Demonstration of Sensing, Information and Communication Technology (SICT) Solutions for Smart Water Management: The Smart Water for Europe (SW4EU) Project

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Executive Summary of the EU-FP7 Sponsored SW4EU Demonstration Project

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Note: *The Executive Summary of the SW4EU project has been adapted by the authors in order to share the project objectives and key lessons as part of the IWRA/K-water report. A more comprehensive Project Description including the main results, outcome analysis and impacts assessment, has been prepared by the authors with contributions of the owners of the SW4EU Demo-sites for publication in the upcoming UNESCO Book on Smart Water Management. The Publishers, UNESCO and W-SMART on behalf of SW4EU, have agreed to grant IWRA authorization for adapted replica of few sections and figures included in this Executive Summary.*

Project Summary

The Smart Water for Europe (SW4EU) Project was developed to contribute to the European Innovation Platform (EIP) Water by accelerating demonstration and thereby deployment of innovative smart water network technology solutions for upgrading the reliability, efficiency, quality control, sustainability and resiliency of metropolitan drinking water supply services. Its outcome is expected to support significant improvements of the utility's capacity to respond to societal challenges and increasing public concerns, while enhancing European SME's competitiveness and effectively promoting economic growth in the emerging sector of Sensing, Information and Communication Technology (SICT) for smart water network applications. Furthermore, the project intent is to bring together the SICT industry experts and water operators to accelerate acceptance of innovations and accelerate their market penetration.

While the technology to implement smart water management is readily available, there are several hurdles that currently impede the successful implementation of smart water management for water distribution networks. Typical to the case of industrial innovation these include lack of: 1) integrated and open solutions to meet industry's standards; 2) ability to comply with all users' requirements; 3) validated demonstration cases for water utilities to implement future projects; 4) business intelligence awareness with an industry's motivation to change traditional water management approaches; and 5) political and regulatory support to address public water security and sustainability concerns.

To address these barriers, the SW4EU Project objectives were to develop and demonstrate integrated smart water management solutions for water distribution networks across four demonstration sites (in the Netherlands, Spain, the United Kingdom and France). The water challenges addressed as part of this project include: water quality management (focused on early bio-contamination detection), leak detection and management, energy optimization and customer interaction, as those issues have been identified as the areas of greatest concern and interest for water distribution networks in Europe.

This case study provides an overview of the SICT solutions developed and/or demonstrated through the SW4EU project, along with lessons learned and recommendations for their integration in the selected applications towards preventive water systems management. These applications have been selected due to their high potential for creating business cases of substantial savings and improvement of resource efficiency. It is expected that sharing the outcome of this case study will contribute to engage water utilities and policy makers in accelerating their deployment and thereby support the competitiveness of European SICT SMEs.

1. Project Objectives – Responding to the European Water Challenges

Currently, 3,500,000 km of water distribution networks exist in Europe. Water utilities face a number of challenges related to these distribution networks. In the next 10 – 30 years, large parts of water distribution networks will need rehabilitation, which is estimated to require considerable budgets. For example, Thames Water anticipates the spending of € 1 billion/year and Vitens (in the Netherlands) anticipates spending € 270 million/year to upgrade infrastructure during this time. By extrapolating these figures to Europe and by taking into account the state and performance of distribution networks, Vitens and Thames Water estimate that € 20 billion/year will be needed in Europe to upgrade the distribution networks. It is therefore accepted that prioritization and optimization of these investments are urgently required.

Furthermore, in many countries water quality also needs improvement. Frequently, the European directive on drinking water is not met with respect to microbiological and chemical parameters, thus posing a threat to human health.

Finally, resources for water production and water distribution need to be used more efficiently. Mostly, the water distribution networks and assets are not managed actively on a real time basis. Production, pressure management, water quality and leakage events are dealt with in a reactive way based on laboratory analysis, complaints from customers and signals of health authorities. Continuous optimization does not take place and hence, resulting in the following challenges: 1) high water leakages (ranging from 5 – 50 % of total water produced); 2) sub-optimal asset management and water production; and 3) sub-optimal pressure management.

These challenges need to be addressed to ensure more efficient, reliable and cost effective management of water resources and upgrading the security, safety and sustainability of the water distribution systems.

The EU sponsored SW4EU project was developed to address the European Innovation Partnership (EIP) concerns and recommendations responding to the challenges water utilities currently face while promoting innovative SICT developments of EU SMEs. While the EIP addresses the European concerns the project objectives can be also related to the UN-SDG framework and more specifically in the European context to the goals of: i) clean water and sanitation (Goal 6); ii) ensuring sustainable energy for all (Goal 7); resilient infrastructure and sustainable industries (Goal 9); sustainable cities and communities (Goal 11); sustainable consumption (Goal 12) and climate action (Goal 13) as they are supported by science and public education (Goal 4).

This chapter provides an executive summary review of the SICT solutions developed and/or demonstrated as part of the SW4EU Project to address the challenges of: i) water quality and ii) leak detection. It also briefly outlines several key points explored by the SW4EU team with regard to i) energy optimization and ii) customer interaction.

The SW4EU Project was implemented across four demonstration sites in Europe, in the Netherlands, Spain, the United Kingdom and France. The project involved 21 partners who provided expertise and innovative technology solutions including:

- 12 SMEs bringing in their sensors, data processing, modeling and ICT technologies for the solutions to be demonstrated;
- 3 Water utilities who have created their own demonstration sites;
- 4 Research organizations and universities of which 1 owns a demonstration site;
- 2 Platform organizations representing water utilities and providers and users of contactless technologies.

The site-specific project objectives and key lessons are briefly described in this executive summary. A more comprehensive Project Summary including the main results, outcome analysis and impacts assessment, has been prepared by the authors with contributions of the owners of the SW4EU Demo-sites for publication in the upcoming UNESCO Book on Smart Water Management.

2. Description of the SW4EU Demo-sites

The 4 demo-sites participating in the SmartWater4Europe project (as shown in Figure 2) are briefly described below.

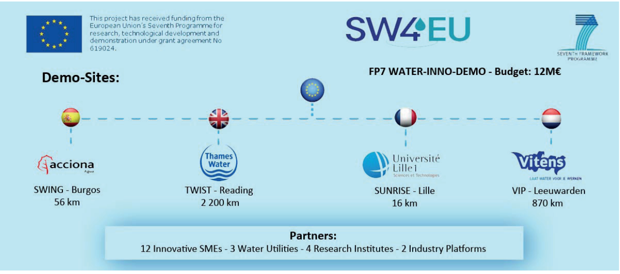
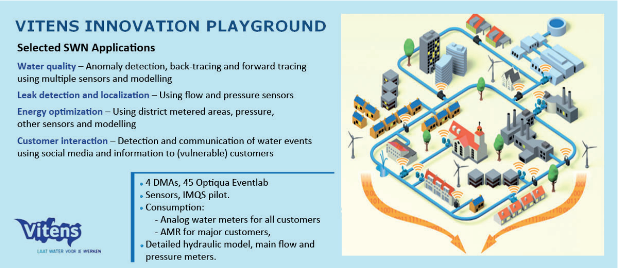


Figure 2. Demonstration site of the SmartWater4Europe project

2.1 The Vitens Innovation Playground (VIP) demo-site

is located in the Northeastern part of the province of Friesland. The supply area of Noardburgum is selected as the demo-site, and has both a rural and an urban character. It consists of 100,000 household connections and 2,200 km of pipe length. Leeuwarden, capital of the province of Friesland and cultural capital of the EU in 2018, has 96,000 inhabitants and is the larger city in the demo-site area. The selected SWM applications and demo-site instrumentation are summarized in Figure 1.



Caption?

Installed sensors - site monitoring for water quality included 45 Optiqua EventLab sensors, 10 S::CAN sensors, 5 intellisonde sensors and 1 Bactiline sensor, which were installed throughout the demonstration site. To demonstrate the accuracy, robustness, service level, maintenance, effectiveness and automation aspects Vitens placed the Eventlab, S::CAN and Intellitect sensor at 3 production plants and a reservoir to evaluate and compare the sensors.

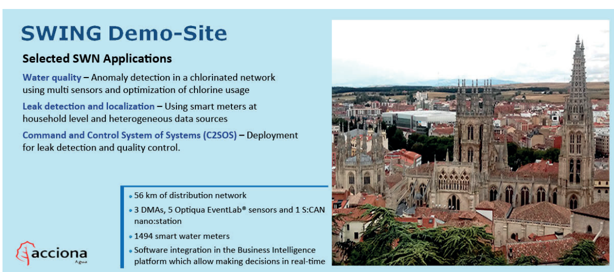
2.2 The Acciona's SWING (Smart Water Innovation Network In the city of BurGos) demo-site

is located at the City of Burgos, which is the capital of, the Castille and Leon region in the northern half of Spain. The city, founded in 884, has an approximate current population of 180,000 inhabitants and a municipality and city area of 107.08 km² (41.34 sq mi). Aguas de Burgos Inc. the municipal society in charge of the Entire Water Cycle Management in the city of Burgos, has actively participated in the project as the demo-site owner. The selected SWM applications and demo-site instrumentation are summarized in Figure 2.

Installed sensors - Site monitoring included three selected urban areas:

1. Traditional city center area with its parks, restaurants and business sector, with a network total length of 9.081 km. For water flow monitoring the instrumentation included 442 remote water meters, one water flow meter and one piezo-resistive pressure sensor in the supply manhole.
2. Residential area of the west of the city with a 20.667 km long network that has been renewed recently. Its instrumentation included 911 remote water meters, one water flow and one piezo-resistive pressure sensor in the supply manhole.
3. Industrial area with several warehouses with a 25.692 km long network, which is covered with 177 remote water meters, one water flow meter installed in the supply manhole and three piezo-resistive pressure sensors.

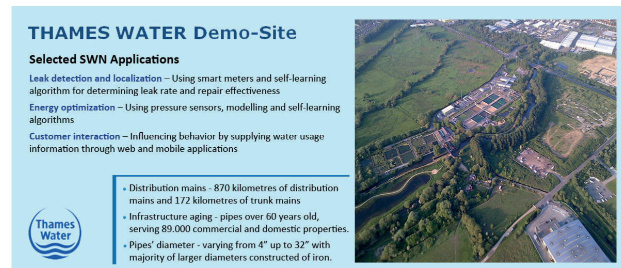
For the purpose of water quality monitoring ACCIONA Agua has installed six water quality analyzers manufactured by two project partners, including five EventLab® from Optiqua and one Nano::station® from S::CAN. Each analyzer is located in a different place of the city to evaluate the water quality in the network.



Caption?

2.3 The Thames Water Innovation and Smart Technology (TWIST) demo-site

is situated in Reading, England, in the Thames Valley, at the confluence of the River Thames and the River Kennet, and on both the Great Western Main Line railway and the M4 motorway. The demonstration site is approximately 71km² in area. It comprises 686 km of distribution mains and 179 km of trunk mains located in and around the city, which has many pipes over 60 years old, serving 89,000 commercial and domestic properties. The majority of these mains are of ferrous material at varying levels of degradation, with plastic (PE) mains now used as a standard for full replacement, and ductile iron generally for larger diameters. The trunk mains network consists of 172 km of mains, which convey about 45 Ml/d of chlorinated potable water from the treatment works into the distribution network. They include installations varying from 4" (100 mm) up to 32" (800 mm) in size, with majority of larger diameters constructed of iron. The selected SWM applications and demo-site instrumentation are summarized in Figure 3.

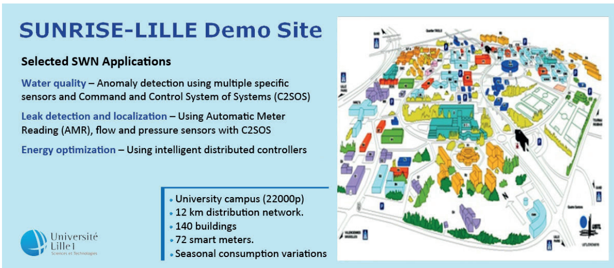


Caption?

Installed sensors - the site monitoring included 2102 smart AMI water meters, 80 Network meters 14 Incertameters, and 20 Syrinix Instruments. The demonstration site is made up of four flow-monitoring zones (FMZs), split up in district meter areas (DMAs), which are bounded by closed valves or district meters for measuring the flow of water entering and leaving the DMAs.

2.4 The SUNRISE Demonstration Site

Lille at the Campus of the University Lille, which is close to the city of Lille in the North of France. The campus was constructed between 1964 and 1966. It represents a small town of about 25,000 users. It includes 145 buildings with a total construction area of about 325,000 m2. Buildings are used for research, teaching, administration, students' residence and sports. The drinking water network is around 50 years old. It is composed of 15 km of grey cast iron pipes with a diameter varying from 20 to 300 mm. It includes 49 hydrants, 250 isolation valves and a set of air valves. The selected SWM applications and demo-site instrumentation are summarized in Figure 4.



Caption?

Installed sensors - The SUNRISE demo-site instrumentation included 100 Automatic Meter Readings (AMR) installed at the galleries of the building connections to evaluate consumption patterns in different zones of the campus as well as 5 pressure cells to monitor the pressure in the network nodes. For quality monitoring both EventLab and S::can sensors were installed in two locations of the Campus. In each building, the sensors were installed in the operational control room. To ensure reliable results, the sensors were pre-tested and calibrated in a lab setting.

3. The Demo-sites Results

3.1 SICT Solutions for Water Quality Control

The demonstration program included three solutions for water quality:

1. Detection, back-tracing and forward tracing of water quality events by using multiple generic sensors, specific sensors and detailed modeling (Vitens)
2. Detection of water quality events using generic sensors (Acciona)
3. Detection of water quality anomalies using generic sensors (i.e: S::CAN and Optiqua), laboratory pilot models of bio-contaminations, and Artificial Intelligence algorithms for bio-anomaly detection and geo-location (University of Lille).

The following section outlines the main results obtained from the field demonstration and associated laboratory studies for the development and/or assessment of the SICT solutions in the three demonstration cases, including the VIP, SWING an SUNRISE demo-sites

3.1.1 Vitens Innovation Playground (VIP) Demonstration Site (The Netherlands)

During this project, multiple solutions were tested, from sensors almost ready to market to newly developed sensors. The tested solutions were the following water quality sensors:

- EventLab sensor (includes server Optiqua): Generic sensor, based on refraction index
- Nano::station sensor (S::CAN): specific sensor for turbidiy, nitrate, colour, TOC, DOC based on (UV) absorption
- Intellisonde water quality sensor (Intellitect): Specific sensor for temperature, O2, pH, O2-Reduction Potential, conductivity
- Bactiline water quality sensor (Mycometer): specific sensor for bacteriological activity

One of the demonstration objectives was to assess the performance and optimize the configuration of these sensors. Beside the demo-site a large-scale model (7m by 3m) representing the Vitens Innovation Playground (VIP) was used. The model enabled to perform experiments, which are not feasible in real-life, simulating the hydraulic network flow and potential scenarios to assess the behavioral response due to transport processes.

The key lessons derived from the VIP demonstration of the selected SICT solutions may be summarized as follows:

- Using both generic and specific sensors enables optimization of the monitoring system to achieve the highest probability of detecting changes in water composition or bio-anomalies
- The most critical task is to ensure real time reliable data pre-processing and quality control. The water analyzed with sensors should be representative for the water quality in the main pipe. Placing sensors in the District Metered Areas (DMAs) could provide additional information about the propagation of water quality changes in the network itself.
- With regard to instrumentation, placing the sensors in households is an effective measure as they are frequently refreshed. This means that these sensors are mostly representative of the water quality in the local distribution network.

3.1.2 Smart Water Innovation Network in the city of BurGos (SWING) Demonstration (Spain)

For real-time water quality monitoring, a network of 5 Optiqua EventLab and 1 S::CAN Nano::station sensors were deployed in the Burgos distribution network. The SWM solution, including both generic and specific sensors, is developed and tested to confirm the high quality and stability of Burgos water. Dosing of chlorine has not been optimized due to a limitation in the devices used for this purpose.

With regard to water quality control, the main objective of this study was to establish the correlation(s) between refractive index measures (a general and not selective parameter related to water quality) with other spectroscopic and physical measurements (specific and selective ones). The sensors employed were the EventlabTM (Optiqua), a single optical sensor based on a Mach Zender Interferometer (MZI), and the Nano::station (S::CAN) with several selective probes: i::scan (for color, FTU/NTU, UV254 nm, TOC and DOC measurements), condu::lyser (for conductivity measurements), pH::lyser (for pH measurements) and chlori::lyser (for free chlorine measurements).

The site demonstration illustrated that the refractive index measurement is a useful generic indicator of water quality and can be used to monitor water quality changes. The Eventlab could also be combined with other sensors for a better determination of the nature of changes detected.

3.1.3 SUNRISE Demonstration Site at the University of Lille (France)

The water quality is monitored using EventLab and S::scan sensors, which are installed in 2 campus buildings. Before this installation, these sensors were tested in a pilot Lab, which enabled to inject chemical and biological substances at control density and duration and to follow upon the responses of sensors to injections.

Facing the lack of recorded bio-anomalies data, in order to simulate the laboratory's experiments and create a numerical database for the assessment of selected Artificial Intelligence algorithms for bio-contamination detection the complex reactions between multiple chemical and biological species (e.g. E.Coli with Chlorine) were modeled through the use of EPANET-MSX, an extension of EPANET (Rossman, 2000). The EPANET-MSX was used to analyze the Chlorine decomposition in the presence of E. Coli. The numerical simulations were found to be consistent with the experimental results of laboratory pilot model testing (Abdallah, 2015; Tinelli et al. 2017).

The water quality monitoring devices, used in the SUNRISE demonstration site, were found to be sensitive to environmental and operational conditions. A continuous observation of the devices as well as a regular maintenance of these devices and calibration re-adjustment is continuously needed. Data analysis requires crossing all the available data, recorded by the sensors, as well as the data related to the water usage.

An Artificial Intelligence based risk assessment model was developed (Tinelli et al, 2017) by integrating i) data processing of water quality parameters (e.g. chlorscan data or numerical data), ii) statistical tools, iii) artificial intelligence algorithms training, testing and validation, and iv) a GIS platform for spatial visualization of the bio-contamination likelihood propagation in the network. It yields a quasi-real time spatial variation of the likelihood indicator for early detection of bio-anomalies in a generic Water Distribution System (WDS) and the visualization of its spatial variation enable to identify the geo-localization of the bio-anomaly source. To improve the accuracy and efficiency of the anomaly detection and minimize false alarms Artificial Intelligence algorithms for signature recognition such as Support Vector Machines (SVMs) and Artificial Neural Network (ANN) were used, adapted and demo-illustrated using a numerical database established from the EPANET MSX scenarios simulations.

This case illustrated that machine learning-based risk assessment methods are useful decision support tools for non-specific bio-anomaly detection and geo-localization. However the future development and deployment of AI based anomaly detection systems will require significant testing data under a variety of operational conditions in order to establish a reliable database for their site-specific calibration raising the challenge of data availability for bio-contamination in water distribution systems.

3.2 SICT Solutions for Water Network Leak Detection

Several leak detection and geo-localization systems and data analysis algorithms were developed and/or demonstrated in the demo-sites under a diversity of operational conditions. The main results are briefly presented below:

3.2.1 Vitens Innovation Playground (VIP) Demonstration Site (The Netherlands)

While District Metered Areas (DMAs) have become useful tools for detecting and locating leaks at a DMA scale, they are far from being a common configuration in the Netherlands. Six DMAs were created in the city of Leeuwarden by installing so called ‘measurement streets’: boundary mains containing 3 sensors that measure **flow** (into and out of a DMA), **pressure**, **conductivity** and **temperature**. The conductivity sensor is built into a PVC pipe and, together with the flow and pressure sensors, installed directly in the ground. The sensors have a wired connection to the roadside kiosk. The data is transmitted every 5 minutes and stored in a data historian.

Several algorithms were developed and/or demonstrated and the key points of their performance evaluation are briefly summarized below:

- KWR’s algorithm of Comparison of Flow Pattern Distributions (CFPD – KWR, 2014) – using on-line monitoring of flow data to recognize different types of changes through continuous comparison with the same timeframe data exactly one year before. The CFPD method provides valuable insights into the state of the network, which enables to distinguish between different types of events. However attempts to apply the CFPD method for real time event detection have not been successful. Its reliable application requires integration of operational data and assets’ deployment (valves, flushing, etc.) records.
- VITEN’s Dynamic Bandwidth Monitor (DBM) – this forecasting algorithm for water usage in a District Metering Area (DMA) was developed to enable detection of any deviations and distinguish events (e.g. leaks, pipe bursts, flushing) from predictable water consumption changes (e.g. unmetered water flow between two DMAs, warm weather, holidays). The DBM filters the predictable events that can be correlated to similar events in neighboring areas and creates a real-time forecast by comparing for a specific timestamp the monitored data with the data of the past 12 weeks. It yields upper and lower thresholds and finally compares the actually measured water usage to the forecasted value. The DBM algorithm was implemented in an operational dashboard to be used in daily operations. Its deployment illustrated that in several cases, the DBM could support the detection of a leak or pipe burst several hours before a customer called or an operator detected the event, especially when leaks occurred in the night or when the water usage was predictable.
- KWR’s Flow Step Analyses - Flow Step Testing is a robust method of leak detection, which consists of closing and opening valves according to an established protocol to ensure that there are no sections without pressure at any time. The method was tested and proven very useful in one case where Vitens suspected a leak but was unable to locate it.
- Quasset’s Leak Localization Detection Algorithm - This algorithm was designed to detect (and eventually predict) sudden bursts. The leak localization analysis includes behavioral pattern analysis of the flow and pressure sensors throughout the DMA’s networks. However, at this stage, only one event was applicable for full analysis and further events field data are required for the assessment of this method.

3.2.2 Smart Water Innovation Network in the city of BurGos (SWING) Demonstration (Spain)

The leakage detection is based on 3 different algorithms, whose combination results in a likelihood assessment of water leakage within the demonstration site network. SWING demo site includes 3 out of the 26 Burgos City DMAs. 1,496 smart water meters have been installed in order to provide the demo-site with the appropriate equipment for leak detection and smart management. The assessment of several leak detection algorithms can be summarized as follows:

- Consumption Prediction Algorithm (CPA) - This algorithm was developed by ACCIONA to identify possible leakage using a predictive methodology based on a multiple linear programming model. It allows comparing the estimated flow within the DMA with the actual flow, warning of a possible leak if the difference exceeds the confidence interval. Its performance was evaluated by monitoring the hourly forecast error, illustrating that the error was less than 1% in the urban DMA (0.70%) during the first nine weeks of 2017.
- Other useful algorithms tested included Minimum Night Consumption Monitoring (MNCM) and Hydraulic Balance Algorithm (HB) designed to distinguish the causes for differences between incoming water and consumption by costumers in DMAs and thereby differentiate non-accounted water due to consumption and unaccounted water due to leakage.

SMART WATER MANAGEMENT APPLICATION TO PAJU SMART WATER CITY

3.2.3 Thames Water Innovation and Smart Technology (TWIST) Demonstration Site

The demonstration site is made up of four flow-monitoring zones (FMZs), split into 61 DMAs, which are bounded by closed valves or district meters that measure the flow of water entering and leaving the DMAs. The sensors installed included: 1 PipeMinder-T, 2 TrunkMinder, 14 Incertameters located in 4 DMAs, 17 Burstminders (PipeMinder-S) located in these 4 DMAs. Additionally, 3000 smart meters installed in household were available.

Thames Water distinguishes different kind of leakages: on the customer side and within the distribution network, operated by the water company. Automated Meter Readings (AMRs) are installed both at the edge of the curtilage of the property customer (underground) and also inside properties. In both circumstances, there are physical challenges to achieving reliable radio communication between the meter and a receiver. The algorithms used for leakage detection at a DMA scale included:

Customer-side-Leakage Discrimination Algorithm (CSL-CDA) – This algorithm is designed to analyze water consumption data from Automated Meter Readings (AMR) and to detect anomalous patterns, distinguishing CSL, for which the minimum night flow rate either remains constant or increases with time, from wastage, the pattern of which is more variable. Its accuracy was evaluated illustrating a satisfactory performance when challenged with a dataset of mixed CSL and wastage, achieving an 80% correct inference rate.

Aura BED alerts and data mining (University of Sheffield) - **AURA-Alert** was developed as an online service for SW4EU. The automated selection of training data is conducted by using n previous weeks in order to capture the current data profile at a network measurement point (for example the diurnal hydraulic pattern). This event detection system is adaptive, as it is retrained continually, at regular intervals and completely automatically, so that training is scalable and not subjective. AURA-Alert processes each time step independently. Therefore its output (of AURA-Alert) can be sensitive to isolated anomalous timestamps. As the water network operator is primarily interested in periods where many outliers occur in close temporal proximity a Binomial Event Discriminator (BED) was developed for aggregation of outliers to arrive at the probability of an event occurring for each time step. However its performance at this stage is variable with the system being able to detect up to 58% of known events on the network under certain conditions, but these conditions lead to a significant increase in false positives.

Syrinix algorithms – The PipeMinder-S and T, which measure and record pressure within the pipe, are capable of measuring up to 128 samples per second. They serve two purposes: i) Detection of pressure changes directly due to bursts and identification of transients induced elsewhere that pose a threat to the network; ii) Predicting the pressure at a PipeMinder using a number of PipeMinder sensors. The algorithm considers the differential arrival times of the transient (change in pressure) at one or more PipeMinder units. The field demonstration illustrated encouraging results, which warrant further investigation to enable a greater length of trunk main to be protected using the Syrinix algorithms.

3.2.4 SUNRISE Demonstration Site at the University of Lille (France)

The SUNRISE site represents a DMA unit model. The EPANET hydraulic model was used to create 3 virtual DMAs and establish a numerical demand driven database of the flow parameters using the off-line AMR data, which included both water supply at the inlets to the campus and AMR consumption data at the building connections.

The Smart Water System at Lille Demo Site is operational and used by the technical staff. Concerning leakage detection, all the components of the system (sensors, communication, software) work well. The system proved to be performing in the detection of water leakage at the Campus. The major problem concerned the communication system of some sensors, which required technical intervention. The system and data processing could yet be enhanced using machine method to recover lost data or to detect leakages at the buildings level.

Several leak detection algorithms were developed, tested and/or demonstrated, including an Artificial Intelligence Application for early leak detection and geo-localization.

An Artificial Intelligence based risk assessment model was developed (Cantos et al, 2018; CEA-LIST, 2017) by integrating i) data processing of water flow parameters (e.g. AMR measured data, aggregated inflow and outflow through the campus network, as well as numerical flow velocity, flow and pressure data obtained with EPANET hydraulic simulations), ii) statistical tools to identify thresholds for leak likelihood assessment, iii) artificial intelligence algorithms training, testing and validation, and iv) a GIS platform for spatial visualization of the leak likelihood propagation in the network yielding a quasi-real time spatial variation of the color-coded likelihood indicator for early network leak detection and geo-localization.

The feasibility of using Artificial Intelligence algorithms for leakage signature recognition such as Support Vector Machines (SVMs) and Artificial Neural Network (ANN) was illustrated as well as their ability to evaluate the percent misclassification error and thereby reduce false alarms. The algorithm used, trained and tested using a numerical database, which was established through EPANET scenarios simulations on the SUNRISE demo-site, provides a rather reliable leak detection and geo-localization tool with misclassification errors in the order of $6^{0}/_{00}$ for the testing scenarios, when multiple pipeline parameters were considered (e.g. Flow, Velocity, Unit Head-Loss). However, the development, adaptation and reliable integration of such AI based leak detection systems will require a significant database represnting a variety of operational conditions.

3.3 SICT Application for Energy Optimization

The goal of this research is to identify SICT solutions and tools for reducing energy consumption when distributing drinking water to customers.

3.3.1 VITENS VIP Site

Vitens yearly electricity consumption is around 77,000,000 kWh. Its aim is to reduce its consumption of electricity in 2020 by 20% relative to 2010. The main contributor to energy consumption within the supply of drinking water is the continuously needed pump pressure within the network. The preliminary conclusions of the research conducted could be summarized as follows:

1. Water transport at a low pressure implies that customers should preferably not be connected to the transport mains during or after installation.
2. For the VIP site, using Dynamic Pressure Regulation based on instrumentation in the 'capillaries' could result in an energy saving of up to 8%. This requires process automation to prevent peak pressures, which may cause pipes to break.
3. In general, the distribution pressure within VITENS' network is more or less based on "worst case" situations. Tighter control would allow VITENS to reduce the distribution pressures by 0.1 bar without leading to complaints.
4. The results illustrate that a customized approach needs to be applied for energy optimization per situation taking into account the dynamic balancing at the zone scale. Furthermore, the savings are not cumulative due to potential interdependency among the measures used.

3.3.2 THAMES WATER TWIST Demo-site

Thames Water developed an Energy Visualization Tool (EVT) to display the energy distribution within the water distribution system. The algorithm enables to estimate energy loss not only in the pipes but also at the demand points and display the results obtained on a GIS platform. It allows identifying highly energy inefficient areas due to unnecessary over-pressure and/or high frictional losses. More specifically, the tool is useful for detecting areas where pressure is lower or higher than required and hence for the assessment of opportunities for optimizing the energy flow balance.

Harvesting energy could be considered as an alternative when the reduction of pressure is not possible and therefore the energy is wasted. However, the cost and complexity are two important factors to consider.

The purpose of the companion demonstration project conducted by CALM Water using the off-line data of the SWING demo-site was to assess the feasibility and illustrate the development, adaptation and deployment of a GIS based algorithm, designated 'Power-Log' algorithm, for early detection and geo-localization of a power deficiency in the water distribution system as well as for its mitigation control. The results demonstrate the feasibility and conceptual development of the 'Power-Log' algorithm application for early detection and geo-localization of a power deficiency in the water distribution network.

3.4 SICT Application for Customer Interaction

The goal of this research is to promote SICT solutions for engaging public education initiatives and customer interaction. It involved VITENS and Thames Water.

3.4.1 VITENS

focused on two activities: i) development of an events dashboard and ii) interactive game to stimulate costumers to reduce water consumption.

VITENS Events Dashboard - a geographical events dashboard for the Central Operations and Dispatch Department (CODD) where real-time customer data (e.g. tweets and phone calls) and sensor data (e.g. pipe bursts and water quality events) were geographically displayed. Events can be detected more easily due to the combination of the data; i.e. suspected pipe bursts confirmed by customer phone calls in the same area. The events dashboard, which is currently used daily, has demonstrated its value in several cases and user experience is presently used for its development.

Waterbattle Game - An interactive game/app was developed based on the actual water consumption within households. Players could score points for reducing water consumption or using water outside peak moments. The aim was to make the customers more aware of their water consumption stimulating them to explore the feasibility of consumption peak shaving patterns, in order to reduce energy consumption and minimize CO_2 emissions. The two pilots of community engagement in the Waterbattle game and app. involved several schools, 485 children and 216 households.

This experience illustrated that the most active app participants have effectively modified their water usage behavior. Up to 60% of participants who had the monitoring system installed used the Water battle app. The app could contribute to behavioral change of the customers and the game, bringing together parents and children, seems to create a "social pressure" motivating the parents to adjust and minimize their water consumption

3.4.2 Thames Water

has conducted customer interaction experience with installed Sensus 640 volumetric water meters at over 3,000 metering points around Reading SWING site. Thames customers were invited to participate in a scheme that rewards them with points for reducing the amount of water that they use on a weekly basis. Using smart meter data, customers' household consumption is compared to historical averages, and if the amount of water used is less than the average, customers receive points, which were available for various rewards, providing incentive to save water and educate oneself on water efficiency. The results suggest that a subset of households responded well to the incentives, however the larger majority did not see a consumption reduction. The benefit of the smart AMRs became evident as it enables near immediate notification of a likely burst or leak in the home, particularly when combined with actuated valves that can restrict flow into a household and may therefore significantly contribute to water saving goals.

4. Key Lessons

This case study demonstrated the high potential of SICT solutions for creating business cases of substantial savings and improvement of resource efficiency. It is expected that sharing the outcome of this case study will contribute to engage water utilities and policy makers in accelerating their deployment and thereby support the competitiveness of European SICT SMEs. The key lessons may be summarized as follows:

4.1 Water Quality Control

- Current practice of non-specific bio-anomaly detection can be optimized using both generic and specific sensors for monitoring and identifying the highest probability of the bio-anomaly/contamination or the change in water composition. The most critical task is to ensure real time reliable data pre-processing and quality control.
- As demonstrated by ACCIONA, Refractive index measurement is a useful generic indicator of water quality and can be used to monitor water quality changes. Eventlab could be combined with other sensors to better determine the nature of the changes detected.
- The water quality devices are sensitive to environmental and operational conditions. The experience led to some practical recommendations:
  - Use several water quality devices and make cross testing control of recorded data;
  - Conduct regularly monitored data comparisons with laboratory analysis and devices calibration re-adjustment;
  - Ensure regular maintenance and probe cleaning;
  - Share experience with sensors manufacturers and integrate the latest development.
- Data analysis requires crossing all the available data, recorded by the sensors, as well as the data related to the water usage.

This SUNRISE demonstration case also illustrates that machine-learning based risk assessment methods are useful decision support tools for non-specific bio-anomaly detection and geo-localization of their sources. The current results demonstrate the feasibility and benefit of such system in real time monitoring for early leak detection and geo-localization filtering false alarms. However their future development and deployment will require significant testing under a variety of operational conditions in order to establish a reliable database for their site-specific calibration raising the challenge of data availability for bio-contamination in water distribution systems.

4.2 Leak detection

Several data analysis algorithms were developed and/or their performance assessed in the four demonstration sites at a DMA scale.

These methods are developed to: i) enable detection of any deviations of flow patterns by monitoring hydraulic parameters (flow velocity and pressure), ii) distinguish events (e.g. leaks, pipe bursts, flushing) from predictable water consumption changes (e.g. sensor flaws between two DMA, weather changes, holidays etc.), iii) monitor variation of minimum night flow or comparing actual flow parameters with their historical time series to detect behavioral changes at a DMA scale. Among these methods Consumption Prediction Algorithm (CPA) developed by ACCIONA to identify possible leakage using a predictive methodology based on a multiple linear programming model seems to provide a reliable leak detection tool with a forecast error smaller than 1% in the urban DMA (0.70%). The field demonstration of the pressure monitoring based Syrinix algorithm illustrated encouraging results, which warrant further investigation.

The feasibility of using Artificial Intelligence algorithms for leakage signature recognition and geo-localization, such as Support Vector Machines (SVMs) and Artificial Neural Network (ANN), was illustrated at the SUNRISE demo-site as well as their ability to evaluate the percent misclassification error and thereby reduce false alarms. The application of such AI based algorithms, integrated with statistical data analysis of spatial time series of the flow parameters (i.e. Flow, Velocity, Pressure) and a GIS platform for spatial visualization of the leak likelihood propagation in the network enables to pin-point and geo-locate the leakage pipe within the network. However, the development, adaptation and reliable integration of such AI based leak detection systems require a significant leakage signatures database under a variety of operational conditions.

4.3 Energy Optimization

The challenge is the continuous pump pressure management within the network. The tools developed and/or demonstrated focused on energy distribution visualization to enable identifying highly energy inefficient areas due to unnecessary over-pressure and/or high frictional losses. More specifically, the tools developed using a GIS platform have illustrated the benefit of detecting areas where pressure is lower or higher than required. Focusing on areas with high demand, gives opportunities to optimize the energy demand. The results illustrate that a customized approach needs to be applied for energy optimization per network attributes, situation, customers demand and other parameters taking into account the dynamic demand-supply balance at the zone scale. Moreover, savings are not cumulative due to potential interdependency among the measures used.

4.4 For Customer interaction

The customers interaction experiences undertaken by VITENS and Thames Water illustrate the potential benefit of SICT deployment for public education using educational games and customer interaction measures to promote public awareness for water saving and reduction of CO_2 emission, which are among the core targets identified by the EIP and the UN SDGs.

5. Conclusions - Potential Impact of the Project Outcome

The SW4EU demonstration project provided and exceptional platform for the development and, more specifically, demonstration of State-of-the-Art SICT solutions developed by European SMEs. Dissemination of the results can greatly contribute to create intelligent business cases for accelerating the market penetration and deployment of these solutions in responding to current water industry challenges and growing customers concerns. They are also expected to encourage Government and Industry to mobilize the investments necessary to engage the development and testing of such innovative solutions in order to address the critical need for real-time preemptive rather than reactive drinking water systems management. Typical to innovation challenges this future development entails financial risks and further technical challenges, which has to involve:

5.1 Creation of a new market for smart water solutions

The project demonstrates innovative solutions for smart water solutions. This demonstration ensures cooperation of SMEs and water utilities in the value chain on jointly creating innovative and integrated solutions for water utility challenges (instead of a regular client-supplier relationship). The project was visible for relevant target groups through large-scale demonstrations. These aspects are vital to SMEs and will facilitate market uptake and stimulate the demand side of the market to adopt innovative solutions. The success of the project already resulted in a significant investment of an extension and replication of the Vitens demonstration site to a 5 times larger area called Friesland Live. Again, this will serve as a great example for SWN implementation and it is expected that more water utilities will follow.

5.2 Public health risk reduction, improved water quality and preemptive assets management

The successful demonstration of water monitoring technologies results build the case for paradigm changing of water utilities from laboratory analyses, which is reactive by its nature, to preemptive Smart Water Management using online sensors. Online water monitoring enables water utilities to react earlier to water quality events, thus reducing public health risks, and undertake preemptive leakage management, thus reducing pipe bursting risks. SWM practice will therefore contribute to improve service reliability, effectiveness, safety and sustainability leading to customer appreciation of the upgraded performance of the water service.

5.3 Change of investment approach

The project has proven that the implementation of Smart Water Networks results in more than just financial benefits. While a fully executed transformation of a whole network to a SMW might even cost more than the direct short term financial benefits other benefits and long term impacts on service performance, safety and sustainability are expected to be generated, which may significantly affect customers reaction towards such modernization efforts. For example, improved customer interaction in the water system management, as an involved 'human sensor' to detect water quality anomalies or leakage, incentives for reduced peak consumption or other information based customer interactive anomaly mitigation measures could contribute to a new cost effective business model(s). Secondly, the increase in customers' knowledge about the distribution network, its performance and weaknesses would gain insight in optimization its management and ensuring the security, safety and sustainability of the network. Investors believe these benefits will strengthen their position in the future and would contribute to a resilient strategy of the drinking water network with respect to climate change, increase in population and protection with regards to terrorism and/or natural disasters.

6. The Next Step

The demonstration of the selected SICT solutions under real operational site conditions enabled the SW4EU project to support business cases for the selected applications and promote their deployment through outcome dissemination of the project results. With an estimated savings potential of about € 10 billion worldwide annually (source: Sensus; Water 20/20, Bringing Smart Water Networks into Focus) Smart Water Management is a major challenge for society and offers an enormous market potential to industries and innovative SMEs. As the water networks face rehabilitation challenges over the next 10 – 30 years, with an estimate of approximately €20 billion/year needed in Europe to upgrade the distribution networks, smart health monitoring of the water networks becomes essential for the risk-based prioritization and optimization of the required investments.

Integration of SICT solutions in engineering and management practice of drinking water systems is critical today as it is essential to move towards preventive management of aging infrastructure; cost efficient upgrades to improve the reliability, safety, security and sustainability of the complex urban networks; interactively integrate consumers in the management of water demand to address growing climate change impacts; and promote public education and awareness to support the required modernization and upgrade of the water distribution systems.

It is therefore imperative that European governments and water utilities support innovative European SMEs in the future developments, demonstration and reliable integration of SICT solutions in engineering and management practice of drinking water systems. Towards this goal the next step of the follow up on the SW4EU outcome is expected to involve:

- Integration Feasibility Assessment and Adaptation studies, under operational conditions, for early deployment monitoring in 'beta' sites of water utilities of the SICT solutions demonstrated in the SW4EU project, as well as other SICT solutions becoming available.
- Public education and awareness building to interactively integrate the consumers in the management of the water demand towards new business models and public culture that supports innovation and understands its strategic and operational needs
- European governments' commitment through regulations that will effectively support SICT innovation and promote its deployment to address growing public concerns, accompanied by the development of industry driven functional and operational standards
- Follow up EU sponsored SICT demonstration projects co-sponsored by the Industry, at a 2-3 years frequency, to provide a continuous demonstration platform for innovative solutions.
- European support to innovative SMEs competitiveness by stimulating the market growth for upgrading the efficiency, quality, reliability, safety and sustainability of the water systems.
- Industry-Universities Research and Development (R&D) partnerships to continuously engage the development and demonstration of innovative SICT solutions and professional education of future water experts to support and accelerate their integration in engineering and management practice.

By moving forward in this way we anticipate that SICT solutions will significantly contribute to improved water management approaches in Europe and around the world.

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Appendix

Links to the Sustainable Development Goals

The SW4EU Project and solutions provided by the project also provide links to SDG goals 6 (clean water and sanitation), 7 (ensure sustainable energy for all), 9 (resilient infrastructure and sustainable industries), 11 (sustainable cities and communities), 12 (sustainable consumption) and 13 (climate action). The targets linked to the project are listed below in Table 1.

Table 1. A list of the SDGs and their specific targets that relate to the SW4EU Project

Sustainable Development Goals and Targets	
SDG 6: Clean water and sanitation **Ensure availability and sustainable management of water and sanitation for all**	
6.1	By 2030, achieve universal and equitable access to safe and affordable drinking water for all
6.4	By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
6.5	By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
6.B	Support and strengthen the participation of local communities in improving water and sanitation management
SDG 7: Ensure sustainable energy for all	
7.3	By 2030, double the global rate of improvement in energy efficiency
SDG 9: Build resilient infrastructure and sustainable industries	
9.4	By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities
SDG 11: Sustainable cities and communities **Make cities and human settlements inclusive, safe, resilient and sustainable**	
11.B	By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
SDG 12: Ensure sustainable consumption and production patterns	
12.3	By 2030, achieve the sustainable management and efficient use of natural resources
SDG 13: Climate Action	
13.1	Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries