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Water analytics and Intelligent Sensing for Demand Optimised Management

WISDOM

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WP.5

D5.3 | **DCWW**

Pilot Demonstrators and WISDOM System Validation
(Final report)

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Project Coordinator: Daniela BELZITI
Tel: +33 4 93 95 64 14
Fax: +33 4 93 95 67 33
E-mail: daniela.belziti@cstb.fr
Project website: **www.wisdom-project.eu**

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Author(s):	Fernando Nardi (IDR), Antonio Annis (IDR), Tom Beach (CU)
Contributor(s):	Anna Taliana (DCWW)
Reviewer(s):	Daniela Belziti (CSTB), Mathew Preece (CCC)

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Author(s):	Fernando Nardi (IDR), Antonio Annis (IDR), Tom Beach (CU)
Contributor(s):	Anna Taliana (DCWW)
Reviewer(s):	Daniela Belziti (CSTB), Mathew Preece (CCC)

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ABBREVIATIONS

Acronym	Full name
AMP	Asset Management Plan
ASP	Provincia della Spezia
ATO	Ambito Territoriale Ottimale (Optimal Territorial Unit)
CCC	Cardiff City Council
CSTB	Centre Scientifique et Technique du Bâtiment
CU	Cardiff University
DCWW	Dwr Cymru Welsh Water
DoW	Description of Work
DWI	Drinking Water Inspectorate
ICT	Information Communication Technology
KPI	Key Performance Indicator
MoS	Measures of Success
NRW	National Resource Wales
Ofwat	Water Services Regulation Authority
SAT	Societa Acquedotti Tirreni
SIM	Service Incentive Mechanism
SMART	Specific Measurable Achievable Realist Time bound

EXECUTIVE SUMMARY

This deliverable presents the outcomes of Task 5.3, concerning the demonstration and validation activity of the WISDOM project with respect to the pilot sites. This task is devoted to the evaluation and validation of the entire WISDOM system, in which the technology created in WP2 & WP3, and the deployments that have taken place in WP4 are evaluated through a validation exercise. The state of the pilots prior to the deployment of WISDOM is used as a baseline for the analysis. The Key Performance Indicators (KPIs) defined in D5.1 are the basis for this validation activity that has the final goal of evaluating quantitatively if the expected WISDOM goals of water/energy management and optimization are achieved. Both socio-economic and technical aspects have been taken into account during the evaluation of the results in order to validate the system from two perspectives.

This deliverable provides a continuation from D5.1, where the KPIs evaluated in this task are defined and the overall validation strategy is described. In this deliverable, the strategy presented in D5.1 is further developed for the purposes of benchmarking the WISDOM solution with respect to the expected project outcomes and goals, using the resulting data collected from the pilots (which is the focus of Task 4.4).

In this document, some of the D5.1 KPIs have been modified to better reflect the situation within the pilots and provide the clearest representation of the impact of WISDOM's deployment (KPI 2, KPI 8 and KPI 11).

In addition to the pilot specific KPIs defined in Task 5.1, this document also considers the overall project goals which are:

(a) reduction in water usage;

(b) reduction in carbon emissions (due to less energy consumption within the water network, for example).

Additionally, this deliverable documents the validation that has been conducted on the WISDOM research focused scenarios that were not covered by the pilot KPIs. This includes the validation of the leakage localisation and the household water usage disaggregation.

Some of the results of the validation, specifically results of KPI 2, 3, 4, 7, 8, 9 and 12 will be presented in the version of the deliverable that will be submitted for the review (31/03/2017); in this current version, the acronym TBC (To Be Completed) has been used to indicate these results.

1. INTRODUCTION

1.1. The proposed value of the work

This deliverable presents the outcomes of Task 5.3, the benchmarking and validation of the pilot-related KPIs developed in Task 5.1, the final validation of the WISDOM system and the validation of the research focused developments conducted within WISDOM.

The proposed benchmarking process is implemented to verify the performance of the WISDOM system with respect to the desired performance defined for each pilot, using a thresholding analysis of the key performance indicators (KPIs). The final goal is to achieve a validation of the WISDOM system against its main goals of improving performance in water usage, energy usage and user engagement.

The validation methodology is linked to the entire set of WPs in the project, starting with WP1 that defines the “User Needs, Use cases, and Business scenarios” and evolves into WP4, the “Stakeholder Centred Real-Life Demonstration and Testing”. All of this driven by the WISDOM ICT architecture, and analytics developed within WP2 and WP3. Figure 1 provides a flow chart representing the interconnections between Task 5.3 and its related tasks.

The WISDOM *Balance Scorecards* (that were called *Dashboards* in D5.1) provide a summary by which the performance of the pilots can be viewed with respect of both the WISDOM KPIs and the project key goals (e.g. water/energy reductions, optimisation etc.).

The implementation of the validation approach throughout the pilot deployments, using these *Balanced Scorecards*, has triggered an iterative procedure that allowed to adapt the deployments in order to ensure that the water/energy reduction and user behave objectives were met.

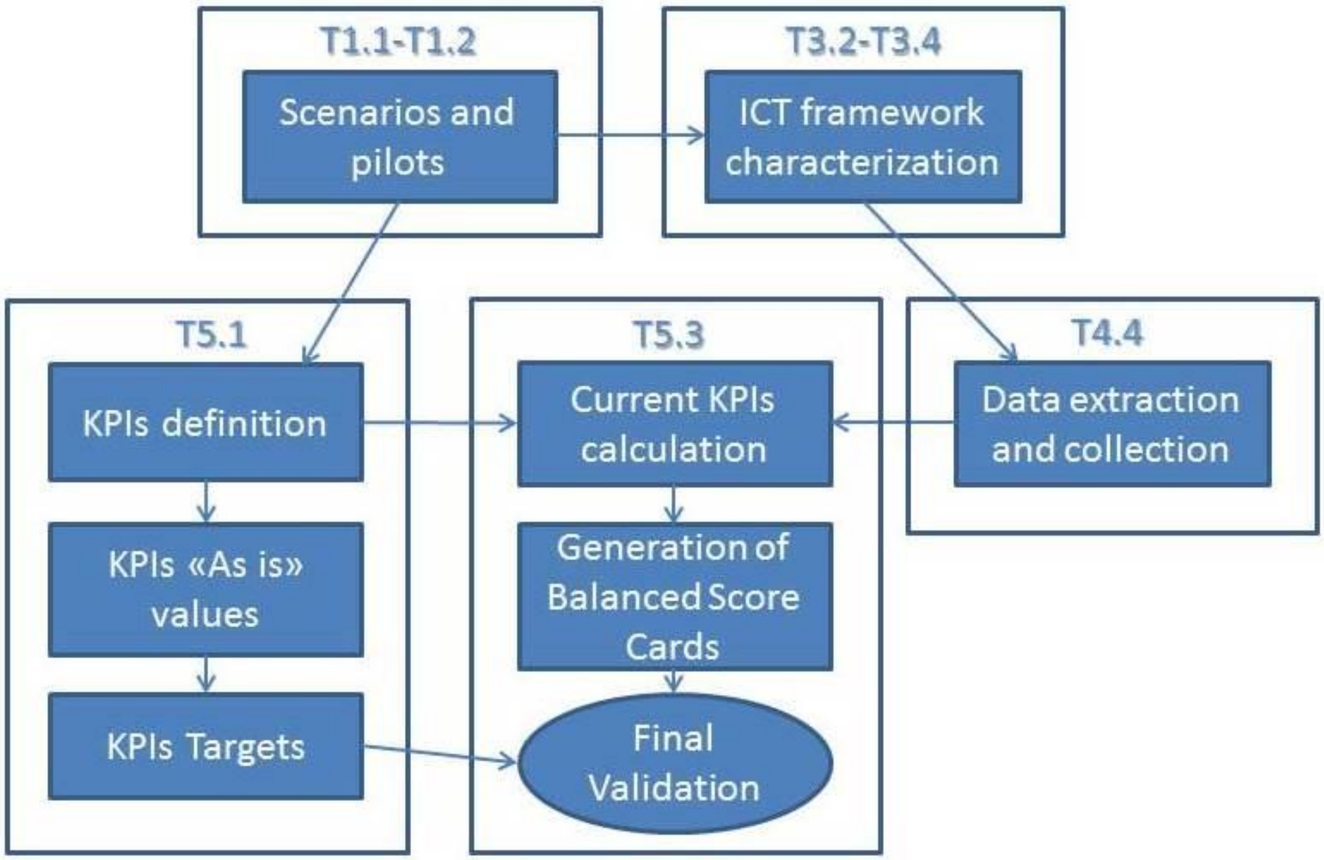


Figure 1: WISDOM WP and related tasks interaction with Task 5.3

1.2. Analysis of progress against objectives

In the following table, the objectives proposed in the DoW are compared with the actions addressed by the consortium:

Proposed Objectives (DoW)	Actions (project activities)
"...This task will be devoted to the evaluation and validation of the entire WISDOM system, in which…"	The entire WISDOM system has been validated proposing and applying a validation methodology on each pilot. The validation takes into account each Key Performance Indicator (KPI) defined in D5.1 and combined them in to a unique pilot success rate.
"...the results obtained from WP4 will be taken into account and evaluated through a benchmarking analysis between the previous years and the year in which the pilot was deployed."	A quantitative benchmarking analysis has been done where pilots' data from previous years were available. In some cases, (e.g. SAT and ASP pilots) if sensors and measurements were absent in "before WISDOM" scenario, more qualitative evaluation have been done, underlining the advantages of the WISDOM intervention.
"… Both socio-economic and technical aspects will be taken into account during the evaluation of the results in order to validate the system from two different perspectives "	Cardiff Pilot KPIs take in to account both of the aspects proposed in the DoW allowing evaluating qualitatively and quantitatively the system in two different perspectives.
"… the most important factors that shall be evaluated in this task will be defined in task 5.1."	This document follows the objectives defined in D5.1, but, in order to improve the effectiveness of the validation strategy, some changes have been done, specifically: 1. The Dashboards defined in D5.1 have been renamed as Balanced Scorecards; 2. Some KPIs' names (KPI 2, KPI 8 and KPI 11) have been changed, as well their target and tolerance values

Table 1 - Comparison of proposed objectives and addressed actions

1.3. Document summary

This document includes the general overview and specifications of the WISDOM benchmarking and validation approach. The validation methodology is presented here, and specifications on the use of the *Balanced Scorecards* for the KPI analysis and verification on the pilot sites are also described. This deliverable also includes the testing and benchmarking results that were performed at the pilot sites using actual testing, monitoring activities and data and the validation of the WISDOM system.

This document is organized as follows: an introduction is inserted in Section 2 including a brief literature review of the benchmarking and validation activities with specific regard to the most relevant activities of the other projects of the ICT4WATER cluster and in scientific literature; in Section 3, after a brief overlook of the WIDSOM KPIs, the WISDOM validation methodology with the Balanced Scorecard is illustrated. Sections 4-9 report the results of the KPI calculation and the balanced Scorecard for each pilot. Section 10 illustrates the research experiments applied to the Welsh and SAT pilot regarding the *Water Usage Disaggregation*, Leakage *Localization* and *Low Cost Water Network Sensing.* Finally, comments and conclusions are carried in Section 11.

2. Literature review of benchmarking strategies and reference work by ICT4WATER cluster projects

This section describes (a) the state of the art of the benchmarking activities following the outcomes of other ICT4WATER cluster projects as well as (b) the benchmarking methodological analysis gathered from scientific references. Thus, the inspiration gathered from the review reported in this section has fed into the development of the WISDOM validation methodology described in Section 3.

2.1. Benchmarking and validation strategies in ICT4WATER cluster projects

The evaluation of the findings from other projects in the ICT4Water cluster is an important activity for the integration into the WISDOM project of the alternative solutions/services developed within the cluster.

The ten ICT4Water projects (Waternomics; DAIAD; EFFINET; ICeWater; ISS-EWATUS; iWIDGET; SmartH2O; Urbanwater; WatERP) have been examined and here a brief summary of the outcomes of the main reference project for the benchmarking analysis is presented. An extended summary of the performance analysis of the selected ICT4WATER cluster projects has already been inserted in D5.1.

This section focuses on extracting the main information concerning the benchmarking and validation methodology (where available) related to the main KPI categories that are:

- Water resource efficiency
- Energy resource efficiency
- Water infrastructure knowledge
- Water managers/users behaviour
- Awareness and socio-economic components

The principal sources of information from the ICT4Water projects' KPIs are related mainly to WATERENOMICS, SMARTH2O and iWIDGET Projects. The survey has not considered results from other ICT4Water projects, mainly due to the fact that their deliverables featuring this information had not yet been approved by the EC – and therefore could not be released – at the moment of the survey.

- In the **WATERENOMICS** project, the first category of benchmarking KPIs refer to building or site water footprint, and their comparison against peers or industry regulations. Upon the release of the WISDOM D5.3, the validation methodologies for those KPIs are not yet available.
- **SmartH2O** gives a more detailed approach of benchmarking analysis in the document D7.1[1] of its project. The impact of the SmartH2O project will be benchmarked using the objectives stated in the *Description of Work* (1. Understanding consumer behaviour, 2. Conserving water by raising social awareness, 3. Saving water by dynamic pricing schemes, 4. Improving the efficiency and business operations of water companies). The methodology to validate the KPIs is based on the principles of Experimental Design and Statistical Inference. Firstly they indicate some benchmark models taken from previous studies about; predicting water consumer behaviours, agent based simulations for modelling

[1] Document SmartH2O - D7.1 available on: http://smarth2o.deib.polimi.it/wp-content/uploads/2015/09/sh2o_D7-1_TWUL_WP7_validation_methodology_V1.1.pdf

residential water demand; water savings by raising environmental awareness; studies for water savings achieved by implementing dynamic and variable pricing schemes; improving the efficiency of water utilities by smart metering technology. The results of these pre-existing models are taken into account for defining the targets of the KPIs.

The validation methodology of **SmartH2O** is based on the concept of controlled experiment. They performed a number of experiments in order to assess the impact of the various **SmartH2O** platform features on the case studies. For each experiment, they have set out to:

- Define the sample size and define the size of the control group;
- Verify the statistical distribution of the sample and ensure that the sample is representative of the universe;
- Define the duration in time of experiment;
- Prepare the data collection infrastructure, making sure that data are collected in a reliable and reproducible manner;
- Identify the factors (controllable variables and parameters) and the responses (performance indicators) of the experiment;
- Design the experiment in order to optimise the data collection effort;
- Perform a statistical analysis on the experiment outcomes and compile a short report.

- The **iWIDGET** project compares their KPIs with reference values (e.g. utility policy targets, regulatory targets). They intend to insert their KPIs, specifically the ones on water losses, in a water utility portal along with these reference values.

2.2. Benchmarking validation methodologies in scientific literature

The most used Water Utility Benchmarking Methodologies, following the review available in Berg S. & Padowski J., (2010) [1], are here summarised:

- ***Core Overall Performance Indicators (OPI)*** are indices, like volume billed per worker, quality of service (continuity, water quality, complaints), unaccounted-for water, coverage, and financial data; they provide the simplest way to perform comparisons and can be used to communicate relative performance to a wide audience. However, an OPI may fail to account for the relationships among the different factors.
- ***Performance Scores based on Production or Cost Estimates*** are based on a metric approach that allows quantitative measurement of relative performance (cost efficiency, technical/engineering efficiency, scale efficiency, allocative efficiency, and efficiency change). Performance can be compared with other utilities and rankings can be based on the analysis of production patterns and/or cost structures.
- ***Engineering/Model Company*** approach requires the development of an optimized economic and engineering model based on creating an idealized benchmark specific to each utility, incorporating the topology, demand patterns, and population density of the service territory.

- ***Process Benchmarking*** regards individual production processes in the vertical production chain in order to identify specific stages of the production process that warrant attention. This is also a way to identify potential benchmarking partners, making benchmarking visits, and implementing best practices.
- ***Customer Survey Benchmarking*** is about the perceptions of customers regarding service quality as a key element for performance evaluation. In addition, trends over time can be used by regulators and policy-makers to evaluate utility performance.

The World Bank (World Bank, 2014 [3]) illustrates an interesting methodology underpinning the approach of The International Benchmarking Network (IBNET) for Water and Sanitation Utilities. IBNET collect data at the local or national levels. Key sector institutions, such as water and wastewater associations, regulators, or research institutes working with these associations, typically reach out to their members to collect the baseline data needed to calculate indicators.

Participants enter data into a standardized Excel spreadsheet under the categories General, Service Area, Water Service, Sewerage Service, Financial, and Tariffs. The spreadsheet can be downloaded easily from the IBNET Web site. Macros in the spreadsheet automatically calculate more than 27 groups of quantitative indicators that characterize the utility's performance with respect to water and wastewater coverage and quality, water consumption and production, cost recovery, operations, financial status, technical efficiency, billings and collections, and capital investment.

Following completion of data entry and submission of the spreadsheet to the IBNET program, the World Bank's Water and Sanitation Program performs quality control on the data submitted and then enters the data into the IBNET database. IBNET data can be accessed at no charge at http://www.ib-net.org. The interface allows users to create tables and graphs showing indicator values by utility, country, or region. The user can customize the tables and graphs to show only specified indicators, for example, the technical or financial performance of a given utility.

From these, more complex tables can be constructed to show a number of utilities' performances on the same indicator. Results can be shown for a specific year or for a number of years. Finally, country reports provide snapshots of national conditions across all utilities represented in the database. For more targeted analysis, filters can be used to select utilities in specific countries or within specific population ranges or to select by indicator or year. Outputs appear in graphic format where time-series data are requested and available, and tables and charts can be copied and saved. In addition to access to the database, the IBNET Web site provides methodological explanations and instructions on benchmarking and measuring water and wastewater performance. Step-by-step instructions guide users through benchmarking exercises. The site defines different methodologies, and bibliographies listing other methodological documents are provided [3].

3. THE WISDOM VALIDATION APPROACH

This section defines the overall validation methodology for the WISDOM project. At the highest level, the WISDOM approach is to perform an analytical validation of the pilots, utilising a series of KPIs. In more detail this process consists of various stages, spread throughout the tasks of the WISDOM project. These tasks are described below:

1) Development of Key Performance Indicators (Task 5.1). This consists of the following steps:
   a) KPI Derivation;
   b) Calculation of "as-is" value for KPIs;
   c) KPI Target Setting.
2) Define what data needs to be collected from the WISDOM cloud/edge data storage devices to measure these KPIs (Task 4.4);
3) Extract this data from the large quantity of data stored on the WISDOM Cloud (Task 4.4);
4) Calculate the current values of the WISDOM KPIs using this data (Task 5.3);
5) Perform final validation by comparing the KPI current values with the targets defined in Task 5.1 (Task 5.3);
6) Calculate the results of the WISDOM *Balanced Scorecards* to determine the overall successes/failures of each of the pilot deployments (Task 5.3).

The remainder of this section will describe the KPIs and *Balanced Scorecards* in further detail.

3.1. Summary of WISDOM KPIs

As part of Task 5.1, KPIs have been derived for the six scenario deployments and refined considering the following sources of data:

(a) Initial brainstormed KPIs described within the WISDOM scenario descriptions;

(b) KPIs utilised by the pilots in which the scenario is being deployed;

(c) KPIs utilised in other ICT4Water Projects,

(d) Feedback from the SIG workshop;

(e) Literature review.

In total 14 KPIs have been defined to assess the different pilots within WISDOM and are listed here with the respective pilot name. Some of these KPIs and their respective targets/tolerances have been adapted since delivery of D5.1 in order to express in a better way the improvements of the WISDOM intervention. The KPIs that have been changed (KPI2, KPI8, KPI11), are highlighted in bold.

Pilot	KPI Number	KPI Name	Scenario Deployment	Description
Cardiff	1	Water companies' understanding of household water consumption	Demand Management	The ability for water companies to understand the amount of water used per household more accurately. To better inform current estimations of water use for water balancing of the distribution network and to help inform regulatory price reviews and water resource management plans. Taking into account seasonal and social impact on water use in near to real time.
Cardiff	2	**Water consumption reduction due to consumer engagement**	Demand Management	The amount of water consumption reduction achieved by consumers who have engaged with WISDOM
Cardiff	3	Water usage awareness of customers	Demand Management	Measuring the changes in the attitudes of consumers towards water savings and their awareness of their own water savings.
Cardiff	4	Changes in the water peak demand profile due to customer engagement	Demand Management	Measuring the changes in the peak demand pattern of consumers. This KPI is drawn from the DCWW measures of success related to operational efficiency of their water network. This is important as a reduction in peak demand can lead to the reduction in pressure. This saves energy and increases the life span of assets.
Cardiff	5	Adaptive pricing and how it affects the customer bill	Demand management	By using theoretical models from the WISDOM solution, how the data collected via smart meters would influence an adaptive pricing scheme for customers and how this scheme is accepted by water companies and consumers.

Table 2: Cardiff pilot KPIs

Pilot	KPI Number	KPI Name	Scenario Deployment	Description
West Wales, Wales	6	Combined Sewer Overflow (CSO) Event Prediction accuracy of the data driven model.	CSO Spill Prediction	A measure that will take into account field weather, flow and level data across the waste network to predict future CSO spillages. Monitored via the outputs of the data driven model and compared to the reality to understand the model accuracy, though it has the advantage of low development cost.

Table 3 – West Wales Pilot KPI

Pilot	KPI Number	KPI Name	Scenario Deployment	Description
Tywyn Aberdovey	7	Water Network Energy Usage	Clean Water Optimisation	With the WISDOM optimisation framework, how the energy consumption would be influenced by using different combinations of pumping strategies, while also satisfying consumer requirements.
Tywyn Aberdovey	8	**Water Network Energy Cost**	Clean Water Optimisation	A measure of the potential cost of energy expended on the pumping of water. Reducing energy cost is part of the DCWW strategic objectives under operational efficiency. It is also a key objective within the overall WISDOM project.

Table 4 - Tywyn Aberdovey Pilot KPIs

Pilot	KPI Number	KPI Name	Scenario Deployment	Description
AQUASIM	9	Potential of energy savings for hot water production and associated environmental impacts	Advanced Devices	Heat exchangers exist for recovering energy from shower greywater. The recovered energy can be used to decrease energy demand for hot water production. This KPI will analyse the performances of such exchangers evaluated in SimulHome/Aquasim, quantifying the potential of energy that can be saved in a household, depending on users' habits.

Table 5: AQUASIM demonstrator KPI

Pilot	KPI Number	KPI Name	Scenario Deployment	Description
SAT	10	Level of knowledge of water network	Network Monitoring	Real time knowledge of the availability and of the correct functioning of all the devices installed in the pipeline.
SAT	11	**Leakage localization time**	Leakage Localization	Reduction of the average time needed to find a leakage in the water network
SAT	12	Pumping optimization	Energy Usage	Pumping optimisation will lead to a reduction in the energy consumption. Therefore leading to reduced costs for every cubic meter of water pumped.

Table 6 - AQUASIM demonstrator KPIs

Pilot	KPI Number	KPI Name	Scenario Deployment	Description
ASP	13	Ground Water Protection response time	Network Monitoring	Measuring the time taken to respond to ground water issues related to turbidity level in springs
ASP	14	Ground Water Protection response time	Network Monitoring	Measuring the time taken to respond to ground water issues related to piezometric levels in water wells

Table 7 - ASP pilot KPIs

3.2. Balanced Scorecard methodology

The term “Balanced Scorecard” has been introduced in this document in place of the term “Dashboard” introduced in D5.1, in order to better express the meaning of the validation process.

The WISDOM Balanced Scorecard is the final phase of the validation methodology with the general aim of providing validation on a per pilot basis while considering the multiple KPIs in consideration in some pilots.

Each of the KPI have been given tolerances limits or ranges, these have been used to determine a Red, Amber, Green (RAG) status for each of the KPIs. Green shows that the KPI has passed by achieving or over achieving the target, amber status is achieved when the pilot results is below a pass but within the tolerance limit, red status is assigned to a KPI which has not been achieved or the target and is not within the tolerance limits.

Further to the RAG status the table below shows the priority of the KPI within each of the pilots, this will give further evidence that the overall pilot has pass or failed.

An estimation of WISDOM KPIs’ success has been performed, comparing the KPIs current value to the respective target values. Every KPI’s success estimation, with an assigned weight, is used to evaluate an overall success S [%] estimation of each pilot that is calculated as:

$$S = \sum_{i=1}^{n} w_i \cdot s_i \qquad \text{[Eq. 1]}$$

Where:

- w_i= is the weight assigned to the i-KPI; the sum of the weights for each pilot is 1 in order to obtain a percentage of success to the WISDOM intervention.
- s_i = is the percentage of success of the i-KPI
- n = number of KPIs assigned to each pilot.

The percentages of are assigned considering the comparison between the current value and the target and tolerance value of each KPI.

KPI VALUE	% of success [s]	RAG Status
In the Target	100	Green
Out of the Target but in the tolerance	70	Amber
Out of the tolerance but better than As Is value	30	Red
Equal to As Is value	0	Red

Table 8 - Assignment of percentages of success and RAG status

The RAG status is assigned also to the whole pilot, according to the ranges of percentages of success:

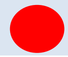
% of success [S] of the Pilot	RAG Status
S > 70%	
70% >= S > 50%	
<= 50 %	

Table 9 - RAG status of the whole pilot based on its success [S] value

In order to calculate the weighting for each KPI within a pilot, a survey has been conducted among the pilot's representatives in WSDOM project. Every representative assigned to each KPI in their pilot an integer value that rated the KPI based on its importance. Subsequently the scores of each KPI have been summed and normalized to give a weighting score.

Pilot	KPI Number	KPI Name	Weights	Priorities
Cardiff	1	Water companies' understanding of household water consumption	0.22	2
Cardiff	2	Water consumption reduction due to consumer engagement	0.27	1
Cardiff	3	Water usage awareness of customers	0.27	1
Cardiff	4	Changes in the water peak demand profile due to customer engagement	0.18	3
Cardiff	5	Adaptive pricing and how it affects the customer bill	0.07	4
CSO in South Wales	6	Combined Sewer Overflow (CSO) event prediction accuracy of the data driven model.	1	1
Tywyn Aberdovey	7	Water Network Energy Usage	0	1
Tywyn Aberdovey	8	Water Network Energy Cost	1	2
AQUASIM	9	Potential of energy savings for hot water production and associated environmental impacts	1	1
SAT	10	Level of knowledge of water network	0.17	3
SAT	11	Leakage localization time	0.33	2
SAT	12	Pumping optimization	0.5	1
ASP (ATO)	13	Ground Water Protection response time (turbidity)	0.67	1
ASP (ATO)	14	Ground Water Protection response time (conductivity)	0.33	2

Table 10 – Weights and priorities for each KPI

3.3. Environmental Assessment

An Environmental Assessment was carried out as a complementary analysis of the KPI calculation in order to validate the WISDOM platform. Final results will be published in the final version. The approach is based on the Life Cycle Assessment method (LCA) cf. ISO 14040 [4] and EN 15978 standards [5] (Sustainability of construction works - Assessment of environmental performance of buildings - Calculation method [CEN / TC 350, 2012]). The LCA method has two main specificities: 1) the assessment is carried out over the entire life cycle of the studied process; 2) different environmental burdens are considered: GHG emissions, energy resources consumption, waste production, etc. ELODIE software was used to carry out the assessment.

In the WISDOM project, the studied process is the "water use during the normal operation of a building". Thus, the environmental performance is calculated over the life cycle of the water service for residential use, from the water abstraction to the wastewater treatment. The analysis allowed the estimation of the environmental gains due to the WISDOM solutions versus a "classical" water management for:

1) Advanced Devices / "Heat recovery" tested within the AQUASIM facility. This deployment was aimed at understanding the impact of the utilisation of innovative energy recovery devices and thus to assess the possible benefits of their implementation on a wider scale. For the environmental assessment, the experimental input data are the Energy consumptions per L of domestic hot water (kWh/m^3).

Figure 2 - : Input data used for the environmental assessment

a) Water abstraction : Generic data

b) Specific data :

-Advanced Devices;
-Demand management/user awareness

c) Wastewater treatment : Generic data

2) Demand Management / "user awareness" demonstrated within the Cardiff pilot. This deployment was aimed at looking at user consumption and behaviour, and developing from this a range of innovative feedback mechanisms. For the environmental assessment, the experimental input data are the water consumption (m^3/person/year) before and after WISDOM actions.

The environmental burdens due to the water abstraction and wastewater treatment (see Figure 2: a) and c) steps into the water chain) are taken into account based on the generic data available in database included in the ELODIE software. Specific data from the WISDOM project are used for the domestic end user step (see figure below: b) step into the water chain). The energy mix for France's electricity production is used for calculation (i.e. majority is nuclear).

The results of the calculations are expressed as six main indicators (see Table 11) per m^3 of water used during the normal operation of a building.

Environmental Indicators based on LCA – Life Cycle Assessment		
Performance indicators	**Description**	**Unit**
Global warming potential, GWP	Estimation the greenhouse gas (GHG) emissions due to the water use, including the pre – and post-use treatment	kg CO_2 equivalent
Hazardous waste disposed	Estimation the hazardous waste production/disposal , due to the water use, including the pre – and post-use treatment	kg
Non-hazardous waste disposed	Estimation non-hazardous waste production/disposal, due to the water use, including the pre – and post-use treatment	kg
Radioactive waste disposed	Estimation the radioactive waste production/disposal, due to the water use, including the pre – and post-use treatment (due to nuclear energy used for treatment or hot water production)	kg
Formation potential of tropospheric ozone photochemical oxidants, POCP;	Estimation the smog formation , due to the water use, including the pre – and post-use treatment	kg/Ethene equivalent
Acidification potential, AP	Estimation the acidification potential of land and water , due to the water use, including the pre – and post-use treatment	kg/SO_2 equivalent

Table 11 - Environmental Indicators based on LCA

4. Cardiff Pilot Results

This section will describe the Cardiff pilot's KPIs, their calculation methodologies, the targets, as-is values, and finally the results achieved. At the conclusion of this section the success/failure of the Cardiff pilot will be evaluated.

4.1. KPI 1

<table>
<tr><td colspan="3"><u>KPI Analysis Summary</u></td><td><u>KPI No:</u></td><td colspan="2"><u>1</u></td></tr>
<tr><td colspan="6">Water companies' understanding of household water consumption</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">The ability for water companies to understand the amount of water used per household more accurately. To better inform the current estimations of water use for water balancing of the distribution network and to help inform regulatory price reviews and water resource management plans. Considering seasonal and social impact on water use in near to real time.</td></tr>
<tr><td colspan="6">WISDOM System Context</td></tr>
<tr><td colspan="6">In terms of the WISDOM system, this KPI tests the system's ability to integrate data originating from smart meters and display it to water network operator users in a way that enables them to better understand the water usage of their customers.</td></tr>
<tr><td colspan="6">Calculation Methodology:</td></tr>
<tr><td colspan="6">When looking at customer usage there are 2 distinct areas (Daily Volumes and Night Use), both of which will be investigated as part of this KPI.

<u>Daily Usage.</u>

This is currently determined by 6 months meter readings using the following formula:-
$$Daily\ Volume = \frac{Current\ Meter\ Reading - Previous\ Meter\ Reading}{Current\ Reading\ Date - Previous\ Reading\ Date}$$
This is compared to daily volumes derived from daily outputs from SMART meter data to see if there is a significant difference. This data are then be converted to an hourly reading using the formula below to see if it's possible to get an accurate hourly rate from 6 month meter readings compared to the SMART meter data.
$$Hourly\ Volume = \frac{Daily\ Volume}{24}$$
<u>Night Usage.</u>
This is currently set using an industry standard 2.2 liters / hour; this is compared to hourly night flow averages from the SMART meter data.</td></tr>
<tr><td colspan="6">Target Setting:</td></tr>
<tr><td colspan="6">As described previously, the goal of this KPI is to enable increased accuracy in the understanding of end users water usage (over the day and night readings) – thus our target is to see an increase in the accuracy of measuring end users usage over that provided by calculation from six monthly readings.</td></tr>
<tr><td>As Is - Value</td><td>Daily – 300.80 l/d
Hourly – 12.53 l/hr
(Calculated from Six Monthly Meter Readings)
Night – 2.2 l/hr (Industry</td><td>Target</td><td>Achieving an increase in the accuracy possible using current six monthly meter readings</td><td>Tolerance</td><td>NA</td></tr>
</table>

	Average)				
Results					
KPI Result:	**Daily Usage.** Daily – 303.27 l/d. Hourly – 12.64 l/hr **Night Usage.** 34 l/hr	% of success	70%	RAG status	Amber

Table 12 - KPI 1 Analysis Summary

In calculating this KPI - comparing averages calculated form six monthly readings with data from the SMART meters, the following results have been obtained:

Daily Usage.

Daily – 303.27 l/d.
Hourly – 12.64 l/hr.

From this it is evident that there is no distinct difference between the smart meter readings and average calculated from six monthly readings. So in regards to the daily volumes, there is no advantage to having smart meters. To confirm this result a t-test was performed which showed there was no statistically significant difference.

Night Usage.

When looking at the hourly usage from the WISDOM SMART meters an Hourly Average of 3.34 l/hr is observed. From this result there is a significant difference between this result and the industry average. This can either mean that the properties in this pilot are using more water or have leakage on them. This is valuable knowledge for the water network operator as they can either investigate possible leakage or use this new knowledge of night flow to adapt their leakage detection thresholds to improve the detection of future leaks.

Conclusion

Overall this KPI has been awarded as a pass (within tolerance) as it has shown that when it comes to night flows, the data from SMART meters shows different (more accurate) results when compared to industry standards.

Even though the readings from smart meters did not show a different from averages there are lots of other bonuses that SMART meters provide. These include:

1. Void Property Analysis.
2. Illegal Use / Connection Analysis.
3. Leakage detection.
4. Night Use Analysis – Dynamic and Accurate.
5. Meter Failure detection.
6. Meter Bypass detection.

All of which have a massive benefit to a water company in terms of; money, saving resources and time wasted on site visits. So in this case, when considering these factors (coupled with the positive result from the night flow analysis) this KP has been awarded as pass.

4.1. KPI 2

KPI Analysis Summary	**KPI No:**	**2**			
Water consumption reduction due to consumer engagement					
Description					
The amount of water consumption reduction achieved by consumers who have engaged with WISDOM					
WISDOM System Context					
In terms of the WISDOM system this KPI is measuring the impact of having an easy accessible portal for the water consumer to monitor their own water consumption on a regular basis as compared to those that do not have the same visibility of their water consumption					
Calculation Methodology:					
A monthly comparison (in percentage) of water consumption between the users that have access to an "in house" display or webpage ($W_{Y,m}$) and the ones who don't have this access ($W_{N,m}$) has been done. $$KPI\_2_{,m} = \frac{W_{N,m} - W_{Y,m}}{W_{N,m}} 100$$ Where the subscript *m* is referred to the *m-month.* Households with similar characteristics will be compared. Other qualitative considerations will be taken into account such as the frequency with which users interact with the displays and the potential change in users' behaviors relating to water consumption.					
Target Setting:					
Currently, no water savings are achieved through customer engagement. This is because this type of water saving exercise is completely new to this pilot.					
As Is - Value	NA	Target	5%	Tolerance	2.5%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 13 - KPI 2 Analysis Summary

4.2. KPI 3

KPI Analysis Summary	**KPI No:**	**3**			
Water Usage awareness of customers					
Description					
Measuring the changes in the attitudes of consumers towards water savings and their awareness of their own water savings.					
WISDOM System Context					
This KPI looks at if a consumer has good visibility of their own water consumption via the WISDOM portal does it have an impact on how a consumer rates their awareness of water saving activities.					
Calculation Methodology:					
The water saving attitudes of households have been assessed by a series of questionnaires. Part of the questionnaire collected views and beliefs about water scarcity, awareness of water consumption and environmental issues, assessed using a 5-point Likert scales ranging from "strongly agree" to "strongly disagree". At the end, participants have been asked to fill in a final questionnaire duplicating these Likert scale questions. Differences or similarities between people's beliefs and knowledge before and after the trial have been compared. Every interview will have a score that will give a level of water usage awareness of costumers. So the KPI 3 will be: $$KPI_3 = \frac{SC_A - SC_B}{SC_B} 100$$ SC_B=Score before WISDOM intervention [%] SC_A=Score after WISDOM intervention [%]					
Target Setting:					
The initial surveys assessing people's views and beliefs about environmental and water issues have shown that people tend to consider themselves as ecofriendly persons but have a limited awareness of their water consumption. They lack knowledge about water scarcity issues, the impact of their consumption on the environment and about the amount of water used by domestic appliances. At the end of the trial, participants will be more informed. The final questionnaire will assess whether their awareness of their water usage and their knowledge about global water issues was increased by the use of the interface. Thus, an improvement of 10% on this KPI is targeted					
As Is - Value	0%	Target	10%	Tolerance	5%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 14 - KPI 3 Analysis Summary

4.3. KPI 4

KPI Analysis Summary		KPI No:	4		
Changes in the water peak demand profile due to customer engagement					
Description					
Measuring the changes in the peak demand pattern of consumers. This KPI is drawn from the DCWW measures of success related to operational efficiency of their water network.					
WISDOM System Context					
This KPI looks at if a reduction in peak demand can lead to the reduction in pressure and therefore lead to a reduced operating cost of the water distribution network due to the reduction in energy costs and by increasing the life span of assets.					
Calculation Methodology:					
This KPI detects the changes in water peak demand after and before WISDOM intervention. Customers engagement have been done through the water audit and water saving tips on the website. The peak is calculated starting from annual consumption averaged for daily usage. The District Metered Flow (DMA) will be the measured for the peak demand: $$KPI\_4_{,m} = \frac{DMA_{h,m} - DMA_{c,m}}{DMA_{h,m}} 100$$ $DMA_{h,m}$= DMA for the –m month (liters/day) DMAc,m= Current DMA for the –m month (liters/day)					
Target Setting:					
Currently, no water savings are achieved in this way. This is because this type of water saving exercise is completely new to this pilot.					
As Is - Value	NA	Target	5%	Tolerance	10%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 15 - KPI 4 Analysis Summary

4.4. KPI 5

KPI Analysis Summary		**KPI No:**	**5**		
Adaptive pricing and how it affects the customer bill					
Description					
By using theoretical models from the WISDOM solution, how the data collected via smart meters would influence an adaptive pricing scheme for customers and how this scheme is accepted by water companies and consumers.					
WISDOM System Context					
This KPI, due to fact that it could not be implemented within out pilot (as described in D3.4) was not connected directly to the WISDOM system developed. However, as an important advancement in water network operation and its links to the existing demand management study, it has been pursued.					
Calculation Methodology:					
In order to prove this KPI a customer engagement session was carried out in conjunction with DCWW. In this session WISDOM representatives presented the adaptive pricing methods and background theory. The key points for the presentation is that this is all currently theoretical and wouldn't be implemented within DCWW as was purely a research stance, as there was concerns it may go against DCWW's 'non for profit' setup. After which the customers were asked to answer the follow questions (Below) on a Likert scale (1-Stongly Agree, 2-Agree, 3-Neither agree nor disagree, 4-Disagree, 5-Strongly Disagree). This was then used to help gauge their understanding and opinions on adaptive pricing. Q.1. Do you understand the principles of adaptive pricing? Q.2. Would you be happy if an adaptive pricing model was adopted to determine your water bill? Q.3. Which of the four models do you prefer? Q.4. Do you feel adaptive pricing is a 'fair' pricing method? Q.5. General Feedback. In total there were 20 customers in attendance, all of which left feedback on the relevant Questionnaire form.					
Target Setting:					
In order to see that adaptive pricing approaches we have defined are good candidate options, a 75% of positive response on adaptive pricing has been set.					
As Is - Value	N/A	Target	75% Positive	Tolerance	-5%
Results					
KPI Result:	80%	% of success	100	RAG status	Green

Table 16 - KPI 5 Analysis Summary

From this questionnaire / engagement sessions the results were as follows:

Question 1
Overall a 90% positive results (Strongly Agree / Agree) for understanding the principals of adaptive pricing.
Question 2
Overall a 70% positive results (Strongly Agree / Agree) for implementing an adaptive pricing model for determining the water bill.
Question 3
90% of those survey wanted the per head consumption model (our chosen model) to be implemented as an adaptive pricing method.
Question 4
Overall 70% believe that adaptive pricing as described in this presentation as a fair way of pricing.

Some useful feedback was recorded in this section. The below bullet points capture a summary of comments received:

- Water Company perception - Implementing adaptive pricing to water stressed areas could be seen as positive, but a larger roll out could have a negative perception i.e. more revenue (calculations required to ascertain if revenue neutrality is achievable)
- Bill system comparison - Clarity over how water bill is currently calculated to determine impact, customers need to be educated to make an informed choice.
- Drawing comparisons to the energy market and whether the water industry can learn from any mistakes made.
- A concern over an adaptive bill being very high for a large family.

With this KPI there is an 80% overall positive response rate in regards to adaptive pricing, therefore shows there is a rationale to look into this. As long as it is used in a positive manner to promote efficient water use and not as a way of making more money.

Overall the customer engagement sessions were positive in relation to their understanding of adaptive pricing and understanding the fairness of it. Through general feedback and discussions at the event most people felt that as long as adaptive pricing is used as incentive mechanism rather than a persecution exercise then it can be considered a success. However this stance has been taken in the past by energy / gas companies and they have turned away from this, could there be a reason for this or a change of thinking (e.g. more money, difficulty to explain bills, loss of customer confidence).

4.5. Cardiff Balanced Scorecard and discussion

As introduced in Section 3.2, The Balanced Scorecard summarize the performance of the whole pilot combining the weight of each of its KPI with the respective percentage of success (Eq. 1) and giving to the Pilot a total percentage of success and a Red Amber Green (RAG) status.

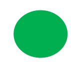
Pilot Area:		Cardiff	
KPI	Weight	% of success s	RAG status
1 - Water Companies understanding of household Water Consumption	0.22	70	
2 - Water consumption reduction due to consumer engagement	0.27	TBC	TBC
3 - Water Usage awareness of customers	0.27	TBC	TBC
4 - Changes in the water peak demand profile due to customer engagement	0.18	TBC	TBC
5 - Adaptive pricing and how it affects	0.07	100	
Final Pilot Result		TBC	TBC

Table 17 - Cardiff Balanced Scorecard

5. West Wales Pilot Results

This section will describe the West Wales pilot's KPIs, their calculation methodologies, the targets, as is values and finally the results achieved. At the conclusion of this section the success/failure of the West Wales pilot will be evaluated.

5.1. KPI 6

KPI Analysis Summary		KPI No:	6		
Combined sewer overflow (CSO) event prediction accuracy of the data driven model.					
Description					
A measure that will take into account field weather, flow and level data across the waste network to predict future CSO spillages. Monitored via the outputs of the data driven model and compared to the reality to understand the model accuracy, though it has the advantage of low development cost.					
WISDOM System Context					
The CSO predictive model demonstrates WISDOM's ability to execute (near) real-time data analytics on live data coming from the water network. Thus, as new data is received from the water network, WISDOM executes the predictive model to produce new predictions upon the update of the current water network status.					
Calculation Methodology:					
A comparison between the actual value of the CSO level and the value predicted by the model will be done. R-squared (R2) is mainly used to assess the CSO model prediction accuracy, which tells the predicted proportion of the total variation of the reality (scaled between 0 and 1). The corresponding formula can be written as: $$KPI_6 = \left[1 - \frac{(y-\hat{y})^T(y-\hat{y})}{(y-\bar{y})^T(y-\bar{y})}\right]100$$ where y, $\bar{y}$ and $\hat{y}$ are the actual CSO value, averaged actual value and predicted value.					
Target Setting:					
As there is no current usage of data driven approaches in the pilot, there is no as is value in this case. The target has been set because a percentage value is easy to understand and compare between predictive performances of different CSOs, as well as the complexity of the water network, the challenge of time-series prediction problem, and the uncertainty and dynamics exhibited between field variables including weather, CSO levels, pumped flows and wet well levels.					
As Is - Value	NA	Target	70%	Tolerance	10%
Results					
KPI Result:	84.53%	% of success	100	RAG status	Green

Table 18 - KPI 6 Analysis Summary

With the implementation of the proposed efficient algorithm for automated CSO predictive model construction as presented in D3.3, it is first shown that the proposed algorithm dramatically saved the computational time needed to construct the data driven model, compared to the original lasso approach. In the pilot trial, roughly 50% reduction was achieved. To facilitate direct comparisons across different constructed data-driven models, the training and predictive accuracies in terms of R2 were obtained for every CSO. Overall, the averaged predictive accuracy is 84.53% over all the CSO identities, better than the training one (79.75%), demonstrating the extraordinary generalisation ability of the constructed CSO predictive models.

Due to the distinct data quality of each CSO and field constraints (e.g., some CSOs may lack monitoring of close neighbour/correlative field identities), different levels of prediction accuracies were presented amongst these CSOs. Overall, the upper middle part of the pilot area received comparatively accurate predictions, as more field monitoring identities are distributed therein. Whilst some CSOs obtained relatively low level of accuracy, others can achieve extremely high predictive accuracy with a value larger than 90%. This demonstrates the effectiveness of the proposed data-driven methodology for tackling the CSO prediction problem; provided that high quality and resolution field monitoring data is made available.

Within the constructed data-driven models, each CSO identity is able to automatically locate and thus exhibit a clear relationship between it and those out of the available weather stations and CSOs, whereas generally other field identities are relatively less engaged. To visualise the model performance, one of the best obtained CSO predictions with training and prediction accuracy of 99.12% and 98.22%, respectively, is depicted in Figure 3 for showing model training in August 2014 and prediction in August 2015. Compared with the measured values, both the trained and predicted CSO levels are well modelled therein. Here, the historical data from 3 weather stations and 10 CSO identities were found to be relevant to construct the underlying model, while a total of 41 model regressors were selected also including various degrees of time lags from these variables.

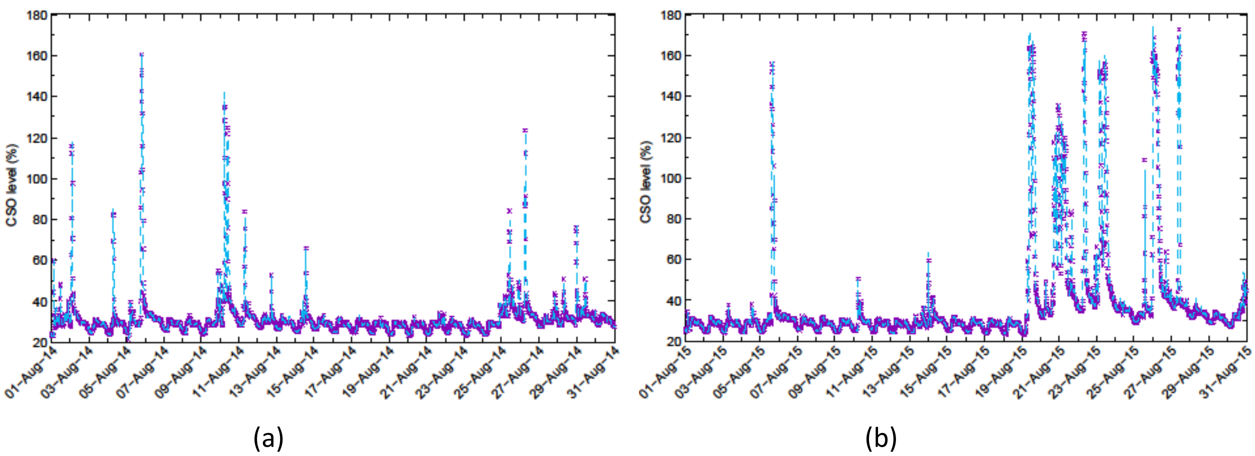
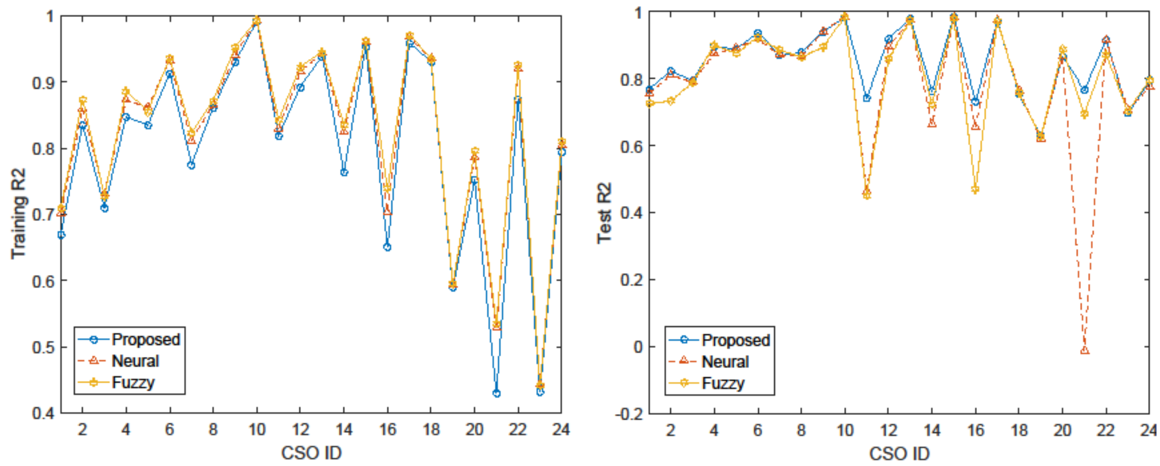


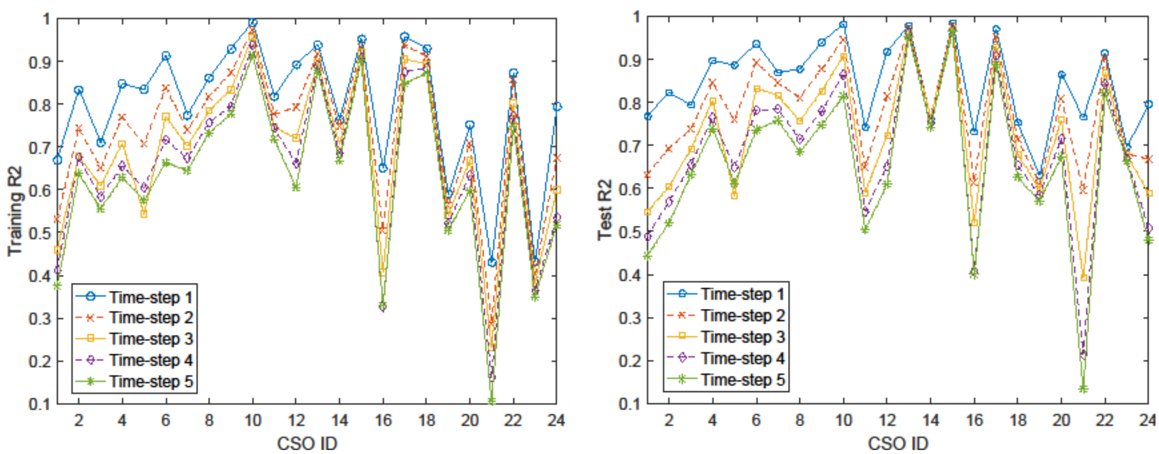
Figure 3 - One of the best predicted CSOs: (a) model training in Aug. 2014 and (b) prediction in Aug. 2015 (The sign "x" denotes the sensor reading and the solid line depicts the model output).

In addition, the superiority of this approach in terms of computational demand and model generalisation performance was also confirmed by comparing with the neural network and fuzzy system approaches. As shown in Figure 4, some CSO identities (e.g., #11 and #21) modelled by neural networks and fuzzy systems are seen giving very poor test accuracies. Furthermore, given the proposed methodology, it is also straightforward to develop multi-step CSO predictive models where needed, by using the required prediction step as the model output. The training and test accuracies across all the CSOs for five prediction steps are illustrated in Figure 5. As expected, with the increase of prediction steps, the prediction accuracy generally reduces due to less recent information about the system is gathered and considered by the model. However, for the CSOs with high accuracy at single-step prediction, they still possessed very good performance where large accuracy reduction was not seen. Based on all the aforementioned facts, in conclusion, the proposed methodology is confirmed capable of quickly and effectively automating the entire CSO predictive model construction process.



(a) (b)

Figure 4 - Modelling accuracy from the proposed, neural and fuzzy approaches for all the CSOs (a) training accuracy and (b) prediction accuracy.



(a) (b)

Figure 5 -Multi-step predictions for all the CSOs (a) training accuracy and (b) prediction accuracy.

5.2. West Wales Balanced Scorecard

KPI 6 value (84.53%) thoroughly exceeds the Target value (70%), thus conferring on its pilot 100% of success

Pilot Area:		West Wales	
KPI	Weight	% of success s	RAG status
6- Combined sewer overflow (CSO) event prediction accuracy of the data driven model.	1	100	●

Table 19 - West Wales Balanced Scorecard

6. Tywyn Aberdovey Pilot Results

This section will describe the Tywyn Aberdovey pilot's KPIs, their calculation methodologies, the targets, as is values and finally the results achieved. At the conclusion of this section the success/failure of the Tywyn Aberdovey pilot will be evaluated.

6.1. KPI 7

KPI Analysis Summary		KPI No:	7		
Water Network Energy Usage					
Description					
With the WISDOM optimisation framework, how the energy consumption would be influenced by using different combinations of pumping strategies, while also satisfying consumer requirements.					
WISDOM System Context					
The optimization module further demonstrates WISDOM's ability to execute (near) real-time data analytics on live data coming from the water network. As new data is received from the water network, WISDOM executes the optimization module, determining improved pumping configurations for the water network.					
Calculation Methodology:					
The current monthly energy usage ($E_{c,m}$) for the water network will be calculated and compared with the same usage for historical data ($E_{h,m}$). $$KPI_{7,m} = \frac{E_{h,m} - E_{c,m}}{E_{h,m}} 100$$					
Target Setting:					
As current energy usage in a water network is confidential a % reduction has been used as the target.					
As Is - Value	NA	Target	5%	Tolerance	2%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 20 - KPI 7 Analysis Summary

When further analysed, it was determined that the energy usage within the pilot is dependent solely on the amount of water consumed – not on the pumping strategy. This means that any optimisation must occur by improving the times at which pumping takes place (see KPI 8) and not by reducing the amount of pumping.

Thus, due to the fact that this KPI could not be properly tested within the pilot (as the pure energy usage therein is dependent on the user-determined water consumption), this means that the change of pumping strategies barely has an effect on the energy usage. This is also evident in the hydraulic model developed by the DCWW modelling team). For this reason, although the KPI is reported here for consistency it will not be used in the overall assessment of this pilot.

6.2. KPI 8

KPI Analysis Summary		KPI No:	8		
Water Network Energy Cost					
Description					
A measure of the potential cost of energy expended on the pumping of water. Reducing energy cost is part of the DCWW strategic objectives under operational efficiency. It is also a key objective within the overall WISDOM project					
WISDOM System Context					
The optimization module further demonstrates WISDOM's ability to execute (near) real-time data analytics on live data coming from the water network. As new data is received from the water network, WISDOM executes the optimization module, determining improved pumping configurations for the water network.					
Calculation Methodology:					
The KPI detects the energy cost reduction for supply of the Tywyn Aberdovey water network after and before WISDOM intervention. Different scenarios are to be considered as a result of promoting adaptive pricing. $$KPI_8 = \frac{C_{h,} - C_{c,}}{C_{h,}} 100$$ Where C_h and C_c are total energy expenses before and after the WISDOM intervention, respectively.					
Target Setting:					
As current energy usage in a water network is confidential a % reduction has been used as the target in accordance with DCWW strategic objectives.					
As Is - Value	NA	Target	5%	Tolerance	2%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 21 - KPI 8 Analysis Summary

6.3. Tywyn Aberdovey Balanced Scorecard and discussion

Pilot Area:		Tywyn Aberdovey	
KPI	Weight	% of success s	RAG status
7- Water Network Energy Usage	0.56	TBC	TBC
8- Cost of supply and demand	0.44	TBC	TBC
Final Pilot Result		TBC	TBC

Table 22- Tywyn Aberdovey Balanced Scorecard

7. AQUASIM Pilot Results

This section will describe the AQUASIM pilot's KPIs, their calculation methodologies, the targets, as is values and finally the results achieved. At the conclusion of this section the success/failure of the AQUASIM pilot will be evaluated.

7.1. KPI 9

KPI Analysis Summary		KPI No:	9		
Potential of energy savings for hot water production and associated environmental impacts					
Description					
Heat exchangers exist for recovering energy from shower greywater. The recovered energy can be used to decrease energy demand for hot water production. The performances of such exchangers are evaluated in SimulHome/AQUASIM (WP4) in order to quantify the potential of energy that can be saved in a household, depending on users' habits.					
WISDOM System Context					
Validating the user of WISDOM in a domestic lab based environment – utilizing the WISDOM system to monitor the water usage in AQAUSIM to determine the performance of the heat exchanger.					
Calculation Methodology:					
This KPI consists in the calculation of the reduction of Energy consumption per liter of domestic hot water before WISDOM and after WISDOM, supposing different scenarios. The reduction is due to the installation of heat exchangers					
Target Setting:					
TBC					
As Is - Value	0%	Target	30%	Tolerance	25%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 23 - KPI 9 Analysis Summary

7.2. AQUASIM Balanced Scorecard and discussion

Pilot Area:		AQUASIM	
KPI	Weight	% of success s	RAG status
9- Potential of energy savings for hot water production and associated environmental impacts	1	TBC	TBC

Table 24 - AQUASIM Balanced Scorecard

8. La Spezia – SAT Pilot- Results

This section will describe the KPIs from the Italian pilot, operated by SAT. Also described will be the calculation methodologies, the targets, as is values and finally the results achieved. At the conclusion of this section the success/failure of this pilot will be evaluated.

8.1. KPI 10

KPI Analysis Summary		KPI No:	10		
Level of knowledge of water network					
Description					
Real time knowledge of the availability and of the correct functioning of all the devices installed in the pipeline.					
WISDOM System Context					
This KPI demonstrates WISDOM's ability to collect data from a water network and provide it to water network operators in a convenient and accessible way (via user interfaces developed in T2.5)					
Calculation Methodology:					
This KPI is expressed in terms of data availability, namely the increasing of the temporal frequency of the flow/pressure measurements control after the WISDOM intervention. In the before WISDOM scenario, the pressure measurements were checked when needed by the network operator. In after WISDOM scenario, the measurements are linked online to the SCADA system, so they are checked easily by the operators.					
Target Setting:					
A minimum of 50% of increasing of data availability, in terms of temporal frequency, has been set as target KPI.					
As Is - Value	0%	Target	50%	Tolerance	30%
Results					
KPI Result:	>> 50%	% of success	100	RAG status	Green

Table 25 - KPI 10 Analysis Summary

Prior to WISDOM, the temporal frequency that the network operators could receive flow and pressure data from the network could not be estimated, because there were no suitable interfaces or sensors to allow to the operators to detect anomalies on the network. The only way for detecting a issues was receiving complaints from users. This means that several hours could pass before problems were detected.

In the course of the project, 4 pressure and 5 flow sensors have been installed, connected to the WISDOM system and their data made available via WISDOM interfaces. The frequency of the measurement (from sensor to interface) is real time, less than one minute. For this reason, the target of 50% of increasing of temporal frequency is reached and exceeded, so the KPI success is deemed as 100%.

8.2. KPI 11

<table>
<tr><td colspan="2"><u>KPI Analysis Summary</u></td><td><u>KPI No:</u></td><td colspan="3"><u>11</u></td></tr>
<tr><td colspan="6">Leakage localization time</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Reduction of the average time needed to find an hidden leakage that is supposed to be detected by a future installed system</td></tr>
<tr><td colspan="6">WISDOM System Context</td></tr>
<tr><td colspan="6">This KPI tests the ability of the WISDOM system to integrate with third party components, not developed by WISDOM partners. In this case the leakage localization tool developed by CMR is tested with the WISDOM platform.</td></tr>
<tr><td colspan="6">Calculation Methodology:</td></tr>
<tr><td colspan="6">This KPI has calculated as the reduction of the average time needed to find hidden leakages in the water network.
$$KPI\_11 = \frac{T_{L,B}-T_{L,A}}{T_{L,B}}100=\frac{L_{TOT}-L_A}{L_{TOT}}100$$
Supposing a default average time needed to localize exactly a leakage per linear length of network [hours/ km], in the before WISDOM scenario, the average time needed to localize exactly an hidden leakage is :
$$T_{L,B} = t_L \cdot L_{TOT}$$
Where:
t_L is the average time needed to localize exactly a leakage per linear length of network;
L_{TOT} is the length of the whole network (12,19 km).
In the after WISDOM scenario, the average time needed to localize exactly the leakage ($T_{L,A}$) is a function of the average length of the network segment (L_A) in which the presence of a leakage is known through the CMR algorithm.
$$T_{L,A} = t_L \cdot L_A$$</td></tr>
<tr><td colspan="6">Target Setting:</td></tr>
<tr><td colspan="6">The reduction of the average time for the leakage localization has been set to 50%</td></tr>
<tr><td>As Is - Value</td><td>0%</td><td>Target</td><td>50%</td><td>Tolerance</td><td>30%</td></tr>
<tr><td colspan="6">Results</td></tr>
<tr><td>KPI Result:</td><td>80%</td><td>% of success</td><td>100</td><td>RAG status</td><td>Green</td></tr>
</table>

Table 26 - KPI 11 Analysis Summary

Considering the flow and pressure sensors positioned in the SAT network after WISDOM intervention, the average length of the network segment (L_A) in which the presence of a leakage is known through the CMR algorithm can be set at 2.58 km, against the 12.9 km of the whole network. This means that the localization of a leakage can be carried out in a section that is reduced by 80% compared to the before WISDOM scenario. The % of success is then 100%

8.3. KPI 12

KPI Analysis Summary	KPI No:	12			
Pumping optimization					
Description					
Pumping optimisation will lead to a reduction in the energy consumption. Therefore leading to reduced costs for every cubic meter of water pumped..					
WISDOM System Context					
This KPI demonstrates WISDOM's ability to collect data from a water network and provide it to water network operators in a convenient and accessible way (via user interfaces developed in T2.5)					
Calculation Methodology:					
The comparison of the total monthly energy E_m used for every m3 pumped in the network after and before WISDOM [kWh/m3pumped] $$KPI\ 12 = \frac{E_{m,pc} - EL_{m,ph}}{E_{m,ph}} 100\ [\%]$$ - $E_{m,pc}$: current total monthly energy used for every m^3 pumped in the network; - $E_{m,ph}$: historical total monthly energy used for every m^3 pumped in the network.					
Target Setting:					
As energy consumption data is confidential a % reduction measure will be used.					
As Is - Value	NA	Target	30%	Tolerance	10%
Results					
KPI Result:	TBC	% of success	TBC	RAG status	TBC

Table 27 - KPI 12 Analysis Summary

8.4. La Spezia – SAT- Balanced Scorecard and discussion

Pilot Area:		La Spezia SAT	
KPI	Weight	% of success s	RAG status
10 - Level of knowledge of water network	0.17	100	● (green)
11 - Leakage localization time	0.33	100	● (green)
12- Pumping optimization	0.5	TBC	TBC
Final Pilot Result		TBC	TBC

Table 28- La Spezia SAT Balanced Scorecard

9. La Spezia – ASP Pilot- Results

This section will describe the KPIs from the Italian pilot, operated by ASP. Also the calculation methodologies, the targets, as is values and finally the results achieved will be described. At the conclusion of this section the success/failure of this pilot will be evaluated.

9.1. KPI 13

KPI Analysis Summary		KPI No:	13		
Ground Water Protection response time					
Description					
Measuring the time taken to respond to ground water issues related to turbidity level in springs					
WISDOM System Context					
This KPI tests the ability of the WISDOM system to receive sensor data and then react to it (via alerts). This is performed using the rule engine developed in T3.1.					
Calculation Methodology:					
Water is monitored with turbidity sensors. A three-valve system excludes automatically the reservoir from the supply when the turbidity values go above the threshold value (10 NTU). The temporal frequency of the sensor measurement is **1 minute.** This KPI has been expressed as: KPI_{13}= timing of turbid water automatic detection and exclusion					
Target Setting:					
The Target has been chosen in order to attempt to allow a real time alerting system for ground water protection. In consultation with the pilot, a time of 5 minutes has been considered adequate for the supply protection. Prior to WISDOM intervention, there was not an automatic system for turbidity detection, so it relied on visits by engineers.					
As Is - Value	None	Target	5 minutes	Tolerance	10 minutes
Results					
KPI Result:	1 min.	% of success	100	RAG status	Green

Table 29 - KPI 13 Analysis Summary

The WISDOM intervention has allowed to the pilot to receive alerts regarding ground water protection with a detection period of 1 minute. This is far below the target value. The decrease in the detection period, however, does not fully express the advantages of the WISDOM intervention.

Other qualitative considerations are:

- Prior to WISDOM, there was no automated system to re-open the valves when the turbidity returned to normal, so every 6 hours the operators had to manually measure the turbity and to decide if re-opening the valves is appropriate.
- Since operators checked the turbidity values only once every several hours, there were a risk of not detect turbidity peaks if increases and decreases in turbidity were occurring in the interval between two inspections

9.2. KPI 14

KPI Analysis Summary		**KPI No:**	**14**		
Ground Water Protection response time					
Description					
Measuring the time taken to respond to ground water issues related to piezometric levels in water wells.					
WISDOM System Context					
This KPI tests the ability of the WISDOM system to receive sensor data and then react to it (via alerts). This is performed using the rule engine developed in T3.1.					
Calculation Methodology:					
In the ground water at the *Fornola* site, the water taken from the well is monitored with Conductivity and piezometric level sensors. These are the two thresholds for each measurement; • Conductivity threshold at 20°C: >0.550 mS/cm (lean period) • Piezometric level threshold: > 6.50 m. a.s.l. (swallen period) When the two thresholds are exceeded, a sampler takes samples for laboratory analysis. If the water is not drinkable, the dosage of disinfectant is changed or, in the worst case, the wells are shut down. The temporal frequency of the sensors that have been installed is **1 minute** but the time needed for microbiological testing of coliforms and E. coli. Is about **24 hours.** As the previous KPI, the KPI_{14} can be expressed as **timing of anomalies automatic exclusion - detection**					
Target Setting:					
The Target has been chosen taking into account the real time detection that is feasible and the time to perform the microbiological testing (which is outside the control of WISDOM). Thus 1 day is the best achievement that can be obtained. For the same reason mentioned in the Target Setting section of KPI 13, the As-IS value cannot be set (due to no automated control being present prior to WISDOM).					
As Is - Value	None	Target	1 day	Tolerance	2 days
Results					
KPI Result:	≈1 day	% of success	100	RAG status	Green

Table 30 - KPI 14 Analysis Summary

During the WISDOM trial, any alarm condition in Fornola occurred, but since the anomaly detection is now instantaneous, the time taken between detection, laboratory tests and the relative actions can be considered as 1 day. The results satisfied the tolerance values, so the KPI has been considered as met.

The same as for the KPI 13, for this Pilot the advantages of the platform go beyond the simple numerical value of this KPI, due to the fact that the automatic system, not available before WISDOM intervention, allowed the detection anomalies that previously could not be detected and the provision of alerts to the network operators through the WISDOM interfaces.

9.3. La Spezia – ASP- Balanced Scorecard and discussion

Pilot Area:		La Spezia ASP	
KPI	Weight	% of successs	RAG status
13- Ground Water Protection response time (turbidity)	0.67	100	● (green)
14 - Ground Water Protection response time (conductivity)	0.33	100	● (green)
Final Pilot Result		100	● (green)

Table 31- La Spezia ASP Balanced Scorecard

10. WISDOM Research Experiments

This section presents the results of the two research based studies that were conducted as part of WISDOM and that are not related to the pilot specific KPIs that have been defined.

10.1. Water Usage Disaggregation

Water consumption disaggregation in domestic settings was identified as a valuable outcome of performing analytics on water data. A number of works in literature give an indication as to the feasibility of such research. However, the key obstacle that is aimed to tackle was the practicability, under realistic conditions, of water usage disaggregation. In fact, most of the existing works are data driven and, even if some of them deploy at the scale of more than one home, they do not take full account of constraints resulting from the complicated entanglement of liability, cost and time.

In fact, within the project, the data science team and water companies held a dialogue on data specification and on technical specifications required to solve this problem in a realistic setting. This led to the requirements from the water companies:

• Water meters need to be battery operated as no mains power is available in boundary boxes.

• Battery life should be the longest possible (> 10 years), hence compromises are need on the observation and transmission rate and may need to be lowered to around few readings per day.

• Members of the public like experiments but only for a short time period.

Data scientists' requirements can be summarized as wanting as much data as possible. Unfortunately, the requirements for a data mining approach to operate optimally would entail the battery life of a water meter as a few weeks.

This tension between the requirements brought the project to work within a new but more realistic type of settings developing a trade-off between the two positions. That resulting in a data collection rate in the range of one observation per minute. A second point is cost and time, predictive models and classifiers need to be trained and this operation is unfortunately intrusive. It is perfectly viable for a short time and when some volunteers are involved, but it is not the case in real life for the majority of customers.

Thus, WISDOM research is probably the first attempt to evaluate machine learning models and their applicability outside the lab settings but in the realistic scope of a sustainable deployment for real customers. The problem of disaggregation has then reformulated in a twofold way:

• Can a supervised classification model be fitted in a few selected homes and thereafter deployed in many others? In other words, is it possible to be intrusive only in a small subset of volunteers' homes and having a model effective in the whole community (e.g. a village)?

• If the above research question gives a negative outcome, would be possible to define an unsupervised model to get some useful insights even accepting a lesser granularity of results?

Both research questions have been tackled during the project. The analysis is based on valuable labelled data collected from a fully instrumented home in France and from the AQUASIM facility. The detailed results are presented in D3.2 and D3.4, but here a number of caveats towards a practical implementation of water disaggregation in homes are listed.

• Supervised models are affected by strong degradation of performances when they are deployed in dwellings other than the ones they were trained. Training on a selected subset of homes only would be of advantage to keep the intrusiveness of the solution low and allow it to be ported to other homes of a similar type, but the extent to which this is able to increase portability needs more research to achieve satisfactory results.

• The granularity of results granted by supervised classifiers is not always required. It would make more sense having less granular results but produced by an unsupervised approach. Remembering that intrusive collection of ground truth for unsupervised models is only needed to assess the feasibility of the methodology. This can therefore be collected in a few selected homes. Whereas, for supervised models, all homes are required to collect ground truth for model training. Unsupervised models seems the best way to proceed even if they extract less knowledge from available data, they can be fitted using past water consumption time series without the costly installation of ground truth sensors.

• The water energy nexus is strongly dependant on the type of house being studied. It has been found that the abstract notion of when hot water is being used is of great help to improve both the supervised and unsupervised models. However, how to get this information changes case by case i.e. depending on how water is heated in a property. A full description is reported in D3.4.

The cost of the solution is less appealing when compared to the benefits coming from mere water savings. The reason for this is that the cost of one cubic meter of water is nowadays very low. Unless regulators start an unpopular policy programme to increase water bills an ICT solution can be justified only if included in the context of a larger and pre-existing business case like an IoT home gateway or smart metering add-on provided as extra feature for some premium users.

10.2. Low Cost Water Network Sensing

The WISDOM project had explored many options regarding how leakage detection and other monitoring could be carried out. Some off-the-shelf designs have been explored in the pilots and in the Water Usage Disaggregation areas of WISDOM. To complement this work next generation sensing technologies have been considered to see what this could provide water networks of the future. To this end, the design of a highly low-power wireless microcontroller based solution that would compose a unit that could be sold at a price acceptable to the water markets has been investigated. Three iterations of this device have been built and tested in labs in Imperial College. The validation of each device tested the following:

1. The ability of the micro-controller to read and process pressure and vibration data at rates of 60 samples a second.
2. The ability of the node to communicate over large distances in both urban and non-urban environments.
3. Ability of the node to process the data and save communications.

The target application for this was leakage detection (which is discussed in the next section) and from this, a suite of test software has been designed to run on the candidate hardware sets. Using these tests, a new sensor device that combines the use of two low-cost state-of-the art technologies and smart edge-processing algorithms has been developed. The hardware and software design was to overcome the dual problem of sensing sensitivity to identify anomalies and at the same time transmitting data in near real-time in a cost-effective manner.

The initial lab tests demonstrated that extremely low-powered nodes such as the Arduino class devices were cost effective and showed that battery life was excellent; however, they could not retrieve and process the data efficiently enough to be a viable solution. Therefore, using the same software, this has been compared with the Intel Edison class node that indeed could carry out the processing but unfortunately has less lifetime capabilities as they consumed more power in their processing.

The next stage in verifying the design is developing the nodes and carrying out communications testing. This cannot be done in the confines of the lab therefore this work was carried out across London as City testing is more difficult than line of site testing found in non-urban environments. To this end a number of technologies has been tested and ensured that conditions were exactly the same for each test by sending and receiving communications packets in a round robin fashion; comparing LoRA with Xbee 868 with the other transceivers in the node. This ensured that the communications environment would be exactly the same for all transceivers therefore making all results comparable.

This was tested with different traffic loads and in different urban deployment contexts in London. Each experiment was run 10 times gathering 1000's of results. The LoRa radio module allowed to reliably communicate more than 80m (over 95% packet delivery rates) in both underground-to-over ground and underground-to underground scenarios from these results believe this is suitable as a communications mechanism for the WISDOM nodes.

This lead to the final experimentation in the Cardiff area specifically placing the communications devices on water network infrastructure and measuring the performance of the nodes and LoRa in situ. These results will be published in the final deliverables.

In summary, the validations of performance of the node indicate with confidence that the design choice was good in terms of communication device and processor in terms of processing capability but that the node does have potential lifetime limitations. From this, the next generation of the same chips from Intel is proposed, which are of similar processing capabilities but with considerably less power requirements.

10.3. Leakage Localization

The aim of the detection and localization aspects of the programme of work were to see if a solution could be developed that increased accuracy of water leakage localisation but at a lower cost of sensing. Essentially the processing ability of the sensor node architecture limited the number of approaches that could be taken. Assuming that these limitations may affect the accuracy of the detection of anomalies such as leaks, transients etc. following hypothesis have been wished to test:

The accuracy of anomaly detection and location will be enhanced fusing vibration data with data from other sensors (pressure and/or flow). This fusion algorithm can be performed in lightweight way and that anomaly detection therefore can be carried out on the edge device, therefore reducing the amount of data transferred over the communications network and back to the main WIDSOM engine.

A number of tests were carried out. Initially the algorithms have been tested in the Imperial College lab simulation device that emulates the node hardware but allows to scale the system to 1000s of nodes. This allows testing the system at scales expected by water network distribution systems. As the solution was entirely distributed the core functionality of the nodes required testing in situ.

To this end, validation of the software and hardware from a detection perspective in an almost real-world situation has been carried out. Obviously a live water network cannot be used as this equipment is in prototype form and it is too risky to be fitted to actual live infrastructure. Therefore, vibration sensors were fixed externally to the DCWW pipe test rig (Figure 6). The vibration method has been experimented as an alternative to flow and pressure because it forms a less intrusive and lower cost sensing solution, which is supposed to be attractive to water companies. However, while experimenting the flow/pressure has been recorded as ground truth for calibration and validation purposes (shown in Figure 7).

Figure 6: DCWW Test Rig

For this experiment the NEC Tokin Ultrahigh-Sensitivity Vibration Sensor that covers a frequency band of 10 to 15 kHz (and acceleration at 0.0001 G) with very low power requirements has been used [1]. Such high fidelity sensors allow to better explore water network transient phenomena, but the cost of fully transmitting that data is prohibitive using battery powered low-resourced devices. Therefore the edge processing techniques have been used to reduce data sent round the network and using the ground truth data it is showed that it does not lose any of the important information required by the water companies.

To evaluate the experiment and examine the data, a basic leak detection algorithm has been added and used the vibration data gathered from the DCWW rig. Initially, the input stream is separated into windows (i.e. 512 bytes) where noise is removed from the data stream using a one-dimensional Kalman Filter and then anomaly detection was carried out. See Figure 8 showing the anomaly that relates to the valve movement that is carried out in the experiment.

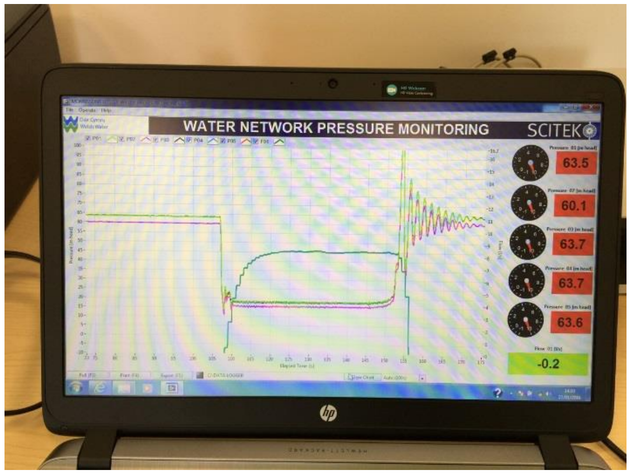


Figure 7: Anomaly (burst) detected in pressure and flow

These early experiments show that early transient or event detection was able run on low resource sensor nodes at the edge, meaning that local control functions can occur with minimal latency. This paves the way for distributed control for next generation water networks. With the event time stamps are all that is required to be sent to the back end to be localized and this information fed into a control decision process to save both water and customer demand issues.

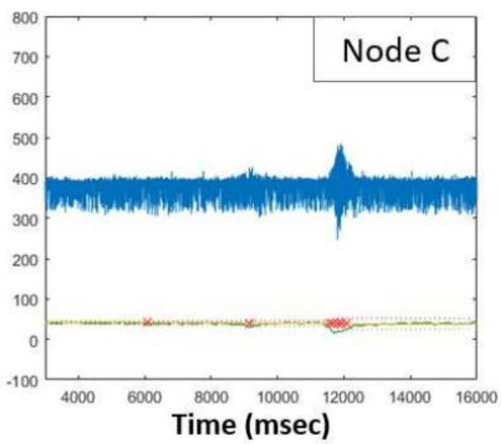


Figure 8: Anomaly (burst) detected in one of the vibration sensors

From these initial experiments, each of which were ran 5 times and amount to 100s of results, it is evident that this approach significantly reduces the amount of communications between sensor devices and the back end servers. Moreover, it is also showed that the off-line algorithms can effectively localize water burst events by using the difference in the arrival times of the vibration variations detected at the sensor locations. The results can save up to 90% communications compared with traditional periodical reporting situations. Further, the Localisation can find the position of the anomaly for this particular scenario within 0.5m error for the DCWW test rig. This data driven approach is significantly better than many hydraulic modelling approaches that at best identify a leak to the length of a given pipe, which can be 10s of meters.

11. CONCLUSIONS

The benchmarking and validation of the WISDOM platform is the main goal of Task 5.3. This validation is a fundamental step in developing the WISDOM system, enabling to quantitatively evaluating the performance of the system in terms of WISDOM's key goals of saving water and energy and positively influencing end users attitudes to water savings. The WISDOM KPIs, defined in D5.1, are at the base of the benchmarking and validation approach and the proposed *Balanced Scorecards* represents the summary of each pilot success.

In this Deliverable, KPI 2, KPI 8 and KPI 11 have been changed from D5.1 in order to better express the meaning of their respective calculation methodology.

In order to validate each WISDOM pilot, a methodology combining KPIs with respective weights, assigned through a survey among representatives, has been proposed and applied, allowing to obtain a percentage of success that numerically represents the pilot validation. The results obtained for each pilot are summarized below:

- KPI 1 shows that, in regards to the daily volumes, there is no advantage to having smart meters in Cardiff Pilot but when it comes to night flows, the data from SMART meters shows more accurate results when compared to industry standards valuable knowledge for the water network operators. KPI 5 showed there is an 80% overall positive response rate in regards to adaptive pricing, if used to promote efficient water use and not as a way of making more profit. The results on the other Cardiff pilot KPIs will be published in the final deliverable.
- West Wales pilot has been successfully validated, obtaining 100% of success. KPI 6 values demonstrates that the algorithm implemented for automated CSO predictive model has given an averaged predictive accuracy of 84.53% over all the CSO identities, better than the training one (79.75%), demonstrating the extraordinary generalisation ability of the constructed CSO predictive models.
- The results on the Tywyn Aberdovey pilot KPIs will be published in the final deliverable.
- The results on the AQUASIM pilot KPI will be published in the final deliverable.
- KPI 10 and KPI 11 reached abundantly the targets values in the SAT Pilot, in which flow and pressure sensors have been installed and allowed to monitoring in real time the network behaviour, detecting potential anomalies due to leakages and reducing the leakage localization time. The results on the KPI 12 will be published in the final deliverable.
- Finally the installation of the turbidity, levels and piezometric sensors in ASP pilot allowed to have a real time detection of anomalies that significantly reduced the Ground Water Protection response time, thus bringing to 100% the success of the pilot.

The last part of the deliverable documented the validation that has been conducted on the WISDOM research focused scenarios that were not covered by the pilot KPIs. This included the validation of household water usage disaggregation, the low cost water network sensing and the leakage localisation.

The cost of the solution for household water usage disaggregation resulted to not justify the benefits coming from mere water savings due to the current low cost of water nowadays.

For the low cost water network, the validations of performance of the analysed node indicated that the design choice was good in terms of communication device and processing capability but there are potential lifetime limitations. From this, the next generation of the same chips from Intel is proposed, which are of similar processing capabilities but with considerably less power requirements.

The leakage localization research approach proved a saving up to 90% of communications compared with traditional periodical reporting situations. Further, the localisation system is able to find the position of the anomaly for a particular scenario within 0.5m error for the DCWW test rig, revealing much better than many hydraulic modelling approaches.

12. References

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