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Grant Agreement no 619024

Smartwater4Europe

Demonstration of integrated smart water supply solutions at 4 sites across Europe

Call identifier: FP7-ENV-2013-WATER-INNO-DEMO

INSTRUMENT: SME-targeted Collaborative Project

Final Report

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Lead partner: Vitens

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CO	Confidential, only for members of the consortium (including Commission Services)	

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This document has been produced within the scope of the Smartwater4europe Project and is confidential to the Project's participants.

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Document Main Author(s)	Vitens, Acciona, Thames Water, Lille University

List of recipients	EC, lead partners

Purpose	This document is the Final Report of the SmartWater4Europe project.

4.1 Final publishable summary report

This section must be of suitable quality to enable direct publication by the Commission and should preferably not exceed 40 pages (excl. figures). This report should address a wide audience, including the general public.

Content

4.1.1 Executive summary

SmartWater4Europe contributes to the 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. It therefore effectively contributes to solving societal challenges, enhancing European SME's competitiveness and effectively supporting job creation and economic growth in the emerging sensing, information and communication technology (SICT) sector for smart water networks applications. Furthermore, the supply and demand should be brought together to accelerate acceptance of innovations and speed up market penetration.

The 'Smart Water Management' addresses the priorities and aims of the EIP Water and consists of:

- Real time measurement and sensing instrumentation;
- Communication between components;
- Data management;
- Real-time data analysis and modelling for decision support and control;
- Automation, control and response strategies.

In principle the main technology and ICT building blocks enabling Smart Water Management have been developed. However, 5 Major hurdles on the road to application of Smart Water Management exist, i.e.:

1. **Lack of integrated and open solutions:** available technology is fragmented, concerns various technology fields (sensors, ICT, water modelling, control) and offers partial solutions. A lack of clear user-friendly, integrated and open solutions exists;
2. **Difficulty to comply with all user requirements:** solutions must be integrated in existing water distribution management systems. As management systems differ strongly with respect to the aspects addressed and their level of automation, it is difficult to comply to all user requirements;
3. **Lack of validated business cases for solutions:** although tested at laboratory and pilot scale, many technologies have not been applied in integrated full-scale solutions. Therefore, business cases have not been elaborated yet based on validation in real life. Technology validation at demonstration scale and the creation of business cases is a 'conditio sine qua non' for further application of solutions;
4. **Lack of business intelligence awareness:** water utilities have been dominated by traditional operations focusing on long-term investments and continuity. Historically, water utilities have separate departments doing separate jobs. Data analysis and algorithmic calculations on all data of all departments are not performed;
5. **Lack of political and regulatory support:** policies and measures of governmental and regulatory bodies do not actively support the application of smart solutions for water supply management. The SmartWater4Europe consortium seeks to overcome these hurdles by developing and demonstrating integrated solutions for smart management of water distribution networks. Integrated solutions will be demonstrated at large scale in 5 themes and at 4 locations in the Netherlands, Spain, the United Kingdom and France.

The demonstration themes concern:

1. Water quality management;
2. Leakage management;
3. Energy optimization;
4. Customer interaction;
5. Smart water supply management (integrating the above mentioned themes and including response strategies at each of the 4 demonstration locations).

The themes have been selected based on the following aspects:
1. High potential of innovation;
2. Major contribution to the objectives of water companies;
3. Substantial potential for creating business opportunities;
4. High potential savings and contribution to resource efficiency.

Based on the demonstration and validation results SW4EU will create business cases for application of the solutions and exploit and disseminate the project results.

4.1.2 Summary description of project context and objectives

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 have to be rehabilitated. Based on their own experiences (Thames Water: € 1 billion/year; The Netherlands: € 270 million/year), extrapolating these to Europe and taking into account the state and performance of distribution networks, Vitens and Thames Water estimate that € 20 billion/year are needed in Europe to upgrade the distribution networks. Prioritization and optimization of these investments are needed urgently.

Furthermore, in many countries water quality 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 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, vast resources are spilt on:
- water leakage (water losses ranging from 5 – 50 % of total water produced; source EU);
- sub-optimal asset management and water production;
- sub-optimal pressure management (savings potential 10 – 15 % of energy usage for distribution; further savings: reduced number of leakages as high pressure and transients are a cause of leakages).

The European Innovation Partnership on Water (EIP Water) has recognized these challenges and established the following priorities of work related to the challenges in water supply distribution networks:
- Thematic priorities:
  - Water and wastewater treatment including recovery of resources;
  - Water energy nexus;
- Cross cutting priorities:
  - Decision support systems and monitoring;
  - Smart technologies.

The ‘Smart Water Management’ concept is shown in Figure 1 and addresses the priorities and aims of the EIP Water and consists of:

- Real time measurement and sensing instrumentation;
- Communication between components;
- Data management;
- Real-time data analysis and modelling for decision support and control;
- Automation, control and response strategies.

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 SMEs providing smart water solutions.

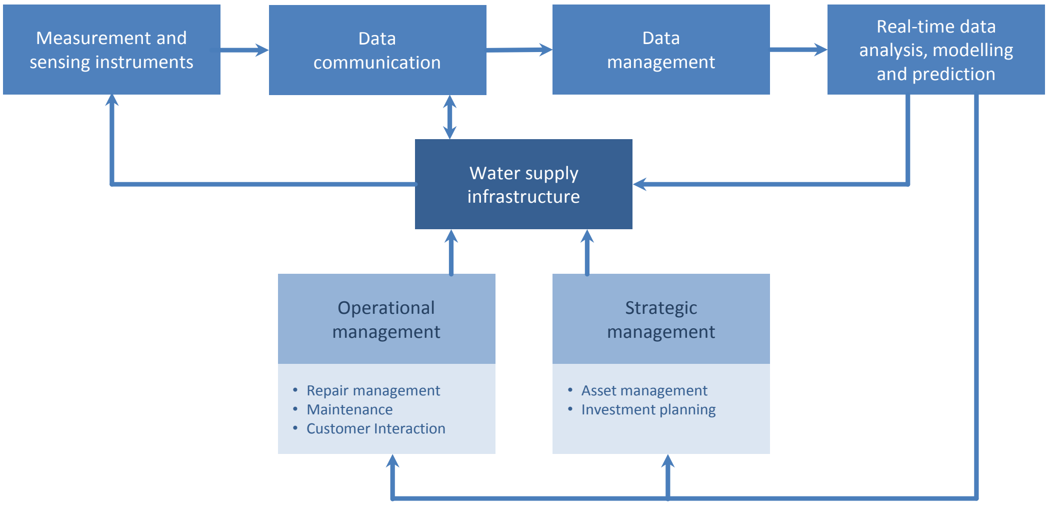

Figure 1. Concept of smart water networks

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5. **Lack of integrated and open solutions:** available technology is fragmented, concerns various technology fields (sensoring, ICT, water modelling, control) and offers partial solutions. A lack of clear user-friendly, integrated and open solutions exists;
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SmartWater4Europe consists of 21 participants of which:

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

Based on the demonstration and validation results SmartWater4Europe will create business cases for application of the solutions and exploit and disseminate the project results. The scientific and technological objectives of the project are:

1. To integrate and demonstrate 12 innovative solutions on water quality management, leakage management, energy optimization and customer interaction.
2. To demonstrate 4 integrated solutions for smart water supply management and verify that these can meet the requirements for smart water supply management.
3. To establish and guard integration and standardisation aspects in order to optimise market uptake.
4. To establish business cases and establish deployment potential and market uptake routes.

In Table 1 the 12 individual solutions and 4 integrated solutions per demonstration theme and demonstration location are indicated.

Table 1. 12 specified solutions divided over 4 demonstrations sites

Theme	Vitens	Acciona Agua	Thames Water	Université Lille1
Water Quality management	1.1 Detection, back-tracing and forward tracing of **WATER QUALITY** events by using multiple generic sensors, specific sensors and detailed modelling	1.2 Detection of **WATER QUALITY** events using generic sensors		1.3 Detection of **WATER QUALITY** anomalies by advanced algorithms using multiple specific sensors
Leakage management	2.1 Detection and localization of **LEAKAGES** by using generic quality, flow sensors, pressure sensors at mains level and detailed modelling	2.2 Detection of **LEAKAGES** by smart meters and data sources	2.3 Detection and localization of **LEAKAGES** by smart meters and determination of leak growing and leak repair effectiveness by self-learning algorithms	2.4 Detection and localization of **LEAKAGES** by using automatic meter readers (AMR) at household level, flow sensors, pressure sensors + algorithms
Energy optimization	3.1 **ENERGY VISUALISATION** by using District Metered Areas, pressure and other sensors and detailed modelling		3.2 **ENERGY VISUALISATION** by pressure sensors, advanced modelling and self-learning algorithms	
Customer interaction	4.1 Detection of water related events by using social media and provision of information to (vulnerable) **CUSTOMERS**		4.2 Influencing **CUSTOMER** behaviour by supplying water usage information through web and mobile	

4.1.3 Description of the main S&T results/foregrounds

This section describes the results of the SmartWater4Europe project, starting with the successful preparation, installation and validation of the four demonstration sites.

Preparatory results

The first 4 work packages were focused on the preparation of the demonstration sites. This resulted in a report on requirements and demonstration protocol (WP1), the preparation on the sensor techniques and related software components (WP2&3) and a full definition of the demonstration sites (WP4).
The result of the preparatory work packages were four fully designed and installed demonstration sites throughout Europe.

4.1.3.1 Description of the 4 demonstration sites

The smart water network solutions were demonstrated at different locations, especially assigned to this project. The sites were selected with the objective of being representative for a large number of situations in Europe. The following aspects were taken into account with respect to representation:

- **Type of area**: city area, old city area, rural area and dedicated areas (scientific campus, industrial area);
- **Chlorination**: chlorinated versus non-chlorinated networks;
- **Size**: isolated network versus large network;
- **Distribution energy**: pump distributed versus gravity distributed network;
- Continuous demand over the year versus seasonal peak demand.

The following sites participated in SmartWater4Europe:

- **Vitens** demonstration site: **VIP** (Vitens Innovation Playground) in the Province of Friesland, The Netherlands;
- **Acciona** demonstration site: **SWING** (Smart Water Innovation Network in the city of BurGos) in Burgos, Spain;
- **Thames Water** demonstration site: **TWIST** (Thames Water Innovation and Smart Technology) in Reading, England;
- **USTL** Demonstration Site: **SUNRISE** in Villeneuve d'Ascq, near Lille, France.

These demonstration sites were used to demonstrate and integrate 12 innovative solutions based on four themes:

- water quality management
- leakage management
- energy optimization
- customer interaction

The innovative solutions are specified for the specific demo site and divided as presented in Table 1.

VIP – Leeuwarden – Vitens

The demo site Vitens Innovation Playground (VIP) 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. In the city of Leeuwarden mixing of different water qualities occurs in several district areas, as water is supplied from two production plants (PPS Noardburgum and PPS Spannenburg) and several reservoirs (SPS). The demo area consists of 100,000 household connections and 2,200 km of pipe length. Figure 2 shows the area of the demo site and how it is situated in the province of Friesland. Leeuwarden, capital of the province of Friesland and cultural capital of the EU in 2018, has 96.000 inhabitants and is the only larger city in the demo site.

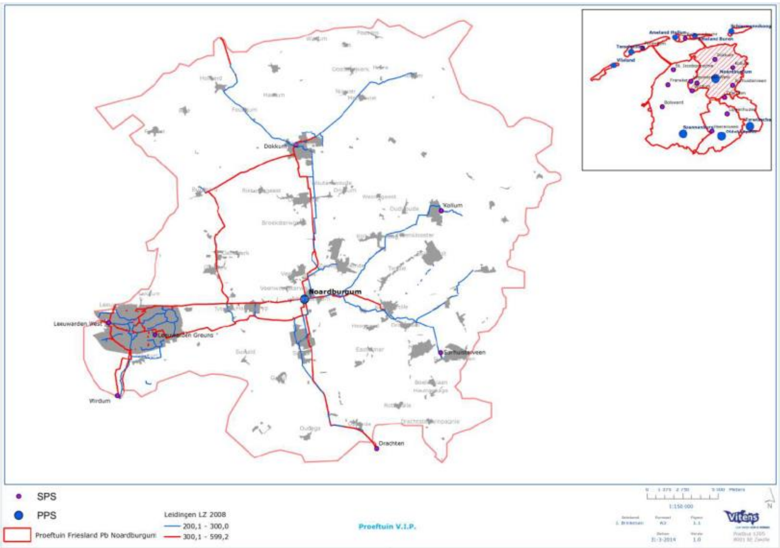

Figure 2. Location of demonstration site VIP

Installed sensors

District Metered Areas (DMAs) are a good solution for monitoring water usage and thus for finding and locating leaks. DMAs are however far from being a common configuration in the Netherlands. In order to implement and demonstrate several leak management solutions and algorithm, Vitens has built 6 DMAs (Figure 3) of different sizes and with different type of customers; e.g. normal households and industrial customers. The metered water usage was used as input for several algorithms used in different solutions.

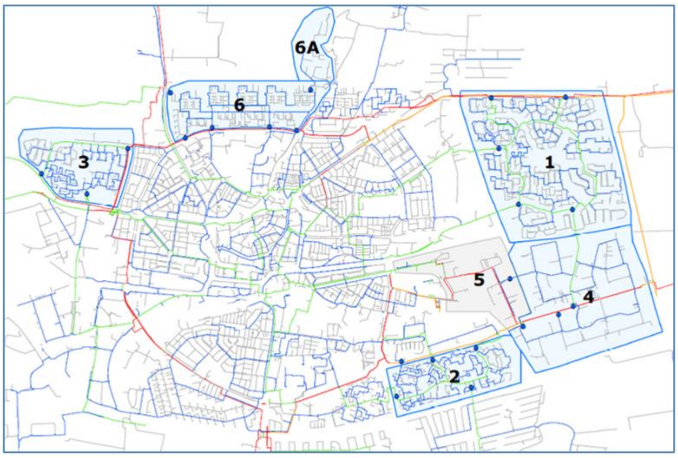

Figure 3. Overview of the six newly created DMAs in Leeuwarden. The black dots are the boundary mains.

45 Optiqua Eventlab sensors were installed throughout the demonstration site; exact locations are shown in Figure 4.

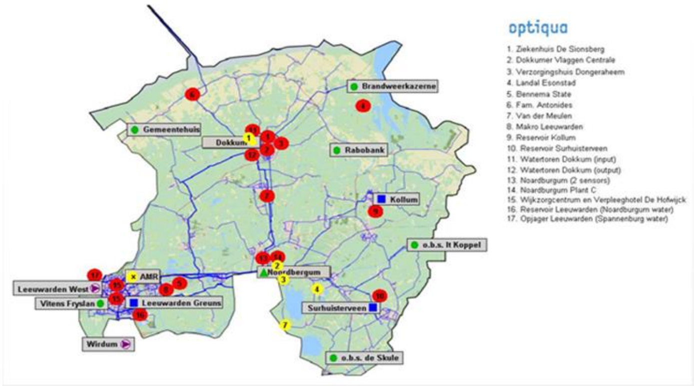

Figure 4. Location of Optiqua Eventlab sensors

To demonstrate the accuracy, robustness, service level, maintenance, effectiveness and automation aspects Vitens placed the Eventlab, S::CAN and Intellitect sensor in a row at 3 production plants (Noardburgum, Pb Spannenburg, Franeker), a booster station (Wirdum) and a reservoir (Greuns) to evaluate and compare the sensors. The pictures below show the placement of the three sensors in a row.

Figure 5. Installation of the Eventlab sensor, the nano::station sensor and the Intellisonde sensor in a row at production location Noardburgum (left) and the picture on the right shows the installation of the Bactiline at the laboratory in Leeuwarden.

In addition, within the customer interaction work package, smart water meters in households were used to monitor the water consumption.

SWING – Burgos – Acciona

Burgos is a city located in the northern half of Spain in the heart of the Castille and Leon region and is the capital of the providence which gives it its name. 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). It has been considered the historic capital of Castille for centuries, in part due to its most important landmark, the Cathedral of Burgos, declared World Heritage Site by UNESCO in 1984, as well as numerous medieval sites that are still conserved in its center. Burgos is a unique city in Spain and presented its candidacy for becoming a European Cultural Capital in 2016, having therefore formulated a coherent cultural strategy.

Figure 6. City of Burgos overview

Aguas de Burgos Inc. is the municipal society in charge of the Entire Water Cycle Management in the city of Burgos, according to the regulation agreed by the Council on 17th October 2003 and published on 1st March 2004, which includes intake, reservoir, potabilization, drinking water distribution, wastewater treatment, sludge management, water discharge on the hydrological cycle, customer management, sewage networks, as well as works related to them or the collection of fees and public tariffs corresponding to the provision of the services that it renders. Thanks to an agreement with Aguas de Burgos, part of this city is used as demo site in the SmartWater4Europe project.

The activities to be developed in Burgos are included in the so-called SWING (Smart Water Innovation Network In the city of BurGos) demo site, coordinated by ACCIONA Agua with the involvement of other SmartWater4Europe partners. SWING demo site comprises 3 out of the 26 district metered areas (DMAs) of the city: Virgen del Manzano, Barriada Yagüe and Villalonquéjar Este. They are highlighted in Figure 7. The three areas were selected taking into account both the Burgos priorities in terms of management of water supply and its different nature:

1. Virgen del Manzano is a traditional area located in the heart of the centre of the city. With its famous park of the same name, this sector is a wide urban area and one of the most visited parts of the city, including a busy restaurant trade and hotels decorating its streets. This area is covered with 442 remote water meters. Regarding measuring devices already installed, there is currently one water flow meter and one piezoresistive pressure sensor in the supply manhole. The network has a total length of 9,081 km.
2. Barriada Yagüe is a 20,667 km network that has been renewed recently; it belongs to a classic residential area to the west of the city. This area is covered with 911 remote water meters. Regarding measuring devices already installed, there is currently one water flow and

one piezoresistive pressure sensor in the supply manhole, in the same way as Virgen del Manzano.

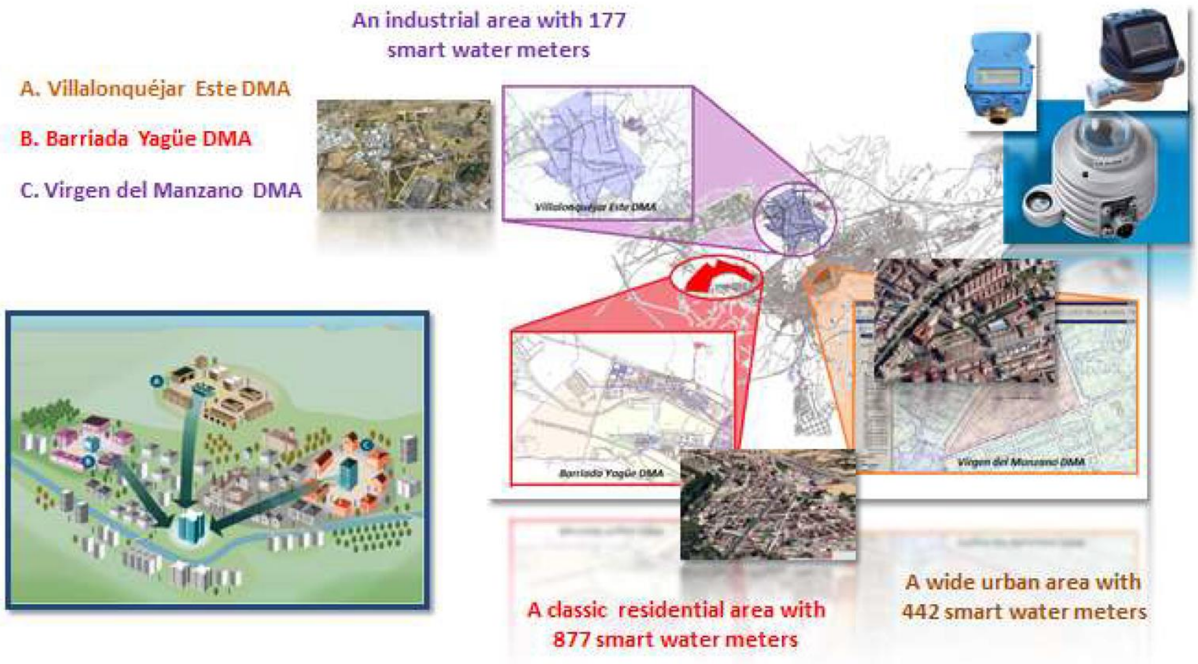

Figure 7. Demo site location map

3. Villalonquéjar Este is an industrial area with several warehouses. This hydraulic area consists of a 25,692 km network, which is covered with 177 remote water meters. Before the project, already one water flow meterwas installed in the supply manhole and three piezoresistive pressure sensors. ACCIONA Agua has installed six water quality analysers from two project partners, five EventLab® from Optiqua and one Nano::station® from S::CAN. Each analyser is located in a different place of the city to evaluate the water quality in the network.

TWIST – Reading – Thames Water

The demonstration site Thames Water Innovation and Smart Technology Centre (TWIST) for the Smart Water 4 Europe project 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. Reading is 58 km west of central London.

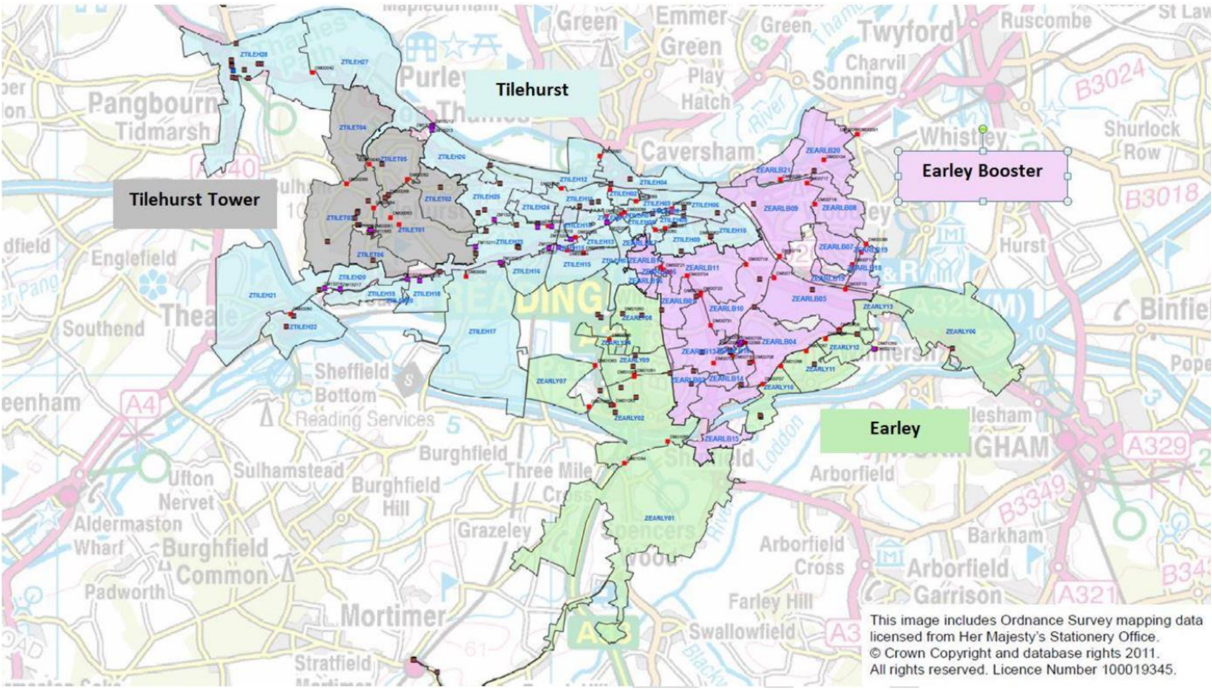

Figure 8. Map of the demonstration site TWIST

The demonstration site is approximately 71km2 in area. It comprises 686 kilometres of distribution mains and 179 kilometres 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. Available infrastructure before the project includes 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): Earley, Earley Booster, Tilehurst and Tilehurst Tower. Each of these zones are split up in district meter areas (DMAs) which are bounded by closed valves or district meters that measure the flow of water entering and leaving the DMAs. There are 61 DMAs in total, distributed as follows: 11 DMAs in Earley, 16 DMAs in Earley Booster, 28 DMAs in Tilehurst and 6 DMAs in Tilehurst Tower.

Installed sensors

During the project, the following sensors were installed: 1 PipeMinder-T, 2 TrunkMinder, 14 Incertameters located in 4 DMAs, 17 Burstminders (PipeMinder-S) located in 4 DMAs. Additionally, 3000 smart meters installed in household were available.

SUNRISE – Lille – University of Lille 1

Lille demo site is located at the Scientific Campus of the University Lille, which is close to the city of Lille in the North of France (Figure 9). 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 m^2. Buildings are used for research, teaching, administration, students' residence and sports. It is served by 100 km of urban networks (drinking water, sewage, electrical grid, public lighting and district heating). Figure 10 shows a map of these networks.

The water Demo Site is developed within a large-scale Smart City project (SunRise), which consists in turning the Scientific Campus of the University of Lille into a "Demonstrator of the Smart City". The project concerns both water and energy networks. It is conducted within a large industrial and local government partnership. SunRise project aims at improving the operational management of campus as well as the development of a living lab for research, innovation and education.

Figure 9. Lille Demo site – Scientific Campus of Lille University in the North of France (25 000 users, 145 Buildings)

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 water network is supplied at points located in the North, West and South of the campus. It serves 150 buildings.

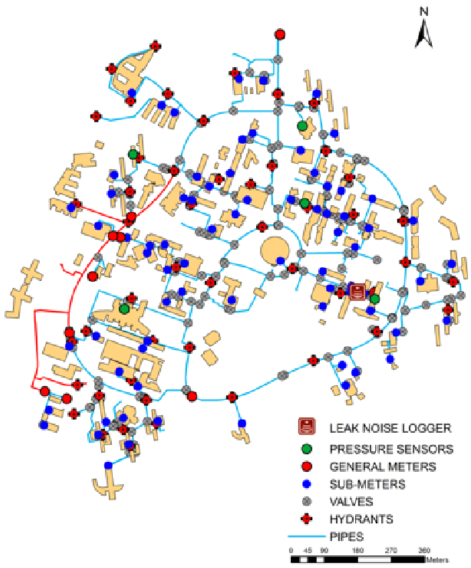

Figure 10. Map of urban networks on University Campus

Installed sensors

Both EventLab and S::can sensors were installed in two locations of the Campus: the Engineering School Polytech"Lille and the Restaurant Barrois. In each building, the sensors were installed in the technical room. A derivation from the water pipe was used for the sensors water supply. The sensors evacuations were connected to the technical room wastewater drainage. To ensure reliable results, the sensors were also tested in a lab setting.

100 Automatic Meter Readings (AMR) were used in the project to evaluate consumption of users. Throughout the demonstration site, 5 pressure cells monitored the pressure within the network.

(a)

Figure 11. Installation of EventLab and S::can in the technical room of Polytech'Lille

4.1.3.2 WP5 Water quality

The three solutions in this theme were:

1.1 Detection, back-tracing and forward tracing of **WATER QUALITY** events by using multiple generic sensors, specific sensors and detailed modelling (Vitens)

1.2 Detection of **WATER QUALITY** events using generic sensors (Acciona)

1.3 Detection of **WATER QUALITY** anomalies by advanced algorithms using multiple specific sensors (Lille)

VIP – Leeuwarden – Vitens

During this project, multiple solutions were tested, from sensors almost ready to market to newly developed sensors. The selected sensors were installed at the demo site Vitens Innovation Playground (VIP), at production locations, booster stations, reservoirs and end users. In total 45 eventlab sensors, 10 S::CAN sensors, 5 intellisonde sensors and 1 Bactiline sensor were installed during the last three years. The optimal sensor placement was based on hydraulic/water quality models for accurate localisation of contamination and prediction calculated by KWR.
The tested solutions are 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

These sensors include generic and specific sensors. Part of the solution was the consideration of best performance of these sensors. Will the outcome be more reliable with only specific sensors? Would a generic sensor generate enough information to determine the water quality? Is a combination of multiple sensors needed to obtain the most effective water quality management?

Beside the demo site, a large scale model (7m by 3m) representing the Vitens Innovation Playground (VIP). The model, named Meeting of Water (MOW) makes it possible to perform experiments not possible in real-life. This one of a kind model mimics the hydraulics, based on the SIMDEUM water demand prediction model from KWR of the actual distribution net and corresponds with reality when looking at the behaviour of transport processes.

Advantages of the model are a save corruption, realistic hydraulics, optical visualisation of the hydraulics, accelerated simulation of one day in 96 seconds. Figure 12 shows the design of the model Meeting of Waters overlaid with Google Maps and the actual model of the VIP.

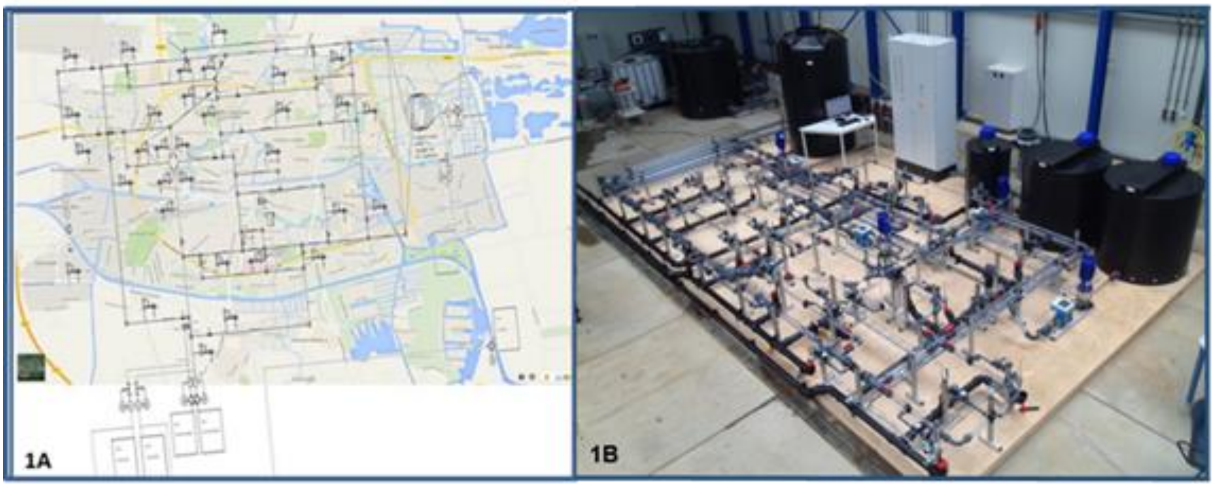

Figure 12. Design of the scale model Meeting of Waters of the VIP overlaying with GoogleMaps (1A) and the actual model (1B).

The model resulted in more insight the change in the hardness, pH, temperature, flow and pressure under different conditions. It also showed how many and which sensors are necessary for a cost effective placement strategy that guarantees the efficient monitoring of the drinking water.

Recommendations

Using both generic and specific sensors will give the highest probability to detect the contamination or the change in water composition. The water analysed with sensors should be representative for the water quality in the main pipe. In addition, expert judgment has indicated that the most interesting areas for measuring water quality are the shuttle areas of the different production sites. Initially, it was expected that water quality changes would occur almost exclusively in these sub-areas.

Leading is the choice to get good data from potentially less interesting areas than to get bad, unusable data from potentially less interesting areas. Therefore, users with highly variable intake with longer periods of intake are still avoided. In addition, placing sensors in the District metered Areas is advised, since these are key locations in the main network and could provide additional information about the water quality in the main network itself. Finally, it is very good to place the sensors in households. The (limited) water consumption of the sensor itself ensures that the connection lead is refreshed in no more than 15 minutes. This means that these sensors are representative of the quality in the local distribution network with a slight small delay in the order of minutes.

The Bactiline should be installed at production locations, booster stations and reservoirs. Placing the Bactiline at those locations will give a stable baseline. Calamities can then be found easily.

SWING – Burgos – Acciona

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 objectives described in DoW have been fulfilled, with the addition of developing a solution that includes generic **and specific** sensors. The solution is developed and tested and it is able to confirm the high quality and stability of Burgos water. Dosification of chlorine has not been optimised due to a limitation in the devices used for this purpose.

Spiking tests at Burgos

To test the response of EventLab to changes in water quality under operational conditions, a series of spiking experiments was designed and performed. From the concentration profiles observed during the experiments it can be concluded that it takes approximately 1 minute before water containing the added compound reaches the sensor. The maximum response to a chemical addition (new steady state) is obtained after 1 – 5 minutes (higher concentrations require longer stabilisation time). Furthermore, the detection limit of several substances was tested for the EventLab system.

Follow-up of real events

The EventLab systems showed the operational working in the Burgos distribution network. Through the measurements it was confirmed that the drinking water in Burgos is of very stable quality, with all 5 EventLab systems showing very little compositional variation in the water.

The Nano::station was installed in the Gamonal reservoir with an event detection system "Pattern Alarm", which compares each reading from the rest of quality parameters and detects water quality variation towards the normal pattern. An example of a sudden increase of "Pattern Alarm" value, is shown below (Figure 13), which correlates to increase of Turbidity readings (Figure 14). This was caused by water pumped in a pipe which was not working for long time before, which caused some release of deposits.

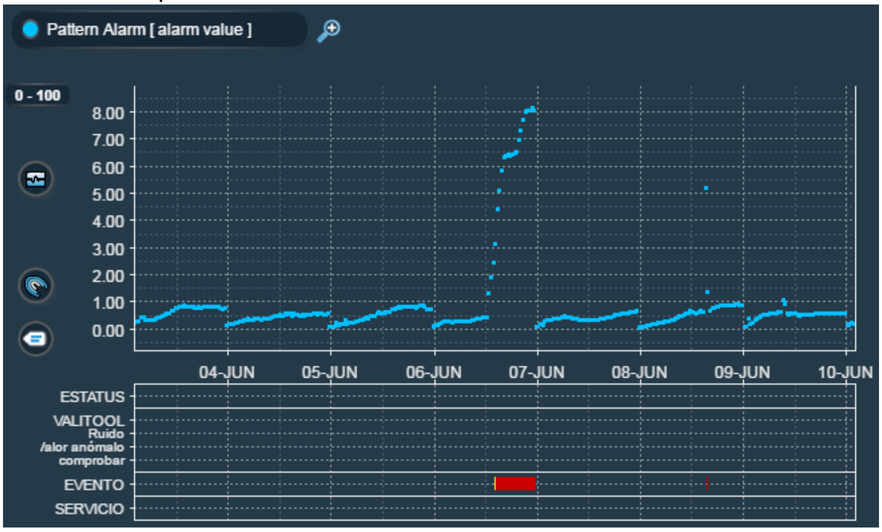

Figure 13. Time series of Pattern Alarm on first week of June 2017

Figure 14. Time series of Turbidity (ISO based method) on first week of June 2017

Correlation generic sensor and specific measurements

With a new focus, the main objective of this study was to stablish the correlation 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 Eventlab^{TM} (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 colour, 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).

It is confirmed that refractive index measurement is a useful generic indicator of water quality and can be used to monitor water quality changes. In the specific case that the differentiation of the nature of the chemical is important then, Eventlab could be combined with other sensors. In this way, the combination of all signals would provide the necessary information to determine the nature of changes detected.

Recommendations

The following items are important to prevent issues when collecting and interpreting data:

- Selection of the correct sampling locations; the sampled water should be representative of water quality in the distribution network.
- The use of commercial telecommunication networks for data transmission means that there is a reliance on the service reliability of a third party. Issues with the wireless network can result in interruption of the data connection.
- It has been proven that the s::can nano::station monitoring is reliable, with consideration of the specific parameter controlled by legislation, also in case of unexpected events.
- It has been demonstrated that the s::can nano::station can operate for long periods (months) with very low maintenance needed and almost absence of consumables. Besides, nano::station has demonstrated its capacity to communicate readings to customer SCADA using different interfaces (LAN-Ethernet and 3G) and protocols (modbus TCP).
- The use of Eventlab sensors is mainly useful when deployed throughout the network, from the treatment plant to the end-users. This allows track and trace of water quality changes and pinpointing of the source.
- Ensure selection of relevant sampling points. The sampled water should be representative of water quality in the distribution network and not be affected by operational effects at the site (filling / emptying of tanks) or water consumption patterns (prevent e.g. small volume

supply lines with risk of stagnant water, end-user locations where water usage patterns fluctuate strongly throughout the day.

- Ensure all installation requirements are met. These include inlet pressure, flow-rate, data connectivity. In case of underground installation, low signal strength for data communication can be solved by using an extension cable to bring the antenna to the surface. Furthermore, switching to a different provider or different protocol (e.g. 3G instead of GPRS) can also help in increasing the signal strength.
- Perform preventive maintenance to realise the highest possible up-time. The sensor comes with two indicators for sensor status which allow the user to predict when maintenance will be required.
- Use of a filtration module substantially decreases the maintenance requirement, in particular by keeping the fluidic infrastructure (flow regulator, pressure reduction valve) clean from (bio)fouling.
- When operating any type of equipment, ensure the guidelines concerning installation, operation and maintenance provided by the manufacturer are adhered to.

SUNRISE – Lille – University of Lille 1

The water quality is monitored using EventLab and S::scan sensors, which are installed in 2 buildings supply : Engineering School "Polytech'Lille" and restaurant Barrois. Before this installation, these sensors were tested in a lab pilot, which allowed injection of chemical and biological substances at control density and duration and to follow the responses of sensors to injections.

Sensors data were compared to laboratory analysis. Discussion with sensors fabricants allowed to understand the differences between the laboratory tests and the sensors data and to operate some adjustment in the sensors calibration. Globally, sensors worked well, but required continuous attention by high qualified persons (PhD students). The major problem encountered concerned the necessity to clean the sensors and to re-adjust the sensors calibration; there was also some perturbation with the signal loss. These difficulties were overcome by a close collaboration with the sensors fabricants.

The water quality was followed for around one year. Some "abnormal" events were observed, which were correlated with the high water debits, which could cause liberation of particles fixed at the pipes surface.

Recommendations

Due to our short experience in the use of water quality devices control, the security of the water quality control was privilege to cost optimization. Several devices still need to be used to make a cross control as well as regular comparison with laboratory tests.

The water quality devices and parameters are sensitive to environmental and operating conditions. A continuous observation of the devices functioning as well as a regular maintenance of these devices and calibration re-adjustment is needed. The interpretation requires crossing all the available data, recorded by the sensors as well as the data related to the water usage.

Some practical recommendations:

- Use several water quality devices and make cross control of recorded data
- Make regular comparison with laboratory analysis, and devices calibration re-adjustment
- Ensure regular maintenance and probe cleaning
- Share experience with devices fabricants and integrate the latest development

4.1.3.3 WP6 Leakage detection

The four solutions in this theme were:
2.1 Detection and localization of **LEAKAGES** by using generic quality, flow sensors, pressure sensors at mains level and detailed modelling (Vitens)
2.2 Detection of **LEAKAGES** by smart meters and data sources (Acciona)
2.3 Detection and localization of **LEAKAGES** by smart meters and determination of leak growing and leak repair effectiveness by self-learning algorithms (Thames Water)
2.4 Detection and localization of **LEAKAGES** by using automatic meter readers (AMR) at household level, flow sensors, pressure sensors + algorithms (Lille University)

VIP – Leeuwarden – VITENS

Three algorithms are described that were tested to detect or locate leaks as soon as possible. The additional algorithm Leak Localisation Detection by Quasset proved to be useful in case of sudden bursts in the distribution network.

Comparison of Flow Pattern Distributions (CFPD) (by KWR)

Contrary to the often applied minimum night flow analysis, this algorithm uses all available flow data (24 hours per day, resolution of 1 measurement per hour or better) and recognizes different types of changes. This is compared to the same timeframe exactly one year before. The analysis of 9 months of data from the Vitens Innovation Playground has resulted in the detection of a large number of anomalies.

The CFPD method was shown to render valuable insights in the state of the network when applied in a retrospective approach. Its capability to distinguish between different types of events adds interpretative power with respect to many other methods. In order to get successful and actionable interpretations of the observed signals, a more accessible and complete logging of the operational actions and manipulations (valves, flushing, etc.) would be valuable. Attempts to apply the CFPD method for real time event detection have not been successful. This appears to be an inherent limitation of the method.

Dynamic Bandwidth Monitor (DBM) (by Vitens)

Vitens has developed an algorithm called the Dynamic Bandwidth Monitor (DBM), which is an algorithm to forecast water usage in a metered area (DMA) and to detect any deviation that might be caused by leaks. Deviations to a water usage forecast can for example be caused by true events (e.g. leaks, pipe bursts, flushing) and known events (unmetered water supply between two areas, warm weather, holidays). The DBM detects all events but will try to suppress the known events that can be correlated to similar events in neighbouring areas.

The DBM algorithm runs on a PI server as a Windows service and creates a forecast in real-time by looking at the past 12 weeks for a specific timestamp, creating an upper and lower limit and finally compares the actual measured water usage to the predicated value.

The DBM results are very promising and resulted in implementing the DBM algorithm in an operational dashboard to be used in daily operations. In several cases, the DBM could detect a leak or pipe burst several hours before a customer called or an operator detected the event, especially when leaks occurred in the night. DBM performs very well when the water usage is predictable; i.e. the demand pattern is not affected by industrial customers of which the water usage is not metered in real-time.

Flow Step Analyses (by KWR)

Flow Step Testing as a method for leak detection is a robust method to find the section within the DMA suspect to leakage.

For the DMA “Aldlân” a protocol is written to close and open valves in such a way that there are no sections without pressure at any time. The different sections move from one part of the DMA to another. For each configuration the expectation of the moving volume flows is known. The only thing that has to be done in the field is closing and opening valves according to the protocol.

The step flow testing methodology offers a relatively simple hands-on approach to leak localization. A broader application of the approach in areas that appear to have above average leakage rates is recommended, at least until model based leakage localization methods have matured. And even then, the more advanced methods may have more difficulty identifying "old" leakages (running for a longer period of time, and thus part of the "normal" signal), which can still be found using flow step testing.

The Flow Step analysis method was tested and proved very useful in one case where Vitens suspected a leak in a metered area but was unable to find it.

Leak Localisation Detection (Quasset)

This algorithm was designed to detect (and eventually predict) sudden bursts. The leak localisation analysis included separate investigations of the behaviour of the sensors that are installed in the hydraulic areas and DMAs respectively. For both approaches, the investigation considered the possibility that flow and pressure sensors in these regions might detect events at different timestamps due to the difference in distance between the sensor locations and the location(s) of the leak. In depth analysis was performed with previous data of events, however, only one event was applicable for full analysis.

Recommendations

Both the CFPD and the DBM algorithm have proved to be very successful and (therefore) useful, although the performance of the leak detection algorithms (DBM) and analysis methods (CFPD) is highly dependent on the data quality. The CFPD method can help a water company to analyse past events regarding unexpected water usage whereas the DBM can detect those events in real-time. The two algorithms can thus be seen as complementary.

SWING – Burgos – Acciona

The leakage detection is based on 3 different algorithms, whose combination results in a possible conclusion that there has been some water leakage within the demonstration site network.
1,496 smart water meters have been installed in SWING in order to provide the demo site with the appropriate equipment for leak detection and management in a smart way.

Consumption Prediction Algorithm (CP)

The objective of this algorithm is the identification of possible leakage using a predictive methodology based on a multiple linear programming model, which allows to compare the estimated flow with the actual flow, warning of a possible leak if the difference of these exceeds the confidence interval.

Minimum Nightly Consumption Algorithm (MNC)

An identification technique called "nocturnal minimum flow" is used, based on the premise that the minimum flow occurs at certain times, usually at night, and that they have a high persistence over time. By studying a behaviour pattern based on the detected minimum values of time series, an identification of a possible leak in the network can be made.

Hydraulic Balance Algorithm (HB)

This algorithm is designed to distinguish the causes for difference is incoming water in the network and the water supplied to the costumers. The purpose is to differentiate non-accounted water due to consumption and unaccounted water due to leakage.

Recommendations

The remote water meter communication is essential for the successful operation of the techniques and models. Weekly detection of transmission/meter anomaly throughout the partners proved to be helpful in this matter. The Water meter communication network has been progressively refined to continue with the evaluation of leak detection algorithms.

Some of the water meters cannot be read remotely, which lead to issues regarding algorithm calculations. These readings have been estimated thanks to an internal Aguas de Burgos forecasting algorithm or manual measurements that have been taken by them.

To perform an optimal initial calibration of algorithms, professionals from the water utilities have lent help to adjust them to the real environment.

TWIST – Reading – THAMES WATER

Within this work package, Thames water distinguishes different kind of leakages: on the customer side and within the distribution network, owned by the water company.

(Smart) water meters 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 reliance on batteries for power adds further challenges to communications that must be considered.

Customer-side-leakage (CSL) Discrimination Algorithm (CDA)

The Customer-side-leakage Discrimination Algorithm (CDA) is designed to analyse water consumption data from smart meters and to detect anomalous patterns which are marked as Points of Interest (PoI).

The way that CSL and wastage are differentiated is that for CSL the flow rate of the PoI (i.e., the minimum flow rate) either remains constant or increases with time as the PoI worsens while with wastage, the pattern is more variable. These conditions have been taken into account in the CDA algorithm. The algorithm cannot distinguish legitimate continuous usage.

The system performed very well and in fact outperformed the method that it was mimicking. This was achieved as the CDA can be tuned to be tolerant of small deviations from the absolute definition of leakage used in the current detection method. The CDA also performed very well when challenged with a dataset of mixed CSL and wastage PoIs, 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 that is adaptive, in that it is retrained continually, at regular intervals and completely automatically, so that training is scalable and not subjective.

The output (of AURA-Alert) can be sensitive to isolated anomalous timestamps as AURA-Alert processes each time step independently yet the water network operator is primarily interested in periods where many outliers occur in close temporal proximity so aggregation of outliers using a moving window is needed to arrive at the probability of an event occurring for each time step. A Binomial Event Discriminator (BED) was developed as an EVP service in Java to achieve this which is applied to windows of thresholded match distances, with alerts produced based on the BED output. 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. The system did not perform well when challenged with the engineered events, however it was able to detect three of these events. This might be caused by the relative size of the “signal” given off by the event to the complexity and the noise on the networks and the confidence in the range of “normal” behaviour in the system’s model.

Syrinix algorithms

PipeMinder-S and T measure and record pressure within the pipe and are capable of measuring up to 128 samples per second serve two purposes: Detection of pressure changes directly due to bursts and identification of transients induced elsewhere that pose a threat to the network.
The algorithm considers the differential arrival times of the transient (change in pressure) at one or more PipeMinder units. The second approach is to use a number of PipeMinder sensors to predict the pressure at another PipeMinder.

In many cases, for trunk mains, the volume of water lost is less important than the risk that a running leak may lead to a sudden catastrophic failure of the main. The large size of trunk mains and the quantities of water released in these circumstances can have significant impact. It is positive to note therefore that the extended bracket between the endmost sensor heads is producing encouraging results which warrant further investigation. An extended range would enable a greater length of trunk main to be protected by Syrinix for a given investment.

Recommendations

The subdivision of DMAs into smaller areas with low cost meters where the challenge of achieving accurate and reliable performance in real world conditions at the low cost envisaged proved beyond the currently available technology. As the cost of reliable technology comes down, the value of subdivision may yet be achievable.

The smart water network technologies are mostly useful when incorporated into the business as usual. This requires some changes in management, in particular the practice to utilize the information, alerts and alarms created by the smart water network, to move to a proactive management model. It is essential that the current knowledge and expertise in use is incorporated, and not discharged, into the development and implementation of the smart network.

Integration of technologies can provide greater benefits than the sum of the parts. Where one method of testing for anomalies does not do so with sufficient confidence to warrant a response, the alerts from other systems should be combined to give a higher level of confidence.

SUNRISE – Lille – University of Lille 1

The work within this work packages on the Sunrise demo site is jointly accomplished by W-SMART and CALM Water in cooperation with the University of Lille, New York University and the University of Pavia.

Network Leak (NetLeak)

The work accomplished aims to develop and demonstrate the technical feasibility of a prototype system for early Network Leak (NetLeak) detection that will efficiently enable water operators to ensure real-time water leak detection and control management, as well as a pre-emptive asset management and operators' warning.

The "NetLeak" prototype algorithms included the pipe distribution network for the flow modelling using the EPANET model, AMR consumption data at building connections, the simulator of leak scenarios, control valves to control the flow direction, instrumentations for water pressure/velocity parameters, and water supply monitoring.

Recommendations

The SW4EU project has provided an exceptional platform for the assessment and demonstration of the relevance, performance and benefit of the NetLeak prototype system using the Lille demo-site and its AMR data along with EPANET numerical simulations output data. The current results demonstrate the feasibility and benefit of the NetLeak system in real time monitoring for early leak detection filtering false alarms. The partners strongly believe that these results will greatly contribute to mobilising the investments necessary to engage the next step of the development and testing of an integrated "beta" prototype to address the critical need for near real-time leak detection for pre-emptive rather than reactive asset management of water distribution systems. Typical to "beta" prototype challenges this future development entails financial risks and further technical challenges.

4.1.3.4 WP7 Energy optimization

The two solutions in this theme were:

3.1 Energy optimization by using District Metered Areas, pressure and other sensors and detailed modelling at Vitens demonstration site (Vitens, KWR, Quasset).
3.2 Energy optimization by pressure sensors, advanced modelling and self-learning algorithms at TWUL demonstration site (TWUL).

VIP – Leeuwarden – Vitens

Vitens consumes around 77.000.000 kWh of electricity each year in order to distribute drinking water to its customers. For reasons of sustainability, Vitens aims to reduce its consumption of electricity in 2020 by 20% relative to 2010. The goal of this research is to identify solutions for reducing energy consumption when distributing drinking water to customers. In concrete terms, this means a reduction of the energy consumption per distributed m3 of water from 0.198 kWh/m3 to 0.158 kWh/m3.

The main contributor to energy consumption within the supply of drinking water is the continuous needed pressure within the network realized by operation of pumps. One of the boundary conditions for this research is Vitens' policy on pressure, which specifies the minimum pressures that must be present at specific locations in the distribution network.
Several research questions were investigated to gain more insight in the possibilities to reduce the use of energy:

- How much energy is saved by increasing the diameter of the infrastructure based on previous change in specific pine replacement?
- What energy saving does the use of a separate transport pipe deliver in comparison to feeding a reservoir via the distribution network? (high pressure is needed in case of connected costumers)
- Is there an energy saving associated with using a reservoir as a supplementation reservoir, and if so how great is that saving?
- How much energy can be saved by regulating based on the pressure measured at the customer as opposed to regulating based on the outgoing pressure at the pumping station?
- Which settings for the pipe characteristic formula for a specific area offer the highest energy efficiency?
- How much energy can be saved by using the "OPIR pressure module"? OPIR is a software tool developed by Royal HaskoningDHV, which predicts the expected amount of drinking water that will be required each day.

Conclusions

The following conclusions can be drawn based on the foregoing arguments and results:

1. Connecting customers to a transport main during or after installation is unwise from an energy efficiency point of view, as water can then not be transported at a low pressure.
2. The use of a reservoir as a supplementation reservoir does not by definition result in a saving in comparison to using it as a distribution reservoir.
3. In situations where there are large pressure fluctuations in the 'capillary lines' in a balancing zone, using Dynamic Pressure Regulation based on instrumentation in the 'capillaries' can result in an energy saving of 8%. Note: Process automation must be set up to prevent peak pressures, which may cause pipes to break.

4. In situations where OPIR is used, energy can be saved by using the native ´pressure module` in OPIR. This can generate a saving in a balancing zone of 5.9% based on current information.
5. In general, the distribution pressure within Vitens' network is more or less based on "worst case" situations. Tighter control (in areas where there are currently no complaints about pressure) would allow Vitens to reduce the distribution pressures by 0.1 bar without leading to complaints.

Recommendations

After performing the series of tests, the conclusion is that there is no single answer to the question: "What innovative solution exists for reducing energy consumption when transporting drinking water to customers?" A customised approach needs to be applied per situation/balancing zone. In some situations, one measure will be effective whereas others will not. Furthermore, the estimated savings are not cumulative; when one measure is implemented, the potential saving offered by a different measure often no longer applies.

TWIST – Reading – THAMES WATER

Thames water developed an Energy Visualisation Tool (EVT) with the goal to show how the energy fed to the system is consumed in delivery. Additionally, the tool would create possibilities to report for identification of opportunities.

In the first stage algorithm is developed to introduce the concept of energy and to include the calculations is in development. This provides the opportunity to calculate energy not only in the pipes but also at the demand points. The second stage consisted of the development of the actual visualisation tool to display the results obtained in the first stage.

The following research questions were defined:

- Where does the energy go and how it is distributed by component, area or time of the day?
- How efficient is the network in delivering water?
- What are areas with hydraulic restrictions?
- What are limits or constraints to pressure manage an area (for example, isolated demand points with very low pressure)?
- Which areas or routes have excess energy that could be reduced in some way?
- Are there energy "hotspots": areas, routes or demand points that consume a significant proportion of the energy?

Main conclusions

One finding for the network under investigation is that only 12% of the energy fed in the system is lost in transmission. A second finding is the identification of two highly energy inefficient areas. Both of them waste significant energy in delivering too much pressure, probably because they are both flat areas and consume a lot of water. Another DMA is far from the WTW incurring high frictional losses.

The tool has proved its ability to detect areas where pressure is lower of higher than required. Focusing on areas with high demand, gives opportunities to optimize the energy balance.

Recommendations

It has been discussed that Pressure reduced values (PRV) might help in reducing leakage, but they do not save energy. Therefore, unless leakage in the area is high or the customers experience problems due to excess pressure, deploying a PRV is not really the best option.

If pressure reduction is required, it should be done from the source. It must be considered that the same main also delivers to other areas. This option relies on a booster to satisfy a whole area, which can lead to a loss of resilience. A second option to reduce the energy wasted in the network is rezoning.

Finally, 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. Turbines could be used to generate some energy; how this energy would be stored or put back in the grid requires a much deeper analysis. However, an energy efficient design is better than recovering energy after losing it.

CALM WATER

The purpose of the CALM Water demonstration project 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 'Power-Log' algorithm enables integration of:

- The GIS spatial visualization of the propagating power deficiency impacts on the flow state parameters (i.e. pressure, flow velocity and head-loss in pipes) throughout the network
- The database of the real time monitored or numerical time series data of the flow parameters
- Operator's experience based classifier of the likelihood-severity of a local power deficiency in the network for pattern recognition of the deficiency spatial signatures and its geo-localization

Recommendations

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. The GIS spatial visualization of the likelihood-severity of a potential local power deficiency throughout the network, based upon the pressure variance monitoring data, could effectively support the operator in real-time power system diagnostics, geo-localization of a pressure deficiency and optimization of its mitigation.

The Power-Log capabilities for early power deficiency detection and geo-localization could be efficiently leveraged by the recent developments of CALM cyber-secure power controllers, using pressure and flow measurements at the building level, integrated with the development and adaptation of AI based algorithms for early warning systems and mitigation control.

4.1.3.5 WP8 Customer interaction

The two solutions in this theme were:
4.1 Detection of water related events by using social media and provision of information to (vulnerable) customers (Vitens, Quasset);
4.2 Influencing customer behaviour by supplying water usage information through web and mobile applications (TWUL, Vernon Morris, Solvd).

VIP – Leeuwarden – Vitens

Within this work package, Vitens focussed on two activities: The development of an events dashboard and an interactive game to stimulate costumers to reduce water consumption.

Events Dashboard

Vitens has built 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) are displayed in a geographical manner. 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.

Although still not fully developed, the events dashboard is used daily within Vitens since the first successful tests. It has proven its value in several cases. User experiences are used for further development of the tool.

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 see if peak shaving of water usage patterns is possible, in order to reduce energy consumption and CO_2 emissions. A second aim is to make the customers more aware of their water consumption.

The first pilot with the Waterbattle game and app started on 28th September 2015 and ended 11th December 2015. 2 schools, 135 children and 43 households were participating in this first live test. The second pilot has started in March 2017 and ended in July. In this pilot 7 schools, over 350 children and 173 households were participating.

The most active app participants have actively modified their behaviour and water usage based on the assignments. Up to 60% of participants who had the monitoring system installed used the Water battle app.

Of the total group of participants, about 50% of the estimated consumption times are actually realised. Looking at the top 5 participants, they scored 70% at the scheduled times. The 2 best households even scored in 87% of the scheduled points.

The pilot has delivered many new insights. Technically, it has been possible to link water usage to a game / app. The size of the pilot was too small to clearly show an effect on peak reduction. Based on this first pilot there were cautious signals that, in particular, the app can contribute to behavioural change. Letting parents and children playing the game together will create a "social pressure" towards the parents to adjust their water consumption.

TWIST- Reading - Thames Water

Reward scheme

Thames Water has installed Sensus 640 volumetric water meters at over 3,000 metering points around Reading. Thames customers are 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 will receive points. Further engagement can also earn customers points, such as pledging changes in behaviour and taking water-related quizzes.

Householders receive 1 point for every 10 litres saved compared to their baseline, and it is forecast that in a year, customers could earn up to 5,000 points. These points will be available to spend on various rewards, providing incentive to save water and educate themselves on water efficiency. Two pieces of analysis by different statisticians employed by Thames Water have not been able to prove that the incentive scheme has in general (and on average) had a positive, lasting effect at the time of registration. The results suggest that a subset of households respond well to the incentives on offer and encouragement given, whilst a larger majority do not see a reduction.

Further study of a larger sample of participants is required to determine what type of household responds well to this particular incentive scheme.

Other advantages of network wide installation of smart meters at household were considered. In theory, smart meters will enable near immediate notification of a likely burst or leak in the home. This is one use of smart meters that may help customers to reduce their insurance premiums, particularly when combined with actuated valves that can restrict flow into a household.

4.1.3.6 WP9 Integration

The four solutions in this theme were:
5.1 Integration of solutions 1.1, 2.1, 3.1 and 4.1, additional functionalities and response strategies at the Vitens demonstration site;
5.2 Integration of solutions 1.2 and 2.2, additional functionalities and response strategies; at the Acciona demonstration site;
5.3 Integration of solutions 2.3, 3.2 and 4.2, additional functionalities and response strategies at the TWUL demonstration site;
5.4 Integration of solutions 1.3, 2.4 and 3.3, additional functionalities and response strategies at the USTL demonstration site.

VIP – Leeuwarden – VITENS

The aim of the integrated solution was to supply data of the different solutions to the Central Operations and dispatch department (CODD). All this much be executed in such a way that it supports the CODD employee in deciding on the most appropriate response on an event, and to supply the right data. Next to that, the solution should enable the CODD employee to communicate to the customers.

The Dispatch department partly consists of a call centre. In case of an interruption with a large impact or when the incident is too large to be handled by one or two engineers, the coordination of is handed over to the Central Operations department.
A map based application was built and integrated in the CODD user environment and different data sources were connected:

- Solution 1.1: Warnings and alerts as generated by the Optiqua Eventlab sensors are shown on the map as orange and red dots. Integration of data from the nano::stations is in development.
- Solution 2.1: Information from the Dynamic Bandwidth Monitor (DBM) is shown as colouring of the DMA, where different shades indicate the severity.
- Solution 4.1: telephone calls are shown on the map, showing the location of the caller. Tweets are shown. Different colours indicate the tweet is about Vitens, quantity, quality, health or other.

Design of the integrated solution

The CODD uses several applications to do their job, such as:

- OSIsoft Pi for displaying and analysing flow data, reservoir levers etc. in graphs.
- OSIsoft Pi for displaying and analysing flow data, reservoir levers etc. on maps (map as static background).
- Spatial workshop for the network topology and valve positions.
- MS Excel for logging events.
- Web browser with Waterstoringen.nl, showing incidents and planned work.

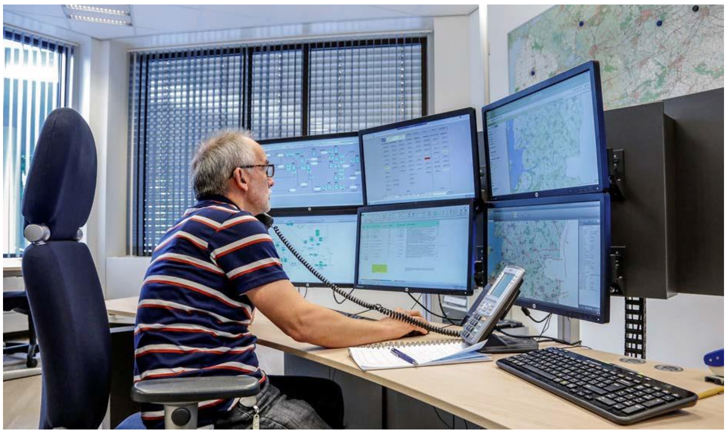

Figure 15. Work place at the Central Operations department

Impression

One of the success factors was the availability of all information in one overview: real-time information (leak, water quality and customer interaction as), dynamic data (e.g. excavations and 911 emergency information) and static data (e.g. network layout, GIS information). All data combined in one GIS system enables the operators to quickly indicate an event, locate an event, conclude on the severity of an event and decide on the proper response to the event.
Another advantage was the pro-active customer interaction which initiated on the GIS system, i.e. the map view that shows all information, including telephone calls and tweets. This enables the operator to both make the best selection of customers and provide the most accurate and up-to-date information about the event.

SWING – Burgos – ACCIONA

The final aim of the Burgos demo site is to integrate the two individual solutions demonstrated on a single Business Intelligence (BI) software platform.
The Data Control Centre receives data from ~1500 water meters of the network. It also receives and stores information from other software such as the subscriber management or geographic information systems.
An integrated smart water solution for SWING refers to a BI platform developed in such a way that each screen of the software provides only the necessary information to make the decisions quickly and easily, avoiding unnecessary information. This application is fed with

- 1496 dynamic or real-time smart water meters
- 6 sensor readings (5 Optiqua EventLab® and 1 S::CAN Nano::station®)
- contract information
- the status of the network elements
- and other data sources as shown in Figure 16

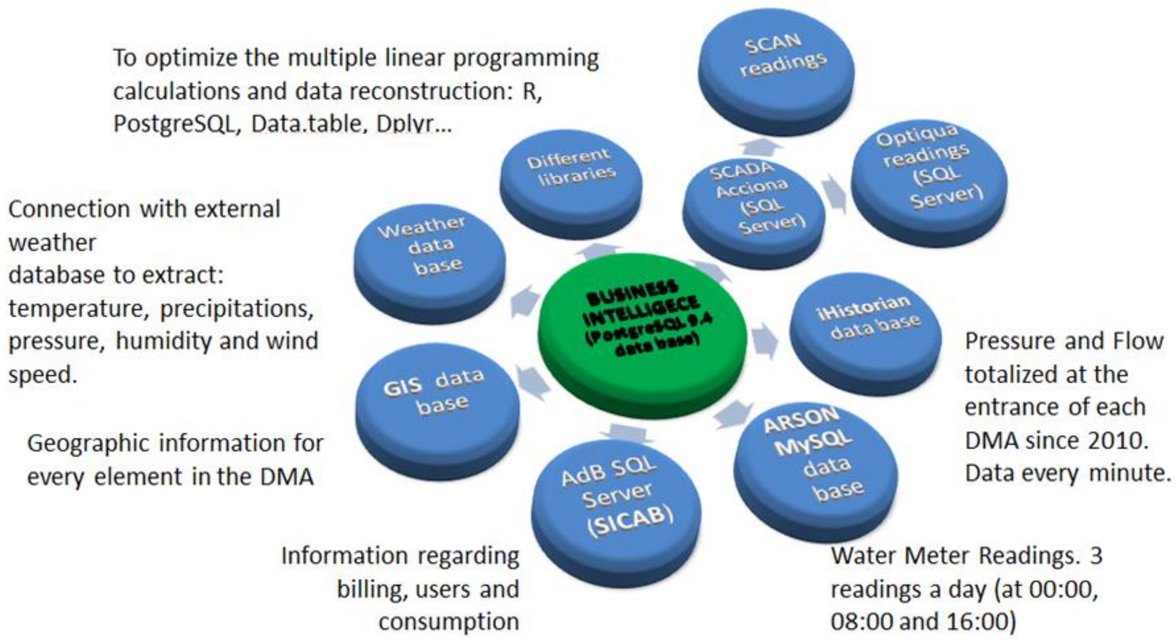

Figure 16. Data sources integration

The various thresholds will generate events and the alarms associated to the algorithms developed to detect leakage online will be triggered to warn of possible alerts.
This platform integrates two individual solutions from each work package and merges it in one visual overview using data from:

- Solution 1.2: Real-time warnings or alarms from Optiqua EventLab® and S::CAN Nano::station® quality sensors
- Solution 2.2: Detecting leakage on line thanks to the combination of three different algorithms which are complementary to each other.

The implementation of algorithms was a success: the water flow estimation model designed by ACCIONA turned out to work successfully in both the urban and residential DMA (average relative error below 10 %). However, this algorithm was not working so well in the industrial DMA due to the difficulty of finding a correct pattern (average relative error was between 27 % and 40 % depending on the selected time). Then, it was improved thanks to the collaboration with the University of Extremadura Mathematics Dpt. by using a pattern similarity approach. The current relative error is below 10% in the industrial DMA.

Figure 17. Business intelligence platform front page

Impression

Data integration means combining information from various sources into something useful. It's about efficiently managing data and making it available to those who need it. The solution shows some of the potential benefits of integration by centralizing data, reducing data complexity, increasing the value of data through unified systems, making data more available and allowing to make smarter business decisions.

The possibility of receiving the readings weekly with a data frequency of 8 hours makes it possible to early correct different events (high consumptions, communication failures, possible manipulations, etc.), in the operation of the water meters.

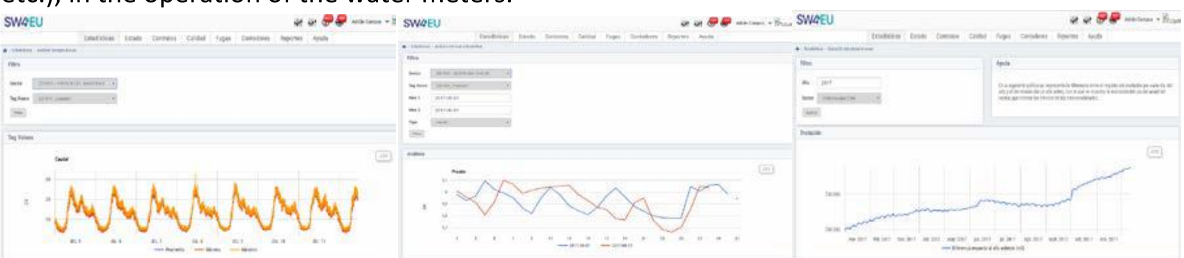

Figure 18. "Statistics" tab. Historical and comparative flow and pressure analysis for every DMA.

TWIST – Reading – Thames Water

The outputs from the different solutions developed during the project were integrated into one single platform. The platform was developed by Solvd, with the collaboration of Thames Water.
The integrated solution is an attempt to develop a holistic visualisation platform that shows the potential of using a centralised data repository and integrating various systems. It combines output from the three work packages and related solutions demonstrated at TWIST:

- Solution 2.3: Leakage management, including data from:
  - Alarms from Customer Side Leakage (CSL) algorithms
  - Alarms from network leakage algorithms: Netbase envelopes developed by Crowder Consulting, AURA-BED alerts developed by the University of Sheffield, Trunk main bursts and leakage alarms from Syrinix PipeMinder devices and pressure transient events analysis developed by Thames Water. An in-depth analysis of all transients that PipeMinder-S devices detect was carried out in order to classify pressure changes into different categories.
- Solution 3.2: Energy visualization. Geographical representation and location of points of interests are displayed in a map together with information about water consumption and pressure analysis.
- Solution 4.2: Costumer interaction showing smart metered customers' response to incentives. A measure of engagement and water efficiency was calculated as a function of points earned through participation in an incentives scheme. This allows us to classify customers in different categories according to their engagement and water savings.

Design of the integrated solution

- A dashboard that shows instruments' information and active alarms.
- A network overview map that shows the locations of supply boundaries, mains, assets, and instruments. A drop down menu to select the zone and DMA of interest.
- Several layers on top of the network overview map, including:
  - Alarms for customer-side leakage from different algorithms
  - Alarms for network leakage from different algorithms
  - Distribution main bursts and leakage alarms
  - Pressure transient events and their classification
  - Customer engagement indicators for smart metered households

Impression

The solution shows some of the potential benefits of integration. By centralising data, there is less of a risk of it being interpreted in different ways, as there is when the data is being sourced and analysed in many different places. In this way, this brings a sense of uniformity to how the data is presented to allow for a 'single version of the truth' to emerge.
It is important to integrate the new tool with existing systems to prevent adding yet another screen or data stream for users to check.
Additionally, with multiple data sources and various systems processing the raw data from said sources, multiple versions of the "truth" can emerge. Integrating systems and centralising data to form "one version of the truth" ensures that this does not happen, so this should be the aim of any new initiative.

However, to fully realise the potential of integration, a change in our culture surrounding data and information would be needed to help data-centric initiatives meet the business' growing expectations, bringing the real-time and automated network closer.

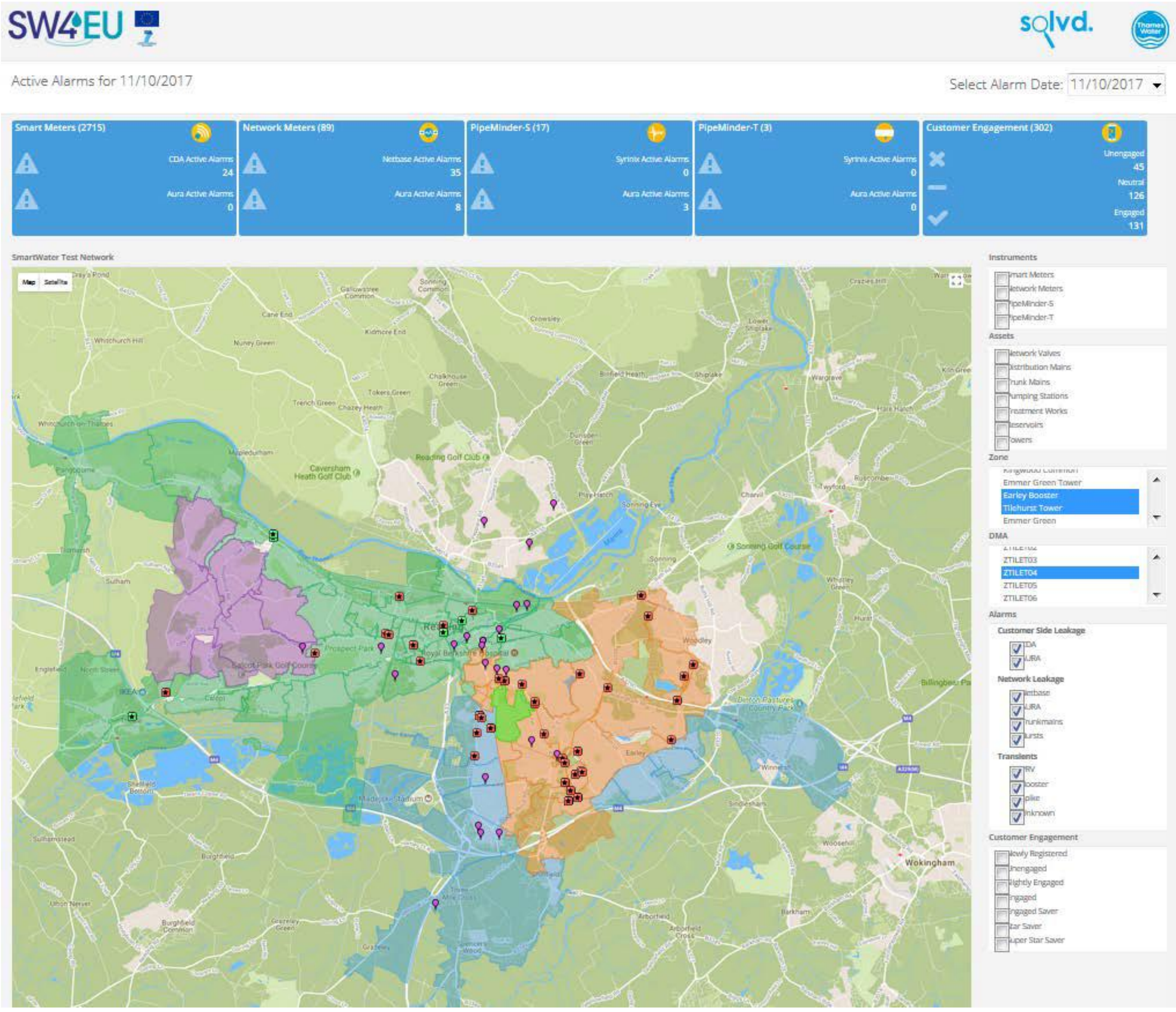

Figure 19. Business intelligence platform front page

SUNRISE – Lille – University of Lille 1

The demo-site had various objectives, mainly

(i) to demonstrate the use of the smart technology for leakage detection and real-time control of the water quality,

(ii) to use the smart technology to reduce the important water leakage in the campus network and to control the water quality in the campus,

(iii) to develop and a research and education activity in the field of smart water and smart urban infrastructure. The demo-site is used as living laboratory for both research and education in the field of Smart Water.

The integration of (i) and (ii) will lead to a useful tool for objective (iii).
The developed platform provided two machine learning algorithms:

• **Supervised approach**: In machine learning, several problems exhibit only a unique class for training (normal class). The decision rule consists of identifying if a new instance belongs to the learnt class or to an

• **Unsupervised approach:** This approach aims at grouping a set of data into homogeneous classes (clusters), so that the data of each class share common characteristics. Clustering is exploited here to group the time series (associated with the sectors or captors) into classes each represented by a prototype.

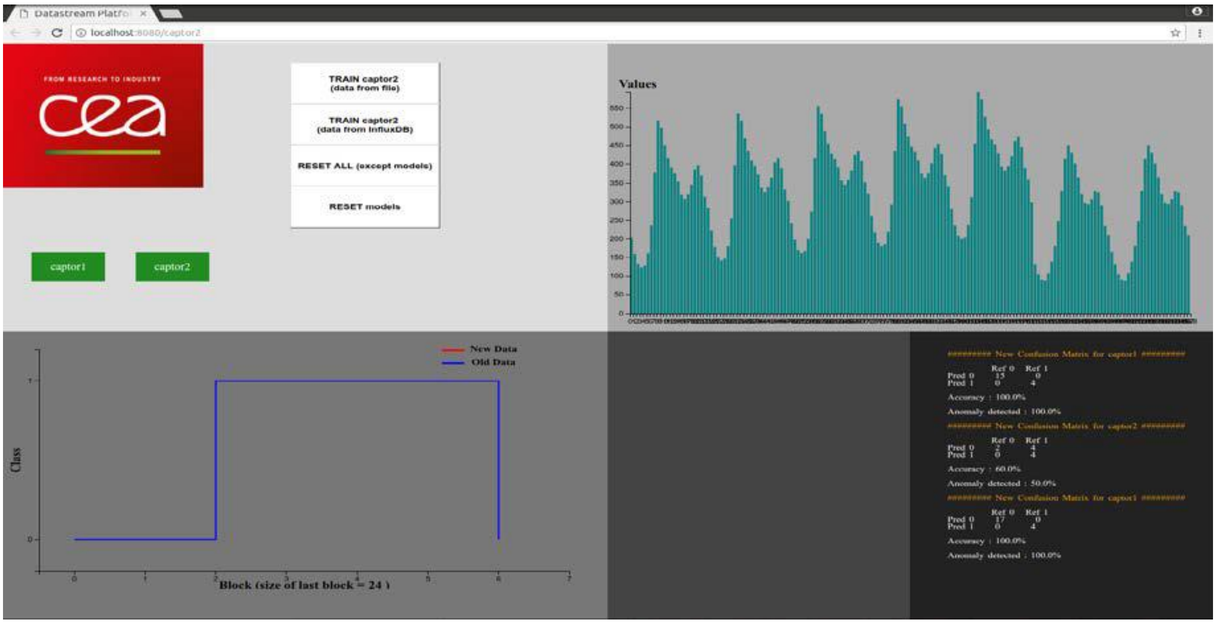

Figure 20. Graphical interface for leak detection result

The interface gives the possibility to train a model using historical data from data files or influx data base and store it. This is useful when historical data are enough to construct a ML model (offline training). Then the platform only applies this prior model on the arriving data (the online training is thus disable).

Implementation approach

Leakage detection

The implementation of the system monitoring for the leakage detection (AMRs and pressure sensors) was conducted. Development of software for data analysis and visualization was realized progressively. The other tasks concerning the (i) execution of demonstration program, (ii) adaption of solutions and (iii) evaluation of solutions were conducted

Water quality control

The water quality devices (Event Lab and nano::station) were tested in a laboratory pilot to understand their functioning and response to water contamination events. The installation in two locations. The development of analysis tools started after a period of observation in order to understand the system responses in the water network. Devices records were compared 3 times to laboratory analysis; some of sensors were re-calibrated. Some abnormal events were detected.

Impression

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 performant 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 could be yet enhanced using learning machine method to cover lost data or to detect leakages at the buildings level.

Concerning water quality control, nano:station and EventLab showed good performances, however vigilance concerning the maintenance such as cleaning, probe replacement and calibration is needed. Developed algorithms seem to work well, but up to now there was no significant contamination data for testing these algorithms and for developing data-based methods for water quality control.
The difference of the Lille approach, compared to the other demo sites, is the use of the tool for scientific research. The other demo sites are directly connected with a water utility and therefore the integrated tools are used to directly take action in case of an event.

4.1.4 Potential impact and main dissemination activities

(including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results.

Potential impact

Impact for the industrial companies and SMEs:

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 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.

Impacts for water utilities:

Customer health and customer satisfaction by improved water quality and improved service level: The successful demonstration of water monitoring technologies results in water utilities changing from targeted laboratory analyses to Smart Water Management using online sensors. Online water monitoring enables water utilities to react far earlier (2 days) to water quality events, thus increasing health, the amount of in-spec water supplied and customer appreciation of the water supplied. Usage of leakage detection methods reduces the number of times water is not supplied to consumers and the time the water is not supplied. Thus, the service level is improved. Also, leakages may affect water quality negatively. Hence, leakage reduction also has a positive effect on water quality.

Change of investment approach: The project has proven that the implementation of Smart Water Networks results in more than just financial benefits. On the contrary, a fully executed transformation of a whole network to a SMW might even cost more than the direct financial benefits on the short therm. Nevertheless, utilities are still interested in the other benefits it will generate. For example, a changed position of the customer, as an involved ‘human sensor’ to detect leakage, could contribute to a new business model. Secondly, the increase in knowledge about the distribution network, its performance and weaknesses would gain insight in optimization 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.

Impacts for society/policy makers:

The technologies demonstrated increase resource efficiency in water supply and awareness/reduction on water consumption. Because of the availability of better operational data, the technologies demonstrated can be used to optimize investments in water supply infrastructure. As water distribution will have an investment boost, this will reduce the costs of supplying water and/or enlarge the effects of investments made in water infrastructure. For policy makers new solutions come available for water monitoring. These solutions may be used for improving water policies.

Policy brief

At the end of the project, a policy brief was prepared containing recommendation for policy maker to facilitate a improved policy for implementation of the results of the SW4EU project. The main recommendations are listed below.

Recommendation 1: A stepwise transition to accept SWNs as water quality monitoring methods.
Based on the results within this project, the SmartWater4Europe consortium recommends a gradual transition to accept SWNs as additional screening methods, alongside the traditional lab analyses. During the process the new method can be fully established, while giving space for new implementations. The ultimate goal is to be able to monitor water quality in real-time, without the frequent manual sampling, and be able to act instantly in case of an event. When this occurs, traditional and new lab analyses will be deployed to provide optimal information about the water quality.

Recommendation 2: Set up only feasible regulatory demands (like limits in leakage or consumption) in collaboration with the utilities to achieve the goal.
The consortium would like to stress policy makers and regulators to restrain from sudden changing regulatory demands to force utilities to look for new avenues (for example, strict annual leakage reduction targets set by the regulator). The underlying political goals could be met in a more efficient matter when water utilities could express the potentials in these affairs.

Recommendation 3: Additional financial aid to support research & development for SWNs.
Although the results of the SmartWater4Europe project are very successful, more research and development is needed to create the optimal solution. Subjects that are still in development are for example: data analytics, modelling, design of the ideal monitoring network (which concerns structure, soil, capacity, etc.), the added value of real-time sensoring, the ideal combination of sensors and the most reliable interpretation of the data. Financial support is still needed, since stable business cases have not yet been elaborated based on real-life validation. Technology validation at demonstration scale and the creation of business cases is a required condition for further application of solutions.

Recommendation 4: Use concession contracts to stimulate the implementation of SWNs.
In some countries, the government is in charge of temporary concession contracts. This role could be used to stimulate the utilities to implement SWNs. For example, the contract could simply include a requirement for SWN installation or utilities have an improved chance of getting the contract when they include SWNs in their applications. Another way is to include an overall requirement of improvement in leakage (in decreased % leakage loss) or energy usage (in decreased kW/m3). This way the utilities are free to choose the methods to reach these goals (renovation or SWNs e.g.).

Dissemination activities

Website

The project website www.sw4eu.com gives a comprehensive overview of the objectives and structure of the project and a description of the different demonstration sites. It includes various informative videos and graphics about the design of the demonstration sites and the approach of the project. The information presented is understandable for a wide public.
The website accommodates a direct line to contact the consortium for possible collaborations, support or inquiries about implementations of Smart Water Networks elsewhere.

Newsletter
It was also possible to subscribe to the SW4EU newsletter on the website. The newsletter contained additional information about other SWN projects, updates on the demo sites, activities of the partners and a list of recent publications.

Publications
The consortium encouraged all partners to publish the results in (peer-reviewed scientific) journals. The involvement of different universities and research institutes within the project ensured the high quality of the published articles. A list of the published articles is included at the end of this report.

Presentations
The SW4EU approach and results were presented world wide at different conferences and symposia. This resulted even in more invitations to present at other events. A list of the presentation is included at the end of this report.

Symposium
On the 2nd of November, 2017 a very successful Smart Water Management symposium was organized by the consortium, in collaboration with event agency Ster. The event took place in the Amsterdam RAI, a convention center in Amsterdam, The Netherlands. Over 120 participants attended the symposium, ranging from experts from other water utilities, engineer consultants to independent researchers.
The symposium was organized during the Amsterdam International Water Week, including the Aquatech Amsterdam to increase the exposure and accessibility to many people in the field, outside of the consortium. The consortium has two goals with this symposium: 1) visibility of the consortium and the thriving topic Smart Water Management and 2) sharing of the project results. A concept was designed to achieve these two goals consisting of a plenary part, informative deep dive sessions on detail level and an informal part during lunch and over drinks after the sessions. During the plenary sessions, results from the project were shared on a more general level. The deep dives were

separated based on theme specific presentations related to the themes specified in the SW4EU project.
All presentations and an impression movie are available on the website.

W-Smart as partner of UNESCO

W-Smart has been recognized by the General Director of Unesco as official partner for innovation in integrated water management.

The work and activities of W-Smart are consistent with the current programmes and priorities of UNESCO in the field of the natural sciences, and cooperation between UNESCO and W-Smart has a solid foundation, based on the close collaboration established with the UNESCO International Hydrological Programme.

This initiative includes a Unesco publication of a book in collaboration with SW4EU and W-Smart on Smart Water Network management.

4.1.5 Project website

Information and contact details are available on the website www.sw4eu.com.