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WATERLOSS project: developing from theory to practice an integrated approach towards NRW reduction in urban water systems

Vasilis Kanakoudis[a], Stavroula Tsitsifli[a,*], Anastasios I. Zouboulis[b]

[a]*Department of Civil Engineering, University of Thessaly, GR-38334 Volos, Greece, Tel. +30 24210 74156; Fax: +30 24210 74135; email: tsitsif@otenet.gr (S. Tsitsifli)*
[b]*Department of Chemistry, Aristotle University of Thessaloniki, GR-54124 Thessaloniki, Greece*

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ABSTRACT

Today almost all Mediterranean countries are facing significant water scarcity problems; therefore, water losses in drinking water supply networks have grown to an urgent problem, requiring the implementation of immediate measures to address them. WATERLOSS project developed an integrated methodology to efficiently address the Non-Revenue Water (NRW) problem. The methodology consisted of the evaluation of the water distribution systems using the second modified Water Balance methodology and the development of a database of Performance Indicators including existing and new ones. NRW reduction measures were developed tackling each NRW component. All components were integrated in a decision support system (DSS) where the user can enter the desired variable values and through a decision tree, the DSS tool, a list of prioritized NRW reduction measures is deduced. The performance of the DSS tool was justified by its implementation in selected pilot cases. Overall, a rational and cost efficient strategy could be developed by water authorities for addressing NRW problems only when using a targeted approach.

Keywords: Water supply systems; Non-Revenue Water; Decision Support System; Performance indicators

1. Introduction

"Water use efficiency" has a twofold meaning: minimization of water volume lost and/or reduction of water losses related revenues. Minimization of water losses volume will increase the water used over the system input volume (SIV). This component is associated to reduction of water volume lost, but does not include other components for example water theft and meters errors, since they represent water used but not paid for. Minimization of water losses related revenues will increase the unit revenues over the SIV, corresponding to Non-Revenue Water (NRW) reduction. Water theft and meters errors are included in this case. "Water use efficiency" can be achieved through the reduction of water losses, by water saving and more efficient water devices and by water recycling. Such measures should be adapted by both consumers and water managers. Water utilities should realize that they should first

*Corresponding author.

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reduce NRW levels in their water distribution systems (WDSs), before looking for new water resources or plan for new water transfer plans. At the same time, the EU Water Framework Directive 2000/60/EC requires the water utilities to implement appropriate water pricing policies to recover the full cost of the water services (direct; environmental, and natural resource costs). Water and revenues losses prevent water utilities from implementing just social water prices. The need to apply effective and just socially water prices is becoming one of the water utilities' top priorities. A few EU Member States (France; Cyprus) already asked the water utilities in their territories to reduce NRW to certain levels.

About 45 billion m^3 of water are annually being lost through leakage corresponding to 35% of the total water supplied [1]. If half of this water was saved, 200 million people would have access to safe water without any further investment. Moreover NRW includes water being lost, revenues, and energy. Water resources stress due to climate change conditions and water demand increase is globally acknowledged as a major environmental problem [2], especially in the Mediterranean area, facing water scarcity conditions. Therefore, water utilities have to become more efficient throughout the entire water supply process/chain, to guarantee sufficient quantities of good quality water [1]. NRW consists of water losses (apparent/commercial and real/physical) and water provided to authorize consumers free of charge [3]. An integrated methodology has to be implemented in order to address the NRW problem.

WATERLOSS project (EU co-financed MED project) aimed at developing a Decision Support System (DSS), using an integrated methodology, to support water utility managers in their efforts to design a NRW reduction strategy, implementing the best measures with the minimum cost. The project started in June 2010 and completed in May 2013. Nine partners from six EU Mediterranean countries participated as given in Table 1, namely France, Spain, Italy, Slovenia, Greece, and Cyprus (Table 1). The project consisted of three main technical parts: (a) Monitoring of the performance of WDSs and evaluation of NRW; (b) Development of a DSS tool of a prioritized list of measures; and (c) Verification of the proposed methodology in the demonstration phase [4,5].

The project implementation depended on some crucial parameters: (a) the development of an effective partnership scheme; (b) the determination of the project's strategic directions; (c) the development of a comprehensive common language and an effective methodology; and (d) the production of the final project output: the DSS.

2. Developing an effective partnership scheme

Since the capture of the project idea, the target was to involve partners with different scientific and technical background, as one of the goals of the interregional projects is the cooperation development and reinforcement between different authorities. Another important parameter that WATERLOSS took into consideration was the development of networking and know-how transfer between more experienced authorities to less experienced ones. All partners contributed and participated from the beginning of the project. The main criteria used to choose the appropriate partners and

Table 1
WATERLOSS partnership and pilot cases

Partner's no.	Partner's full name	Partner's city/country	Pilot case
LP=PP1	Aristotle University of Thessaloniki (AUTH)	Thessaloniki/Greece (EL)	
PP2	Conseil Général des Pyrénées Orientales (PO)	Perpignan/France (FR)	Baho; Argeles-sur-mer; Thuir
PP3	Water Board of Nicosia (WBN)	Nicosia/Cyprus (CY)	Nicosia
PP4	Regional Development Centre (RDC)	Slovenia (SI)	Velenje
PP5	Metropolitan Area of Barcelona (AMB)	Barcelona/Spain (ES)	Castellbisbal
PP6	Kozani Municipal Water and Sewerage Utility (DEYAK)	Kozani/Greece (EL)	Kozani
PP7	Autorità di Bacino dei Fiumi Liri-Garigliano-Volturno (LG)	Caserta/Italy (IT)	Melito di Napoli
PP8	University of Ljubljana—Civil and Geodetic Engineering Faculty (UL)	Ljubljana/Slovenia (SI)	
PP9	Department of Herault (DH)	Herault/France (FR)	SIEL

finally to achieve the expected goals included the research and development results implementation; the exploitation of the experience in the field; and formation of an appropriate environment for horizontal implementation of the developed methodology within the project. The involvement of cutting edge knowledge authorities, such as universities, contributed to the development of an integrated methodology and the rational implementation of research results.

The universities that participated in the project were the Aristotle University of Thessaloniki (AUTH) and the University of Thessaly (UTH) acting as AUTH's Technical Expert and the University of Ljubljana (UL), who developed the DSS tool. Water authorities managing WDSs were necessary for the implementation of project results. Thus, two water utilities participated, one from Greece (DEYAK) and one from Cyprus (WBN). WBN is one of the most advanced water utilities in NRW management across the EU since Cyprus suffers from water scarcity conditions. It must be noted that in 2007 and 2008 WBN operated under intermittent water supply conditions, providing water to its customers for 12 h every 48 h. On the other hand, DEYAK suffers from high NRW levels (as also resulted from the project implementation) but does not implement any NRW reduction measures as it is situated in an area with a great availability of water resource reserves in Greece. DEYAK is also not as experienced as WBN is. Finally, authorities of local and regional government were included to ensure that the developed methodology would have been implemented horizontally. The involvement of the Italian partner LG, which is the regional competent authority to implement the WFD, was deemed necessary to connect the WFD requirements with the water losses in WDSs.

3. Developing an effective methodology

The project's strategic directions included the formation of a methodology, the formation of a common terminology, and finally the production of the DSS tool. The methodology developed within the project adopted the background concept of the International Water Association (IWA) methodology, consisting of the IWA Standard International Water Balance (WB). The IWA WB is widely used, globally, by several water utilities to estimate the NRW levels and its components. A common language was adopted through the IWA Performance Indicators (PIs) aiming to use the same system of WDSs' performance evaluation. This enables water utilities to compare their results and propose efficient and effective measures to better manage their systems. Finally, the production of the DSS tool took place, using the cause-effect logic and analyzing the NRW components. The investigation of the NRW component causes can lead to the selection of the most appropriate measures to address it.

3.1. Developing phase

The project primary steps included the present status imprinting to evaluate the performance of the WDSs selected from the partners as pilot cases. A common methodology had to be implemented and a common terminology had to be adopted. Previous research showed that regional conditions lead to the modification of the IWA WB [7,8] (Fig. 1). Therefore the second modified IWA WB was selected and used since the Mediterranean countries show the same (more or less) local conditions (e.g. full data-sets unavailability; common pricing policies including high fixed charge levels) [10]. The WB analysis results showed that the highest NRW level (as % SIV) is met

<table>
<tr><th colspan="5">IWA International Standard Water Balance [6]</th><th>1st modification by McKenzie et al. [7]</th><th>2nd modification by Kanakoudis & Tsitsifli [8]</th></tr>
<tr><td rowspan="7">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td><td>Water billed and paid for (Free Basic Recover Revenue)</td><td>Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td><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 Consumption</td><td>Unbilled Metered Consumption</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 Non Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="3">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors</td></tr>
<tr><td colspan="2">Real Losses</td><td>Water Losses generating revenues (Minimum Charge Difference)</td></tr>
</table>

Fig. 1. The proposed second modified WB including McKenzie et al. [7,9] first modification.

in Kozani (58.4%), followed by SIEL (54.0%) and Thuir (52.9%) (Fig. 2). The lowest NRW level is met in Castellbisbal (10.3%), followed by Argeles-sur-mer (10.2%). Minimum Charge Difference (MCD) levels (as % SIV) ranged from 40.6% (Kozani) to 8.5% (Thuir). The results from the second modified IWA WB in the nine pilot cases (Table 1) verified that NRW levels are high and the water utilities do not implement NRW measures since they recover part of the losses through the fixed charge [10] (Fig. 2). For example, Kozani although losing more than half of the water entering its WDS, it does not implement any NRW reduction measure, as it recovers 40% of the water entering the system (and almost 70% of its NRW) through the fixed charge. Moreover the city is situated in a water resources rich water district.

3.2. Common terminology adoption

The assessment of the performance of a DSS includes the calculation of PIs in addition to the estimation of the various components in a WB. WDSs' PIs are used to evaluate the systems and monitor the measures impact. IWA has proposed a detailed list of 170 PIs and 232 variables needed to be monitored and registered to calculate the PIs [11]. The whole idea of IWA methodology is based on the super-market concept: each water utility should study and prioritize its needs regarding the WDS evaluation process. During the last five years, although PIs have been highly acknowledged as very efficient tools, significant discussions on their appropriateness emerged [9,12]. A full PIs database used to evaluate the performance of Mediterranean WDS 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.

During WATERLOSS project a database of critical PIs was developed, including PIs already existing and new ones based on specific conditions met in the Mediterranean area, such as social, health, environmental factors, and water quality problems etc. A methodology was used based on surveys in the project partners' countries [13]. These PIs, based on the way they are being formed, are distinguished in: (a) existing ones widely used by the Water Utilities in the partners' areas; (b) modified indicators i.e. those 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 [13]. The first group of existing PIs included 75 out of the 170 IWA PIs mainly addressing water losses issues. These PIs are ranked in 3 priority groups. The set of derived ones from existing PIs includes 11 PIs properly modified to address special issues, mainly including operational PIs associated to real losses, apparent losses, water losses, and NRW. Parameters like pipe material and pipe diameter are used to form new PIs derived from the existing ones. In addition, apparent losses are affected by the existence and the volume of roof tanks [13]. Finally 31 new PIs were suggested, covering issues, such as social, environmental and health factors, energy use, and conservation. Topics such as carbon footprint and energy losses are also being addressed [13]. Finally, the PIs database included 117 PIs and 39 new variables need to be measured in the field.

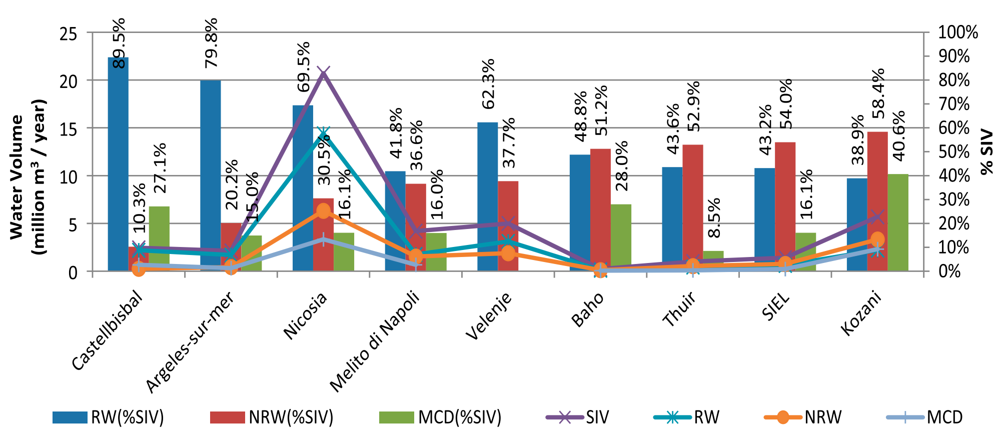


Fig. 2. WB components results for the nine pilot cases (2010).

4. The product: DSS tool

The project's final product is a user friendly DSS tool that provides a prioritized list of NRW reduction measures, focused on the Mediterranean area. The DSS tool covers the whole water supply process, from water entering the system up to the customer's meter, considering all potential NRW parameters. The DSS specifications include [14]: (a) the second modified WB and PIs estimation on annual, biannual, quarterly, etc. basis; (b) monitoring through historic data; (c) selection of the most appropriate PIs to tackle the right problem; (d) PIs classification and prioritization; (f) critical PIs set; (g) water networks evaluation based on the critical PIs set; (h) NRW reduction measures (depending on the NRW cause); (i) connection of measures to PIs values resulting in proposed actions using benchmarking; and (j) dynamic monitoring and evaluation (Ex-ante, on-going, and Ex-post).

The main features of the product are: (1) my reporting DSS: the user enters the WDS's data; (2) my reporting experiences: the user enters his experience on specific measures; (3) report status: it provides information about the status of reporting; (4) search for dependent variables: having chosen certain PIs, the tool shows the variables whose values are needed; (5) PIs: the tool shows the list of PIs and all the available information (formulas, units, etc.); (6) evaluate me:

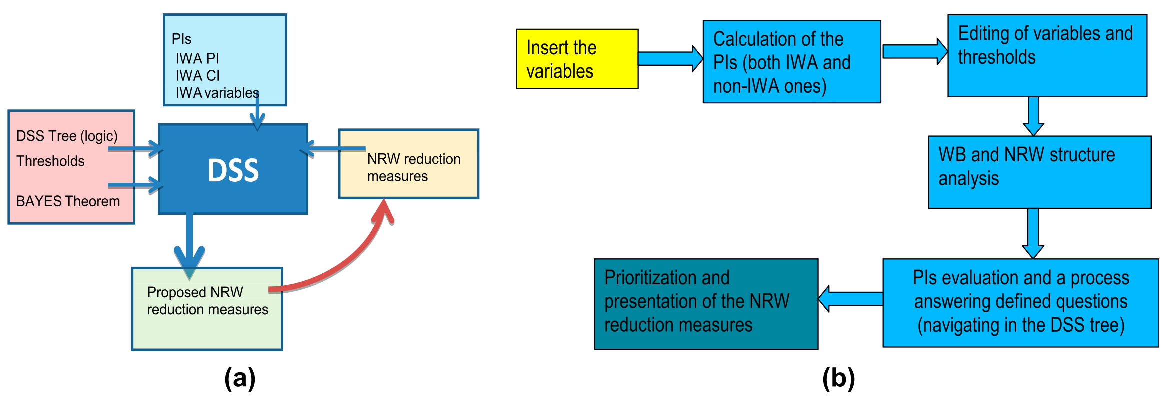


Fig. 3. (a) DSS structure and (b) DSS components and flow chart.

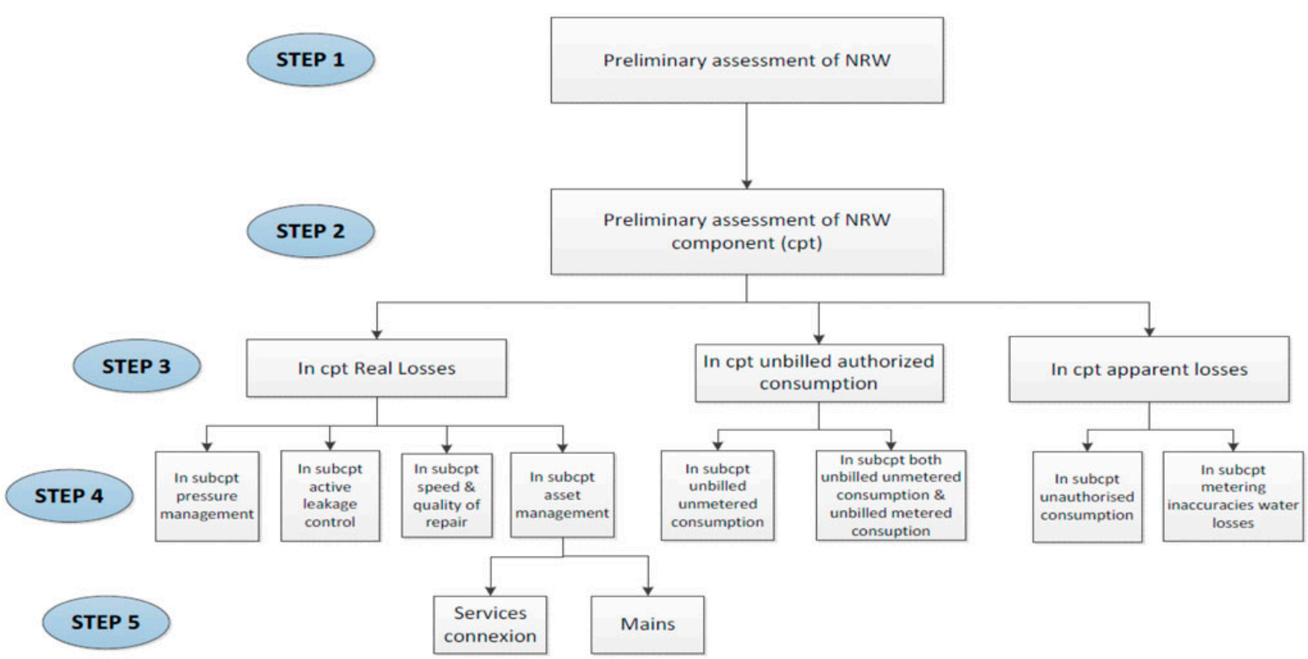
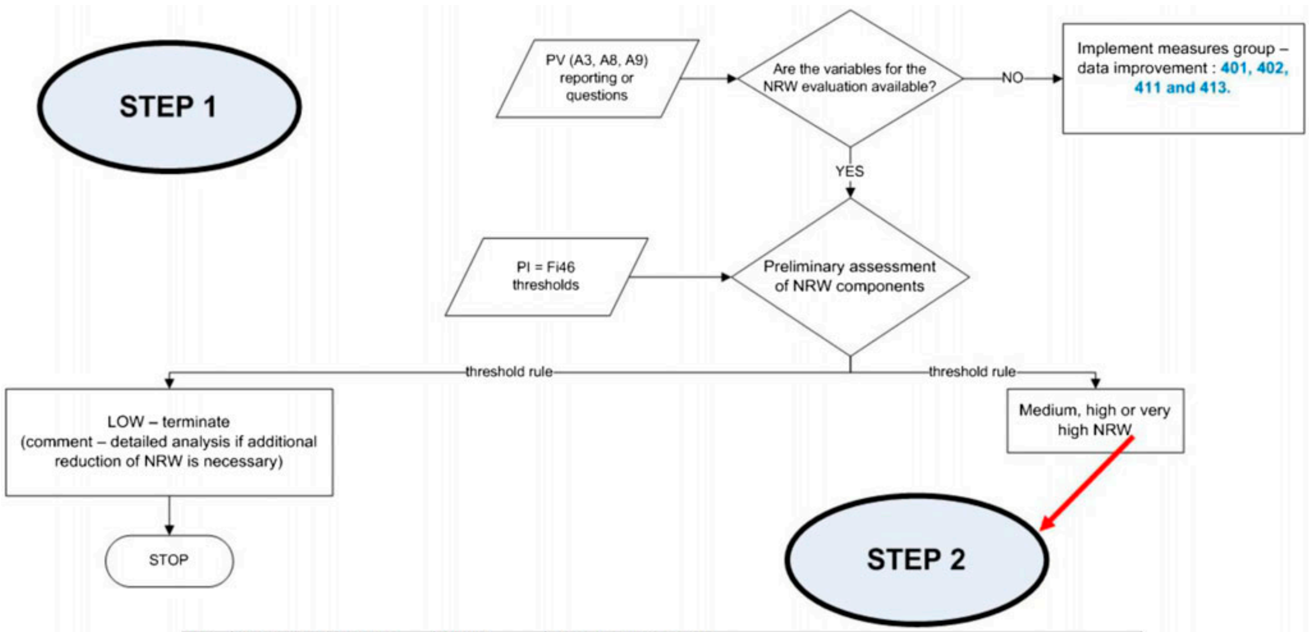


Fig. 4. The hierarchical tree in brief.



Strap m ID	Strategic approach to measures	OM ID	Operational measures
401	Improve bulk meter accuracy and knowledge	DH-MA01	Volumetric accuracy checked using a second meter
		RM-04	Calibration of water meters, managing inaccuracy of water meters, age of water meters
402	Improve customer meter accuracy and knowledge	DH -MA02	Monitoring water quality (the build-up in sediment affects the meter's accuracy)
		DH -MA03	Monitoring intermittent water supply (sudden large increase in pressure damage the meter's components)
		DH -MA04	Test of a representative sample of customer meters
		DSS-OM4	Calibration of water use metering network
		RM-28	Metering of revenue water
411	Implement standards and procedures	DH -MA05	Establishment of guidelines for WB volumes calculation
		DSS-DA5	Systematic control of billing records
		Ljub-4111	Permitting procedures for other constructions in the impact zones of the WSS infrastructure, also permitting procedures for the re-classification of
		Ljub-4112	Revision of the procedures for the construction and maintenance of the
		Ljub-4113	Planning details and standards for example Soil type mapping (stability, aggresive, geology, etc.)
		Ljub-4114	Construction details and standards i.e. construction under frost depth
		Ljub-4115	Interaction with other underground services for example development and operation of the central cadastre of underground infrastructure
		RM-14	Planning process standards
		RM-17	Constructed WSS commission process standards
		RM-31	Supply chain management (verification of suppliers – CE standards?, supply standards and reliability)
		RM-34	Permitting procedures for other constructions in the impact zones of the WSS infrastructure, also permitting procedures for the re-classification of
		RM-36	Document management and archives in the management company (archiving the documents on construction, service connections, permits etc.)
		RM-50	Development of programme of measures for the NRW reduction (documentation, evaluation, designs...)
413	Education of staff	Ljub-4131	Education of staff on operational procedures taking into consideration existing affirmated practices
		RM-45	HRM – company culture (every drop counts), permanent, targeted education of employees.
		RM-46	HRM – adequate staffing for different processes, adequate tools, equipment, education

Fig. 5. The decision tree.

benchmarking between the users; (7) NRW Reduction measures: the list of NRW reduction measures tackling different NRW components; (8) partner experience; (9) administration pages; and (10) classifications.

The DSS's inputs include the necessary variable values and the related context information, the PIs threshold values set by the water utilities, the DSS decision tree, and the Bayes theorem (Fig. 3(a)); in addition an NRW reduction measures database is connected to the tool. The DSS tool provides a list of proposed NRW measures that after being implemented result to new inputs for the DSS [14]. Fig. 3(b) presents the tool's components and flow chart.

The DSS tool has a self-learning property: it binds the data provided by the user (e.g. type of NRW measure taken; costs and timeframe; measure efficiency (in water volume and in €); reduction of NRW; and comments with the NRW reduction measures database.

The tool is based on a hierarchical tree, trying to address the actual cause of each NRW component (unbilled authorized consumption; apparent losses; and real losses) (Fig. 4) [14]. A fully detailed hierarchical tree has been designed and used. Then through a decision tree, answering a list of questions regarding the actual value of specific PIs compared to the related thresholds values, the user is guided (navigated) in the DSS tree and finally arrives in the proposed NRW reduction measures (Fig. 5) [14]. The latter are divided in strategic ones providing guidance; and operational ones. Fig. 6 provides an example, showing that an operational NRW measure to tackle high real losses and infrastructure leakage index values is to report the time needed to repair each failure, included in the "speed of repairs" strategic measure.

The classification and evaluation of the NRW reduction methods is performed using six criteria:

(1) "Importance": based on the measure's significance from 1 to 5 stars the amount of water saved rapidly increases.
(2) "Implementation Timeframe": based on the measures' implementation foreseen period—from 1 to 5 stars the time needed to implement the measure rapidly decreases (from more than two years, to less than a week).
(3) "Duration Effect": based on how long the effect of measure lasts—from 1 to 5 stars the duration of the impact rapidly increases (from less than a week, to more than two years).
(4) "Organizational Complexity": based on the Organizational Complexity required to implement the measure—from 1 to 5 stars the Organizational Complexity required rapidly decreases.
(5) "Constructive Measures": based on whether the measure requires constructive works or not—from 1 to 5 stars the need for constructive works rapidly decreases.
(6) "Cost Efficiency": based on how cost efficient each measure is –1 star means that the measure is of high costs and low efficiency, where 5 stars mean that the measure is of low cost and high efficiency.

The DSS operates according to the following: the user enters the WDS's variables values and the desired thresholds. Alternatively the user can enter the country-specific thresholds (if they are available already in the tool). The first step is the WB estimation and analysis (Fig. 7). Then using the threshold values the user is navigated in the system according to which NRW component value is higher than the relative threshold one (Fig. 8). Finally the user gets a list of NRW reduction measures to tackle the WDS's NRW cause (Fig. 9). Additionally when some variable values are not known, the DSS tool provides measures to estimate the specific PIs and/or measure the variable values. These NRW measures can be prioritized using the six criteria mentioned above, depending on the user's needs. The DSS tool is currently available is three languages (English, Greek, and Slovenian) and

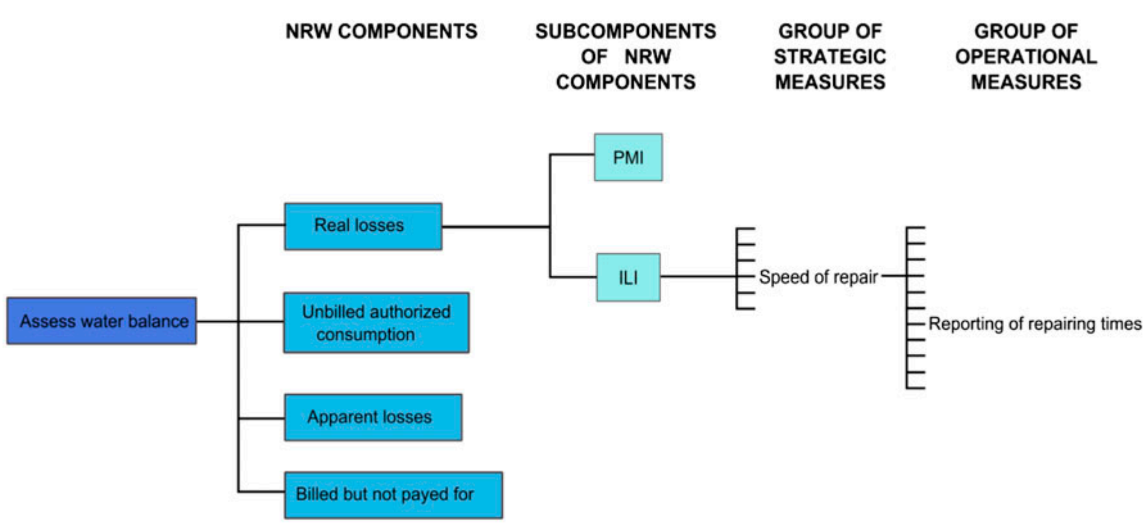


Fig. 6. Example of the DSS decision tree.

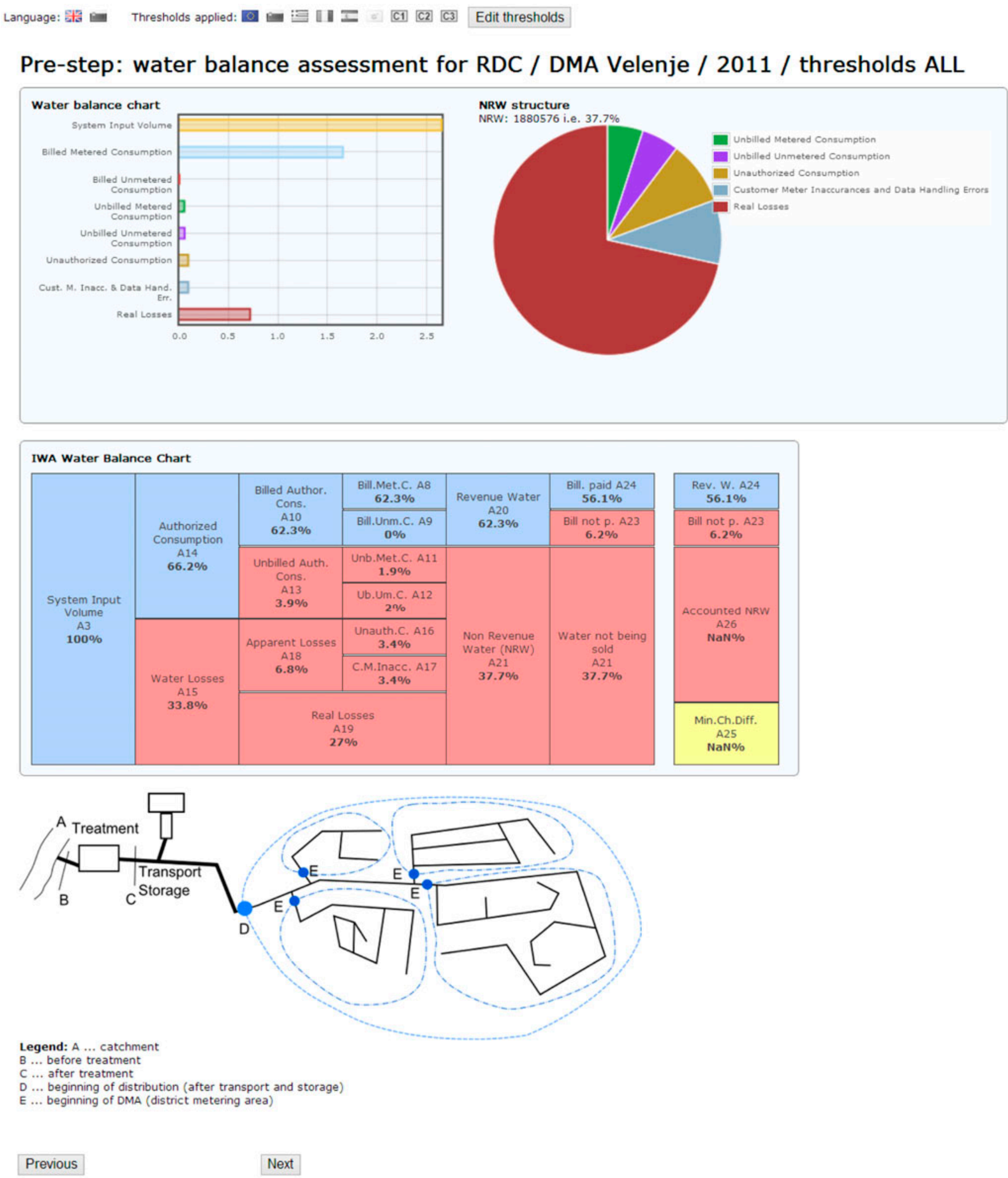


Fig. 7. WB analysis (image from the DSS).

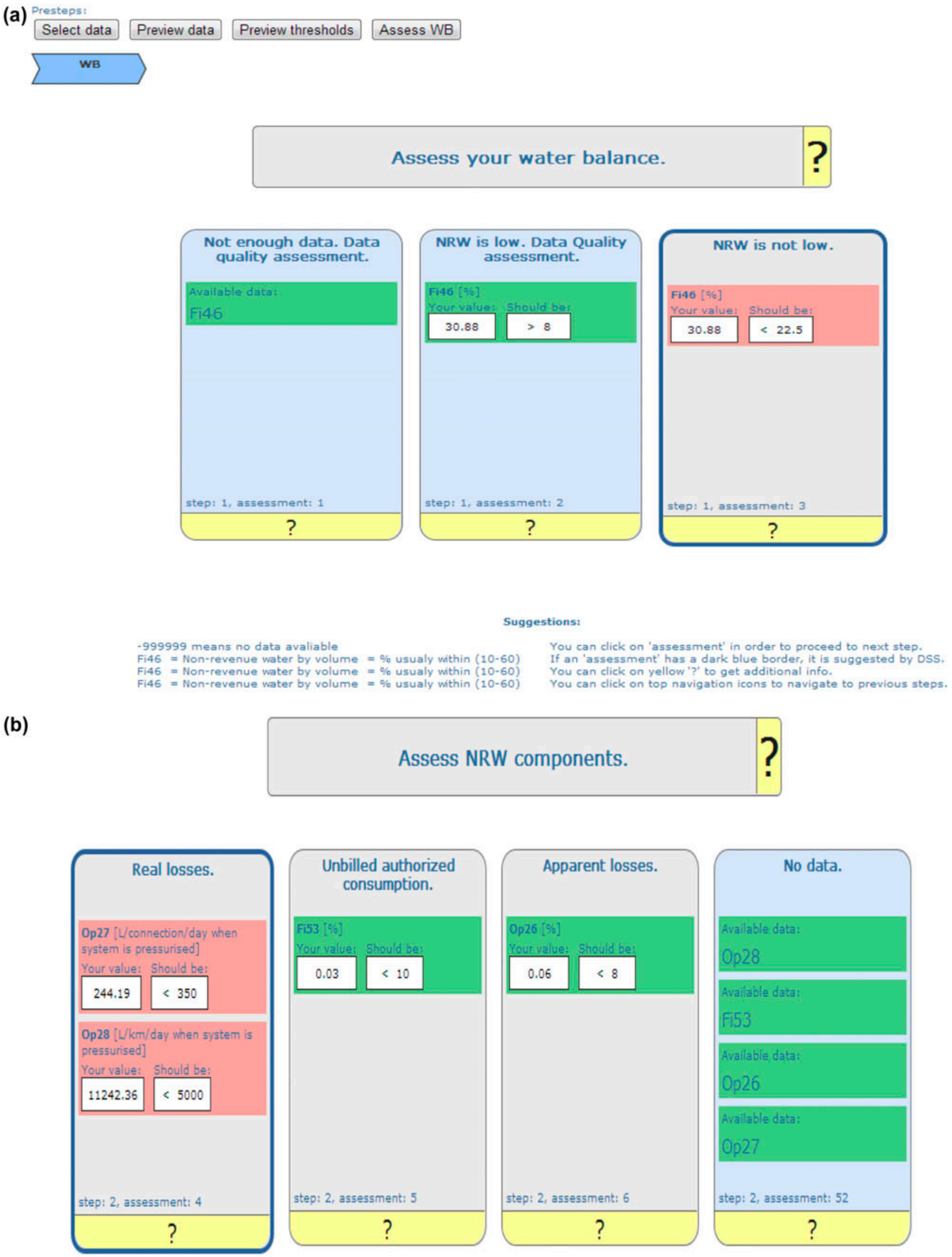
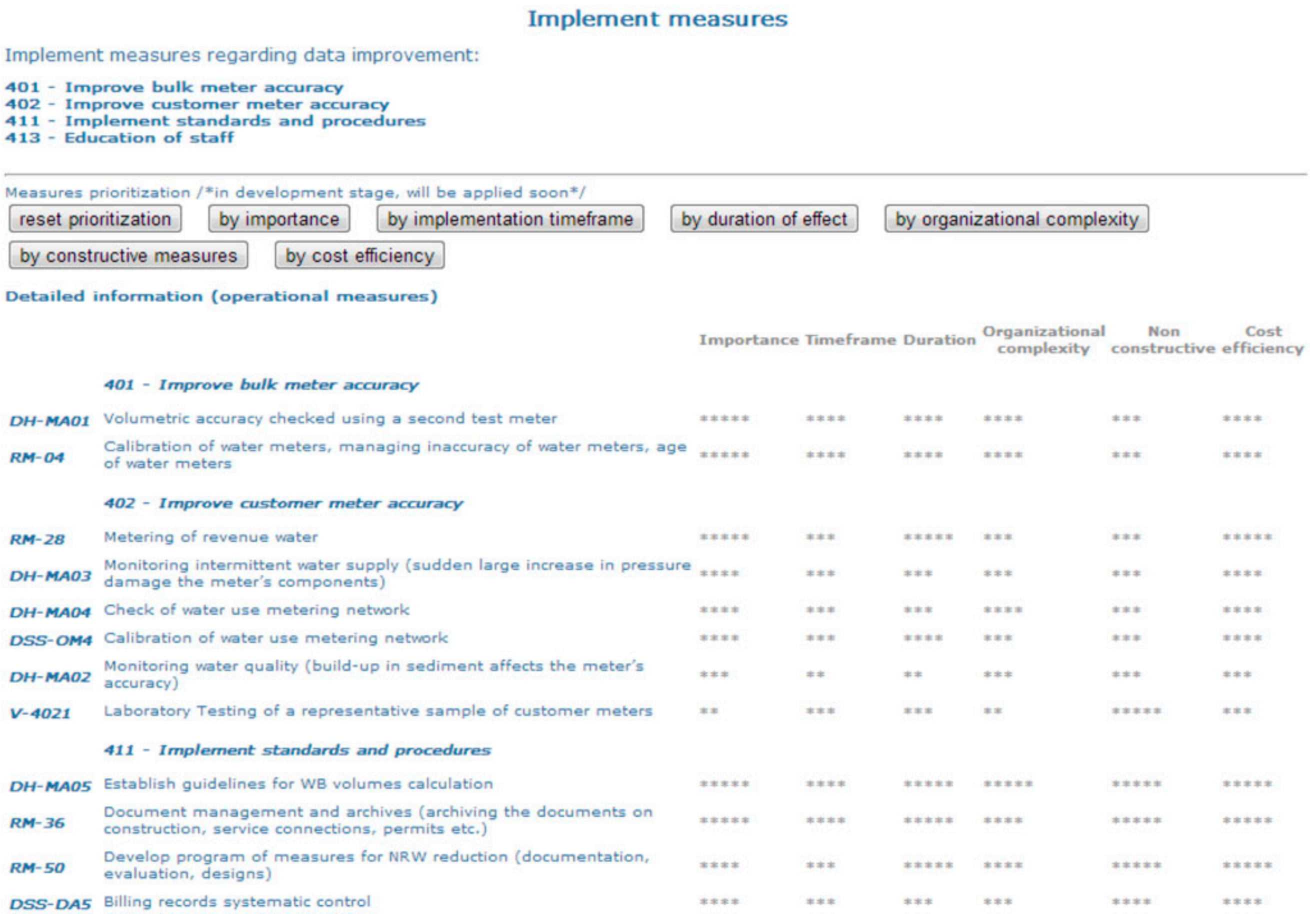


Fig. 8. (a) WB and (b) NRW components assessment (images from the DSS).



Implement measures

Implement measures regarding data improvement:

401 - Improve bulk meter accuracy
402 - Improve customer meter accuracy
411 - Implement standards and procedures
413 - Education of staff

Measures prioritization /*in development stage, will be applied soon*/

reset prioritization | by importance | by implementation timeframe | by duration of effect | by organizational complexity | by constructive measures | by cost efficiency

Detailed information (operational measures)

		Importance	Timeframe	Duration	Organizational complexity	Non constructive	Cost efficiency
	401 - Improve bulk meter accuracy						
DH-MA01	Volumetric accuracy checked using a second test meter	*****	****	****	****	***	****
RM-04	Calibration of water meters, managing inaccuracy of water meters, age of water meters	*****	****	****	****	***	****
	402 - Improve customer meter accuracy						
RM-28	Metering of revenue water	*****	***	*****	***	***	*****
DH-MA03	Monitoring intermittent water supply (sudden large increase in pressure damage the meter's components)	****	***	***	***	***	****
DH-MA04	Check of water use metering network	****	***	***	****	***	****
DSS-OM4	Calibration of water use metering network	****	***	****	***	***	****
DH-MA02	Monitoring water quality (build-up in sediment affects the meter's accuracy)	***	**	**	***	***	***
V-4021	Laboratory Testing of a representative sample of customer meters	**	***	***	**	*****	***
	411 - Implement standards and procedures						
DH-MA05	Establish guidelines for WB volumes calculation	*****	****	*****	*****	*****	*****
RM-36	Document management and archives (archiving the documents on construction, service connections, permits etc.)	*****	****	*****	****	*****	*****
RM-50	Develop program of measures for NRW reduction (documentation, evaluation, designs)	****	***	*****	****	*****	*****
DSS-DA5	Billing records systematic control	****	***	***	***	****	****

Fig. 9. NRW proposed strategic and operational measures (image from the DSS).

the thresholds already applied in the system are general ones (estimation made for European Union); Slovene ones (estimation for Slovenian average); Greek ones (case-specific); and French ones (case-specific).

5. Conclusions

The present paper aims at presenting the implementation of the WATERLOSS project and its critical success factors. WATERLOSS project implementation process followed 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 [8]; (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. As NRW is globally acknowledged as one of the most important (financial and environmental) problems water utilities are facing today, an integrated methodology was necessary to tackle it, especially in countries such as the Mediterranean ones facing water scarcity conditions. The first critical parameter taken into consideration was the partnership scheme development. Different authorities with different scientific and technical background from different administrative levels participated as partners. Universities providing the state-of-the-art knowledge and research, water utilities providing their priceless experience in the field, and local and regional authorities which could implement the project's results horizontally, were the project partners. The level of expertise was also different between the partners and finally know-how transfer was achieved. Six Mediterranean countries were involved in the project: Spain, France, Italy, Slovenia, Greece, and Cyprus. Then, the determination of the strategic directions of the project constituted the second critical success factor. These strategic directions included the methodology formation, the common language adoption, and finally the production of the DSS tool. International literature and well acknowledged tools were adopted and adjusted in the Mediterranean conditions, such as the second modified IWA WB [8]; the IWA PIs [11]; and the NRW reduction measures. A user-friendly DSS tool was finally developed to tackle successfully the important NRW problem. The successful implementation of the WATERLOSS project demonstrates that when the approach is targeted, the results are effective solutions.

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