to stress out the importance of specific PIs in certain areas and (b) A set of NRW reduction strategies and a set of corresponding targets for NRW control. These targets will be based on the specific policies and goals that each water utility implements. The final outcome will be a proposed set of NRW reduction strategies that the water utility will be able to implement and check their results. A cost–benefit analysis will be also implemented to choose the most cost-effective strategies. Finally, the assumptions will be validated, the parameters will be readjusted, and the DSS tool will be certified by comparing the actual and the predicted NRW reduction values.

Acronyms

ALI	—	apparent losses index
AWWA	—	American water works association
DSS	—	decision support system

EARL	—	economic annual real losses
GHG	—	greenhouse gas
ILI	—	infrastructure leakage index
IWA	—	international water association
LP	—	lead partner
NRW	—	nonrevenue water
MCD	—	minimum charge difference
PI(s)	—	performance indicator(s)
PP	—	project partner
RBM	—	river basin management
UARL	—	unavoidable annual real losses
WB	—	water balance
WSS	—	water supply systems

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