WADI

INNOVATIVE AIRBORNE WATER LEAK DETECTION SURVEILLANCE SERVICE

www.waditech.eu

Foreword

The WADI project started in October 2016 with the aim of addressing the **Horizon 2020 challenge of building a water and energy efficient and climate change resilient society**.

This challenge was addressed by focusing on **improving leak management: this could bring about significant.** environmental benefits since, in some places in Europe, as much as 50% of water resources are being lost before they reach the tap. Furthermore, problems with leakages are not only related to the efficiency of the network but also to water quality. For this reason, detection of leakages in large diameter mains, which represent a high share of the total water losses, is key but it has been poorly addressed due to the challenges it faces (less frequent access to pipe, high frequency noise is quickly attenuated, multiple travel paths, etc.).

In response to this overarching objective, WADI developed an **airborne water leak detection surveillance service** to provide water utilities with adequate information on leaks in water infrastructure outside urban areas, thus enabling prompt and cost-effective repairs.

The project idea relies on the innovative concept of coupling and optimising off-the-shelf optical remote sensing devices and their application on two complementary aerial platforms - manned and unmanned - used for distinctive purposes in infrastructure performance observation, i.e.: long distance and strategic infrastructure monitoring and difficult and/or dangerous areas observation. WADI technology was also applied in two demonstration cases in France (Provence region) and Portugal (Alqueva).

1. Data about environmental and economic costs of the present water leaks situation

Data about environmental and economic costs of the present water leaks situation

The European water sector is a major economic player (1% of GDP) with an annual turnover in the EU of about €125 billion and is a global leader in terms of service provision and technology development with a global market share of over 30% and a huge growth potential (global annual water sector growth of 6%) aiming at €240 billion turnover in 2020. Considering these economic figures, it is also expected that any efforts to conserve the maximum amount of water (just like energy efficiency at industrial facilities) are required.

Main issues related to water leaks in water distribution systems

In some parts of Europe, water loss caused by leaks can exceed 50% of total supplies. Considering an average power of 1 kWh/m^3 for water treatment and 0.4 kWh/m^3 for pumping, electrical consumption could lead to an increase (in the worst scenario) of 0.7 kWh/m^3 supplied.

Regarding economic costs, this would consider a price increase up to (EU-28 prices, 0.0797 €/kWh) 0,044 €/m^3. In a framework of applying water leaks detection technologies to 5% of the facilities (225 Mm^3 water leaked/year), this could imply (when water leaks exist) up to €25 M/year. Regarding CO_2 emissions, just based on electricity consumption, this could imply a CO_2 increase per year of (0,528 kgCO_2/kWh, EU-28) 166.5 Million kgCO_2.

Technical issues	Pipe failures
	Utility device failures
Environmental issues	Water contamination
	Additional power consumption for water extraction, distribution and treatment
	Additional chemical consumption
	Freshwater overexploitation and depletion
Management issues	Lack of reliable supply
	Farmers finding alternative sources for water supply
Economic issues	Increasing operational costs
	Fewer commercial products sold
	Price increases

2. Leak detections systems market analysis

Leak detections systems market analysis

As water loss greatly impacts the economy and the environment, a number of leak detection solutions are available on the market. These solutions naturally represent the potential competition of WADI's technology and are organised into two main categories: the **ground methods for detection of water leaks** from large transmission mains and **satellite issued products**, able to provide mapping, cartography and soil/vegetation identification.

An analysis of technical state-of-the-art aspects of detection of water leaks from large transmission mains was conducted.

The main **Ground Leak Detection** methods applicable to large water mains are: Acoustic methods, Gas-injection methods, Ground Penetrating Radar, and Inline methods. Each method has pros and cons, with the common denominator of not being feasible in difficult-to-access environments. Inline methods seem to be the best option for long and large water mains, in terms of accuracy and potential applicability, but have the limitation of being extremely expensive.

All these techniques based on acoustic methods have been used since many years but they have constraints in terms of cost, time consuming and efficiency if applied in large areas with few or difficult access points or for large water mains.

A non-invasive leak detection technology based on **Satellite Aperture Radar (SAR)** has reached the market in recent years. It is based on ground-penetrating electromagnetic waves sequentially transmitted from a radar mounted on the satellite. The received data are then processed to detect the "dielectric signature" of leaked out water.

For analysis of large areas this technology is relatively cheap, though its detection rate is still not as satisfactory as that of traditional ground leak detection methods.

2. Leak detections systems market analysis

Focus on weak points of existing leak detection systems

Despite greater understanding over the past 15 years of the economic management of real losses on water distribution systems, **little information is available on the true extent of transmission mains leakage**, and how best to quantify and manage it.

Leakage detection in transportation mains is generally more problematic than leakage detection in distribution pipes, due to a number of technical drawbacks of the current methods and to the high cost of detection, location, and repair, which can lead utilities to simply exclude transmission mains from leak detection programs. Below some of the most relevant drawbacks of the currently available methods for leak detection are presented:

Ground methods

All different ground techniques are generally **unfeasible in difficult-to-access environments**.

- **a.** Acoustic methods – **Highly labour and cost-intensive**, since sound waves attenuate more quickly as diameters increase and access points need to be very close together;
- **b.** Gas-injection methods – Although very accurate, due to high gas prices this method is particularly **cost-intensive and suitable for small diameter pipes**;
- **c.** Ground Penetrating Radar – Not applicable **on long pipes** and involves complex **data interpretation**;
- **d.** Inline methods – particularly cost-intensive and suitable for small and non-complex networks;

Satellite imagery

The main drawback is the lack of adequate precision that determines an unsatisfactory detection rate, due to the weak signature of the leaks compared to natural and artificial elements and the coarse resolution of the images relative to the size of the leaks investigated.

How WADI's system can overcome the common weak points of existing solutions on the market

As confirmed by the feedback gathered from end-users in the course of the WADI idea elaboration, there is a strong need for developing transmission mains surveillance methods that will dramatically, but also cost-effectively, speed up pipeline monitoring.

The proposed WADI technology and service meets all these expectations and addresses the most common drawbacks of existing methods:

1. Availability on all kind of terrains – WADI's technology, being airborne, is particulary apt to reach inaccessible or secluded locations;
2. Labour- and time-effective – WADI offers high operational efficiency (50 to 90 km/h) depending on the use of un-manned or manned aircraft;
3. Cost-effective – The cost of WADI's solutions is considerably inferior to other methods, being between 50 and 200 €/km;
4. Suitable for all diameter pipes and complex networks – Using optical means, the complexity or diameter of pipes does not influence WADI's accuracy;
5. Scalable resolution – WADI's location accuracy varies from few to 1m and 0.5-1m (depending on the equipment and altitude).

3. Multispectral approach for detection of losses in water transmission systems

Detecting soil moisture

Water loss in the transmission networks is a perennial problem which challenges the efficiency of water transmission systems and represents a waste of limited natural resources. Currently, active leakages in water distribution networks (WDN) are detected and located by ground sensing and monitoring techniques based on the measurement of pressure differences, acoustic sounding and ground penetrating radar.
These ground methods become difficult or inadequate for water transmission mains, especially out of urban areas, and for open canals. New efficient and cost-effective pipeline surveillance methods are required.

The H2020 project WADI (Water-tightness Airborne Detection Indicator) objective is to contribute to the reduction of losses in water transmission systems for water supply, irrigation, and hydropower. For this purpose, it aims at **providing an efficient airborne surveillance system for leakage detection in long range water transmission mains outside urban areas**.

The project relies on an innovative concept of coupling and optimizing off-the-shelf optical remote sensing devices and their application on two complementary aerial platforms - manned and unmanned aimed at detecting anomalies in ground moisture, vegetation water content and thermal inertia that could lead to the conclusion that there is a leak. These platforms are used for distinctive purposes in infrastructure performance observation, i.e.: long distance and strategic infrastructure monitoring, and the observation of difficult/dangerous areas.

Water leaks lead to increased soil moisture by diffusion and capillarity which can reach the upper surface depending on the pipe damage severity. In a vegetation context, water leaks increase the water content in the plants and the vegetation vigour.

Measuring the surface temperature with an infrared camera to detect increased water content is a well-known method. Both evaporation, in the case of bare soils, and transpiration in plant life contribute to cooling down surface. However, for a given variation in soil water content, the variation in temperature is not the same over bare soil and over vegetated soil. As a consequence, **the most competing aspect is to infer soil moisture from a mixed pixel, i.e. when the sensed infrared radiation is a mixture of radiation coming from bare soil and from vegetation**.

The resulting ambiguity can be removed by introducing a **temperature-dependent humidity scale which varies according to the vegetation cover fraction**.
The vegetation cover fraction can be inferred from a series of vegetation indexes (VI) among them the NDVI, which is evaluated from the red and near infrared (NIR) signals provided by an additional camera.
Combining temperature and a VI like NDVI or OSAVI leads to the so-called Triangle (or Trapezoïd) Method. This method consists first of all in building a temperature-VI scatterplot from all the pixels belonging to an area exhibiting great diversity in terms of vegetation cover fraction and water content. The name of the method is related to the (roughly) triangular shape of the obtained scatterplot.
The vertex of the triangle is often truncated, giving a trapezoidal shape.
The scatterplot allows inferring a water index for each point or pixel by evaluating its relative position with respect to the dry edge and the wet edge of the triangle/trapezoid.

3. Multispectral approach for detection of losses in water transmission systems

Scatterplot of temperature and vegetation index data obtained over a broad area

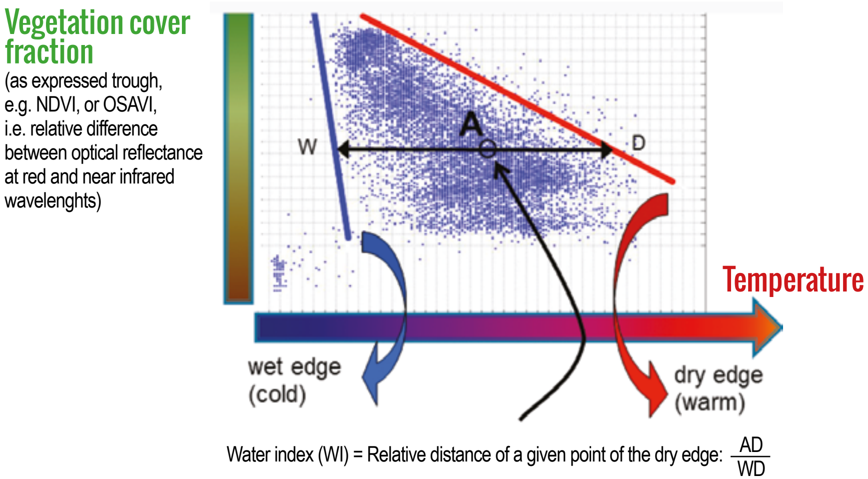


Figure 1 : triangle (or trapezoid) method

Method

The multispectral approach was gradually developed during the project in three stages:

1 Assessment of the optimal optical wavelengths during trials performed over SCP network (France) by using an aerial platform equipped with two hyperspectral cameras and an infrared camera.

2 Selection, integration of WADI sensor systems on both manned and unmanned platforms, and validation over the SCP network.

3 Validation in operational conditions over EDIA water transportation means (Portugal) of the WADI system (sensors, onboard and at-ground data processing) intended for the detection of water leaks.

The first airborne remote sensing campaign was conducted during February, April and July 2017 over several areas covering the water network infrastructure of SCP to evaluate the applicability of the temperature/Vegetation Index space (i.e. the triangle/trapezoid method) in a water leak detection method based on airborne data.

The campaigns were conducted with ONERA's BUSARD aerial platform equipped with two hyperspectral Hyspex VNIR and SWIR cameras and a microbolometer infrared camera (FLIR A325 or FLIR A655sc 7.5-12µm). The best results were obtained by applying the triangle method while combining a thermal infrared image and a vegetation index image based on a visible image (red) and a NIR image.

Figure 2 : Busard platform

An airborne and UAV remote sensing campaign was carried out in October 2018 over several areas belonging to the water network infrastructure of SCP to validate the choice of the onboard instrumentation for both types of platforms (manned & unmanned) associated with the multispectral approach (Triangle method)

3. Multispectral approach for detection of losses in water transmission systems

Technical features	Hyspex VNIR	Hyspex SWIR	FLIR A325 pag. 03	FLIR A655sc pag. 04
Acquisition mode	Push-broom	Push-broom	Snapshot	Snapshot
Number of pixels	1600	320	320x240	640x480
Waveband	0.4-1.0 mm	1.0-2.5 mm	8-14 mm	8-14 mm
Number of spectral bands	160	256	1	1
Spectral resolution	3.7 nm	6 nm	-	-
Viewing geometry	Nadir-looking	Nadir-looking	Nadir-looking	Nadir-looking
Swath width @ 800 m (AGL)	239 m	194 m	355 x 266 m	355 x 266 m
Pitch on the ground @ 800 m	0.15 x 0.30 m	0.60 x 0.60 m	1.10 x 1.10 m	0.55 x 0.55 m

Figure 3 : Airborne & UAV platform equipped with WADI sensors system

A second airborne and UAV remote sensing campaign was performed to validate the WADI technique at different scales by means of a manned aircraft platform and an UAV with data acquired in May and September 2019 over an area belonging to EDIA company (Portugal) with artificial water leaks and natural water flows.

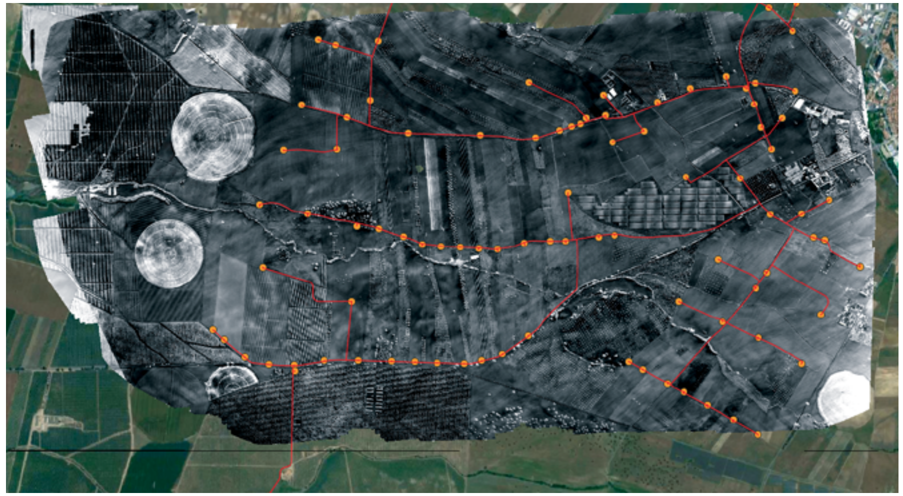


Figure 4 : EDIA network & Water index map (data processing result)

Results

The multispectral approach has been validated on the images of the EDIA sites in Portugal (Monte-Novo and Ferreira sites) where artificial leaks were introduced (a deep leak with a new secondary pipe connected with the existing pipe and a surface leak powered by a hydrant) by applying the triangle method fusing a thermal infrared image and a vegetation index based upon a visible image and a NIR image.
Additional work is now needed for speeding up the data processing and making safer the detection of anomalies related to water leaks in the contrasted water-index images.

How accurate is the WADI service?

The WADI service was next evaluated using a methodology named *Performance Matrix Analysis*. The purpose of this analysis is **to assess the ability of the proposed WADI technique to detect water leaks in a water supply infrastructure**, and determine which conditions are more favourable for its accurate application. This methodology can be thus summarized. The images collected during the UAV and MAV flights were processed and analysed, and potential leakage events were identified. Each event of detection was then classified as true positive (TP) /true negative (TN) /false positive (FP) /false negative (FN), for all events that occurred during the SCP (France) and EDIA (Portugal) flights.

A potential leak event is defined as a result of a flight in which aerial images were obtained, processed and analysed with success. An event may be characterized by the technology used (UAV/MAV), the network type (channel/buried pipe), the type of pipe material (concrete, metal, PEAD) as well as by the environmental conditions during or shortly before the flight. These environmental conditions include: soil type, vegetation type, soil humidity, soil temperature, irrigation presence and precipitation in the 10 days previous to the flight. The performance of the WADI system was analysed based on 60 events from all flight campaigns in France and Portugal.

The overall performance of the WADI system in detecting true events is approximately 50% (a significant number of events resulting from natural flows were classified as false positive; these events are due to the precipitation water retained in the soil or to water from the irrigation of neighbouring fields).

On the other hand, the global performance of the WADI system in detecting water in the soil is around 70%.

The type of technology has no impact on performance as the UAV and MAV platforms provide approximately the same numbers of true event classifications. The type of vegetation however has a major impact. Agricultural zones characterized by bare soils, crops (at the early stage of development) and mixed areas are the most adequate places where WADI technology has the greatest capacity for success in detecting leaks, while forested zones provide a poor performance (Figure 2). Results also suggest that in clay and sandy clay soils WADI service has the best performance, although silty clay soils perform otherwise.

Type of vegetation

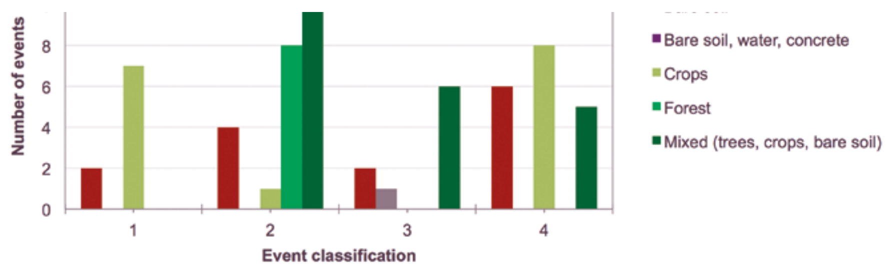


Figure 1. Relation between the type of vegetation and the event classification

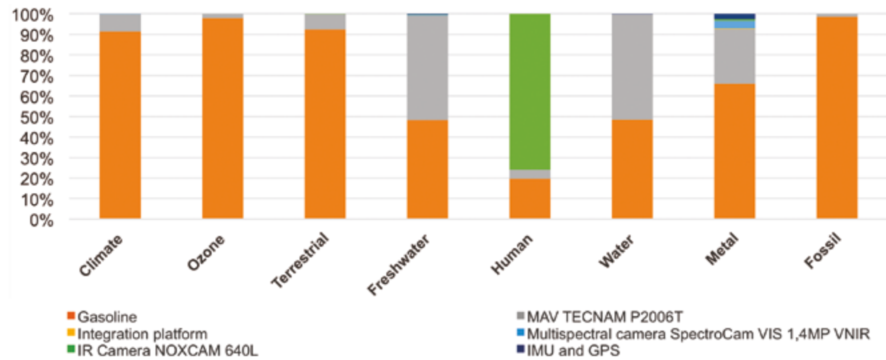
WADI's environmental and economic benefits

To ensure that WADI's techniques are environmentally sustainable, an Environmental and Economic Life Cycle Assessment was performed, in order to calculate its most relevant environmental impacts indicators, and to compare the results with a current existing mainstream technology such as acoustic methods.

Regarding the **Manned Aircraft Vehicle**, the carbon footprint of this unit is about 270,000 kg CO_2eq and the water footprint is 158,000 m^3.

The greatest contributor to most of the environmental categories is the impact associated with the fuel consumed during the aircraft flights.

Besides, it is very relevant the contribution of the plane manufacturing over some indicators such as freshwater eutrophication and water depletion, and the contribution of the IR camera over the human toxicity indicator.



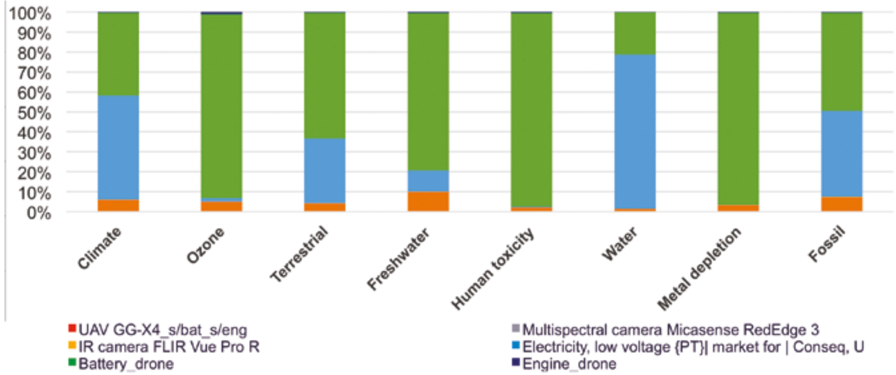
Relative environmental impact per indicator of the MAV WADI unit

Regarding the **Unmanned Aircraft Vehicle unit**, its carbon footprint is 545 kg CO_2eq and the water footprint is about 7,300 m^3.

The relative environmental impact of the UAV components, as well as the impacts of the consumption involved during the use stage are depicted in the figure below. The drone batteries have the greatest contribution in many environmental categories such as ozone depletion, human toxicity or metal depletion. This fact is mainly caused by the periodicity with which the batteries must be replaced along the lifetime of the drone.

On the other hand, the electricity consumption required to charge the batteries has the greatest impact in the climate change indicator and in the water and fossil fuel depletion indicators. In this case, it is very important to specify the electricity mix of which country is used because the results can significantly vary.

5. WADI's environmental and economic benefits



Relative environmental impact per indicator of the UAV WADI unit (Portuguese electricity mix)

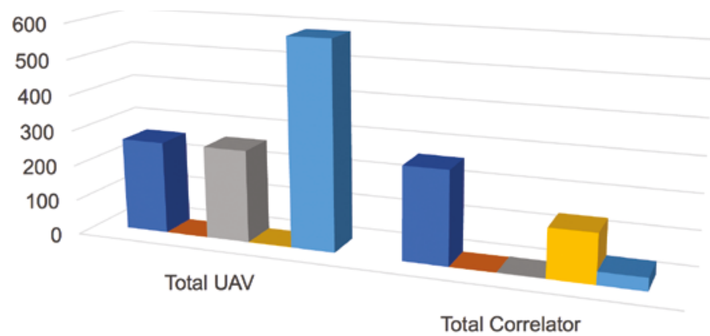
Considering the application potential of both technologies (MAV for large and UAV for detailed areas) the potential from the CO_2 emissions point of view, it was estimated that applying the WADI techniques to 5% of European water distribution systems could potentially reduce 166.5M kg of CO_2/year by reducing the energy consumption for the water supplying.

In comparison to the total carbon footprint associated with the MAV and UAV WADI units (270,471 kg CO_2 and 545 kg CO_2 respectively), the benefits are enormous.

WADI techniques were compared to acoustic detection systems for 5 relevant environmental indicators. Additionally, Acoustic Correlator were directly compared to UAV because the application is more similar than MAV systems.

Impact category	Unit	Total MAV	Total UAV	Total Correlator
Climate change	kg CO_2 eq	2,31E+04	261,75	263,42
Ozone depletion	kg CFC-11 eq	1,79E-03	3,76E-05	1,52E-04
Terrestrial acidification	kg SO_2 eq	109,84	261,75	1,45
Freshwater eutrophication	kg P eq	14,37	0,94	137,95
Human toxicity	kg 1,4-DB eq	2,50E+04	584,45	36,35

LCA results of WADI technologies and Acoustic Correlator



WADI's technology environmental services impact: Societal benefits

The application of WADI service was tested in two different demonstration areas: Region of MonteNovo (Alqueva, Portugal), and PACA Region (Provence, France). For these demonstration areas, a methodology applied for measuring environmental provisioning services due to water uses and the impact of water leaks presence and avoidance was used (CICES methodology) and translated into potential economic value.

In the case of Alqueva, the presence of water leaks provides no substantial advantage (no wild forest, no underground aquifers to be recharged etc). On the contrary, the identification of water leaks would lead to additional water resources (around 1.4 Mm^3/year) and a reduction in power consumption for pumping (6 GWh/year, 2,400 $TonCO_2eq$/year).

The direct consequence of identifying all the water leaks present in the area would be **an increase of economic margin for the water distribution company valuated in around €55.000/year**. Regarding the overall numbers for the region, the total amount of water distributed is around 27.2 Mm^3/year with an annual economic impact around €31.6 M/year.
In the case of PACA region, the three areas are totally different.

Relative environmental impact per indicator of the MAV WADI unit

		Cabardèle	Vauvenargues	Verdagne
Water consumption (m^3/y)	Crops irrigation	3,143,273	765,750	3,567,753
	Industrial + livestock	10,542	7,258	15,041
	Forest	0	0	3,005
	Domestic	1,101,571	53,655	613,200
	TOTAL	**4,255,385**	**826,662**	**4,198,998**
Economic impact (€/y)	Crops irrigation	14,226,888	981,575	23,796,658
	Industrial + livestock	729,126	732,257	1,385,888
	Forest	38,440	32,840	65,965
	Domestic	3,098,100	150,730	1,724,660
	TOTAL	**18,092,514**	**1,987,402**	**26,973,171**

Regarding the environmental impact of water leaks, in the three demo areas there are groundwater repositories, forest areas, wild flora/fauna, irrigation crops and human/industrial provision.

Regarding the water-forest nexus, there is no doubt about the symbiotic relation between them. Because of forests, water availability is multiplied, due to water retention (avoiding ground erosion that will lead to an increase in the economic impact in the area up to a 51%) and to an increase in the water rainfall. Additionally, higher water availability generates higher wild biodiversity. It is not easy to account for the economic impact related to water provisioning services in forest environments.

6. WADI's technology environmental services impact: Societal benefits

Woodlands and grassland forests (the ones present in Provence area) could represent an economic impact between €13 and €179/ha/year respectively. Water leaks that could provide a greater amount of water to forests that could increase their surface would lead to an indirect increase in the area's economic impact. Nevertheless, water transfer structures in Provence's area are not built under forests and only a small amount of water is dedicated to firefight purposes.

Another positive effect of water leaks when underground repositories are present is the **free groundwater repositories recharge and an improvement in their water quality**. Some studies dedicated to this effect quantify it between €6 to €8.8/m recharged. No information is available about the amount of water leaked that could be naturally derived into this effect, neither the amount of leaked water but, in all the three areas it is possible to find groundwater repositories, so this effect could be also beneficial.

However, water leaks **negatively impact the environment and the water distribution company's finances**. The indirect effects related can be identified based on the existence of water leaks: an increase in the total amount of energy for pumping water and an increase in the amount of chemicals used in water treatment plants for human water delivery.

Water savings for SCP based on water leak detection capacity of WADI service.

	Cabardèle	Vauvenargues	Verdagne
Water consumption (m^3/y)	4,255,385	826,662	4,198,998
Electricity consumption (kWh/y)	2,127,692	413,331	2,099,499
Chemical additives (€/y)	110,157 – 308,440	5,365 – 15,023	61,320 – 171,696
Potential water savings (m^3/y)	212,769	41,333	209,950
Electricity reduction (kWh/y)	106,384	20,666	104,975
Chemical savings (€/y)	21,277 – 59,575	4,133 – 11,573	20,995 – 58,786
Economic savings for SCP (€/y)	**31,639 – 75,894**	**6,146 – 14,743**	**31,220 – 74,890**
Electrical CO_2 savings (kgCO_2/y)	**14,255**	**2,770**	**14,067**

7. End-users' voices and lessons learnt

End-users' voices

SCP - Société du Canal de Provence

> **We are considering using WADI in the future**, after further improvements, perhaps in case of a bad efficiency in a hydraulic network, so **for specific situations**.

Mr. Christian Magnin,
Head of the Operating Direction

EDIA - Empresa De Desenvolvimento e Infra-Estruturas do Alqueva

> We are **overall satisfied with the testing conducted in our pilot**: the WADI service does detect water in the soil, although with a light percentage of false-positive to leaks. **With more accuracy, it could be employed in a more systematic way**.

Mr Jorge Vasquez
Administrator

Lessons learnt

After more than four years since its beginning, the WADI project has come a long way in the implementation of its technology and **is now showcasing a running prototype and an exploitation plan**.

Starting from the evaluation of the WADI's performance and from the contributions of the end-users, the project has learnt **a few important lessons** that will benefit its work in the last few months of activity and the exploitation path beyond the official end of the project.

On the technical side**, the performances of the technology will need to be enhanced**, especially on terrains with specific or abundant vegetation, while the **improvement of flight efficiency** will also be a priority in terms of the reduction of implementation costs for the final service.

From a more general point of view, during its lifetime, WADI faced challenges and shifts in the operational environment that frequently required adjusting its strategy and work plan. In this process, some key factors have been the continuous **dialogue with the involved end-users and stakeholders** together with the continuous **monitoring of the state of the art of technology and competition**, in order to maintain the final service as innovating and cutting-edge as it had been designed.

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