Water-tightness Airborne Detection Implementation

Document title: Report on state-of-the-art, end user requirements, demonstration scenarios and risk analysis

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Executive Summary

1 STATE-OF-THE-ART

1.1 Airborne Services Provision

Remotely Piloted Aircraft Systems (RPAS), have a great potential for developing different civil applications in a wide variety of sectors like pipeline inspection, where this technology is intended to complement others existing for leaking detection, and would be cost effective to manned operation in some cases (typically short distance applications).

Two different aerial platforms are available, i.e. manned and unmanned, typically used for distinctive purposes in infrastructure performance observation. The manned aircraft is being used in long-distance and important infrastructure monitoring, whereas the unmanned platform is used for surveying branched water networks with short conduits or in particular/sensitive areas i.e. those with a limited/difficult physical access, located in dangerous areas or requiring detailed closer monitoring upon earlier detection of anomalies during the aircraft missions.

1.2 Infrared and Multi-Spectral Sensors Application

The use of optical remote sensing data is nowadays recognized as a valuable tool for evaluation of Soil Moisture Content (which is used for instance in agronomy as an information on the hydric state of soil and its temporal variation). Several methods exist to estimate SMC from airborne TIR (Thermal Infrared) and Multi-Spectral/Hyperspectral measurements.

1.3 Ground Leak Detection Methods

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

1.4 Inventory of Satellite Issued Products

A non-invasive leak detection technology based on Satellite Aperture Radar (SAR) has reached the market in recent years. 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 END USERS' REQUIREMENTS FOR WADI TECHNIQUE

2.1 Service Users (Water Companies)

The requirements for the WADI technique from the water companies have been determined through the distribution of questionnaires to project partners and end-users committee members. The main expectations from this technique are related to its promising aptitude for fast analysis of large areas especially in difficult-to-access zones, requiring at the same time a low manpower input and cost.

The outcome of the data collection and processing exercise showed that: the precision of leak pinpointing (if used as a standalone tool not intended to complement other leak detection techniques) should be at least 5m and ideally lower than 1m; the required flight surveillance frequency should be at least 2-3 times per year and ideally more than 4 times per year; the processed data release should occur at least within 1 month and ideally within 1 week.

2.2 Airborne Surveillance Developers

The development of WADI's innovative technique and service will use ONERA's aerial platform called BUSARD. This platform is instrumented by two hyper-spectral imaging devices in one pod, and an IR imaging device in the second one. In order to be operated correctly and safely, this platform and its payload have to be managed taking into account some constraints and risks linked to the airborne measurement.

2.3 Airborne Service Providers

Aircrafts and drones are considered as vector to support the complex WADI airborne system. With a flight duration of 45 min, it means that in standard conditions the RPAS can be used to survey pipes of approximately 18 km length.

To be operated correctly and safely, aircrafts and drones have to be managed taking into account some constraints and risks like weather, energy available or payload form factor and mass.

3. WADI IMPLEMENTATION (OUTLINE)

3.1 Innovative Airborne Remote Sensing Adapted to WADI

The WADI's innovative concept relies on coupling and optimizing off-the-shelf remote sensing devices and their application on two complementary aerial platforms (manned and unmanned). This concept requires determining the optimized wavelength for water leak detection and selecting, purchasing and integrating the devices in the WADI airborne prototype. The second stage of the concept is to adapt the two methods "*Reflection Variation*" and "*Triangle Methods*" for a smart data processing.

3.2 Principle of Scenario Definition and Outline Mission Plan for the Demonstration

As in project management, the success of a mission depends a lot on the level of preparation: few details can stop the action for several days or weeks. Therefore, it is important to pay attention to each of them and list them as soon as possible.

WADI will consider two different sites to experiment the leak detection system: France (SCP infrastructure) for the validation demonstration, and Portugal (EDIA infrastructure) for the operational demonstration.

The RPAS equipment employed in the project (fixed wing platform), is designed to perform fully automatic flights in a specified study area which cannot be left without authorization. Before the flight, the study area is covered by waypoints and several check procedures are implemented; risk analyses are established in the checklists of the RPAS, which specify the entire procedure step by step.

3.3 Multidimensional Risk Analysis

WADI project will have to manage a range of multidisciplinary issues: technical risks, issues related to privacy of people, legislative aspects, and regulations concerning the use of aerial technology.

WADI project is challenging different operational restrictions and diverging national standards from countries like France and Portugal, so all these restrictions are studied and taken into account from the very beginning of the project.

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List of Acronyms

BLOS	Beyond Line-Of-Sight
CLC	Corine Land Cover
EASA	European Aviation Safety Agency
EU	European Union
GISCO	European Commission geographical information system
GNSS	Global Navigation Satellite System
GPR	Ground Penetrating Radar
ISER	Inverse Soil semi-Empirical Reflectance model
MAV	Manned Aerial Vehicle
NSMI	Normalized Soil Moisture Index
ppm	part per million
RMSE	Root-mean-square deviation
RPAS	Remotely Piloted Aircraft Systems (drones)
SAR	Satellite Aperture Radar
SASI	Shortwave Angle Slope Index
SMC	Soil Moisture Content
SMGM	Soil Moisture Gaussian Model
SWIR	Short Wavelength InfraRed
TIR	Thermal infrared
UAV	Unmanned Aerial Vehicle
WISOIL	Water Index SOIL
WP*n*	Work Package *n*

Foreword

WADI is a H2020 funded project (Grant Agreement No. 689239) aimed to develop an airborne water leak detection surveillance service in water transportation infrastructures. The project relies on 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.

The current deliverable D2.1 "*Report on state-of-the-art, end user requirements, demonstration scenarios and risk analysis*" belongs to Work Package 2 viz. "*End-user requirements and mission plan*", whose primary aim is to define requirements, possible constraints, corresponding mission plan and preliminary trial scenarios for airborne platform application in detection of water leaks from large transmission mains.

The WP includes a multidimensional risk analysis, comprising not only WADI's technical issues, but also operational application aspects, especially concerning legislative and ethical dimensions in order to assure the robustness and wide use of the project technology. In addition, WP2 provides an inventory of technology's potential application in other fields.

The results of WP2 will serve as a basis for the adaptation, integration, and assessment of the proposed innovative WADI technique as well as its subsequent validation and demonstration in project pilot sites (i.e. WP3 and WP5 and 6, respectively).

Deliverable D2.1 specifically refers to the outcomes of Task 2.1, 2.2 and 2.3, as detailed below.

- Task 2.1 *State-of-the-art* looked into the state-of-the-art in: (a) airborne service provision and related, recently completed and ongoing EU-funded projects; (b) infrared and multi-spectral sensors application; and (c) ground leak detection methods. The task focused on the analysis of technical state-of-the-art aspects such as range of application, specifications, precision of leak pinpointing, potential limitations etc. It also comprised the inventory of satellite issued products, able to provide mapping, cartography and soil/vegetation identification in the test areas as well as other possible applications.
- Task 2.2 *End user requirements* determined the preliminary requirements for the WADI technique from both service users (water companies), airborne surveillance developers and service providers, whose needs have been scaled from a minimum acceptable to an ideal level. Specifically, water companies' requirements have been determined by: (a) The nature of required information and the way of its presentation for decision-making (i.e. leak magnitude, area map and pictures, leak history etc.) as well as the level and accuracy of expected parameters; (b) The definition of required flight surveillance frequency and the time in which processed data should be made available. Whereas airborne surveillance developers and

service provider needs have been referred to: (a) Constraints imposed by airborne instrumentation (e.g. dimension and weight, energy consumption); (b) Suitability to work under aeronautical stress conditions (i.e. vibration, acceleration, heat, power supply); (c) Compatibility of sensor data with an on-board exploitation, flight range (aircraft/UAV possible altitude and speed); (d) Weather conditions acceptable for WADI's two flying platforms.

The requirements for the WADI technique were determined through the distribution of questionnaires to the project end-users directly involved in the project and will be updated along with the project dissemination and communication activities targeted to the relevant stakeholders. In order to contribute to the increase of WADI's potential for a significant technological impact, the possibilities to extend the service to other related fields and applications were also investigated.

- Task 2.3 *Definition of demonstration scenarios and risk analysis* will provide an outlook into the forthcoming implementation, verification and demonstration activities: adaptation and integration of WADI's innovative airborne remote sensing (WP3) for the demonstration in the project's pilot sites (WP5 and WP6), based on the determination of user requirements and identification of potential technical constraints. Moreover, a detailed risk analysis from the perspective of both demos implementation and airborne water leak detection service provision was conducted. The scope of such assessment has been multidimensional and included such aspects as: technical (concerning the WADI technique but also data reliability), legislative (particularly with respect to flight regulation in France and Portugal) and ethical (especially regarding data protection).

The report's preparation has been coordinated by SGI, with key content inputs from ONERA, NTGS, AM, GG and TLEX and with active collaboration from other EDIA and SCP and End Users Committee members.

1 State-of-the-art

WADI develops an airborne water leak detection surveillance service in water transportation infrastructures. The project relies on 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.

This section focuses on the analysis of technical state-of-the-art aspects of airborne service provision, infrared & multi-spectral sensors application, and ground methods for detection of water leaks from large transmission mains. It also comprises an inventory of satellite issued products, able to provide mapping, cartography and soil/vegetation identification in the test areas, as well as other possible applications.

1.1 Airborne services provision

1.1.1 Focus on Manned aircraft services

Airborne services are mainly used for surveillance and detection mission. There are many fields requiring these services and the most common are for safety and security at the government level (borders patrol, maritime watch, Search & Rescue missions). Aircrafts and helicopters used for these missions require strong capability in terms of useful load, cruise speed, flight range and high stress operating conditions.

Besides governmental missions, some big industrial infrastructure and environmental situation also require surveillance and detection missions. Railway, gas & petroleum pipeline networks which require periodic surveillance are the most common markets. Those missions do not require aircrafts with strong capability because the flight plan is fixed and it does not have to change. This allows to significantly reduce the operational costs.

Nowadays these industrial surveillance missions do not require technologic equipment such as cameras and sensors, as surveillance and detection is made by an observer who is part of the crew. Nevertheless, this operational process is changing thanks to the technological progress. Formerly, high quality sensors and camera were used only by governmental institution due to their price and their big size which could be integrated only on big planes. Recently, companies like Air Marine have been developing new systems to facilitate the onboard integration of high quality sensors, trying to reduce the operational costs, improve the quality of surveillance and thus potentially reach new markets.

Air Marine started to develop the Airmon (Air Monitoring) console system in 2010. The main objective of this equipment was to integrate in a four seats aircraft the following components, without having to make the certification process each time one of the component is changed:

- One gyrostabilized mount
- Up to two sensors
- One onboard computer
- Dual display 21,5"

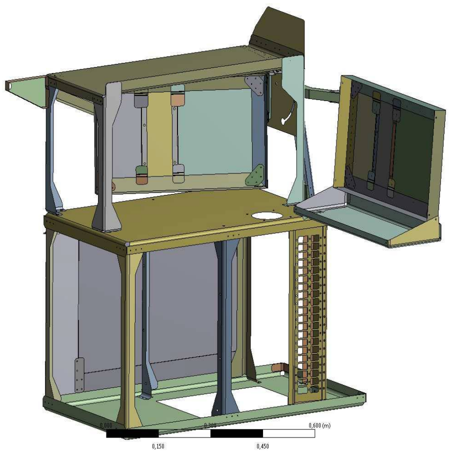

Figure 1-1 Overview of Airmon console

For the WADI project, Air Marine will use the Tecnam P2006T aircraft to accommodate the Airmon Console in which the specified sensors will be set up. A two people crew will operate the aircraft and the WADI system for test and demo flights.

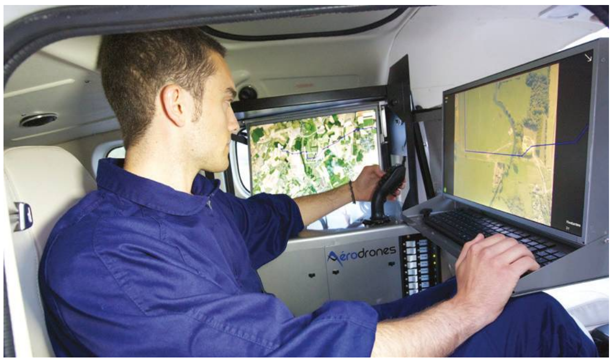

Figure 1-2 Operation with Airmon

1.1.2 Focus on RPAS services

The current start of the art of airborne services of Remotely Piloted Aircraft Systems (RPAS), commonly called drones, is growing quickly as soon as each country can offer a legal status for the civil operations of these aircrafts. RPAS offer huge potential for developing innovative civil applications in a wide variety of sectors that benefit European society, and will contribute to create new businesses and jobs.

However, the current regulatory system for RPAS based on fragmented rules for ad hoc operational authorizations is an administrative bottleneck and hampers the development of the European RPAS market. National authorizations do not benefit from mutual recognition and do not allow for European wide activities, either to produce or to operate

RPAS. The regulatory framework should reflect the wide variety of aircraft and operations, keep rules proportionate to the potential risk and contain the administrative burden for industry and for the supervisory authorities. The regulatory framework would first focus on areas where technologies are mature and where there is sufficient confidence. Regulatory measures will be introduced step by step and more complex RPAS operations will be progressively permitted. Wherever certificates or licenses need to be issued, European rules will effectively deliver a system of mutual recognition within the single market for RPAS manufacturers, operators and other organisations.

Based on its strategy to support the progressive development of the RPAS airborne services provision in Europe, the European Commission adopted the proposal for the revision of EASA Basic Regulation 216/2008 on 8 December 2015. The proposal covers the necessary elements to enable the development of European safety rules for RPAS. It also proposes an extension of EU regulation to cover RPAS of all sizes, including RPAS below 150 kg, which today are regulated at national level.

In parallel, the European Aviation Safety Agency (EASA) has published a first draft of Commission implementing rules (‘Prototype’ Commission Regulation on Unmanned Aircraft Operations and its Explanatory Note) to provide a clearer idea of what could be a European regulation and further engage with stakeholders. These 'prototype' rules are building on the Technical Opinion on the operation of RPAS published in December 2015, the related public consultation, based on a Concept of Operations for RPAS and a Proposal to create common rules for operating RPAS in Europe (A-NPA 2015-10) issued earlier in 2015.

In spite of living in constant updates of RPAS regulations for civil applications, they are already being used for civil services provision and are expected to increasingly influence our daily lives. Just as the internet technology in the early nineties gave rise to many different applications, RPAS technologies are leading now the development of a wide variety of different services, especially if combined with other technologies, such as precision positioning thanks to Galileo, or to support other technologies, such as telecommunications in disaster relief situations or in dynamically increasing network capacity. There is a wide range of areas where RPAS can compete and fill some niches of the manned aircraft services, especially in the market for non-military applications that is much larger than the defence sector.

RPAS services are currently provided in different sectors such as security applications, agriculture, television & movie industry, and aerial services such as inspections of pipelines, railway lines or electric lines. RPAS will also become integrated in transport and logistics chains. Finally, there are more innovative sectors, such as energy provision or satellite coverage where RPAS operations may enable new methods of production and delivery. In the longer term, RPAS technology may not only enable new applications but also transform air transport itself, as technologies steadily take over more and more tasks from humans also on large aircraft. RPAS thus carry the promise of a disruptive technology, opening up previously impractical unavailable or uneconomical aerial applications and replacing existing services at a dramatically lower cost.

The world market is forecast to more than double by 2022 and represent by then around €4 billion per year. The share of global spending on RPAS for civilian (as opposed to military) applications could increase, as a proportion of total RPAS spending, from 11 to 14 per cent in the next 20s decade.

Europe would represent about 25% of the world market. In terms of jobs, for Europe, employment is estimated to increase to about 150,000 jobs by 2050 in manufacturing, hence excluding RPAS operator services employment. In the USA, a study forecasts that in the first three years of integration of RPAS in the national airspace, more than 70,000 jobs will be created with an economic impact of more than $13.6 billion. The number of jobs created through new RPAS activities in the US is estimated to exceed 100,000 by 2025.

In any case, RPAS services provision start off mostly in countries where RPAS rules are adopted and the full potential of RPAS will only be realized if they can safely fly in non-segregated airspace – alongside manned aircraft. This is not the case today, as RPAS face operational restrictions and diverging national standards. A number of other legal, operational and technical issues linked to the civil use of RPAS, like liability and data protection, also hamper their deployment.

There is a huge market already in place for RPAS applied to pipeline inspection, particularly with the utilities (water, oil, gas, and electricity) and infrastructure companies. There is a need for cost effective solutions, provision of reliable and timely accurate data as well as a capability for rapid deployment and enhanced safety. BLOS missions could be considered for monitoring, inspection, survey and mapping and possibly communications relays.

From a cost benefit perspective pipeline inspection and monitoring are considered the most profitable industrial application for long range RPAS operations. RPAS operation must be cost effective compared to manned operation.

Figure 1-3 RPAS in operation

1.1.3 Airborne services provision under WADI

WADI solution application will be carried out on two complementary aerial platforms, i.e. manned and unmanned, typically used for distinctive purposes in infrastructure performance observation. The manned aircraft is being used in long-distance and important infrastructure monitoring, whereas the unmanned platform is used for surveying branched water networks with short conduits or in particular/sensitive areas, i.e. those with a limited/difficult physical access, located in dangerous areas or requiring detailed closer monitoring upon earlier detection of anomalies during the aircraft missions.

The following Table summarises the operational use of onboard manned and unmanned aviation system under WADI.

Platform type & WADI system capabilities	**Manned Aerial Vehicle**	**Unmanned Aerial Vehicle**
Difficult and/or dangerous areas access	No	Yes
Autonomy	Yes >4 hours	Yes From 30 min to few hours (depending on UAV type)
Small areas scanning	Long-range use	Short-range use
Quick reaction ability & mission plan change	No	Yes
Miniaturisation necessity	No	Yes

Table 1-1 Operational use of onboard manned and unmanned aviation system under WADI

An evaluation of WADI innovative airborne detection services is provided in the following Table.

Technique	**Application**	**Characteristics**	**Cost per km**
		WADI's innovation – aircraft service evaluation	
WADI innovative detection system on aircrafts platform	airborne	Very high operational efficiency (155 km/h); location accuracy from few to 1m (depending on the equipment and altitude)	EUR 50
WADI innovative detection system on UAVs platform	airborne	High operational efficiency (60-90 km/h); location accuracy 0.5-1m; low-altitude flight range possibility; low energy requirements due to lightweight (electric or fuel, depending on the platform) and simple infrastructure needs (no airfield for take-off and landing); more sustainable over short distances	EUR 200

Table 1-2 WADI aircraft service evaluation

Currently unmanned aircrafts turn out to be more expensive to operate than manned aircrafts, mainly due to regulations not allowing the use of such technology and to the big issue of control navigation.

However, it shall be noted that the km unit should not be considered alone but rather in correlation with the covered distance: currently if payloads are suitable, short distance applications (<10km) are in favour of UAV operations VS Manned aircrafts. As technology evolves and thanks to expected modification on regulation and the reduction in operation costs due to recurring deployment, it is likely that UAV applications will become convenient for long distance applications too.

1.1.4 Recently completed and ongoing EU-funded projects

In order to enhance the engagement in networking and cooperation for increased business development opportunities and value chain strengthening, an inventory of European projects relevant to WADI technologies and application has been updated.

The WADI consortium has identified a number of EU-funded projects relevant to the project's objectives with which, for a greater synergy, it is planned to exchange information, and use them as another dissemination channel to further enhance WADI's outreach.

The following information are supplied for each project identified:

- the objective and/or a summary
- the WADI partner concerned by the issues of the project
- the status of the project (open, closed)
- the contact of the project and the address of the website and/or of the final project report.

Two lists of projects are delivered:

a) related to an update of the 7th Framework Program (FP7) projects identified on the WADI proposal

b) related to the H2020 projects funded on Water calls 2015 and 2014.

The collected information will be exploited on WP10 or directly by the addressed partners.

1.1.4.1 Inventory of funded FP7 projects relevant to WADI's scope

The inventory of the FP7 projects identified on the WADI proposal is provided in the following Table.

Name /FP	Status	Objective	WADI partners	Contacts/results
AG_UAS LIFE+	closed	Applications using IR and multispectral cameras	Scientific partners and service providers as ONERA, NTGS, AM, GG	*Final report:* http://www.lifeaguas.es/en/proyecto-aguas/resultados
DESSIN FP7	OPEN	Water scarcity and water quality issues	End user water providers and water management expert. EDIA, SCP, SGI	www.dessin-project.eu

Name /FP	Status	Objective	WADI partners	Contacts/results
WaterDiss/FP7	closed	To support and speed-up the transfer of outputs from EU funded water research to sector stakeholders	Dissemination partner and bussiness plan partner. YOURIS SST consult	www.waterdiss.eu *Final report:* http://cordis.europa.eu/result/rcn/149211_en.html
STEP-WISE FP7	closed	To facilitate bridging the communication gap between policy, research and industry through the WISE-RTD Knowledge Portal	Dissemination partner and bussiness plan partner YOURIS, SST consult	http://www.wise-rtd.info/ http://www.spi-water.eu/ *Final report:* http://cordis.europa.eu/result/rcn/56936_en.html STEP-WISE and STREAM *Final conference conclusion:* http://cordis.europa.eu/event/rcn/133387_en.html
WE@EU CSA/FP7	closed	Dedicated to water efficiency in urban water management, innovative products, services and skills in the water efficiency sector	Service provider partner and and water management expert. GG, AM, SGI	http://www.weateu.eu/visualizadorWEatEU/ *Final report:* http://cordis.europa.eu/docs/results/320/320007/final1-finalreport-promotional-contacts.pdf

Table 1-3 Funded FP7 projects relevant to WADI activity

Brief summaries of each of the above-listed projects are reported hereinafter.

AG_UAS

Sustainable Water Management at Regional Scale through Airborne Remote Sensing Based on Unmanned Aerial Systems, 2010-2013, www.lifeaguas.es - LIFE+ funded project. AG_UAS differs in its approach from WADI. It focuses on one type of thermal infrared sensor (IR-8-12 μm), one multi-spectral camera (250-850 nm) and observations at the local scale, considering only the use of RPAS platforms. Further, the project takes into account many different remote sensing applications for water management with the aim of proving their feasibility and effectiveness. Although AG_UAS is not focused on developing a water leak detection service like WADI, the overall purpose of both projects is similar (i.e. water management supported by airborne remote sensing techniques) and it will be very useful to exchange key observations and findings. Several water management applications listed in AG_UAS will be examined also in WADI.

Contact: http://www.lifeaguas.es/en/contacto

DESSIN

Demonstrate Ecosystem Services Enabling Innovation in the Water Sector (DESSIN), 2014-2017, www.dessin-project.eu - FP7 funded Water-Demo-Innovation project aiming at demonstrating and promoting innovative solutions related to water-challenges with a focus on water scarcity and water quality issues for a more resource-efficient and competitive water sector in Europe. In addition, an evaluation framework to account for changes in the value of ecosystem services of water bodies that result from implementation of the solutions will be developed and applied. The latter output will be particularly useful from the perspective of integrating ecosystem services valuation concept in water leaks management that is foreseen under WADI.

Contact: David Schwesig
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WaterDiss

2011-2013, www.waterdiss.eu - FP7 funded project that aimed to support and speed-up the transfer of outputs from EU funded water research to sector stakeholders with a time frame of maximum three to five years. The key project concept is based on adding an intermediate step following research activities (sort of marketing initiative). WaterDiss developed a communication platform to allow water stakeholders to benefit from a common space dedicated to water research in Europe - European Water Community (www.europeanwatercommunity.eu) that has gathered over 400 members representing various European water management and policy-making organisations. Progress of WADI activities and results will be disseminated also using this network.

Contact: Gilles Neveu, (director for Innovation and Development)
Tel.: +33 680 68 38 81; Fax: +33 555 63 52 23

STEP-WISE

2011-2012, http://www.spi-water.eu/step-wise - FP7 funded project aimed to facilitate bridging the communication gap between policy, research and industry through the WISE-RTD Knowledge Portal (http://www.wise-rtd.info/). WISE-RTD Knowledge Portal has been expanded to include all EU water related directives, all information on EU funded research (FP and LIFE projects) and to facilitate dissemination of RTD results to scientists and non-scientific stakeholders (policy, industrial sector; from SMEs to larger industries).

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WE@EU

Water Efficiency in European Urban Areas – (WE@EU), http://www.weateu.eu, is dedicated to water efficiency in urban water management. This European platform will enable an innovation friendly ecosystem to be generated where academia and business will work together, in coordination with regional authorities and other stakeholders, transforming knowledge into innovative products, services and skills in the water efficiency sector. This partnership will thus enable strengthening regional capacities, which can unlock business opportunities among the participating regions and stimulate investments in R&D&I. We@eu is dedicated to "urban areas", links and connections are evident in the field of leak detection.

Contact: Oscar Lopez, (Head of European Projects Office)
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1.1.4.2 Inventory of projects funded on Horizon 2020 water calls in 2015 and 2014 relevant to WADI's scope

WATER Call 2015: WADI (IT), INTEGROIL (ES) SMART-Plant (IT) SALTGAE (ES) INTCATCH (UK) INNOQUA (FR) AquaNES (CH) INCOVER (ES) INTEGROIL (ES), SIM4NEXUS (NL), MAGIC (ES) MADFORWATER (IT) WATERSPOUTT (IE) VicInAqua (DE) DAFNE (CH) FLOWERED (IT) SafeWaterAfrica (DE), Waterworks2015 (FR), FERTINNOWA (BE), AfriAlliance (NL).

WATER Call 2014: CYTO-WATER, POWERSTEP, Eco-UV, iMETland, REMEB, SUBSOL, MOSES, ECWRTI, CENTAUR, MASLOWATEN, BINGO, IMPREX, FREEWAT, BlueSCities , WIDEST, KINDRA, PIANO.

The inventory of the H2020 projects funded on Water calls 2015 and 2014 and relevant to WADI's scope is provided in the following Table.

Name /FP	Status	Objective	WADI partners	Contacts/results
MAGIC H2020-WATER 2015	OPEN	To contribute to raise the competitiveness of SMEs from the 4 regions by offering support services in the area of innovation management	French SME partner (AM) and partner in charge of innovation management (SGI)	AGENCE DE DEVELOPPEMENT ET D'INNOVATION AQUITAINE LIMOUSIN POITOU CHARENTES 6 ALLEE DU DOYEN GEORGES BRUS 33600 PESSAC France

Name /FP	Status	Objective	WADI partners	Contacts/results
MOSES H2020-WATER2014	OPEN	To put in place and demonstrate at the real scale of application an information platform devoted to water procurement and management agencies (e.g. reclamation consortia, irrigation districts, etc.) to facilitate planning of irrigation water resources, with the aim of: • saving water; • improving services to farmers; • reducing monetary and energy costs.	Water provider and service provider, water management experts (AM, GG, EDIA, SCP, SGI)	ESRI ITALIA SPA VIA CASILINA 98 00182 ROMA Italy

Table 1-4 Funded H2020 projects relevant to WADI activity

Brief summaries of each of the above-listed projects are reported hereinafter.

MAGIC

The project involves five partners of the Enterprise Europe Network South West France consortium which covers four regions (Aquitaine, Limousin, Midi-Pyrénées and Poitou-Charentes).

The general objective is to contribute to raise the competitiveness of SMEs from the 4 regions by offering support services in the area of innovation management. The project will also contribute to develop more efficient and more effective innovation processes and higher quality innovation management capacity assessment and support services.

The support will be delivered as service packages of 7 days to 2 groups of SMEs -

1) Beneficiaries of the SME Instrument of Horizon 2020: to enhance the probability of a successful exploitation of the innovation project results and lead to the sustainable growth of the beneficiary beyond the participation in Horizon 2020. The support service will pinpoint weaknesses in the innovation capacities of the beneficiary, select suitable coaches to address the identified weaknesses and monitor the coach-client relationship and to accompany the beneficiary through the SME instrument project
2) SMEs with significant innovation activities and a high potential for internationalisation: to enhance their innovation management capacities to be

able to gain new international markets and leaderships. The support service will consist in an in-depth innovation assessment in order to develop and implement a tailored action plan to improve the SMEs capacity to manage innovation processes. The partners will use a dedicated assessment tool: IMP3rove.

Coordinator:

Agence De Developpement Et D'innovation Aquitaine Limousin Poitou Charentes
6 Allee Du Doyen Georges Brus- 33600 Pessac - France
Aquitaine Developpement Innovation
Allee Du Doyen Georges Brus 6 Parc Scientifique Unitec 1- 33600 Pessac- France

MOSES

The main objective of MOSES is to put in place and demonstrate at the real scale of application an information platform devoted to water procurement and management agencies (e.g. reclamation consortia, irrigation districts, etc.) to facilitate planning of irrigation water resources, with the aim of:

- saving water;
- improving services to farmers;
- reducing monetary and energy costs.

To achieve these goals, the MOSES project combines in an innovative and integrated platform a wide range of data and technological resources: EO data, probabilistic seasonal forecasting and numerical weather prediction, crop water requirement and irrigation modelling and online GIS Decision Support System.

Spatial scales of services range from river basin to sub-district; users access the system depending on their expertise and needs. Main system components are:

- early-season irrigated crop mapping
- seasonal weather forecasting and downscaling
- in-season monitoring of evapotranspiration and water availability
- seasonal and medium/short term irrigation forecasting.

Four Demonstration Areas will be set up in Italy, Spain, Romania and Morocco, and an Indian organization will be acting as observer. Different water procurement and distribution scenarios will be considered, collecting data and user needs, interfacing with existing local services and contributing to service definition. Demonstrative and training sessions are foreseen for service exploitation in the Demonstration Areas. The proposed system is targeting EIP on Water “thematic priorities” related to increasing agriculture water use efficiency, water resource monitoring and flood and drought risk management; it will be compliant to INSPIRE. This SME-led project address to the irrigated agriculture users an integrated and innovative water management solution.

Coordinator:

ESRI ITALIA SPA, VIA CASILINA 98, 00182 ROMA, Italy

1.2 Infrared and multi-spectral sensors application

Surface soil moisture plays a key role to understand the exchange of water and heat energy between the land surface and the atmosphere through evaporation, to evaluate soil trafficability [Kourdian et al., 2009], to characterize plant health [Lambers et al., 2008] or soil texture features like soil organic carbon or clay contents [Nocita et al., 20113, Ben-Dor et al., 2009].

Remote sensing techniques for monitoring Soil Moisture Content (SMC) have several advantages in comparison with other *in situ* methods (gravimetric, electromagnetic, thermal…) [Vauclin, 1983], as they provide better temporal and spatial coverages [Bryant et al., 2003].

The estimate of the surface soil moisture with remote sensing techniques amongst a variety of different land cover types may be deducted through two techniques:

- *Direct detection*, based on optics or radar systems, which gives direct information on the SMC but is highly affected by the type of soils;
- *Indirect detection*, based on optics sensors, which uses the parameters of the effects on vegetation (structure, plant growth, leaf growth etc.) and soil (temperature, emissivity etc.) to confirm the presence/absence of excess water, though these information depend on plant species.

1.2.1 Direct detection with remote sensing techniques

1.2.1.1 Soil moisture retrieval from Microwaves measurements

At high spatial resolution, the most popular technique to sense soil moisture is based on active microwave sensor. This is due to the high sensitivity of the backscattered signal to the dielectric constant of soil and of its moisture [Shi et al., 1997] completed to its soil penetration capability. Nevertheless, the quality of the retrieved soil moisture is highly dependent on the surface roughness [Shi et al., 1997].

1.2.1.2 Soil moisture retrieval from Hyperspectral sensors

Hyperspectral imagery has demonstrated its potential to retrieve the soil moisture but its performance depends on the soil colour and texture, the presence of organic material and crusts [Shi et al., 1997, Ben-Dor et al., 1994, Baumgardner, 1985, Goldshlegeret al., 2002]. Further, the penetration depth in the optical domain is significantly lower and can only allow to quantify the uppermost layer in a soil column. Despite these drawbacks, there is a real interest to estimate the SMC from such sensors [Goldshleger et al., 2004, Mulder et al., 2011] particularly in the reflective domain from 0.4 µm to 2.5 µm. Such characteristics open the way to retrieve SMC from remote sensing technic as proposed by [Helsel, 2002].

1.2.1.2.1 SMC method based on the soil spectral reflectance in the solar domain

Numerous studies have been conducted, mainly with laboratory measurements, to characterize the influence of SMC on the spectral reflectance. Angström, 1925, demonstrated through laboratory measurements that soil moisture content had an impact on the behaviour of soil spectral reflectances in the solar domain. This work exhibited a decrease of the reflectance level as SMC increased, due to a darkening of the soil surface. Further, two strong absorption bands are identified due to the presence of water at 1.4 and 1.9 µm (see Figure 1-4 and Figure 1-5).

The depth and the width of these absorption bands increase with the water amount. Later, other laboratory results over bare soils [Bach et al., 1994] confirmed this behaviour which has, then, been used to develop SMC approaches based on spectral reflectances.

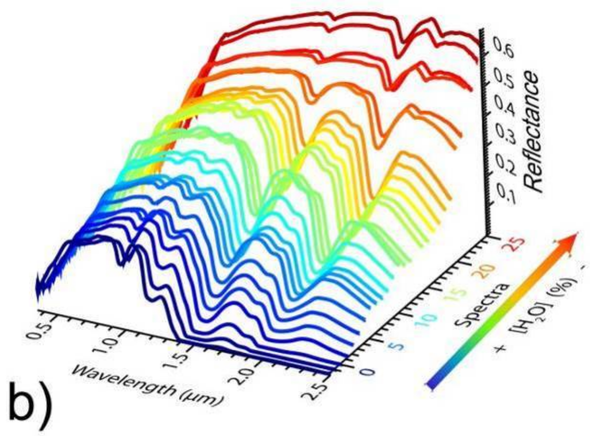

Figure 1-4 Impact of the SMC on the spectral signature (Verpoorter, 2009)

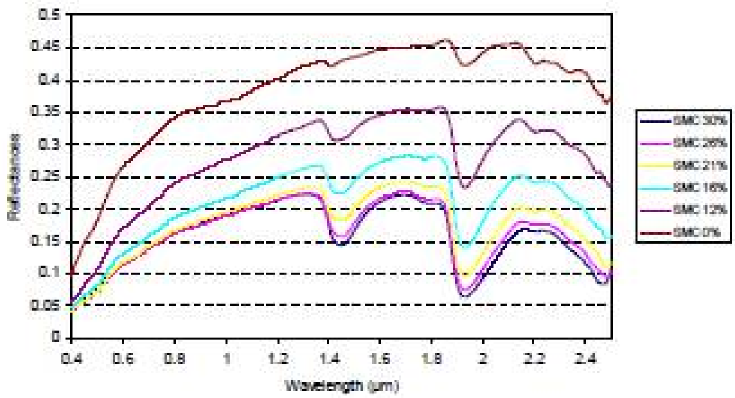

Figure 1-5 Spectral signatures according to SMC (in %g) for a soil sample (Fabre et al., 2015)

Nevertheless, investigations to explore the possibility of estimating soil moisture content from multispectral or hyperspectral remote sensing data were penalized by the lack of specific databases. Liu et al., 2002, measured the spectral reflectances of ten soil samples controlling the SMC during a drying process. These measurements have been completed using the database described in [Lesaignoux et al., 2013] including the spectral reflectances of about thirty natural soil samples in (0.4–2.5 µm) depending on the SMC and measured in the laboratory. This database was used to analyse the relationship between the SMC and the reflectance spectra. The laboratory measurements were limited to a few SMC levels (five or six) due to experimental constraints (drying time for example). In order to go beyond this limitation, a semi-empirical soil model was then proposed in [Lesaignoux et al., 2013] to simulate bare soil spectral reflectances for SMC levels not determined by experimentation and compared to state-of-the-art models. The conclusions pointed out that a representative database is necessary to analyse the impact of the SMC variation on soil spectral reflectances, to model this spectral behaviour according to SMC and then to specify robust SMC assessment methods based on spectral signatures in the (0.4–2.5 μm) domain.

1.2.1.2.2 Approaches of SMC estimation

Three main approaches of SMC estimation can be distinguished: combination of spectral bands [Haubrock et al., 2008, Liu et al., 2003, Khanna et al., 2007], exponential or Gaussian spectral models [Whiting et al., 2003, Lobell et al., 2002], and geostatistical methods [Ben-Dor et al., 2002, Brocca et al., 2007, Sanchez, 2003].

Liu et al., 2003, tested the first type of approaches using eighteen bare soil samples with different moisture contents characterized in the laboratory. Several analytical methods were tested: a relative approach normalizing the spectral reflectance of wet soil by the spectrum of the corresponding dry soil, a derivative approach based on the finite difference method, and an approach by difference computing a waveband difference. They concluded that SMC estimation using the relative method in the Short Wavelength InfraRed (SWIR) domain (1.4–2.5 μm) was more efficient. Concerning the use of spectral indices for estimating SMC, the best results were obtained with Water Index SOIL (WISOIL) [Bryant,et al., 2003], Shortwave Angle Slope Index (SASI) [Khanna, et al., 2007] and Normalized Soil Moisture Index (NSMI) [Haubrock et al., 2008]. These indices have been validated by reflectance measurements in the laboratory at different SMC over many bare soils. The main drawback of these indices is the use of wavelengths located in the water vapour absorption bands, making them very sensitive to the quality of the atmosphere compensation. Lobell et al, 2002, have developed a spectral exponential model and applied it on four bare soil spectra measured in laboratory. Their results confirmed the strong potential of the SWIR domain for SMC estimation.

Whiting et al., 2003, proposed the Soil Moisture Gaussian Model (SMGM) to fit an inverted Gaussian function to the convex hull boundary points in the (1.8–2.8 μm) region of a bare soil spectrum. The area of one side of the Gaussian function above the spectral continuum was then related to SMC. The model performance estimated in laboratory measurements were: R^2 of 94% and a mean RMSE of 0.027 $g \cdot g^{-1}$ [Whiting, et al., 2003]. However, the SMGM displayed poor performance for high soil water contents (like contents higher than 0.32 $g \cdot g^{-1}$). These models need *a priori* knowledge of the soil texture or have to be calibrated previously on soil samples taken from the analysed area before the processing of the entire area.

The geostatistical methods are based on the knowledge of the spatial distribution of soil moisture for predicting runoff at the observation area scale. These methods require *in situ* humidity measurements and use interpolation techniques for the analysis of the distribution of the soil moisture at spatial scale [Ben-Dor et al., 2003, Brocca, et al., 2007, Sanchez, 2003]. The most common interpolation techniques are moving average, trend surface and kriging. The applicability of these techniques depends on various factors such as distribution of sampled data in the observation area, the type of surfaces to be generated and tolerance of estimation errors. An adequate geometric correction processing in order to limit the high influence of topography in soil moisture estimation is necessary for the geostatistical methods.

Stamenkovic et al., 2013 studied the use of support vector regression to estimate soil moisture in bare soils directly from hyperspectral imagery. HyperSpecTIR, which had a spectral range from 400nm until 2450nm, characterized by 178 spectral bands with approximately 10nm resolution and 2.5m GSD, was used for the study. The original image was spatially smoothed by a 3x3 low pass filter. The estimation in the general setting (all fields mixed) gave very good model fits R^2=0.7670. The author emphasized that good atmospheric correction models were essential for the success of the method. Hence, for the estimation of soil moisture content, other than the requirement of good atmospheric correction models, the varying condition of soil properties and presence of sparse vegetation (mixing effect) were important factors to be considered.

1.2.1.2.3 New spectral indices and method to estimate SMC

To reduce the limitations of existing SMC tools due to the water vapour absorption and the quality of the atmosphere compensation, Fabre et al., 2015, proposed two new spectral indices defined using the determination matrix tool by taking into account the atmospheric transmission: Normalized Index of Nswir domain for SMC estimation from Linear correlation (NINSOL) and Normalized Index of Nswir domain for SMC estimation from Non-linear correlation (NINSON).

These spectral indices are completed by two new methods based on the global shape of the soil spectral signatures: the Inverse Soil semi-Empirical Reflectance model (ISER), using the inversion of an existing empirical soil model simulating the soil spectral reflectance according to soil moisture content for a given soil class, and the convex envelope model, linking the area between the envelope and the spectral signature to the SMC.

These methods were compared with a database composed by 32 soil samples, each sample with five or six soil moisture contents (190 spectral signatures). The results show that the four new methods lead to similar or better performance than the one obtained by the reference indices. The RMSE is ranging from 3.8% to 6.2% and the coefficient of determination R^2 varies between 0.74 and 0.91 with the best performance obtained with the ISER model.

In a second step, simulated spectral radiances at the sensor level are used to analyse the sensitivity of these methods to the sensor spectral resolution and the water vapour content knowledge. The spectral signatures of the database were then used to simulate the signal at the top of atmosphere with a radiative transfer model and to compute the integrated incident signal representing the spectral radiance measurements of the HYMAP airborne hyperspectral instrument. The sensor radiances were then corrected from the atmosphere by an atmospheric compensation tool to retrieve the surface reflectances. The SMC estimation methods were then applied on the retrieve spectral reflectances. The best performance was obtained with the ISER model (RMSE of 2.9% and R2 of 0.96) while the four other methods led to quite similar RMSE (from 6.4% to 7.8%) and R^2 (between 0.79 and 0.83) values. In the atmosphere compensation processing, an error on the water vapour content was introduced.

The most robust methods to water vapour content variations were WISOIL, NINSON, NINSOL and ISER model. The convex envelope model and NSMI index require an accurate estimation of the water vapour content in the atmosphere.

1.2.1.3 Thermal-based methods

1.2.1.3.1 Principle

Thermal infrared (TIR) remote sensing has been recognized for a long time as a valuable tool for evaluating soil moisture. As a matter of fact, the sensed temperature is a strong indicator of the presence of water both in soil and in plants. Temperature is a state variable which evolves during day as a function of the surface radiative fluxes (both from solar radiation and from atmospheric and environment infrared radiation), the atmospheric turbulent sensible and latent fluxes and the heat diffusion inside the soil. A coupling also takes place with the water transport inside the soil and through the plants up to the atmosphere by involving phase changes into or from water vapor through evaporation, transpiration and condensation. The main governing parameters are the surface albedo, the surface emissivity, the resistance to evapo-transpiration and soil thermal inertia (or thermal effusivity). They depend on the water content at the soil surface and in the upper soil layers, on the water content in the possibly present vegetation and on its possible water stress. Despite some antagonist effects, the relative contributions of all these parameters make that on the whole, a higher presence of water induces a lowering of the day-night temperature amplitude. It is thus expected that, during a sunny day, moist sites should show a lower radiance temperature as compared to drier sites, whereas after sunset and before dawn one should observe the opposite [Myer, 1975]. Thermal cross-overs should between water and other surfaces occurr at sunset and about 1,5h after sunrise [Cundill et al., 2014, after Jensen, 2007]. Based on this interpretation a large number of remote sensing experiments involving TIR sensors were conducted for assessing the moisture state at the Earth’s surface or the evaporation rate over vegetated lands.

1.2.1.3.2 Airborne TIR measurements

Airborne TIR has been considered for water leaks and seepage detection along aqueducts, canals, and dikes for more than thirty years [Nellis, 1982, Tracey et al., 1989, Pickerill et al., 1998, McGowen et al., 2001, Huang et al., 2009, Thomson et al., 2012, Charles et al., 2013, Arshad et al., 2014, Cundill et al., 2014]. TIR was sometimes used independently by implementing infrared cameras or linescanners [Nellis, 1982, Tracey et al. 1989, Thomson et al., 2012]. Out of the 39 sites detected by Nellis, 1982, as potential canal leakage sites, 12 were verified through field analysis as actual leakage sites, i.e. a

31% detection accuracy and 69% false positives. In addition, during the field checking process, no other leakage sites were discovered (no false negatives). Nellis, 1982, concluded that, although the detection accuracy was low, the amount of time saved by checking this limited number of sites rather than the entire canal system for leakage was tremendous. Misinterpretations were commonly caused by dense natural vegetation, farm canals or drainage ditches adjacent to the main canal, small holding ponds or low depression areas of natural drainage. He suggested using color photography to supplement thermal imagery would significantly reduce misinterpretations. At least it should aid image interpretation.

1.2.1.3.3 combined TIR and visible imagery

As a matter of fact, the next works on this topic often combined TIR with visible imagery, but also with images obtained in other spectral bands. TIR was used simultaneously with visible and NIR cameras [Huang et al., 2009] with visible, multispectral and hyperspectral cameras [Cundill et al., 2014] or though a multispectral sensor spanning from the visible to the thermal infrared range [Pickerill et al., 1998, Arshad et al., 2014]. Aerial remote sensing data have also been interpreted through a combined analysis with satellite imagery like Landsat TM [McGowen et al., 2001] or Google Earth [Arshad et al., 2014]. The additional visible-to-SWIR spectral bands were used as standalone information or they have been fused for providing various indicators like well-known vegetation indices or moisture indices (NDVI, MSAVI, CRI, SRWI, WBI, NIRRR, etc...). Referring to this various additional information allowed increasing the TIR performance for the detection of seepage areas, more precisely it allowed reducing the number of false detections as for example assisting in identifying sites likely to be confounded with seepage on the thermal imagery (e.g. dense vegetation) [Huang et al., 2009]. Indeed trees and their shadows cause a temperature signature that can lead to a false positive. By simply processing the NVDI, the NIR and red images could differentiate the tree and shadow from nearby seepage areas whereas the thermal image could not [Huang et al., 2009]. A 93% rate of success was achieved for leak detection in canal systems based on a combined TIR and NDVI image analysis [Huang et al., 2009]. Even simple images from Google Earth allow rectifying the false identification of water activity provided by tree shades in the TIR images [Arshad et al., 2014]. On the other side, Landsat TM data provided information on interactions of the land use and vegetation with seepage zones (processing MSAVI proved to be more efficient than NDVI in case of low vegetation cover) [McGowen et al., 2001].

1.2.1.3.4 Triangle Method

A more synergetic use of TIR and vis-NIR data like in the Triangle Method and its various improvements may yield more robust water leak detection along aqueducts. As a matter of fact, since the temperature response of the vegetation (leaves or grass) and the temperature response of the underlying soil follow different functionalities with water content, the mean temperature as it is sensed by the remote TIR sensor not only depends on water content but also on the cover fraction. For this reason, trying to deduce moisture or simply detect leakage spots *from the mean temperature alone* as provided by a thermal sensor integrating the infrared radiance from mixed pixels exposes to an intrinsic ambiguity. Independent information about the vegetation cover fraction is therefore required to release the ambiguity. An efficient approach consists in combining the apparent temperature and a vegetation index like NDVI which is evaluated from the visible and near infrared (NIR) signals provided by one or two additional cameras. When plotting the temperature and the NDVI for the different pixels over an area presenting a broad diversity both in cover fraction and in humidity, a scatter with a roughly triangular shape is obtained. For this reason, the method is called the Triangle Method [Moran et al., 1994, Calson et al. 1995, Sandholt et al., 2002]. It was applied with success on satellite images (MODIS, ASTER) and on airborne remote sensing images (multispectral sensor Daedalus, hyperspectral sensor AHS, or simply an association of visible, NIR and TIR cameras). More involved approaches consist in using a SVAT model (Soil Vegetation Atmosphere Transfer) in combination with the triangular scatter for the moisture identification process [Carlson et al., 1995, Krapez et al., 2009]. More recent works consist in considering an additional index in order to remove some residual ambiguity problems which appear when soil and vegetation both experience large reflectance variations. Proposed additional indexes are the albedo [Chauhan et al., 2003, Krapez et al., 2011, 2012] and the CAI-Cellulose Absorption Index [Krapez et al., 2011, 2012]; the latter index intends to differentiate between green and senescent vegetation. A broad absorption band near 2.1 μm appears in all compounds possessing alcoholic -OH groups such as sugars, starch and cellulose. This absorption band appears in the reflectance spectra of dry plant residues. A cellulose absorption index (CAI) based on the reflectance at three wavelengths - one at the band center 2.1 μm (cellulose–lignin absorption maximum) and two at the band edges 2 μm and 2.2 μm was then proposed in [Daughtry et al. 2001]. Adding a third observation parameter to the two parameters considered in the classical triangle method, namely radiance temperature and NDVI (or SAVI), is expected to allow discriminating areas having different moisture content but otherwise presenting the same temperature and vegetation index values. A better correlation is thus expected between the calculated moisture and the measured one. For the crop fields analyzed in [Krapez et al., 2011], the addition of CAI proved to be efficient, contrarily to the albedo.

1.2.1.3.5 TIR measurement recommendation

Since heat transfer between atmosphere, vegetation and soil is a dynamic process, the temperature signatures of dry and wet surfaces evolve with time. The temperature contrast between these two types of surfaces itself evolves with time. The time scales of the temperature variations are of course directly related to the time scales of the thermal fluxes (the solar flux is modulated by the presence of clouds and other atmosphere transmission variations; the sensible and latent heat fluxes are modulated by the variations of wind speed, air temperature and air humidity). The thermal inertia of soil and the (apparent) thermal inertia of vegetation also have an influence on the temperature dynamics. Furthermore, depending on the atmospheric conditions (precipitations, turbulent fluxes), the moisture content in a seepage zone and in the surrounding area also evolves with time with different time scales. As a consequence, one can easily imagine that the TIR success for detecting leakage zones depends to various extents on the time chosen in the year, in the day, on the delay since the last precipitations [Charles et al. 2013], and more generally on the time in relation to the current and past environment conditions. An optimum time is hard to determine, especially since the vegetation has a high impact (vegetation type, cover fraction, vegetation height, etc…). For this reason, post leaf season (from late autumn to early spring) is sometimes recommended to obtain a relatively unobstructed view of moist and wet areas, depending on the vegetation type and size [Tracey et al. 1989]. Other investigators preferred to apply TIR in summer for maximizing the chance to see a dry period and thereby to increase the contrast between leak areas and the surrounding [Pickerill et al., 1998].

The optimal time in the day for TIR investigation is still a matter of discussion. An evaluation based on the thermal property variations with moisture as expected for *condensed* materials would favor performing the measurements just before dawn or after the sunset (the wet areas would then show a higher temperature) [Jensen, 2007] (Tracey et al. 1989 came to the same conclusion however after an erroneous interpretation of the parameter impacts). The other reason is to avoid sun perturbations [Tracey et al. 1989, McGowen et al., 2001] (by the way, the infrared measurements performed in the 3-5µm range may be affected by solar reflections whereas those performed in the 8-14µm range are not).

The TIR measurements performed just before dawn or after the sunset proved to be successful for detecting leakage zones along an open water concrete-lined conduit but the interpretation of the TIR images in the case of a concrete-covered conduit (2.4m diameter, 3m below the ground surface) proved to be considerably more difficult [Tracey et al. 1989]. The oversimplified interpretation arguing that due to a higher thermal inertia, moist areas should present a higher temperature than dry areas before dawn was not always experimentally verified: Pickerill, 1998, observed either positive or negative infrared contrasts depending on the considered leak zone. Moreover, the warm areas on the thermal imagery obtained by McGowen et al., 2001, after sunset were not associated with seepage, contrarily to the previous expectation. They were primarily irrigated paddocks, free water (where irrigation was under way) and timber. Instead, areas of known seepage were associated with very cool zones on the thermal images (it was not surface seepage but deep seepage correlated with a prior network that intersected the supply channel system).

Recent measurements performed during a whole day at a series of spots with wetter and drier soils in a dike excavated area highlighted the fact that the contrast is maximum in the afternoon (the exact optimal time actually depends on the considered spot pair) and that it nearly vanishes after the sunset and before the sunrise, in contradiction to the previous expectation [Cundill et al., 2014].

Taking into account the vegetation influence through the use of a SVAT model would probably help selecting the optimum time and conditions for thermal remote sensing.

1.2.2 Indirect detection with remote sensing techniques

Water leakage may take many forms which has implications for the type of surface feature to be detected [Pickerill et al., 1998]. The area of water-logging associated with a leak could range from a few centimetres to several meters, depending on the severity of the leak and its length of existence [Critchley and Aikman, 1994]. In typical mid-summer conditions, leaks at the ground surface should generally be visible as patches of greater soil moisture and/or a change in vegetation biomass, either as increased vegetation growth or, if water logging persists beyond critical tolerance levels, the vegetation may become stressed and reduce productivity. Soil temperature may also be expected to be reduced.

If marked, these properties should be measurable using conventional remote sensing methods as long as the applied technique identifies leaks as being different from their immediate surroundings. It is important to note that these effects vary greatly between species and between plant growth stages. Generally speaking, the earlier in the plant growth stage the leak occurs, the more dramatic and more inhibitory the effect on plant physiology is.

The presence or lack of water in a soil locally can induce a different behaviour of the vegetation as the amount of water in the leaves can change. Remote sensing techniques can detect such change in an environment and thus alert the end user on such anomaly. The scenario where the presence of excess water has a positive effect on vegetation growth has a very short temporal window of maybe only a few days and is limited to a very few plant species. This makes it unlikely to be encountered in the field [Taylor, 2003]. The other scenario, where the presence of water has had a negative effect on vegetation growth, has a longer temporal window which makes it good for image acquisition.

1.3 Ground leak detection methods

Ground leak detection methods represent the traditional way of detecting leaks from water mains, as opposed to Airborne methods.

The main ground leak detection methods applicable to large water mains are:

- Acoustic methods
- Gas-injection methods
- Ground Penetrating Radar
- Inline methods

The same are reviewed in detail in the following. Please note that only the methods for detection of leaks in existing mains are examined, whereas permanent telemetry systems and/or installation of sensors alongside new pipelines when they are laid (common in the Oil&Gas industry but recently being applied on water mains as well) are not considered.

1.3.1 Acoustic methods

Historically, acoustic leak detection is the method that has more often been applied for identifying leaks on water pipelines, as the first acoustic correlator was developed back in the early 1960s. Acoustic methods are based on the fact that pressurized water that is forced out through a leak emits soundwaves that travel through the pipe walls, the surrounding ground and along the fluid flowing into the pipe. These soundwaves can be sensed and amplified by means of electronic transducers.

1.3.1.1 Range of application

Acoustic methods can be applied to all pressurized pipe systems, with best performances obtained at high pressures, metallic pipes and environments with low background noise.

Based on the tests of Huchs and Richle (1991), for some favourable conditions, leaks with discharges as small as 0.05m^3/hour have been located using acoustic correlation.[1]

1.3.1.2 Specifications

Acoustic leak detection is a dynamic process which requires skilled personnel and implies the use of several technologies and procedures.

In large transmission mains, once the existence of a water loss has been confirmed (i.e. the outflow from the system is lower than the inflow), acoustic leak detection typically consists of three phases:

1) Direct Sounding of contact points using electroacoustic listening rod
2) Acoustic correlation to pinpoint leaks
3) Surface (Indirect) Sounding to confirm leak position using ground microphone

Each phase implies the use of the instrumentation described herewith.

Electroacoustic Listening Rod

Not all leaks produce a noise audible to the human ear. For this reasons, an electroacoustic listening rod is used to amplify, filter and transmit the noise generated by water escaping from buried pipes under pressure to the operator’s headphones.

[1] Wang, X.J., Simpson, A.R., Lambert, M.F. and Vítkovský, J.P. (2001). “Leak detection in pipeline systems using hydraulic methods: a review”. Conference on Hydraulics in Civil Engineering, The Institution of Engineers, Australia, Hobart, 23-30 November, 391–400.

Electroacoustic listening rods are applied on pipe *contact points* (i.e. wherever the pipe can be physically touched: valves, washouts, hydrants, stretches of pipe above ground level, etc.) to verify whether a leak is occurring nearby (as far as the sound propagates along the pipe wall).

However, owing to the lack of contact points on trunk mains, and the short sound propagation distance of large diameter pipes, Direct Sounding with listening rod is rarely done on large water mains.

Figure 1-6 Engineer using an electroacoustic listening rod for Direct Sounding

Acoustic correlator

Correlation is a method used to detect leakages in buried pipes. The noise is detected at two separate contact points by highly sensitive microphones, either *accelerometres* or *hydrophones*.

Accelerometres have the advantage of being non-intrusive and therefore simpler to install (they are simply placed on the contact points to detect sound propagation through the pipe wall), whilst hydrophones are intrusive into the pipeline as they need to be in contact with the water to detect pressure waves. Accelerometres show weaker performances at low frequencies (i.e. softer pipe materials and large diameters) and longer distances, that is why hydrophones are preferred for installations on large water mains.

The sound first arrives at the closer of the two sensors; then a *time delay* occurs before the sound arrives at the further sensor. Utilizing this and other information (the distance between the sensors and the sound velocity in the pipe), the exact leak position can be calculated by the correlator.

The first analogue acoustic correlator was developed by the Water Research Association in the early 1960s, and marketed in the late 1970s. Since then, technology beyond correlators have kept improving, with the first digital correlator being developed by Flow Metrix Inc. in the late 1990s and introduced to the market in the early 2000s. Nowadays, advanced correlators have integrated GPS capabilities and allow better and better performances on all pipe materials and diameters, advanced signal processing techniques, more reliable signal transmission, quicker and easier use.

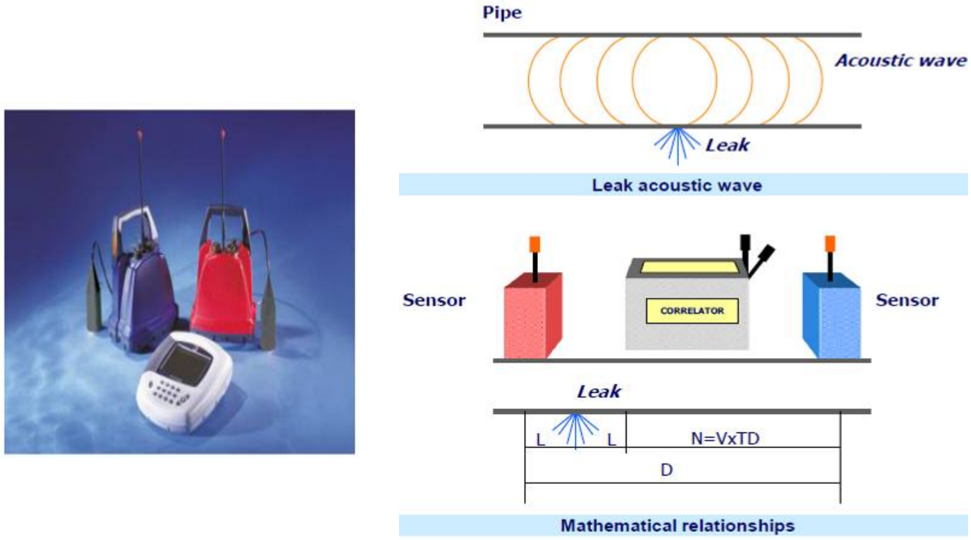

Figure 1-7 Acoustic correlator and its principle of operation

Ground microphone

The ground microphone is based on the same principle of an electroacoustic listening rod, with the difference that the instrument is not directly applied on pipe contact points (to detect sound propagating along the pipe wall), but on the ground surface above the buried pipe (to detect sound propagating through the soil), so it is referred to as an *Indirect Sounding* technique.

Figure 1-8 Ground microphone

An advanced form of ground microphone was developed and brought to the market in 2003; this piece of equipment consists of a number of sensors (up to 16) incorporated into what the manufacturer describes as a “magic carpet”.[2]

Ground microphones are particularly useful to confirm the precise location of a leak following a correlation and prior to digging for repair.

1.3.1.3 Precision of leak pinpointing

In its simplest application, the correlator pinpoints a leak between two sensors through a formula in which the leak position is a factor of the pipe length (between the sensors), the recorded time delay and the soundwave velocity, with the latter typically being the most difficult-to-determine value, as it depends on pipe material, size, age and conditions. However, thanks to recently developed inbuilt simultaneous multi-correlation systems, that allow to quickly calculate the leak position using many different soundwave velocities, the chance of error has reduced, the reliability of correlation has increased and the accuracy of leak pinpointing have noticeably improved.

Today the accuracy of pinpointing a leak using advanced - and most expensive - correlators equipped with hydrophones is reportedly within a few centimetres[3] (depending upon the local conditions).

1.3.1.4 Potential limitations

Not all leaks produce a detectable noise. Furthermore, contrary to common perception, it is not always the largest leaks which are the loudest: often a large split in a water pipe will produce a less clear noise than a small hole.

With both direct sounding of contact points (i.e. electroacoustic listening rod) and surface sounding (i.e. use of ground microphone) the position of highest sound intensity is not necessarily the position nearest to the leak.

Generally speaking, the factors negatively affecting the quality of a leak sound (hence the effective applicability of acoustic methods) are: softer pipe materials (plastic); large pipe diameters; low pressure; lined pipes; encrusted pipes; deep buried pipes; wet loose soil; soft ground cover (grass lawns or loose dirt); presence of obstructions, valves, pumps, etc. generating background noises; level of environmental noise.

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[2] IWA Water Loss Task Force, (2007) “Leak Location and Repair. Guidance Notes” - International Water Association.

[3] IWA Water Loss Task Force, (2007) “Leak Location and Repair. Guidance Notes” - International Water Association.

The following graph shows how the pipe material and diameter affect the Sound Propagation through the pipe wall: potentially at about 1000mm electroacoustic listening rods become almost useless for detecting leaks in underground pipes, even for metallic pipes.

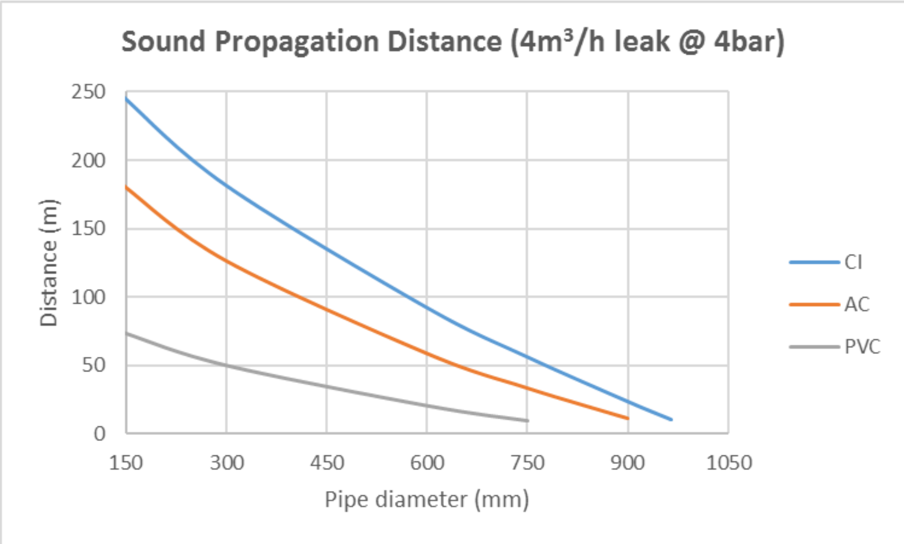

Figure 1-9 Sound Propagation Distance as function of pipe material and diameter, extrapolated from literature values

Some of the currently available advanced correlators have been used very successfully on transmission mains, but it is the distance between contact points (particularly hydrants for the installation of hydrophones) that can be the limiting factor; therefore acoustic leak detection might not be feasible in difficult-to-access environments.

As already stated, whenever water in pipe is not under pressure, acoustic methods are always inapplicable.

1.3.2 Gas-injection methods

Gas-injection methods for leak detection work on the principle that a water-insoluble and lighter-than-air gas injected into a pressurized pipe escapes from the leak opening and finds its way to the surface, hence, by scanning the ground surface directly above the pipe with a gas detector, it is possible to pinpoint the leak position.

Gas injection and tracing techniques for the location of leaks are not so commonly used as they were 30 years ago. This is mainly because of the advancement of acoustic techniques.[4]

1.3.2.1 Range of application

For environments with high background noise, non-metallic pipes, and/or low pressure, gas injection and tracing techniques overcome the limitations associated to acoustic methods and become a valid option for leak detection.

This technique is very suitable for trunk mains and rural mains where the absence of contact points prevents the use of acoustic methods and bar holes can be made easily. It can also be used in urban areas but the problems and cost of producing and reinstating the bar holes in roadways make it less attractive.

1.3.2.2 Specifications

Leak detection using gas-injection is considered by many practitioners to be very specialized and will call in an expert contractor to carry out the work.

The ideal gas used for leak detection in water pipelines should meet the following specifications: lighter than air, insoluble in water, non-toxic for humans, not corrosive for pipes, safe for operators to use, low atomic mass and viscosity, low Natural Ambient Concentration, detectable with sufficient accuracy with existing available sensors, easily available at a low cost.

Over the years a variety of substances has been tried for leak detection purposes including radioactive tracers, carbon tetrachloride, freon and mercaptans. As of 1980, the most common tracer used for potable water mains was nitrous oxide gas, which was then replaced by suphur hexafluoride (SF_6), and then again with helium. Nowadays, practically all the gas-based leak detection kits available on the market use a non-flammable standard gas mixture of 5% hydrogen and 95% nitrogen (also known as *Forming Gas*), which is commercially available at a low price (about 5 €/m^3). Being the smallest element on Earth, on its way to the surface hydrogen can penetrate through all porous media such as mud, gravel, snow, concrete, asphalt and various types of tiles and cobble-stone paving.

[4] IWA Water Loss Task Force, (2007) "Leak Location and Repair. Guidance Notes" - International Water Association.

In large transmission mains, once the existence of a water loss has been confirmed and the system is pressurized with gas, gas-injection leak detection typically consists of two phases:

1) Sniffing of ground surface using bell probe (or carpet probe)
2) Where detected gas concentrations are higher, dig bar holes every 2 metres and pinpoint leaks using cone probe

Each phase implies the use of the instrumentation described herewith.

Tracer gas sniffer

The tracer gas sniffer is the detector that senses the hydrogen concentration and displays it on the operator's handheld unit, as he walks along the pipeline route.

Figure 1-10 From left to right – Probes (carpet, cone and bell type) and Sniffer handheld unit[5]

The sniffer is provided in kits comprising a bell probe (for preliminary sniffing of the ground surface), a carpet probe (for quick preliminary sniffing of large smooth surfaces), and a cone probe (for sniffing of bar holes). The latter is normally used to confirm the precise location of a leak following the preliminary sniffing of ground surface and prior to digging for repair: in the stretches where the preliminary sniffing has shown highest H_2 concentrations, bar holes are dug every 2 metres (to increase the detectable gas concentrations) and the measurement is repeated to identify the leak position at the bar hole showing the highest concentration.

[5] Sources: primayer.com; sewerin.co.uk.

Typical specifications of commercially available tracer gas sniffers are given below.

- Analysis bandwith up to 50,000ppm
- Sensitivity down to 0.1ppmH_2
- Response time 2-6s
- Operating time 8h

1.3.2.3 Precision of leak pinpointing

Gas-injection methods can potentially detect leaks of any size and with a higher detection rate (i.e. number of detected leaks / total leaks) than acoustic methods, thus avoiding costly guess work. In terms of precision of leak pinpointing, it depends on the pace at which the bar holes are excavated, so typically ±1m.

1.3.2.4 Potential limitations

Hydrogen has a low natural concentration (0.5 ppm) in ambient air. Still, the effectiveness of this method strongly depends on the weather conditions and wind direction (Black 1992; Furness and Reet 1998).

To carry out the sniffing procedure, there should be no obstructions preventing the operator from walking above and all along the pipeline route (which is not the case for acoustic correlation). When long water mains are to be inspected, this method inevitably becomes time-consuming.

Finally, in most applications the tracer gas will have to be injected within an isolated stretch of the pipeline, thus making this method unsuitable for systems where water supply cannot be disrupted.

1.3.3 Ground Penetrating Radar (GPR)

The Ground Penetrating Radar is a non-destructive and non-invasive near-surface geophysical method used for mapping the subsurface, that has primarily been used for the location and surveying of pipes, cables and other buried objects. Its applicability to leak detection is based on the principle that water leaks can be found by observing the disturbed ground or cavities around the pipe.

1.3.3.1 Range of application

Potentially, GPR can be applied wherever the acoustic methods are not suitable: environments with high background noise, non-metallic pipes, low pressure, etc. However, it shall be noted that GPR sensing is mainly applied for local investigations: GPR sensors are nadir-looking devices whose coverage is limited in space (i.e. very time consuming for large extent mapping operation).

1.3.3.2 Specifications

GPR waves in the frequency range of 10MHz to 2GHz are partially reflected back to the ground surface when they encounter an anomaly in dielectric properties, for example, a void or pipe. The time lag between transmitted and reflected radar waves determines the depth of the reflecting object.

An image of the size and shape of the object is formed by radar time-traces obtained by scanning the ground surface, so that leaks can be located either by detecting voids in the soil created by leaking water circulating near the pipe, or by detecting segments of pipe which appear deeper than they are because of the increase in the dielectric constant of adjacent soil saturated by leaking water.

GPR effectiveness depends on local soil conditions: some soils are transparent to GPR waves and others are not (e.g. salt content is a main parameter affecting waves propagation capacity). As a result, GPR exploration depth varies from area to area.

Promising frequency for water leak detection, representing a good trade-off between ground resolution and propagation capacity (the lower the frequency is, the better the penetration capacity is, but the worse the resolution is, and vice versa), ranges from around 200 to 400 MHz.

Figure 1-11 Ground Penetrating Radar device

1.3.3.3 Precision of leak pinpointing

The use of these technique is still very limited and its effectiveness is not as well established as that of acoustic and gas-injection methods.

1.3.3.4 Potential limitations

As of today, the single biggest factor that limits GPR application is the high cost.

Moreover, there should be no obstructions preventing the operator from walking above and all along the pipeline route (which is not the case for acoustic correlation). When long water mains are to be inspected, this method inevitably becomes extremely time-consuming.

1.3.4 Inline methods

Two main types of inline methods for leak detection exist: *Free Swimming* type (also known by its trademark *SmartBall*®) and *Tethered* type (*Sahara*®).

The Sahara system was the first of this methods and was first used in the early/mid 1990s and still is to this day with much success.

1.3.4.1 Range of application

Inline methods can be applied to any trunk main under pressure and larger than 150mm in size; provided that these conditions are met:

- for Smartball application, two access points of size 50mm or larger are required (one for insertion and one for extraction);
- for Sahara application, only one access point of size 50mm or larger is required (insertion and extraction points coincide).

According to the manufacturer, inline methods can identify leaks as small as 0.006 m^3/h i.e. about 10 times smaller than those detectable via acoustic methods.

1.3.4.2 Specifications

Both *Free Swimming* and *Tethered* leak detection methods are based on a noise recorder being deployed into the water within the pipe and using the velocity of the water to carry the equipment along.

SmartBall®

The SmartBall is a free-flowing tool of the size of a tennis ball, equipped with a highly sensitive acoustic sensor able to locate pinhole sized leaks and gas pockets in pressurized pipelines.

Figure 1-12 SmartBall® kit[6]

[6] Source: http://www.canadianbusiness.com/technology-news/leak-detector-is-on-a-roll/

The SmartBall is inserted into a pipeline and travels with the water flow for up to 24 km in length and a deployment runtime of up to 12 hours. It is tracked throughout the inspection at predetermined fixed sensors located along the pipeline route, which receive and store the data collected by the SmartBall.

Sahara®

The Sahara platform is a tethered tool equipped with a highly sensitive acoustic sensor able to locate pinhole sized leaks and gas pockets in pressurized pipelines. A small parachute uses the flow of water to draw the sensor through the pipeline while it remains tethered to the surface. This allows for realtime results and maximum control, as the tool can be moved back and forth using a winch system, to confirm suspected leaks.

Sahara can inspect up to 1.6km per each insertion. It is tracked above ground using sensors, which allow for the precise marking of leaks.

When coupled with a high-accuracy Global Navigation Satellite System (GNSS), the Sahara system can be utilized to gather GPS data points with sub meter accuracy to identify the location of the water main from ground level. Recent developments of the Sahara system have also equipped it with a camera and a light, which allow for realtime monitoring of internal pipeline conditions, detection of illegal connections and branches, and so on.

Figure 1-13 Engineers deploying the Sahara® tool inside a water main[7]

1.3.4.3 Precision of leak pinpointing

According to the manufacturer, Smartball can pinpoint leaks with an accuracy of less than 2m, while Sahara can even go down to 0.5m.

[7] Source: http://chinawaterrisk.org/opinions/more-than-pipe-dreams-non-revenue-water/

1.3.4.4 Potential limitations

The SmartBall is unsuited to branched systems and/or pipe network whose structure is not well known, as there is the risk of losing the equipment.

This limitation is not there for the Sahara, as it can always be winded back to the insertion point; its only limitation lies on the fact that there should be insertion points at least at every 1.6km from each other.

As already stated, being the inline methods based on acoustic principles, they are always inapplicable if water in the pipe is not under pressure.

Last but not least, the cost of inline methods is still very high compared to most leak detection techniques.

1.4 Inventory of satellite issued products

1.4.1 Competitor satellite-based techniques

Satellite-based remote sensing for leak detection represent the potential competitor of the WADI technique. The use of remote sensing for leak detection from underground water mains is not as new as one may think, as the first investigations into the use of this technique were undertaken jointly by the Water Research Centre and Plessey Radar Ltd back in 1977.[8]

Two main remote sensing techniques have been investigated:

- infrared thermography (a technique that forms an image based on differences in temperatures), and
- multispectral photography (a technique for capturing image data at specific frequencies across the electromagnetic spectrum).

Infrared thermography is based on the principle that water leaking from an underground pipe changes the thermal characteristics of the adjacent soil, for example by making it a more effective heat sink than the surrounding dry soil. Among the two techniques, it has so far proved to be the most effective, especially with the aid of computer analysis of thermal images and application of GPS systems (Williams et al. 1983; Weil et al. 1994).

[8] Technical Working Group on Waste of Water, (1985) "Leakage Control Policy and Practice" - Water Authorities Association.

However, the undetermined ambient conditions around the pipeline limit its application in urban areas.[9]

The efficiency of early application of remote sensing for leak detection was largely affected by factors such as weather/visibility conditions, type of vegetation, moisture content of surrounding ground and the position of shadows. Much improvement has been done thanks to technological development, however, as of now both infrared thermography and multispectral photography remote sensing for leak detection are still at a research and development stage and not yet established as market products. Results are promising though, and satellite systems equipped with thermal sensors and with a high resolution may possibly detect areas with leakage problems (Huang and Fipps, 2002; Agapiou et al., 2014).

Another technology, based on Satellite Aperture Radar (SAR), has made it to the market in the mid 2010s and is allegedly taking some hold among water companies. The SAR technology consists on ground-penetrating electromagnetic waves sequentially transmitted from a radar mounted on the satellite, while the reflected echoes are collected, digitized and stored for later processing. The data are subsequently filtered to remove the spectral signatures of manmade objects and vegetation, and to detect the spectral signature of water leaked out in the soil, which differs from that of natural groundwater. The results are then displayed on a user-friendly GIS report to indicate the presence of leaks. Service providers claim to have a turnaround time of about 7-8 weeks, and a precision of leak pinpointing of ±50m.

For analysis of large areas this technology is relatively cheap and allegedly not affected by weather or light conditions, however, according to interviewed customers, the detection rate is still not as satisfactory as that of traditional ground leak detection methods (see also Figure 1-14): at 0.006m3/h and 0.05m3/h (i.e. the minimum leak flow allegedly detectable via inline methods and acoustic methods, respectively) the calculated detection rate is barely 7 and 33%. The overall rate of false positives in real field applications is – in the best cases - around 50%.

Given its modest detection rate and high rate of false positives, this service is marketed as an “optimization tool” to better organize traditional ground leak detection activities, rather than a standalone service.

In conclusion, the use of non-invasive satellite-based leak detection appears particularly suited for long water mains, due to the great area extension that can be photographed and analysed at once (virtually thousands km^2); nonetheless, most of the current applications are done on distribution networks. The limitation of satellite issued products often lies on the long time needed to acquire the satellite images, which summed up to

[9] Wang, X.J., Simpson, A.R., Lambert, M.F. and Vítkovský, J.P. (2001). “Leak detection in pipeline systems using hydraulic methods: a review”. Conference on Hydraulics in Civil Engineering, The Institution of Engineers, Australia, Hobart, 23-30 November, 391–400.

the time for data processing may result in letting leaks run for long times before they are identified. However, this aspect seem not to be of much interest for most Water Utilities, which are instead more concerned with accuracy and precision of leak pinpointing.

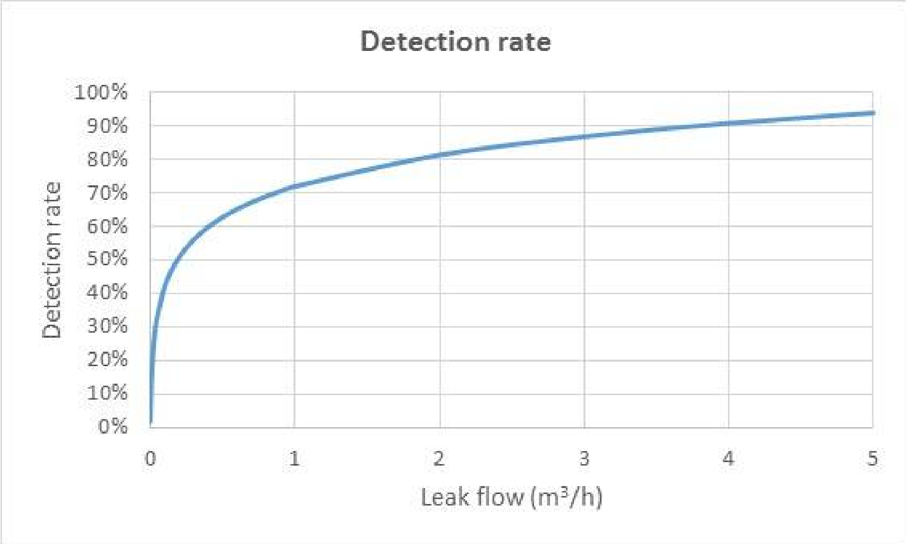

Figure 1-14 Detection rate as function of the leak flow, extrapolated from case study values

1.4.2 Satellite database for WADI land classification application

1.4.2.1 Requirement for WADI

The identification of the soil and vegetation types on the End User sites determines the possibility to provide an efficient WADI service use.

Several satellite databases provide a classification of land cover on a European wide scale (Eurostat data, Corine Land Cover, GISCO and ESPON).

Corine Land Cover database is an inventory of land cover in 44 classes and presented as a cartographic product, at a scale of 1:100000. This database is operationally available for most areas of Europe, and it will fully answer to the need of identification of soil and vegetation types for future WADI service.

1.4.2.2 Corine Land Cover (CLC) description

The Corine programme[10] was initiated in the European Union in 1985. Corine means 'coordination of information on the environment' and it was a prototype project dealing

[10] Extracted from http://www.eea.europa.eu/publications/COR0-landcover

with many different environmental issues. The Corine databases and several of its programmes have been taken over by the European Environment Agency (EEA).

Corine Land Cover is an inventory of land cover in 44 classes, and presented as a cartographic product, at a scale of 1:100000, with a minimum cartographic unit (MCU) of 25 ha and a geometric accuracy better than 100 m. This database is operationally available for most areas of Europe (39 countries). Original inventories are based on and interpreted from satellite imagery obtained from Landsat (5 and 7), SPOT 4/5, and now also IRS P6 and RapidEye[11].

The database is regularly updated and has a fast and an ergonomic user interface. The access to The Corinne Land Cover is free of charge and the use is open.

The European reference database is owned by GISCO, the European Commission geographical information system, which is a part of the European Statistic Agency, Eurostat. ETC/TE manages the Corine database (the production database) on behalf of EEA and delivers the updated database to GISCO every 12 months.

1.4.2.3 CLC Nomenclature

The nomenclature adopted by CLC is a 3-level hierarchical classification system and has 44 classes at the third and most detailed level.

The first level is divided into 5 categories[12]:

1) Artificial surfaces
2) Agricultural areas
3) Forest and semi natural areas
4) Wetlands
5) Water bodies

The categories belonging to the second and third level are reported in the following Table.

[11] http://land.copernicus.eu/pan-european/corine-land-cover

[12] http://www.igeo.pt/gdr/pdf/CLC200

Level 1	Level 2	Level 3
1 Artificial surfaces	1 1 Urban fabric	111 Continuous urban fabric 112 Discontinuous urban fabric
	1 2 Industrial, commercial and transport units	121 Industrial or commercial units 122 Road and rail networks and associated land 123 Port areas 124 Airports
	1 3 Mine, dump and construction sites	131 Mineral extraction sites 132 Dump sites 133 Construction sites
	1 4 Artificial, non-agricultural vegetated areas	141 Green urban areas 142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land 212 Permanently irrigated land 213 Rice fields
	22 Permanent crops	221 Vineyards 222 Fruit trees and berry plantations 223 Olive groves
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops 242 Complex cultivation patterns 243 Land principally occupied by agriculture, with significant areas of natural vegetation 244 Agro-forestry areas
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest 312 Coniferous forest 313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands 322 Moors and heathland 323 Sclerophyllous vegetation 324 Transitional woodland-shrub
	33 Open spaces with little or no vegetation	331 Beaches, dunes, sands 332 Bare rocks 333 Sparsely vegetated areas 334 Burnt areas 335 Glaciers and perpetual snow
4 Wetlands	41 Inland wetlands	411 Inland marshes 412 Peat bogs
	42 Maritime wetlands	421 Salt marshes 422 Salines 423 Intertidal flats
5 Water bodies	51 Inland waters	511 Water courses 512 Water bodies
	52 Marine waters	521 Coastal lagoons 522 Estuaries 523 Sea and ocean

Table 1-5 Corine Land Cover (CLC) nomenclature

1.4.2.4 Example of CLC application on WADI pilot site#1

The area that will be used for the demonstration task 3-1 is located between Marseille and Aix en Provence, in the south of France. The map in Figure 1-15 shows the SCP water network's section named 'VALTREDE' in blue colour.

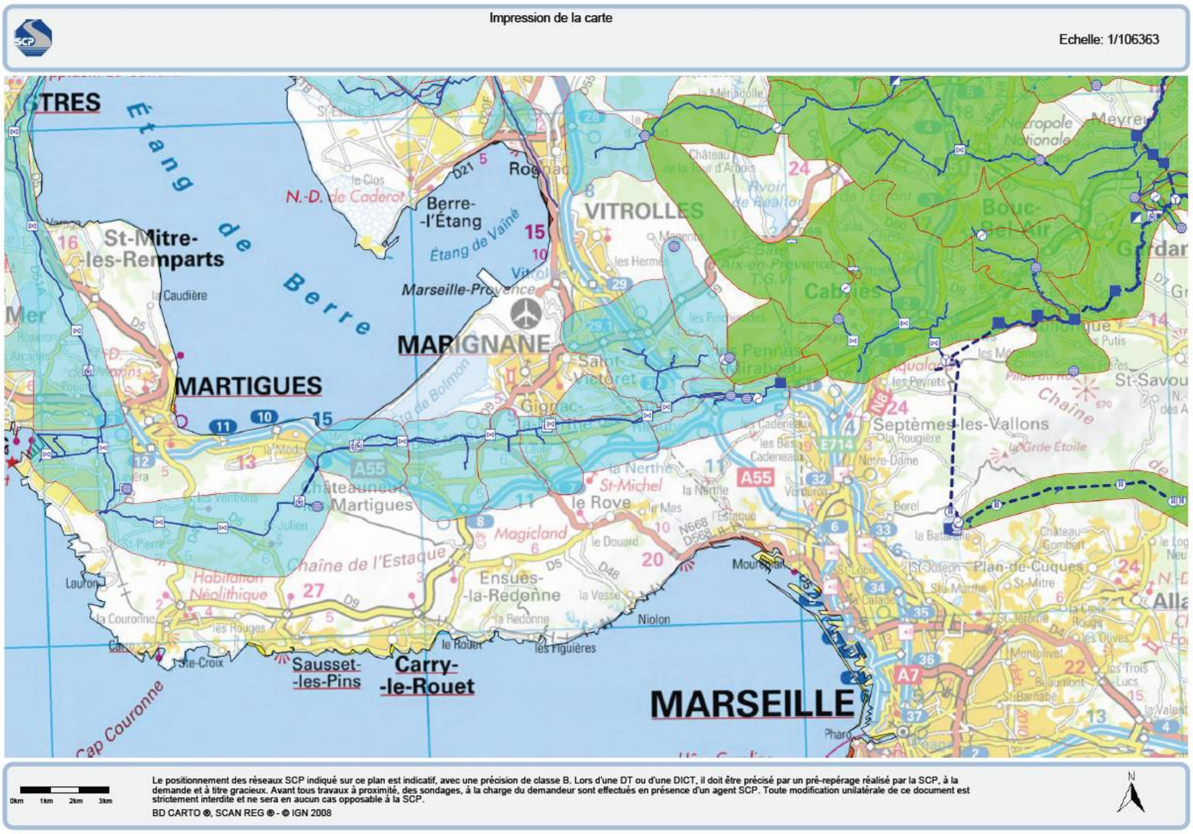

Figure 1-15 Map 1 – SCP water network's section named 'VALTREDE' (in blue colour)

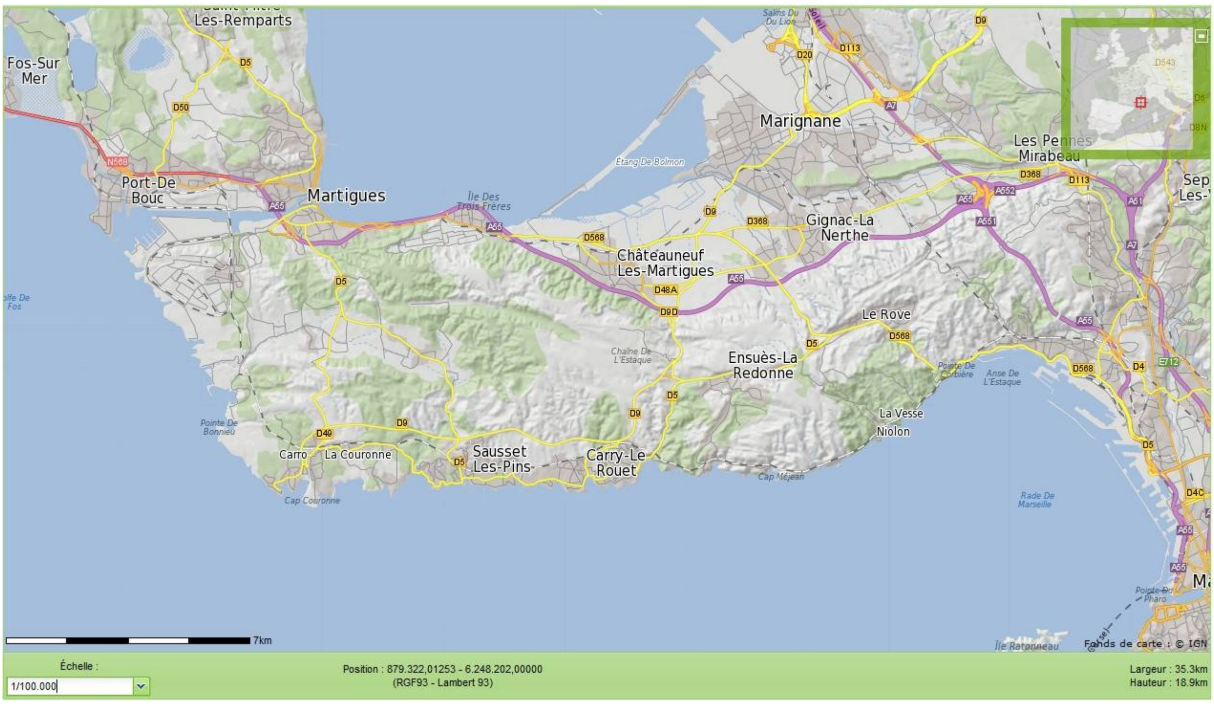

Figure 1-16 Map 2- Cartography map of the area between Aix en Provence and Marseille (France), without land classification

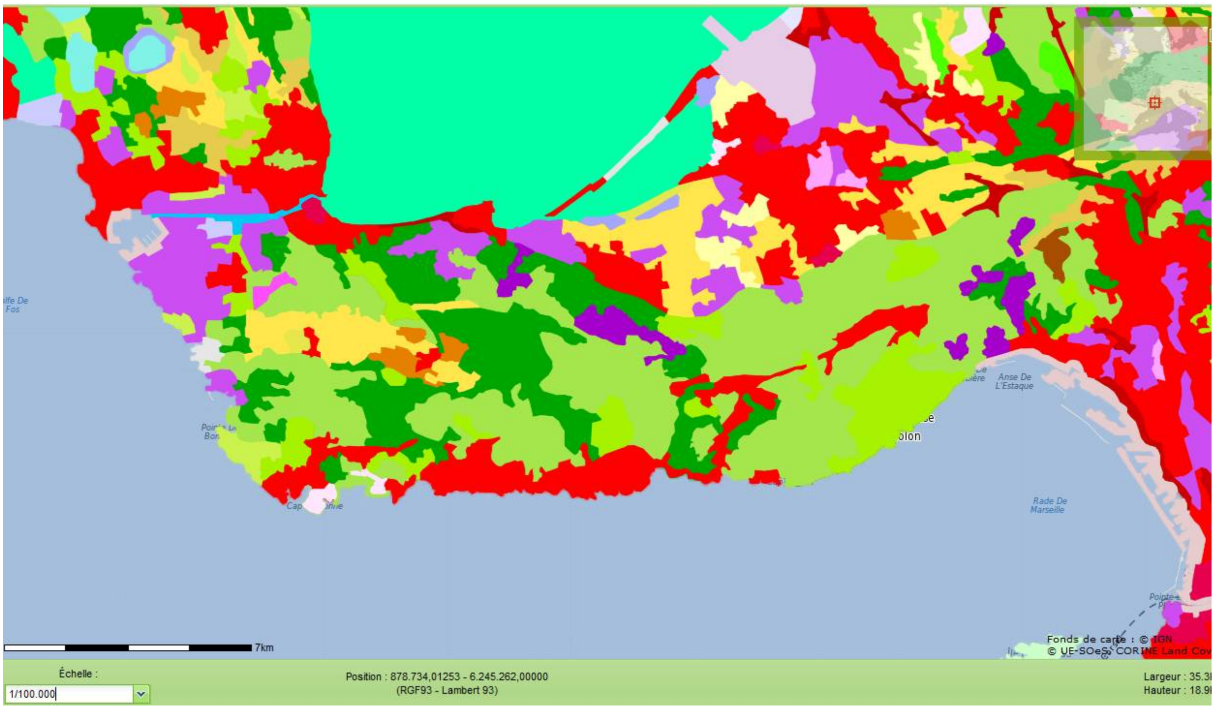

Figure 1-17 Map 3 - map of the area between Aix en Provence and Marseille (France), with land classification using French data-base access[13] (see colour code in Table 1-6)

The map colours refer to the colour code reported in Table 1-6: each colour is associated to one of the 44 CLC classes[14].

13 http://www.statistiques.developpement-durable.gouv.fr/clc/carte/metropole

14 http://image2000.jrc.ec.europa.eu/reports/technical_guide.pdf

Corine land cover classes

1. Artificial surfaces

- **1.1 Urban fabric**
  - 1.1.1. Continuous urban fabric
  - 1.1.2. Discontinuous urban fabric
- **1.2 Industrial, commercial and transport units**
  - 1.2.1. Industrial or commercial units
  - 1.2.2. Road and rail networks and associated land
  - 1.2.3. Port areas
  - 1.2.4. Airports
- **1.3 Mine, dump and construction sites**
  - 1.3.1. Mineral extraction sites
  - 1.3.2. Dump sites
  - 1.3.3. Construction sites
- **1.4 Artificial, non-agricultural vegetated areas**
  - 1.4.1. Green urban areas
  - 1.4.2. Sport and leisure facilities

2. Agricultural areas

- **2.1 Arable land**
  - 2.1.1. Non-irrigated arable land
  - 2.1.2. Permanently irrigated land
  - 2.1.3. Rice fields
- **2.2 Permanent crops**
  - 2.2.1. Vineyards
  - 2.2.2. Fruit trees and berry plantations
  - 2.2.3. Olive groves
- **2.3 Pastures**
  - 2.3.1. Pastures
- **2.4 Heterogeneous agricultural areas**
  - 2.4.1. Annual crops associated with permanent crops
  - 2.4.2. Complex cultivation patterns
  - 2.4.3. Land principally occupied by agriculture
  - 2.4.4. Agro-forestry areas

3. Forest and seminatural areas

- **3.1 Forests**
  - 3.1.1. Broad-leaved forest
  - 3.1.2. Coniferous forest
  - 3.1.3. Mixed forest
- **3.2 Shrub and/or herbaceous vegetation associations**
  - 3.2.1. Natural grassland
  - 3.2.2. Moors and heathland
  - 3.2.3. Sclerophyllous vegetation
  - 3.2.4. Transitional woodland shrub
- **3.3 Open spaces with little or no vegetation**
  - 3.3.1. Beaches, dunes, and sand plains
  - 3.3.2. Bare rock
  - 3.3.3. Sparsely vegetated areas
  - 3.3.4. Burnt areas
  - 3.3.5. Glaciers and perpetual snow

4. Wetlands

- **4.1 Inland wetlands**
  - 4.1.1. Inland marshes
  - 4.1.2. Peat bogs
- **4.2 Coastal wetlands**
  - 4.2.1. Salt marshes
  - 4.2.2. Salines
  - 4.2.3. Intertidal flats

5. Water bodies

- **5.1 Inland waters**
  - 5.1.1. Water courses
  - 5.1.2. Water bodies
- **5.2 Marine waters**
  - 5.2.1. Coastal lagoons
  - 5.2.2. Estuaries
  - 5.2.3. Sea and ocean

Table 1-6 Corine Land Cover colour code[15]

[15] http://www.eea.europa.eu/

2 End users' requirements for WADI technique

This section focuses on the determination of requirements for the WADI technique from both service users (water companies), airborne surveillance developers and service providers.

2.1 Service users (water companies)

The requirements for the WADI technique from the water companies have been determined through the dissemination of questionnaires to two project partners – *Société du Canal de Provence* (abbreviated to SCP, based in France) and *Empresa de Desenvolvimento e Infra-estruturas do Alqueva* (EDIA, Portugal). Additionally, three end-users committee (EUC) members have been involved - *Société Wallonne Des Eaux* (SWDE, Belgium), *Acquedotto Pugliese* (AQP, Italy), and *Cyprus University of Technology* (CUT, Cyprus).

2.1.1 Service users' questionnaires data processing

In order to collect the information needed at the present stage in the most complete and uniform possible way, two questionnaires (one focused on *Leakage Detection* and another focused on *Aerial Operation and Data Acquisition*) were prepared and disseminated to the following organizations:

- SCP - Société du Canal de Provence (France)
- EDIA - Empresa de Desenvolvimento e Infra-estruturas do Alqueva (Portugal)
- SWDE - Société Wallonne Des Eaux (Belgium)
- AQP - AcQuedotto Pugliese (Italy)
- CUT - Cyprus University of Technology (Cyprus).

Wherever possible, the collected information have been integrated through direct interviews and clerical data collection.

To overcome the fact that not all respondents could reply to each single question - due to temporary unavailability of data or else - the collected data have been processed to determine the service users' requirements as a "weighed average" of the given answers.

Subsequently, to prevent generation of excessively high level requirements - leading to an unreasonably expensive service - the service users' requirements have been scaled from a minimum acceptable to an ideal level.

The outcome of the data processing exercise is reported in paragraphs 2.1.2 and 2.1.3.

2.1.2 Required information

The water companies' requirements have been determined by the nature of needed information and the way of its presentation for decision-making (i.e. leak magnitude, area map and pictures, leak history etc.) as well as the level and accuracy of expected parameters.

The following Table reports the outcome of the data collection and processing as regards the required information.

Required information	Minimum acceptable level	Ideal level
Expected performance level of WADI compared to Ground leak detection methods	• Faster analysis of large areas (tens of km² per deployment) especially in difficult-to-access zones, requiring less manpower and lower costs	• Faster analysis of large areas (hundreds of km² per deployment) especially in difficult-to-access zones, requiring less manpower and lower costs • Estimation of leak flowrate • Higher precision of pinpointing • Improve leak detection in large transmission mains
Expected number of categories of leakage (as function of leak flow)	3 (low, medium, great)	5
Great leak flow	5 to 10m³/h	~4m³/h
Precision of leak pinpointing	5m (for a standalone leak detection method)	<1m
Operational information	• Location of leak (GPS coordinates) • Leakage category	Also include: • Aerial photo • Shooting date • Leak probability • Leak flowrate

Table 2-1 Information required by water companies from WADI

2.1.3 Required flight surveillance frequency and processed data release

The water companies' requirements have been determined by the definition of required flight surveillance frequency and the time in which processed data should be made available.

The following Table reports the outcome of the data collection and processing as regards the required flight surveillance frequency and processed data release.

Required flight surveillance frequency and processed data release	Minimum acceptable level	Ideal level
Expected services provided by surveillance	• Regular network monitoring • Checking after repair interventions	Also include: • Provision of recent aerial photos for update of GIS • Localization of inaccessible manholes • Identification of buildings above pipes • Leak detection on canals and evolution of cracks associated • Evolution of aquatic plants in canals
Infrastructures targeted by surveillance	Underground pipe network (buried at depth of 1m or more)	Also include: • Irrigation system • Canals
Frequency of surveillance	2-3 times per year	>4 times per year + in case of specific problems
Delay from surveillance operation to obtain results	1 week to 1 month	1 week

Table 2-2 Flight surveillance frequency and processed data release required by water companies from WADI

2.1.4 Stakeholders involvement

A number of stakeholders has been involved in the determination of the WADI end users' requirements, in particular five key stakeholders have been identified: SCP, EDIA, SWDE, AQP and CUT.

At the time of submission of this report, the degree to which each stakeholder has replied to the questionnaires differs as detailed in the following bulleted list:

- the two Project Partners – SCP and EDIA – have positively and thoroughly replied to both questionnaires;
- the EUC member SWDE has thoroughly replied to both questionnaires;
- the EUC member AQP has replied to both questionnaires, even though some questions had been left unanswered;
- the EUC member CUT has replied to both questionnaires though only partially, due to their nature of scientific researchers rather than end users.

Even though not all the requests of information have been satisfied, the general degree of stakeholders' involvement can be considered as good, excellent if referred to WADI partners only.

2.1.5 Beyond WADI (possibilities to extend the service to other related fields)

In order to contribute to the increase of WADI's potential for a significant technological impact, the possibilities to extend the service to other related fields have also been investigated and an inventory of pertinent applications has been drafted.

Considering the needs of the interviewed stakeholders, the possibility to extend the services of WADI beyond leak detection exists for the following applications:

- Provision of updated aerial photos;
- Localization of inaccessible manholes and other buried infrastructures;
- Evolution of aquatic plants in canals.

Other possible applications in the domain of water resources management - though not identified by the interviewed stakeholders - are:

- dikes surveillance;
- wetland restoration;
- emergency management in case of disasters.

2.2 Airborne surveillance developers

This task will be developed in the workpackage WP3.

2.2.1 Constraints imposed by airborne instrumentation

Airborne instrumentation and Flight characteristics for BUSARD Research Platform:

The STEMME S10-VT is a twin side-by-side seat self-launching sailplane by Stemme AG (Germany). It has obtained FAA certification on September 1997 (JAR22).

Figure 2-1 BUSARD Onera research platform

The motorglider is fitted with two composite exchangeable wing pods that can carry a range of radar or optical payloads. Each pod can accommodate up to 60 kg/80 liters payload + dedicated 1.5 kVA (28V) alternator for power supply of payloads.

Figure 2-2 FLIR A325 IRT camera mounted in the right pod

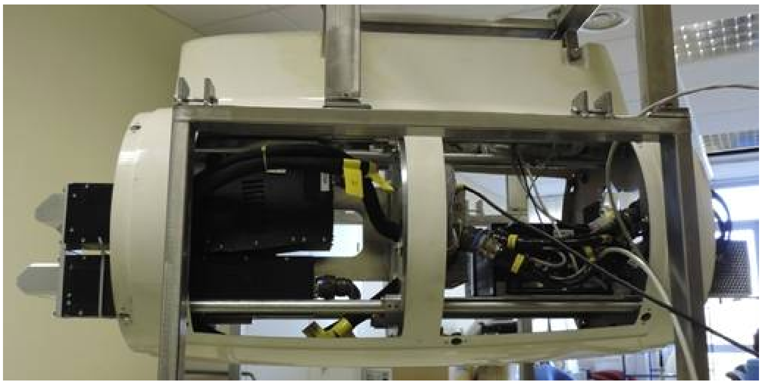

Figure 2-3 Hyspex VNIR and SWIR hyperspectral cameras integrated in the left pod

Aircraft and crew safety should comply with the following characteristics to operate the WADI acquisition system.

Characteristics	Ideal Level	Minimum acceptable	Maximum Acceptable
Crew	2 persons	2 persons	2 persons
Flight altitude	2625 Ft AGL (800 m from Ground Level)	500 Ft AGL (150 m)	12,000 Ft AMSL (3660 m)
Flight rules	VFR (Visual Flight Rules)	VFR	VFR
Acquisition speed	70 KTS (130 Km/H)	62 KTS (115 km/H)	108 KTS (200 Km/H)
Flight Range	300 km	NA	1200 km
Flight Duration	2.5 hours	NA	7 Hours
Max T-O & landing Weight	980 kg (Limited by Permit to Fly)	NA	Higher payload authorized (S10+pods) with special approval: 980 kg (VNE = 200 km/h)

Characteristics	Ideal Level	Minimum acceptable	Maximum Acceptable
Rate of climb	500 Ft/min (150m/min)	NA	1000 Ft/min (300m/min)
Available Energy	3000 W (28VDC)	3000 W (28VDC)	3000 W (28VDC)
Cameras Operating temperatures	NA	0°C	45°C

Table 2-3 WADI BUSARD characteristics acquisition system

2.2.2 Suitability to work under aeronautical stress conditions

2.2.2.1 Risks and consequences of aeronautical stress conditions on the WADI BUSARD Aircraft

Safety and security are some the most important aspects of aircraft industry. They are considered from the aircraft design to its use. Professional pilots are trained to measure and manage them daily.

ID	Criticity	Name	Description	Action	Prescription
1	High	Engine failure	The engine looses power	If possible, join the closest airport. If not emergency landing	Regular maintenance
2	High	Bird collision	A bird or any other flying object	If possible, join the closest airport. If not emergency landing.	The pilot must watch the sky Contact with ATC
3	Moderate	Out from flight envelope	Weather conditions are stronger than the airplane can handle	Return to the base	Get informed of the weather forecast before flight
4	High	Loss of Visibility	The crew lose visibility due to entering in a cloud	Apply IFR (Instrument Flight Rules)	Watch the sky
5	Moderate	Desease	One of the crew member feels seek	Depending of the seekness level. In the worst case return to the base	
6	Moderate	Hyperspectral or IRT camera failure	Malfunction of the optical sensors or acquisition systems	In the worst case return to the base	Ground tests before flight
7	Moderate	High wind speed	Wind speed > 30 km/h	Take-off impossible	Check weather forecast before flight

ID	Criticity	Name	Description	Action	Prescription
8	Moderate	Weather conditions	Presence of cirrus clouds or cloud cover > 2 oktas	Processing of hyperspectral data not possible	Check weather forecast before flight

Table 2-4 WADI BUSARD operation risks

Frequency	Risk Level				
	Insignificant	Minor	Moderate	Major	Catastrophic
Likely					
Moderate	5	4	7; 8		
Unlikely		3			
Rare			6		
Exceptional				1; 2	

Table 2-5 Risks Level/Frequency reference list

2.2.3 Compatibility of sensor data with an on-board exploitation, flight range

The definition of optimal wavelength and cameras will be done in the task 3.1. ONERA's aerial platform called Busard (motorglider) will be instrumented by two hyper-spectral imaging devices and one IR imaging device. All the optics sensors used in this task are compatible with an on-board exploitation on the Busard platform.

The muti-spectral cameras running at the optimized wavelength defined under the the task 3.1 will be selected according to requirements elaborated in WP2 and onboard platform constraints (onboard computing system, inertial platform, integration console).

The compatibility of sensor data of the wadi prototype with an on-board manned aircraft will be done in the task 3.2 and tested and validated during a flight.

2.2.4 Weather conditions acceptable for WADI's two flying platform

2.2.4.1 Weather conditions acceptable for BUSARD aircraft and optical sensors

Flights can be performed when weather conditions fit with the BUSARD flight envelope and optical sensor constraints. However, the flight crew is the only one to decide if the mission can start according to flight safety.

Weather condition (maximum wind, rain, fog, snow …)

- Flights have to be performed under VFR (Visual Flight Rules).
    - o The minimum horizontal visibility must be at least 10 kilometres, throughout the area of operation.

  - The minimum vertical weather visibility should be upside the flight level. Cloud-free below 6500 feet(2000 meters) throughout the flight area.
  - However, no cloud is accepted between the aircraft and the ground.
- Wind conditions under the maxima established by the S10-VT manufacturer: maximum 30 km/h cross wind on the runway.
- Absence of precipitation.
- Absence of cirrus clouds.
- Amount of uniform cloud cover: less than 2 oktas
- Temperature condition min and maximum: 0°C ~ 45°C.

Conditions	Ideal Level	Minimum acceptable	Maximum acceptable
Wind speed	0 KTS	NA	16 KTS (30Km/H)
Horizontal visibility	Horizon	10 Km	NA
Ceiling	None	No cloud	NA
Sunshine	Sunny	Sunny	NA

Table 2-6 Weather conditions acceptable for BUSARD motorglider

2.3 Airborne service providers

2.3.1 Constraints imposed by airborne instrumentation

2.3.1.1 Airborne instrumentation and Flight characteristics for Manned Aircraft

The P1006T is an Italian high-winged, four seats and twin engines aircraft built by Costruzioni Aeronautiche Tecnam. It is certified by EASA and Federal Aviation Administration.

Figure 2-4 Air Marine TECNAM Aircrafts

Aircraft and crew safety require to follow the following characteristics to operate the WADI acquisition system.

Characteristics	Ideal Level	Minimum acceptable	Maximum Acceptable
Crew	2 persons	2 persons	2 persons
Flight altitude	800 ft AGL (250 m from Ground Level)	500 ft AGL (150 m)	3300 ft AGL (3050 m)
Flight rules	VFR (Visual Flight Rules)	VFR	VFR
Acquisition speed	120 KTS (220 km/h)	80 KTS (148 km/h)	130 KTS (240 km/h)
Flight Range	215 NM (400 km)	NA	215 (400 km)
Flight Duration	4 hours	NA	4 Hours
Takeoff Weight	900 kg	NA	1180 kg
Rate of climb	500 ft/min (150m/min)	NA	1000 ft/min (300m/min)
Available Energy	12V - 40A	12V – 40A	12-40A
Operating temperatures	NA	-5°C	45°C

Table 2-7 WADI aircraft characteristics acquisition system

Constraint on payload:

- Volume
- Height
- Weight (kg)
- Center of gravity location
- Maximum power supply (voltage, ampere)
- Spectrum of Vibration and stress compliance
- On board temperature and humidity rate compliance

2.3.1.2 Airborne instrumentation and Flight characteristic for RPAS

Figure 2-5 WADI fixed-Wing RPAS

Number of on board operator:

- One.

Range of altitude and speed as a function of altitude:

- Flight maximum altitude.
- Ceiling: 3000 m AMSL.
- Can be via software configured to comply with the corresponding national normative.

Cruise and maximum operational speed:

- Design cruise speed: 50 km/h.
- Maximum operating limit speed: 75 km/h.

Normal and maximum lift speed:

- Normal lift speed: 4 m/s.
- Maximum lift speed: 5 m/s.

Normal and maximum descent speed:

- Normal descent speed: 4 m/s.
- Maximum descent speed: 6 m/s.

Flight duration (standard conditions):

- 45 min

Frequency of flight by day or week:

- It could be used all times needed respecting the aircraft maintenance procedures stablished by the RPAS manufacturer.

For UAV (distance from ground monitoring station):

- According to national regulations (Max 500 m).

Accuracy to fly over the same area / on the same path airborne service constraints:

- Provided by navigation instruments (GNSS+IMU), +- 3 m DRMS.

2.3.2 Suitability to work under aeronautical stress conditions

2.3.2.1 Risks and consequences of aeronautical stress conditions of the WADI Manned Aircraft

Safety and security are some the most important aspects of aircraft industry. They are considered from the aircraft design to its use. Professional pilots are trained to measure and manage them daily.

The main risks and the likely frequency of each risk associated to WADI Manned Aircraft operation are reported in Table 2-8 and Table 2-9, respectively.

ID	Criticity	Name	Description	Action	Prescription
1	High	Engine failure	The engine lose power	If possible, join the closest airport. If not emergency landing	Regular maintenance
2	High	Bird collision	A bird or any other flying object	If possible, join the closest airport. If not emergency landing.	The pilot must watch the sky
3	High	Aircraft stalling	The airplane loose altitude whereas the attitude is good	Increase power engine	The pilot looks frequently its avionic instrumentation
4	Moderate	Out from flight envelope	Weather conditions are stronger than the airplane can handle	Return to the base	Get informed of the weather forecast before flight
5	High	Loss of Visibility	The crew loses visibility due to entering in a cloud	Apply IFR (Instrument Flight Rules)	Watch the sky
6	Moderate	Desease	One of the crew member feels seek	Depending of the seekness level. In the worst case return to the base	

Table 2-8 WADI aircraft operation risks

Frequency	Risk Level				
	Insignificant	Minor	Moderate	Major	Catastrophic
Likely					
Moderate	6	5			
Unlikely		4			
Rare				3	
Exceptional				1; 2	

Table 2-9 Risks Level/Frequency reference list

2.3.2.2 Risks and consequences of aeronautical stress conditions of the WADI RPAS

The main risks and the mitigation factors associated to WADI RPAS operation are listed hereinafter.

1) Gravity centre displaced: Some parts of the RPAS will be removable in order to make more comfortable transportation to each workplace. This can cause that

gravity centre not to be assembled in the correct position, which causes the attitude of the aircraft to be incorrect.

Mitigations factors:

a) Before starting each flight, the pilot must check that the correct gravity centre of the aircraft.

b) In order to facilitate this work to the pilot, it will be assisted of marks previously fixed in the RPAS for each component.

c) All components shall be fixed as indicated in the aircraft maintenance manual, so they cannot be detached during the flight.

2) Control servos or Horns breakage.

Mitigation factors:

a) With correct use of the Maintenance Manual, it can be very simple to detect a fault in the system.

b) Servos have a very long service life, besides, we can detect easily a failure of these components following a maintenance program.

3) Attachment between wings and fuselage breakage.

Mitigation factors:

a) The life of that material is specified in the Maintenance Manual and how much time needs to be replaced, whether it has been used or not.

b) The pilot, with a visual inspection before each flight must check the degree of deterioration the attachment.

4) Wings or fuselage lining breakage: Such situations occur in the event of an emergency landing or a collision with an object.

Mitigation factors:

a) After any incident a review of all components of the aircraft will be carried out to ensure the correct operation on the following flights.

b) The pilot must decide whether the breakage can be fixed in the field or if it should be transferred to some facilities for its completion.

5) Electric motor failure. WADI RPAS fixed wing only has an engine, a failure in this assumes the immediate termination of the flight.

Mitigation factors:

a) The pilot is trained to perform emergency manoeuvres without motor, only controlling the RPAS moving parts.

b) Detecting a motor failure is relatively simple following a checklist, in which before each flight, it is checked the power of the engine and unusual noise.

6) Electronic speed controller failure. WADI RPAS fixed wing only has an ESC, a failure in this assumes the immediate termination of the flight.

   Mitigation factors:

   a) The pilot is trained to perform emergency manoeuvres without motor, only controlling the RPAS moving parts.
   b) Although the ESC fails, it is prepared to continue supplying a minimum of power to the control system, so control of the aircraft will not be completely lost.

7) Engine Battery failure.

   Mitigation factors:

   a) The pilot is trained to perform emergency manoeuvres without motor, only controlling the RPAS moving parts.
   b) Although the ESC fails, it is prepared to continue supplying a minimum of power to the control system, so control of the aircraft will not be completely lost.
   c) In case of a complete loss of control of the RPAS, its design allows it to plan and progressively loose altitude. RPAS can be recovered since its last position is known.

8) Video link feed failure.

   Mitigation factors:

   a) The pilot is trained to conduct third person flights, so in case of video link feed failure, the pilot can continue with the flight and make a smooth landing.
   b) The pilot is trained to perform emergency manoeuvres without motor, only controlling the RPAS moving parts.
   c) Although the ESC fails, it is prepared to continue supplying a minimum of power to the control system, so control of the aircraft will not be completely lost.
   d) In case of a complete loss of control of the RPAS, its design allows it to plan and progressively loose altitude. RPAS can be recovered since its last position is known.

2.3.3 Compatibility of sensor data with an on-board exploitation, flight range

This task will be will be achieved in the WP3.

2.3.4 Weather conditions acceptable for WADI's two flying platform.

2.3.4.1 Weather conditions acceptable for Manned aircraft

Flights can be performed when weather conditions fit with the airplane flight envelope. However, the flight crew is the only one to decide if the mission can start according to flight safety.

Conditions	Ideal Level	Minimum acceptable	Maximum acceptable
Wind speed	0 KTS	NA	30 KTS (55km/h)
Horizontal visibility	Horizon	5 km	NA
Ceiling	None	1000 ft AGL (300m)	NA
Sunshine	Sunny	Rain	NA

Table 2-10 Weather conditions list

2.3.4.2 Weather conditions acceptable for RPAS

The weather conditions acceptable for RPAS are listed hereinafter.

1) Flight has to be performed under VFR (Visual Flight Rules). The minimum horizontal visibility must be at least 5 kilometres, throughout the area of operation, which is required for visual flight in G class airspace, on flights with a height equal to or less than the highest 900 meters AMSL or 300 meters AGL.
2) The minimum vertical weather visibility should be 500 feet (150 meters) AGL, throughout the area of operation. Cloud-free below 500 feet throughout the flight area.
3) Wind conditions below the maxima established by the RPAS manufacturer: 50 km/h and maximum 65 km/h (2 m AGL).
4) Absence of precipitation.
5) The aircraft must be visible to the pilot in all phases of the flight (line of sight) in VLOS conditions and up to a distance of 500 meters from the pilot.
6) Temperature condition max and minimum: -5°C ~ 45°C.

3 Definition of demonstration scenarios and risk analysis

WADI scenarios will be fully reviewed and defined at the beginning of the workpackages WP5 and WP6. At this step of the project, only the description of the global approach of the scenarios is provided.

3.1 Innovative airborne remote sensing adapted to WADI

3.1.1 Principle of WADI's Innovative airborne remote sensing

The efficiency of soil moisture measurements using airborne hyper-spectral cameras has been successfully demonstrated (see Section 1.2) but their use requires a specific know-how, an expensive hyperspectral camera, a complex data processing and a high computing power, which represent a barrier for WADI market deployment.

The WADI innovation principle is to get the same benefits as hyper-spectral, without any disadvantage and using affordable, scalable, robust instrument compatible with smart data processing.

This possibility is offered by the two methods described in Sub-Section 1.2.1 (reflectance variation and triangle methods) which use few (3 or 4) detection wavelengths associated to thermal infrared measurements. The efficiency has been proved but the optimization of the wavelengths detection as a function of the dedicated application is required.

3.1.2 The WADI's innovative concept implementation

The concept implementation requires:

- The determination of the optimized detection wavelengths in the VNIR – SWIR optic domain, depending on water leak detection in WADI's case (task 3.1)
- The selection of the most suitable, existing (off-the-shelf) cameras running at the defined wavelengths
- The purchase of selected cameras and associated equipment (task 3.1) taking into account all relevant end user requirements and technical constraints as defined in Section 2
- The integration and assessment of airborne prototype instruments (task 3.2)
- The demonstration of water leak detection service (both manned and unmanned) by deploying the prototype in operational test condition on the two pilot sites (WP5 and WP6).

3.1.3 Optimized wavelengths determination process

The wavelengths determination process will involve the ONERA's aerial platform called Busard (motorglider), equipped with the two hyper-spectral imaging devices coupled with an IR camera. The measurement campaign will be carried out under task 3.1, on the water network infrastructure of Société du Canal de Provence (SCP).

The mission plan and scenario dedicated to this specific test campaign results from a trade-off between several parameters such as: end users' requirements, the water network configuration, flight constraints, onboard instrument constraints (see Section 2.3) and the measurement strategy. These parameters are described in Table 3-1.

Water companies end users' requirements	Complementary End Users' requirements for WADI technique (see Table 2-1 and Table 2-2 in Section 2.1)
The water network configuration and environmental condition	• Nature of the network pipe and water leak • Ground measurement available for validation • Soil/vegetation classification • Nearness to Airport/town, industrial site.
Flight constraints	(see Section 2.3) • Range of altitude and speed as a function of altitude • Weather condition (maximum wind, rain, fog, snow, ...) • Temperature condition max and minimum • Flight duration • Frequency of flight by day or week • Distance from ground monitoring station (for UAV) • Accuracy to fly over the same area / on the same path • Authorization procurement
Onboard Instrument constraints	• On board constraints • Instrumental configuration
Measurement strategy	Possible need of multi-temporal measurements, calibrated or reference scene,...) related to the measurement observed (anomalous vegetation, soil moisture, thermal effect, soil surface structure,...)

Table 3-1 Parameters for mission plan

3.2 Principles of scenario definition and outline of mission plans

WADI technique and service will be applied in an operational environment represented by two pilot sites (WP5 and WP6), in France and Portugal, characterized by a range of conditions regarding the infrastructure type and age, water uses, accessibility, soil and plant cover type etc. This variety of conditions constitutes an excellent test bed for WADI technique and service, providing an ideal opportunity to demonstrate its full potential in real settings to end-users - as two of the partners are SCP and EDIA - and validate the results.

3.2.1 Strategy for Demonstration

An overview of the strategy for demonstration is shown in Figure 3-1. The process flow of the "Strategy for Demonstration of Airborne Innovative Techniques" and of the "Strategy for Validation and Operational Demonstrations" is schematized in the following Figure 3-2 and Figure 3-3, which illustrate the inputs/outputs.

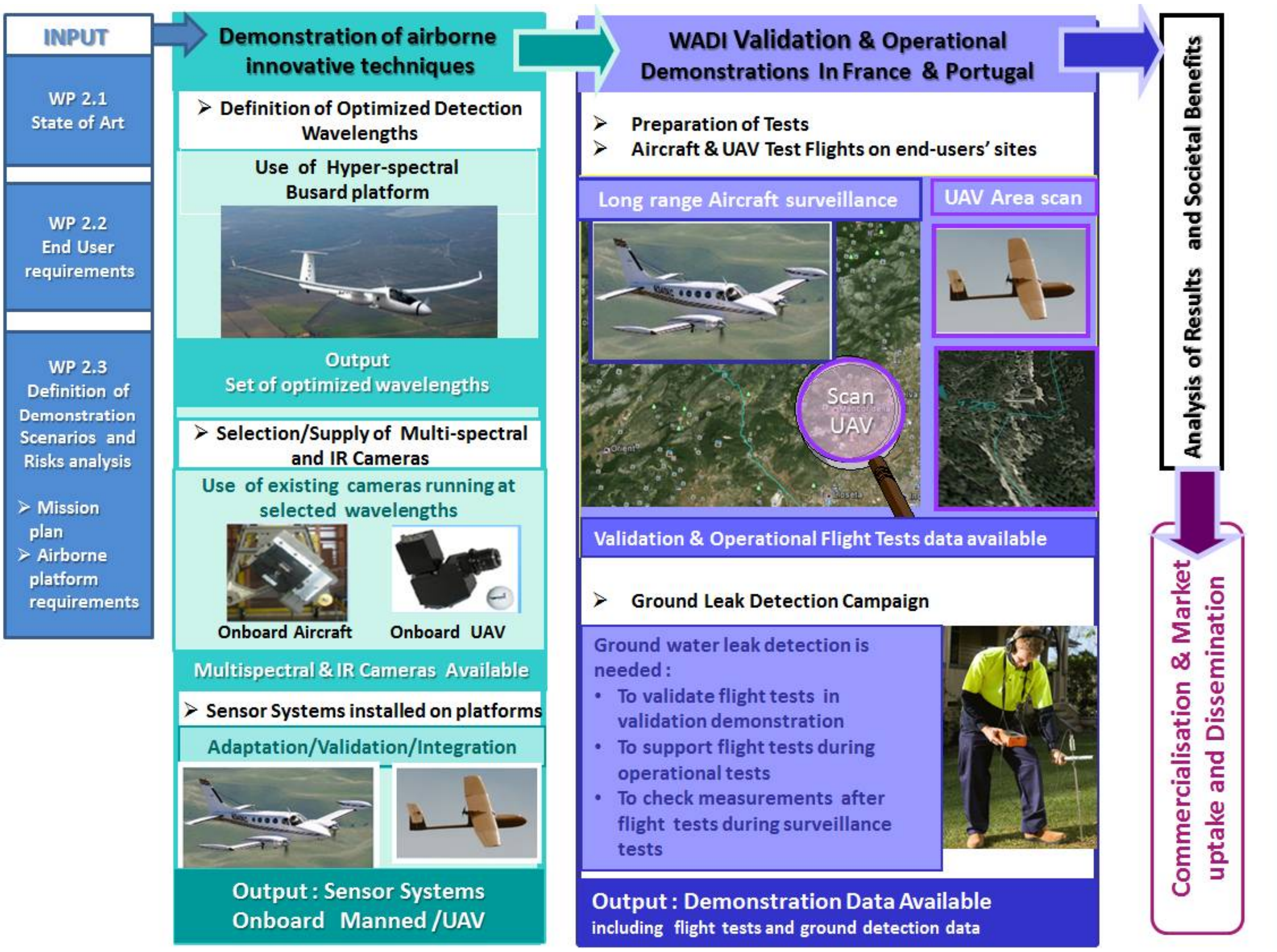

Figure 3-1 Overview of demonstration strategy

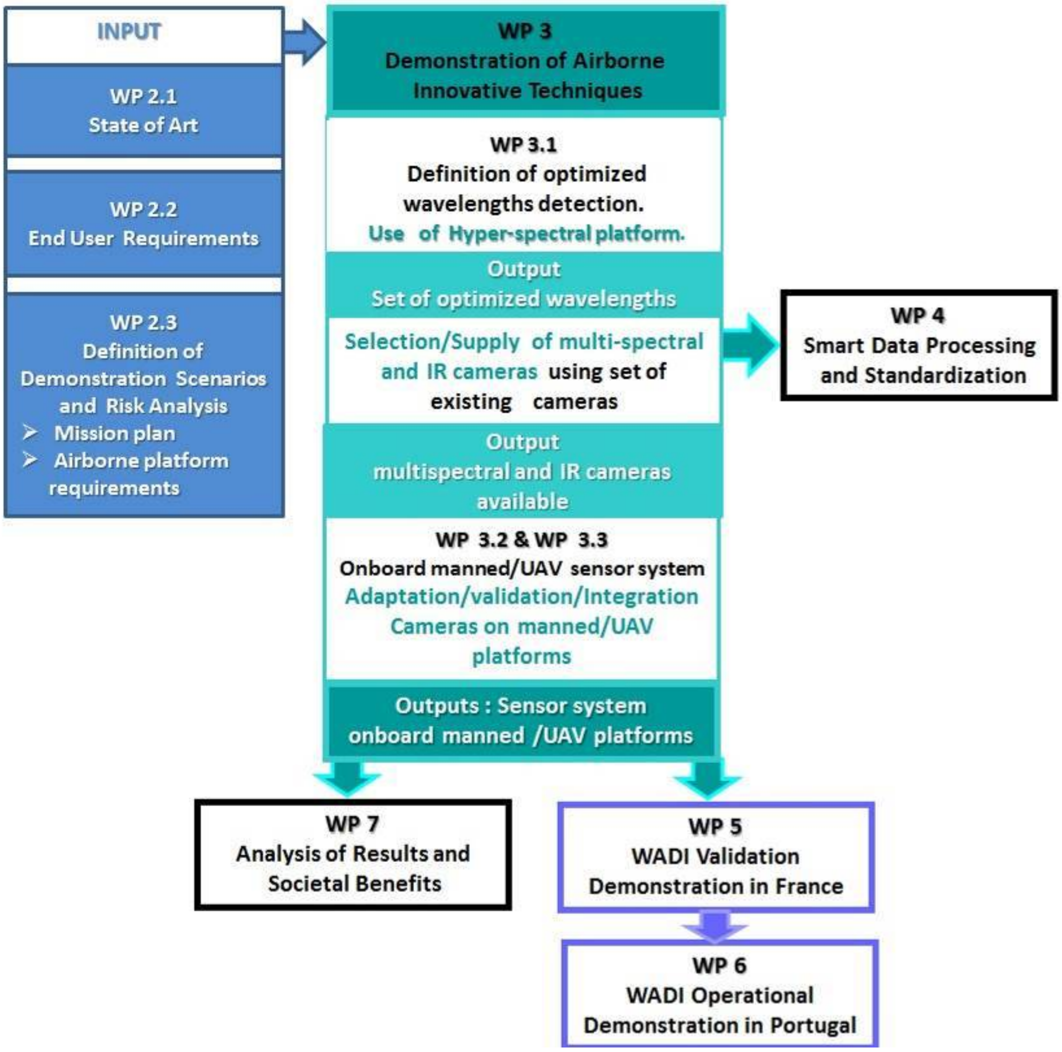

Figure 3-2 Strategy for Demonstration of Airborne Innovative Techniques

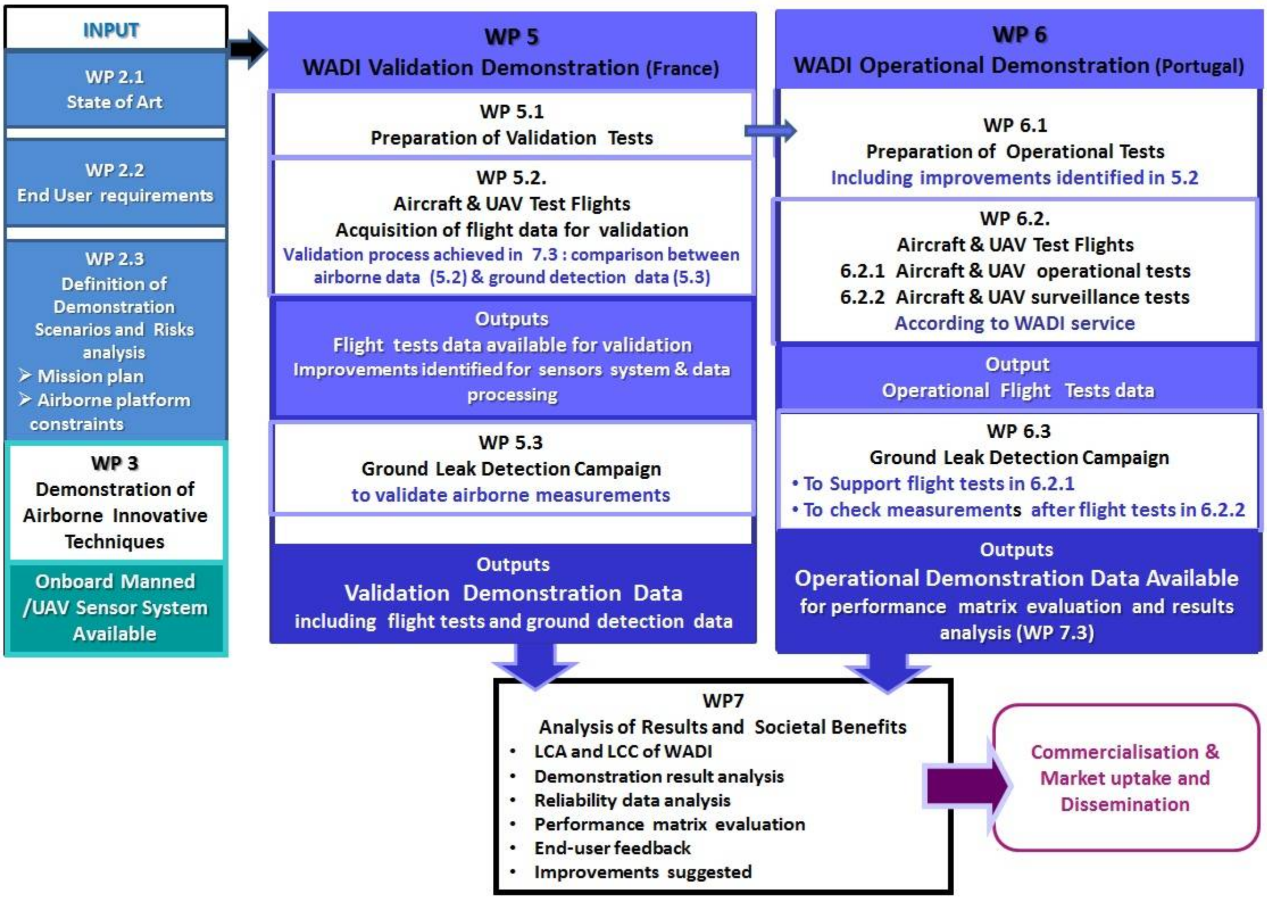

Figure 3-3 Strategy for Validation and Operational Demonstrations

3.2.1.1 Mission Plan for Manned Aircraft demonstration

Preliminary

- Onboard integration done
- Training of the crew to the acquisition system done
- First test flight at Air Marine's facility done

Before mission starts

Each mission is planned and prepared in advance (D is the first day of the planned mission):

D-90:

- Identification of the area to overfly and evaluation of the flight time required to realize the mission
- Resources (aircraft, onboard system and crew) booking and re-booking in case the first attempt didn't work (Weather forecast, system failure, etc.).
- Selection of the best area to establish a departure place

D-60: Flight plan preparation and launching of the derogation process (in case the mission the flight plan require to fly through a regulated zone)

D-30: Pre-test flight with the system to ensure it is working.

D-15: Validation of every demand of derogation.

D-3: Weather forecast checking. The aircraft can fly 99% of the time but the WADI system must comply with the weather conditions

D-1: Sending of the flight plan to the authorities (if necessary).

Arrival of the aircraft and crew at the mission area

D:

- Briefing with local and technical partner before launching the first acquisition mission
- Weather forecast checking. The aircraft can fly 99% of the time but the WADI system must comply with the weather conditions
- Ensure aircraft and system are ready to work
- Launching

From the moment the mission starts

(H is the launching time)

H 0:

- Preflight check list and flight crew briefing
- Turning on WADI system

H 0: Take off and reach of the starting point of the acquisition mission

H 0:

- Launching of the acquisition process
- First review of the collected data

Inflight:

- Pilot follow-up of the water transmission systems (using a 2D moving map with infrastructure and real time aircraft position)
- Onboard "Airmon" operator can ask to the pilot to overfly a part of the infrastructure (e.g. in case of sharp turn)
- Time duration: infrastructure elongation or flight time limit)
- Altitude = [600 ft – 800 ft]

H+4 (flight time limit):

- Landing back to the airport
- Data backup
- Data delivery

3.2.1.2 Mission Plan for RPAS demonstration

Checks to perform at mission day-3 (MD-3)

1) Three days before the mission you should check the weather conditions forecast for the area you want to operate into. You also need good visibility conditions for take-off and landing. You should also re-check the weather conditions at MD-2, MD-1 and at mission day.
2) You should also check that all the material is in good conditions (structure and avionics). Perform a visual inspection for the structure and a system start up to verify that the system is fully operational.
3) For the payload checks see the user manual for the payload.

Mission planning (between MD-3 and MD-1)

Prepare a mission plan adapted for the weather conditions and the mission you want to carry out. You should be particularly cautious when planning the mission, in fact, the compliance with the regulation and the safety depends on it.

General recommendation for the operator/pilot (between MD-3 and MD)

⚠ Drugs (including alcohol) consumption for the operator/pilot is forbidden. He/she should also be in good resting conditions.

Mission preparation at MD-1

1) Charge all the system batteries,
2) Put the plane into its container
3) Prepare the toolbox case
4) Prepare a bag with sunglasses, water, and a baseball hat for the operator/pilot.
5) Charge all the material into your transport vehicle

Transport recommendations

⚠ The transport container and the suitcase are designed to reduce vibration and shocks faced by the plane and the ground station during the transport. Nevertheless, during the transport of the drone system, avoid driving at full speed in a pothole or on a speed bump, braking or turning sharply and, more generally, avoid strong shocks.

⚠ If during the transport you need to park your transport vehicle, look for a parking place in the shade. NB: The maximum allowed temperature inside the container and the suitcase is 50° Celsius (122°Fahrenheit).

Preparation of the launching site at mission day (about 25 minutes)

1) Unload your transport vehicle
2) Assembly the catapult in a place where there are no obstacles (e.g. trees, buildings, antennas etc.) in a 50 m radius
3) Put the catapult as much as possible upwind, with no obstacles within 200 m in a 90 degrees’ cone

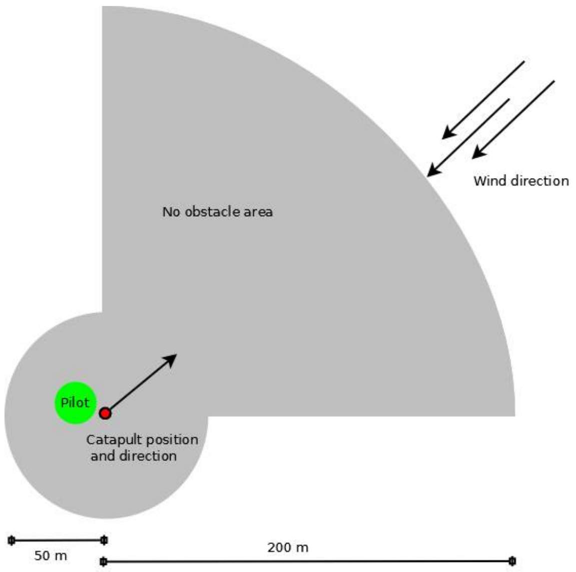

Figure 3-4 Take off site

4) Check the horizontal level of the catapult with a spirit level, adjust if needed.
5) Uncase the plane.
6) Assembly the plane.
7) Position the ground station suitcase in a place out of the rain, and if possible in the shade.
8) Charge the catapult.
9) Load the plane on the catapult, and lock it with the safety pins.

System start-up (about 5 minutes)

The system start sequence is made up of five phases:

1) Initial state preparation
2) Computer start
3) Datalink start
4) Plane start
5) System start-up verification

⚠ To correctly perform the system start-up you should wait for one phase to be finished before starting the following phase. If you fail in following the nominal start-up sequence you should re-perform the system start sequence from the very beginning.

The system start sequence is terminated.

Engine start-up

1) Perform the engine start-up

2) Apply full throttle to check the RPM stability

Take off

1) Check that
    a) The catapult is armed and locked, positioned upwind
    b) The plane is locked in the trolley
    c) The system is running
    d) The engine is idle
2) Remove the security pins (the catapult is no longer locked)
3) Apply full throttle during a few seconds, then pull the catapult trigger keeping full throttle
4) During the first seconds of the take-off, put the aircraft on a straight line trajectory on a steep climb keeping full throttle
5) After the take-off, put the aircraft on a straight and level flight path, preferably facing the wind, gradually reducing the throttle to reach the cruise level
6) If necessary, adjust the trims on the transmitter so the plane stays straight and level with no input
7) Switch the system in automatic flight mode.

Automated flight supervision

Landing

1) Verify that there are no obstacles in a 150x50m area, the axe of the area as much as possible in the axe of the wind
2) The pilot should target the landing area (50x20m) inside the no obstacle area

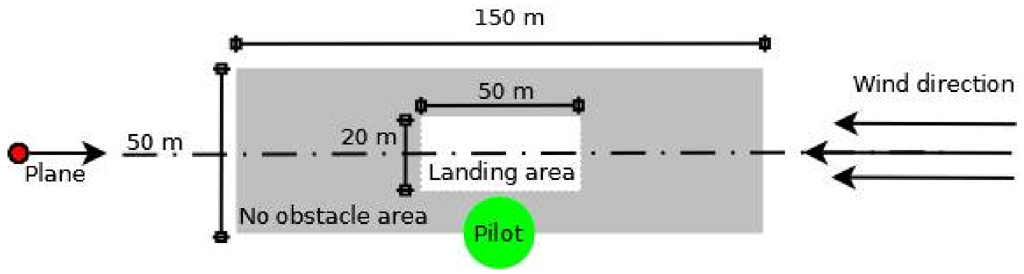

Figure 3-5 Landing site

3) Place the plane in an approach cone upwind, using the engine speed to control the descent rate (i.e decrease/increase the engine speed to increase/decrease the descent rate)

4) When the plane is at 1 meter height do the landing flare (the nose of the plane is raised, slowing the descent rate, and the proper attitude is set for touchdown): put the elevator stick in full nose up position.
5) Once the plane landed, switch off the engine
6) Switch off the system
7) Transport the drone from the landing point to the transport vehicle
8) Disassemble the drone, put it into the transport container, load the transport vehicle.

3.2.1.3 Requirements and constraints

- Water provider End user requirement
- Airborne service provider end use requirement
- Sensor onboard constraint (will be defined in WP3)
- Water Site Knowledge
- Knowledge of soil and vegetation of the site and climate data
- Possible access by ground for water leak validation using ground water leak detection system

3.2.1.4 Flight constraint and measurement strategy

Due to physical effect observed for water leak detection and prototype measurement system defined (ref. work to perform in WP3)

3.2.1.5 Three demonstration cases

1) Demonstration of airborne service (WP3),
2) validation demonstration (in France),
3) operational demonstration (in Portugal).

3.2.2 Mission plan for the demonstration in the project's pilot site#1

<table>
<tr><td>Pilot site:
Provence region, France</td><td rowspan="3"> </td></tr>
<tr><td>Provider of demo site:
Société du Canal de Provence</td></tr>
<tr><td>Purpose:
Multipurpose water infrastructure in rural and suburban areas</td></tr>
</table>

Description:
Société du Canal de provence (SCP) operates and maintains a large scale hydraulic infrastructure totaling 5,500 km of canals, galleries and pipes over a territory of 31,400 square kilometers. Its infrastructure delivers water for cities, industries and irrigation. The pilot sites will be chosen according to different characteristics: efficiency, type and age of pipes, environment, … The presence of more than 250 flow meters allows SCP to evaluate a global efficiency ratio in addition of detailed efficiency ratios for each independent hydraulic system. These detailed ratios are useful for a fine analysis of the supposed leaking zones.
Challenges:
Despite the fact that Société du Canal de Provence (SCP) has a good efficiency ratio of 89% in 2014, the total amount of non-revenue water is about 24 millions of cubic meters.

Administrative clearances:

According to the pertinent flight regulations and other legislative requirements, SCP will provide institutional support to AM and GG in the process of obtaining necessary authorizations/permits to carry out flights over Provence region (France). It is mandatory to obtain some clearances (technical or operational) from DGAC. Both AM and GG partners are well aware of such requirements and will launch related procedures well ahead of the flights due period.

Test flights:

We plan various type of flights over the project demo site with both the aircraft and UAV and includes in particular:

- Conducting technical validation flights (to make sure that all the equipment installed is working properly) and operational rehearsal flights (done in the same condition as the test flights, i.e. the same time of the day, the same configured aircraft, the same path, the same crew, in order to check material, flight trajectories, timings, fuel, etc.);
- Executing flight tests (to gather the data itself) using the two platforms, according to the specific mission planning and the available weather forecast;
- Collecting and recording data for post flight analysis; and
- Recommending improvements, relevant to sensor system and data processing to be applied during the preparation of the following operational demonstration (6.1).

3.2.3 Mission plan for the demonstration in the project's pilot site#2

Pilot site: Alqueva, Portugal	 
Provider of demo site: EDIA	
Purpose: Irrigation, water supply and hydropower (large scale)	
Description: The general system consists of 69 dams, reservoirs and weirs, 380 km of primary network, 1 620 km of pipes in the secondary network, 47 pumping stations, five mini-hydroelectric plants and one photovoltaic plant. The primary network has some channels and tunnels in reinforced concrete and the majority of the adduction is made by conduits in reinforced concrete and steel. These conduits have diameters varying usually from 1.40m to 3.00m. The secondary network has conduits varying usually from 0.20m to 2.50 to in reinforced concrete, cast iron and high density polyethylene (for the smallest diameters). Usually, the conduits are buried in trench. Depending of the specific conditions, many conduits have both pressure flow and gravity flow.	
Challenges: Alqueva is composed of a large network of pipelines and several subsystems, which represents a challenge for traditional leakages detection technologies.	

Administrative clearances:

As already introduced, the possibility to use UAV/aircraft heavily depends on legal regulations enforced in a given country. In case of the demo site #2, mandatory clearances (both technical and/or operational) will be required from the Portuguese regulator. Both AM and GG partners are well aware of such requirements and will launch related procedures well ahead of the flights due period

Aircraft and UAV test flights:

Two flight tests will be performed:

- *Aircraft & UAV operational tests*
- *Aircraft & UAV surveillance tests*

The flight tests have specific goals but will be performed at different time and conditions.

The flight tests encompass various type of flights over the project demo site with both the aircraft and UAV and includes:

- Adaptation of flight scenario to EDIA water network specifics.
- The flight scenarios will be finalized and tailored to the specifics of the EDIA site taking into account all possible constraints and the specific scenario relevant to each of the two aerial platform capabilities.
- *Executing flight tests* (to gather the data itself) using the two platforms, according to the specific mission planning and the available weather forecast.
- Collecting and recording data for post flight analysis.

3.3 Multidimensional risk analysis

WADI project will touch upon a range of multidisciplinary issues. First, since aerial surveillance affects the citizens' right of freedom and privacy, within WP8 WADI partners will take into due consideration pertinent legislative and regulatory issues related to the use of the project technology. In addition, aspects related to the standardization and certification of UAVs lighter than 150 kg, which currently remain under the competency of national authorities, will be looked into.

3.3.1 Technical

Technical risks related to the set-up of the WADI innovative techniques (i.e. components availability, adaptation, demonstration achievement, data processing, results assessment etc.), which generate a risk that depends on the use of new concepts. These risks (Table 3-2) have been addressed and considerably reduced in the proposed work plan by the development of an adequate mitigation strategy. For instance, in case of rather unlikely technical troubles with the aerial platforms used (both aircraft and UAV types are very reliable machines), there always exists the possibility to replace them by other platforms from the fleet of AM and GG;

Description of risk	WP(s) involved	Proposed risk-mitigation measures
Technical risks		
Delay in components delivery or unavailable sensors	WP3	The components will be purchased at reliable suppliers as possible with whom partners have a long-term good working relations. The ONERA can lend optical sensors if necessary.
Aircraft/UAV platform carrier broken down	WP5 and 6	This risk is very minimal since the aircraft/UAV models foreseen in the test have a strong reliability. Besides, there always exists the possibility to exchange the measurement console to another airborne platform available in AM and GG fleets.

Description of risk	WP(s) involved	Proposed risk-mitigation measures
Delays on data processing software delivery	WP3, 4, 5 and 6	In the most unlikely event, the software could be delivered until month M21, when flight tests takes place (WP5, task 5.2); without any major problem on data results process to be achieved in WP7. Inversion process risks and demonstration possible delays have been minimized by specific cautions described in WP3 and WP5&6 risks analysis.
Difficulty in gathering required data for the LCC approach	WP7	If some of the required data are confidential, standard compilations of diverse costs will be used to carry out the complete LCC of both WADI and alternative measures to reduce water leaks

Table 3-2 Technical risks

Specific Technical risk for RPAS operation:

It is foreseen to adopt an automatic flight for fixed wing profile for the demonstrations in the project's pilot sites.

The WADI equipment, is an automatic flight equipment. To perform automatic flights first it must be carried out a flight planning with a planning flights software (Mission Planner), in this planning it has to be taken into account the maximum separation expressed in the nationals normative. While setting these limits on the map, the aircraft can't leave the allowed flight area.

Once the area of work is limited, it has to be planned the corresponding waypoints according to the operation that it is going to develop in the study area. Before starting each flight, it has to be checked the link between the control station and the RPAS, so that all the information be available on the screen of the control station. Once the connection is established the RPAS has to obtain all the necessary satellites to secure the flight, after which the mission can start. All these procedures are established in the checklists of the WADI RPAS, which specifies step by step the entire procedure.

Some common risks that can appear during the flight test could be:

1) The pilot needs to make an emergency landing due to a failure in the avionics, power plant or power supply system. This situation poses a serious risk to the aircraft, to the people and property on land. Mitigation factors:
    a) The operation areas are sufficiently far from places of normal transit of persons and of buildings and infrastructures that could be damaged in the event of an impact on them of the aircraft.
    b) Pilots have received specific training to deal with such situations.
    c) The pilot can take manual control of the aircraft at any time in order to try to maintain attitude and minimum speed in the air.

   d) The aircraft cell has energy dissipating elements, which in case of impact, minimize damage to the aircraft itself and to the affected object or person.
   e) The RPAS are meticulously checked in accordance with the manufacturer's instructions, before and after each flight.
   f) In the same sense, the RPAS are subject to the maintenance program established by the manufacturer, in order to ensure the proper functioning of all subsystems.
2) With the engine running, a propeller brushes against the ground or nearby vegetation and throws fragments of different nature in all directions. This situation can cause injuries to people who are close to the RPAS. Mitigation factors:
   a) Access to the aircraft is restricted to authorized crew members.
   b) The crew members handling the aircraft are equipped with individual protection elements, specific to face these situations without danger.
   c) The equipment has a motor locking system.
3) A failure occurs in the system of subjection of a propeller or a breakage of its blades that are expelled without control. This situation can cause injuries to people who are close to the RPAS. Mitigation factors:
   a) The operation areas are sufficiently far from places of normal transit of persons and of buildings and infrastructures that could be damaged in the event of an impact on them of the aircraft.
   b) Pilots have received specific training to deal with such situations.
   c) The aircraft has active and passive safety elements, which are activated automatically and manually by the pilot, in order to minimize its own damage and the one suffered by that against which it impacts, in case of failure of any of the subsystems.
   d) The RPAS are meticulously checked in accordance with the manufacturer's instructions, before and after each flight.
   e) In the same sense, the RPAS are subject to the maintenance program established by the manufacturer, in order to ensure the proper functioning of all subsystems.
   f) Access to the aircraft is restricted to authorized crew members.
   g) The crew members who handle the aircraft are equipped with individual protection elements, specific to face these situations without danger.
   h) The aircraft has a checklist, whose purpose is to avoid such incidents with a simple visual inspection.
4) Some screw or fixation element of the aircraft or some major element of the cell like fuselage are unsecured. These types of incidents can compromise the safety of the aircraft and those under it and in its environment. Mitigation factors:

a) The operation areas are sufficiently far from places of normal transit of persons and of buildings and infrastructures that could be damaged in the event of an impact on them of the aircraft.

b) Pilots have received specific training to deal with such situations.

c) The aircraft has active and passive safety elements, which are activated automatically and manually by the pilot, in order to minimize its own damage and the one suffered by that against which it impacts, in case of failure of any of the subsystems.

d) The RPAS are meticulously checked in accordance with the manufacturer's instructions, before and after each flight.

e) In the same sense, the RPAS are subject to the maintenance program established by the manufacturer, in order to ensure the proper functioning of all subsystems.

f) The crew members who handle the aircraft are equipped with individual protection elements, specific to face these situations without danger.

g) The aircraft has a checklist, whose purpose is to avoid such incidents with a simple visual inspection.

5) The control radio link is interrupted due to interference or degradation of the signal. Failure in one of the devices, by fall, blow of the emitter or the exhaustion of the battery of the pilot emitter. This situation entails the loss of control over the aircraft, which must operate autonomously, using the on-board systems. Mitigation factors:

a) Aircraft have on-board safety systems (automatic return home, automatic landing program), which prevent the aircraft from leaving the pilot's control.

b) The crews have received training for this type of situation, and have the necessary procedures to try to re-establish the radio link of command and control.

c) The areas of operations are sufficiently far from places of habitual transit of people and of buildings and infrastructures that can be damaged in case of impact against them of the aircraft or of one of its parts.

d) RPAS are meticulously checked in accordance with the manufacturer's instructions, before and after each flight and each operation.

e) In the same sense, the RPAS are subject to the maintenance program established by the manufacturer in order to ensure the proper functioning of all subsystems.

f) Pilots are aware of the limitations of their equipment, in order to not to force dangerous situations.

g) The equipment has both sound and visual warnings that alert the pilot in case the signal starts to be too low and endanger the operation.

6) There is a failure in the on-board systems that also affects failsafe systems and the aircraft is out of control. Mitigation factors:
    a) The areas of operations are sufficiently far from places of normal transit of persons and of buildings and infrastructures that could be damaged in the event of an impact on them of the aircraft.
    b) The pilot can take manual control of the aircraft at any time.
    c) The system has a data link and telemetry, which allows to know the position of the aircraft at all times.
    d) The crews have received training for this type of situation, so that even if all radio links fail, they can estimate the aircraft's course and range to delimit a search area.
    e) RPAS are meticulously checked in accordance with the manufacturer's instructions, before and after each flight and each operation.
    f) In the same sense, the RPAS are subject to the maintenance program established by the manufacturer, in order to ensure the proper functioning of all subsystems.
7) The number of GPS satellites is below the minimum set by the manufacturer for the start of the flight. Mitigation factors:
    a) If the aircraft is on land, the start of operations is postponed until the conditions are as required.
    b) If the aircraft is in flight, the pilot takes manual control of the aircraft and lands immediately.
8) Malicious spoofing of the GPS signal (spoofing) occurs and the aircraft performs unexpected manoeuvres. These types of incidents can compromise the safety of the aircraft and those under it and in its environment. Mitigation factors:
    a) The areas of operations are sufficiently far from places of habitual transit of persons and of buildings and infrastructures that could be damaged in case of impact against them of the aircraft or of one of its parts.
    b) The crews have received training for this type of situation and are trained to disconnect all navigation aid systems and to land the aircraft safely in manual mode.
    c) As far as possible, the aircraft is configured in such a way that its autonomy is strictly necessary for the proposed objective.
    d) RPAS are meticulously checked in accordance with the manufacturer's instructions, before and after each flight and each operation.
    e) In the same sense, the RPAS are subject to the maintenance program established by the manufacturer in order to ensure the proper functioning of all subsystems.

9) GPS signal loss during a flight in automatic or assisted navigation mode. Mitigation factors:
    a) The pilot can take the manual / ATTI control of the aircraft at any time.
    b) In case of automatic flight, the aircraft has a specific program for this situation, which is activated automatically.
    c) The crews receive specific training to detect and successfully deal with this type of eventualities
10) Compass failure on the RPAS. Mitigation factors:
    a) The aircraft may continue flight in ATTI mode, or in manual mode.
    b) The crews receive specific training to detect and successfully deal with this type of eventualities. The pilot will make a landing by controlling in ATTI or manual mode the aircraft.
11) An attempt of unlawful interference is made by interception of the radio link of command or control. This situation poses a potential danger to both the aircraft and the people and property on land and other airspace users. Mitigation factors:
    a) The crews receive specific training to detect and act on such contingencies and are trained to disconnect all navigation aid systems and to land the aircraft safely in manual mode.
    b) As far as possible, the aircraft is configured in such a way that its autonomy is strictly necessary for the proposed objective.
    c) The modulation and coding system of the radio link control is considered sufficiently robust against attempts of unlawful interference.
12) The mission to be performed requires the embarkation of an unknown payload so far, which may affect the stability and performance of the aircraft. Mitigation factors:
    a) Operational procedures provide that no payment charge shall be carried on the aircraft if it has not previously been verified that it can be safely loaded and that it will not affect the performance of the aircraft.
    b) The pilots are trained and to verify that the mass and the centre of gravity of the aircraft are within the specifications set by the manufacturer.
13) The pilot doesn't have a legal accreditation about his authorization for performing the flights. This can lead to the application of sanctions and suspension of the operation, if required by an authority or member of a state security force. Mitigation factors:
    a) Checklist verification that the documentation proving the operator's entitlement is present during the flights.
    b) If once on the field, it is verified that such documentation is not available, the pilot must suspend the operation.

3.3.2 Legislative and Ethical

3.3.2.1 Brief introduction

In this section we identify the main legal risks to be expected when demonstrating WADI's airborne platform at the pilot sites. Please note that these risks extend beyond the WADI demonstration phase, however, and should therefore be construed as drivers for specific requirements during the development of the platform. Indeed, all of the risks identified below are, from a general point of view, not scenario-specific. What we mean by this, is that these legal risks will be encountered in a more or less extent in any scenario in which the WADI airborne platform is used to detect water leaks in water distribution systems in the EU.

Note that this section does not cover legal risks associated with the commercial exploitation of WADI's results beyond the action's lifetime. It is not that these risks are not deemed important or ignored. They are covered in Work Package 8 where specific tasks are foreseen for identifying and dealing with these legal risks.

The risks covered here are situated in two principal dimensions: the data and information processing dimension and the (drone) flight regulations dimension.

The first dimension covers three themes: (a) the processing of personal data, (b) the processing of spatial data and information, (c) the processing of data concerning critical infrastructure.

A. Personal data

First the WADI platform will process data pertaining to individuals. Personal data will be sourced from two principal sources. On the one hand personal data will be received from the end users, i.e. the water utilities, when detailing the layout of the water distribution network. On the other hand, personal data will be collected through the WADI platform itself, more particularly via the cameras filming/photographing large areas. However, given the fact that WADI in its first stages focuses mainly on transmission mains in non-urban areas and specifically on remote locations, personal data processing will in many circumstances most likely be an occasional occurrence rather than a structural practice. Nevertheless, since personal data processing will occur, the legal requirements set out by applicable data protection law must be observed, so that the rights of the individuals whose data are used, are respected.

B. Spatial data

Second, in order for the WADI platform to detect leaks in transmission mains, it must first know where these mains are located. Moreover, the general geographical context of where the transmission mains flow are also highly relevant. The WADI platform will therefore require significant spatial data input. End users have indicated that they currently use spatial data systems (GIS) to process these data. On the other end the WADI platform will produce data which has geographic significance, given that it will visually map leakage related information to geographic areas.

The fact that spatial data and GIS are used, is legally interesting from two different perspectives. On the input side, the WADI platform could benefit from available data sources made accessible under Directive 2003/98/EC on the re-use of public sector information (the so-called PSI Directive) either held by the end-users themselves or by other public or private entities. However, these data sources are most likely governed at Member State level by an instrument determining access and use requirements and conditions. On the output side, it might be interesting for end users to receive the WADI output data in a certain structured format, for instance when these data have relevance in an existing spatial data infrastructure (SDI) model implemented by the end user.

C. Data concerning critical infrastructure

While WADI in its first stages looks at water distribution networks transporting raw water, its solutions may also be used to analyse drinking water infrastructure as well. In many countries water distribution networks – and particularly drinking water distribution networks – are considered critical infrastructures. Critical infrastructures are all assets, systems or parts thereof which are vital to one or more broad governmental or societal functions or attributes. The security of such critical infrastructures are (or at least should be) high on the agenda of governments all over the world, especially in a time when the threat of terrorism is quite high.

It would seem quite likely that the WADI platform both receives strategically sensitive information on water distribution networks as well as generates such information. The reason is that the WADI platform will process detailed information on the network's technical and geographic specifications as well as identify weaknesses in that network (i.e. places where leaks occur). Security and legal security requirements are therefore to be taken into consideration when developing and demonstrating the WADI system.

The second dimension, i.e. (drone) flight regulations, deals with the fragmented legal framework governing the rules and requirement of developing and/or using Remotely Piloted Aircraft Systems (RPAS). For the moment drone flight regulations remain the business of the EU Member States. That is to say, as long as the UAV's operational mass remains below 150 kilograms (which would be the case in WADI), it falls outside the scope of Civil Aviation Regulation (Regulation (EC) 216/2008 of the European Parliament and of the Council of 20 February 2008 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, and repealing Council Directive 91/670/EEC, Regulation (EC) No 1592/2002 and Directive 2004/36/EC). As a result the legal framework across the European Union for small drones is quite fragmented. For the WADI action this means that first and foremost the applicable rules in France and Portugal are of relevance, since pilot test sites are located in those countries.

3.3.2.2 Protection of personal data

While personal data processing by WADI's airborne platform is rather of an incidental nature than a core activity, due regard for the legal obligations and requirements is important. Indeed, the recent update of the legal framework has made attention to these obligations and requirements more pressing than ever: it (a) provides national authorities and data subjects with new tools to verify as well as enforce compliance and (b) imposes (very) high fines on non-compliance with the new rules.

These new rules, bundled in an instrument that is commonly referred to as the "General Data Protection Regulation" or GDPR, are set to apply from May 25th, 2018 onwards. Considering that the WADI action extends well beyond this deadline, we advise that the new rules are taken into account from the very beginning of every pertinent WADI activity.

The GDPR focuses, more than the directive it replaces, on the need to demonstrate compliance. It is thus not enough to "merely" comply, you must be able to prove it. This requires that many things need to be documented and consolidated in writing. The first step is that personal data processing activities must be logged into a register. This register serves as an inventory, which in turn is the basis for every compliance activity under the GDPR. The WADI data management plan would be the natural starting point for the WADI personal data register.

However, as said, the register is only the starting point, there are other elements needed. Some things must be dealt with in agreements between WADI partners responsible for personal data processing, or between WADI partners and third party service providers.

Also, individuals must be informed of what happens with their personal data and of their rights vis-à-vis the processing of their personal data. All of the information to the individual is usually consolidated in a privacy policy.

The necessary technical and organizational measures must be taken in order to ensure the security of the personal data processed. In order to show that security is a key concern taken seriously, it is highly recommended to foresee an information security policy. Where possible personal data should also be pseudonymized and kept in encrypted form.

Apart from all of the aspects that focus on demonstrating compliance, the GDPR contains legal, operational and functional requirements regarding personal data processing, which are very similar to the existing requirements under current data protection law. These include:

- the need to have a legal basis for processing personal data (e.g. consent of the individual, observing a public interest or complying with a legal obligation);
- certain qualitative demands regarding the processing itself (e.g. clear purpose definition, accuracy, limited in time, etc.).

All of these requirements need to be observed for each individual processing activity. As stated earlier, mapping the personal data the will be processed as well as the reasons and means used for processing them, is the first step. From there on it is possible to determine for each processing activity the appropriate measures required to comply with the demands of the GDPR.

3.3.2.3 Spatial data

Quite specific information is needed regarding the locations where the WADI platform is deployed. As mentioned above, the data may pertain to locations of distribution networks but also to the more general geographic context or even other elements and attributes which are relevant to leak detection. The main source of the data will most likely be the end users, which may be privately held companies or public organisations. There are, however, other data sources imaginable. Other public or private entities may be the rightful holders of relevant datasets.

Certain datasets may be made available by public sector bodies to commercial or non-commercial entities under the framework of re-use of public sector information as set out in the PSI Directive. End users may well be subject to this framework. The PSI framework attempts to harmonize the rules on cross-border use of public sector documents by private companies for use in added-value information products and services (see recital (25) PSI Directive). WADI benefit from access to such information sources and use them to develop its solutions.

The PSI Directive is a directive, which implies – as we saw earlier – that Member States should adopt national rules implementing the principles fixed at the EU level. This automatically means that if and when WADI consortium members wish to make use of a data source made available by an entity under the PSI framework, they must turn to national law to assess the conditions for access to and use of that data source. It is therefore important to assess whether data collected from end users is subject to a specific legal instrument regulating re-use of public sector information and if so, what the conditions for re-use are.

Also, end users, being public sector bodies, may themselves be required to make certain information public. It may therefore be necessary to ensure that WADI data outputs are compatible with popular SDI models. Moreover, it is an explicit WADI objective to ensure that the solutions developed are interoperable with existing water information systems. To that end the WADI consortium members responsible for data outputs may want to conform to the EU spatial data infrastructure.

The main instrument governing this infrastructure is the so-called INSPIRE Directive. This INSPIRE Directive is meant to promote the European spatial data infrastructure in order to support environmental policy initiatives. It is really a framework of rules aimed at fostering interoperability between the spatial data infrastructures of the Member States. In order for the INSPIRE framework to work, several implementing rules in a number of different areas were necessary. The six identified areas are metadata, data specifications, network services, data and service sharing, spatial data services, and monitoring and reporting. These implementing rules take the form of Commission Decisions and Regulations.

While the INSPIRE Directive and the implementing rules are more of a framework on how to ensure the interoperability through Member State regulatory action, there are also thematic technical guideline documents. These technical guideline documents are developed in working groups and contain quite specific data specifications to ensure the interoperability in INSPIRE. For WADI consortium members it will of course be the lower level detailed guideline documents that are most relevant, as well as the national Member State laws that transpose the INSPIRE framework into national law.

3.3.2.4 Data concerning critical infrastructure

Many Member States consider the water sector to be a sector in which there are national critical infrastructures (CIs) to be found. Examples include France, Germany, the Netherlands, Poland and Spain. The national focus on which types of infrastructures in the water sector constitute critical infrastructures differs from country to country. The Netherlands for instance recognizes infrastructures for drinking water supply and flood defences as critical in the water sector, while Scotland recognizes infrastructures in drinking water, waste water and dam services as critical. These differences between Member States' critical infrastructure protection (CIP) frameworks may mean for instance that in one country a raw water distribution network is not a critical infrastructure but a drinking water distribution network is, while in another both are considered critical.

The designation of an infrastructure as critical essentially means that stringent security requirements will apply in order to protect that infrastructure from all kinds of threats, risks or vulnerabilities. Security requirements and protective measures take many shapes and forms, and they will be situated in multiple domains. Indeed, it does not suffice to require CIs to invest in their physical security if all details on the infrastructure's vulnerabilities or the implemented physical security measures are publicly accessible due to sloppy information management. CIP must therefore be complemented with critical information infrastructure protection (CIIP).

CIIP is the protection of ICT systems that are critical infrastructures themselves or that are essential for the operation of critical infrastructures. These ICT systems are the informational arteries of the critical infrastructure landscape, often interdependent, even across sectors. Several Member States have national authorities who are competent to supervise the protection of critical information infrastructure and this in a cross-sectoral manner. The French authority ANSSI for instance has issued guidelines and regulations governing information security in the 12 identified critical infrastructure sectors.

The framework on protecting critical ICT systems has recently been strengthened with a new Directive on Network and Information Security (NIS Directive). The NIS Directive endeavours to improve security by setting up an international cooperation mechanism, an obligation for essential service operators and digital service providers to take appropriate technical and organisational security measures and to notify incidents to competent authorities. Member States have until May 2018 to transpose the provisions of the NIS Directive.

Essential service providers are (art. 5(1) NIS Directive) entities providing a service which is essential for the maintenance of critical societal and/or economic activities, which is dependent on network and information systems such that an incident in relation to those systems would have a significant disruptive effect on the provision of that service. Annex II of the NIS Directive lists the sectors and subsectors in which one would find such operators and one cannot escape the observation that there is a near perfect match with what most Member States consider the critical infrastructure sectors. Those same Member States are now required under the NIS Directive to draw up lists of essential service operators in each of the sectors listed in Annex II. Drinking water supply and distribution is specifically mentioned as a sector where essential service operators are active.

In the paragraphs above we made it clear that water, and especially drinking water, is a sector in which most Member States situate critical infrastructures. With the arrival of the NIS Directive it is also a sector where one will find essential service operators. This leads to the necessary conclusion that many water utilities in the EU are or will be critical infrastructure / essential service operators, although there still might be national differences between Member States on who is included and who is not.

Nevertheless, many water utilities are or will be obliged the observe the security requirements and constraints imposed by national implementing measures both under the CIP and NIS frameworks. Under both frameworks the water utilities are among other things required to draw up security plans and policies. These policies and plans must take the information assets (i.e. both systems and data) into account which are instrumental to the underlying water services such as distribution. One could definitely argue that information assets which are necessary for managing losses in distribution systems and reducing NRW are instrumental to the distribution service.

The question could also be raised whether the WADI platform as a service can qualify as an essential service operator. If the answer would be positive, the obligations under the NIS framework would apply directly to WADI service and not only via the end user. The WADI service itself would have conform in its own right with the relevant national laws and regulations relating to network and information security.

These observations have a number of implications for WADI.

First, the data management plan to be developed in Work Package 10 will be of the utmost importance in order to be able to apply the end user's data classifications to the WADI input and output data.

Second, the operation of the WADI platform itself should be subject to a security policy, which of course will be ancillary to the security policy of the end user. The drafting of this policy will be an essential part of D8.3. We think that it is important to have a security policy specifically for WADI to demonstrate to end users that security is engrained in all of the solutions and products developed. It also forces the consortium members to reflect on who among them needs access to what, because not everyone should necessarily have access to everything.

Third, each agreement with an end user will be different and strongly dependent on the latter's specific activities, its requirements and legal obligations. That does not mean that it is useless to develop a template contract, since such an exercise helps to identify the WADI consortium members' own needs. Moreover, it is not inconceivable that some smaller water utilities are less mature in their contractual and policy framework, and WADI may help to bridge this gap.

Fourth, the WADI platform is not only a set of systems and procedures in which security should be a key concern, it may also be a security asset in and of itself. As a set of solutions and products meant to monitor the state of end users' water distribution networks, it is ideally placed for quickly identifying incidents relating to the physical infrastructure in places where such detection and identification would normally be very difficult. The WADI consortium members in their role of Service Provider must in any case agree with the end users on clear communication lines and procedures in case incidents are detected, even accidentally. Given that both the CIP and NIS frameworks entail an obligation to notify incidents to competent authorities, it should be mapped to whom these obligations may be directed (the end user or even the Service Provider directly) and how it will practically be complied with (e.g. are there notification templates with standardised fields etc.).

3.3.2.5 Drone flight regulations

As we highlighted earlier, the current legal framework for drone flight regulations in the EU is really a patchwork due to the lack of one harmonized European approach. This naturally complicates things for services such as WADI's leak detection method, whereby the airborne platform should of course be deployable in the whole of the EU (and preferably also beyond).

The European institutions are aware of the fact that the differences in drone treatment between Member States have an adverse effect on the internal market and may therefore require EU legal action. Hence, the European Commission asked the European Aviation Safety Agency (EASA) to develop a first prototype regulation with specific rules for civil use of drones. The draft rules are quite technical, as may be expected, and are accompanied by an explanatory memorandum explaining the rationale behind the rules. As we move during the WADI action toward real live testing of the airborne platform, it is the ambition to evaluate both the existing framework as well as the proposed rules on their effectiveness and to identify possible gaps or inconsistencies. All of this with the specific WADI use case in mind, i.e. leak detection over large areas.

For Portugal the rules on drone flights have changed very recently (i.e. 14 December 2016). Up until the beginning of 2017, the existing rules for model airplanes applied, which frankly were quite simple. RPAS can fly without any further formal requirements as long as there is a direct line of sight between pilot and RPAS and the RPAS remains below 120 meters AGL. The pilot was not allowed to fly his drone over urban areas, over gatherings of people, near airports, airfields, paragliding or parachuting areas or any place where third parties would be endangered. The new rules are more detailed and formal.

In France there are two legal instruments that are relevant: (a) a decree relating to the design and conditions of use of the RPAS and the qualifications of the pilot ; and (b) a decree relating to the conditions of integrating RPAS into French airspace . Both decrees started to apply on the first of January of 2016. The French legal regime makes a distinction between drones that are used for entertainment purposes, drones that are used for experimental purposes and drones used for particular purposes. The French rules make a clear distinction between four risk scenarios. Depending on the applicable scenario, the authorized weight of the UAV changes as well as the need to obtain a design attestation from the competent authority, the Directorate for the safety of civil aviation (DSAC). The scenarios are sorted in order of risk, with the first one being the least risky.

With regard to the ethical risks, we refer to the section above on the protection of personal data.

4 Conclusions

The document reviewed the state-of-art of airborne services provision (either manned or unmanned), of infrared and multi-spectral sensors application and of ground leak detection methods, with a special focus on large infrastructure.

The most significant findings can be outlined as follow:

- Surveillance and detection airborne missions are already an available option for large infrastructure (railway, gas & petroleum pipeline networks), though not used up to its potential. This is particularly true for drones (RPAS) due to the current fragmented regulatory system. Nevertheless, the opportunity to operate upon fixed mission plans not requiring high capability, would allow large savings if compared to the more common governmental surveillance missions for security reasons.
- The development of new systems to facilitate the onboard integration of high quality sensors, trying to reduce the operational costs and to improve the quality of surveillance on one hand, and the efforts of the European Commission and the European Aviation Safety Agency to promote a common European regulatory framework is making airborne services potentially able to reach new huge markets.
- Remote sensing techniques for monitoring Soil Moisture Content have proven to have several advantages in comparison with other *in situ* methods (gravimetric, electromagnetic, thermal…), as they provide better temporal and spatial coverages.
- Thermal infrared (TIR) remote sensing has been recognized for a long time as a valuable tool for evaluating soil moisture and its combination with airborne service is a sound opportunity for water leaks and seepage detection along aqueducts, canals, and dikes. Although the proven detection accuracy is still low, the amount of time saved by checking a limited number of sites rather than the entire system for leakage is tremendous. The next step forward in the application of this technique, actually within the scope of WADI project, is the integration of TIR with visible imagery and with images obtained in other spectral bands.
- Traditional ways of detecting leaks from water systems present some apparent disadvantages, mostly if referred to large transfer lines: they can only apply to pressurized pipes, they require minimum distance between inspection points (acoustic and in-line methods), or the absence of any obstacle preventing the operator to walk along the pipeline (gas-injection and ground penetrating radar); moreover, they are generally time consuming and unsuitable for hardly-accessible areas.

Finally, the matters that will be further and thoroughly addressed and defined in the following Work Packages WP3, WP5 and WP6, were anticipated in an integrated approach to provide a common framework to the forthcoming activities:

- The identification of end user (i.e. the water companies) requirements regarding the kind of information and the way of its presentation for decision-making (i.e. leak magnitude, area map and pictures, leak history etc.) as well as the level and accuracy of expected parameters was obtained through the active involvement of stakeholders.
- Opportunities and constraints referred to the airborne platforms and to the on-board instrumentations to be used were described.
- An overview of the strategy for validation and demonstration mission plans was provided, both for manned and unmanned aircrafts, investigating technical and legal issues and relevant mitigations or actions due.

The comparison between the performance of the main state of the art techniques for leak detection, the capabilities of the main potential competitor of WADI currently on the market (SAR) and the End User requirements provides the benchmark for WADI: the following Table summarizes the comparison between Acoustic correlation (most traditional technique for leak detection), Inline methods (highest-performing technique on transmission mains), SAR (main potential competitor for WADI), the End User requirements and WADI.

	Acoustic correlation	**Inline methods**	**SAR**	**End Users Requirements**	**WADI**
Accuracy	Smallest detectable leak = 0.05 m^3/h	0.006 m^3/h	0.05 m^3/h @ 50% false positives rate	< 0.8 m^3/h	(yet to be demonstrated)
Precision of leak pinpointing	Few cm	Smartball®: <2m. Sahara®: 0.5m.	50m	<5m	(yet to be demonstrated)
Turnaround time	3km/d	Smartball: up to 24km per deployment. Sahara: 1.6km.	7-8 weeks to cover huge areas	1 week to 1 month	Likely <1 week

Table 4-1 Comparison between leak detection methods, End user requirements and WADI performance

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