D6.2 WATERNOMICS Integrated outcome (Methodology, Software & Data Management and Analysis Components)

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Project Acronym:	**Waternomics**
Project Title:	**ICT for Water Resource Management**
Project Number:	**619660**
Instrument:	**Collaborative project**
Thematic Priority:	**FP7-ICT-2013.11**

D6.2

Work Package:	WP6 Methodology, Platform and Analysis Refinement	
Due Date:		M36
Submission Date:		M39
Start Date of Project:		01/02/2014
Duration of Project:		36 Months
Organisation Responsible of Deliverable:		R2M
Version:		1.0
Status:		Ready
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Nature:	☒ R – Report ☐ P – Prototype ☐ D – Demonstrator ☐ O - Other	
Dissemination level:	☒ PU - Public ☐ CO - Confidential, only for members of the consortium (including the Commission) ☐ RE - Restricted to a group specified by the consortium (including the Commission Services)	
Project co-funded by the European Commission within the Seventh Framework Program (2007-2013)		

Revision History

Version	Date	Modified by	Comments
0.1	06/09/16	Domenico Perfido	Initial Version of Document and outline
0.2	19/12/2016	Wassim Derguech	Data Management and Analysis
0.3	22/12/2016	Souleiman Hasan	Lessons Learnt from Realtime Data Management (Section 4.1.1.1)
0.4	02/01/2017	Sandra de Vries and Leonardo Alfonso	Section 4.3; Leakage detection
0.5	09/01/2017	Umair Hassan	Lessons Learnt from Historical Data Management (Section 4.1.1.2) and Catalog Service (Section 4.1.1.3)
0.6	10/01/2017	Domenico Perfido & R2M team	Introduction and Methodology sections completed
0.7	11/01/2017	Sander Smit	Focus on business aspect and validation added
0.8	12/10/17	Christos Kouroupetroglou	Waternomic Platform section completed
0.9	13/01/2017	Louise Hannon Domenico Perfido	Rule based FDD section completed Model based FDD section completed
0.10	13/01/2017	Jan Mink	Flow meters section completed
0.11	14/01/2017	Domenico Perfido & R2M team	Amalgamate Pilot Contribution and completed Conclusions section
0.12	17/01/2017	Schalk Jan van Andel Wassim Derguech	Revisions
0.13	23/01/2017	Domenico Perfido	Edits prior to Team Review
0.14	26/01/2017	Domenico Perfido	Edits following Team Review
0.15	31/01/2017	Domenico Perfido	Final Edits / Revisions
1.0	11/04/2017	Wassim Derguech	Final version prepration

Executive Summary

WATERNOMICS aims to engage the end-users into optimizing their water usage. To meet this need Waternomics makes available for different users their water usage in a new way: by using ICT technologies, tools to create new forms of awareness and by allowing comparisons with benchmarks, providing information about how to implement Water Efficiency Measures (WEMs), developing new Fault and Leakage detection methods in order to provide information at a time scale useful for decision making.

This deliverable describes the different final versions of outcomes developed under the scope of Waternomics project as the following:

- Standard based Methodology for implementing a Water Management Plan (WMP)
- Waternomics Applications Platform (WApP)
- Data management and analysis
- Fault and Leakage detection method and sensors
- Flow meters

The before mentioned outcomes have been already detailed in earlier deliverables and are now refined in order to capture the feedbacks from the pilot sites experience (WP5).

The first version of the standards-based methodology for the development and implementation of ICT-enabled water management programs has been already presented in the deliverable D2.1. The methodology aims to give constraints, standards, corporate preferences, and key performance indicators (KPIs), provide decision makers and designers with a systematic way to select technologies, measurement points, data collection methods, and data management techniques for ICT-based water management systems. This report details the final version of the methodology after the lessons learnt captured from the pilot sites experience.

The Waternomics Application Platform (WApP) has been discussed earlier in the deliverable D3.3 and it represents a key component of the Waternomics project, because it aims at collecting water consumption and contextual information from different sources to be used for effective data analytics to drive decision making: e.g., planning, adjustments and predictions and to raise user awareness of water consumption. This report presents the final version of the WApP and together with the methodology; it can be regarded as the integrator of all the outcomes of the project because it uses effective data from smart water meters, provides information to the users about fault detection and leakage detection in real time.

Data management and analysis already have been discussed in the deliverables D3.1.1 and D3.1.2. In this report the lessons learnt and platform validation within the Waternomics project are presented.

Leak detection and Fault Detection and Diagnosis (FDD) rules have already been discussed in the deliverables D4.1, D4.2 and D4.3. This report presents the final version of the methods and sensors developed for the different environments targeted by the Waternomics project.

Flow meters and devices have already been discussed in the deliverable D4.1 and this report provides the lessons learnt from each pilot site and user guidelines for implementing the installation and the maintenance phases.

This report is divided in the following way:

- Section 2 presents the final version of Waternomics methodology to implement a Water management plan.

- Section 3 details the final version of the Waternomics Application Platform (WApP) developed in the project. It helps in pointing out the water system related information to help carry out the Water management plan in accordance with the methodology.
- Section 4 provides details of the Data Platform, Fault Detection and Diagnosis, Leakage Detection, Meters and data transfer technologies developed within the project
- Section 5 provides the conclusions of this report.
- Appendices are used to provide a complete set of tools such as users guidelines and instructions for use for Waternomics Application Platform, Flow meters and Decision Support System components.

In the project itself, the methodology as well as the other outcomes are implemented in four pilots and the refined version that incorporates lessons learnt from pilot activities is available in this report entitled Deliverable 6.2 (Integrated Outcome: Methodology, Software & Data Management and Analysis Components).

The report describes the work conducted in the Waternomics project and its outcomes, and it shows how the Waternomics overall system can be one step and contribution in the development of a Smart Water Management System that will lead to increased user awareness regarding their water consumption and so to an overall behaviour change.

Some aspects of the outcomes (leakage detection and FDD) yet need some effort to meet in the best way the market needs but the future plans of some of the Waternomics consortium partners are working in this way by exploring new market opportunities and new funded projects in order to increase the technology readiness level and maturity.

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1 Introduction

Waternomics is targeted to explore how ICT can help households, businesses and municipalities with reducing their consumption and losses of water in the framework of a water management program. To this end a key component of the Waternomics project is to provide water consumption and contextual information from different sources to be used for effective data analytics in order to drive decision making that optimises water consumption and to raise user awareness of water consumption. In doing this, The project has developed some tools and products like:

- a standards-based methodology with which to plan, implement and assess Water Efficiency Measures.
- a web based Platform with which provide information to the different end-users targeted about their water consumption
- a data management plan aimed to support all the web based system
- a Rule based and Model based fault detection and diagnosis (FDD) tools with wich to point out what's wrong in the operational phase of a water network at different scale and avoid in this way loss of water
- a leakage detection method coupled with new acoustic leakage sensors with which to asses at an early stage water leakages in an house water network environment
- flow meters and an innovative data transmission system by using the beagle Bone Black board

The objective of this report is to prepare the afore mentioned project results for the post project uptake.

1.1 Work Package 6 (WP6) Objectives

WP6 is the repository of the lessons learnt from the different Waternomics pilot sites in applying the tools / products developed within the Waternomics project and it is intended as a deliberate feedback loop from pilot activities into the project technical and methodological development prior to post project exploitation. In doing this the WP6 objective is to finalize the technical outcomes and to ensure they are complete, accurate and polished.

The objectives of WP6 are:

- to refine data management, analysis, FDD and lead detection methods;
- to reflect pilot lessons learnt into the project methodology
- to finalize the water information services platform and user environment.

The work of this WP relies on the expertise and field experience of the consortium partners as well as input from the Pilot sites and Pilot managers. Through this, the WP produces as output the final version of the methodology, Platform, FDD methods, Data Management plan, Leakage detection method and flow meters. To prepare the outputs for the post-project uptake, also support-tools such as users' help guidelines and instructions for use will be presented for the appropriate project outputs.

1.2 The Role of Deliverable D6.2

To align itself with the WP6 objectives this report (D6.2) is aimed to capture the learnings from the technical validation, end-user validation and business validation of the Waternomics Platform and Methodology as a whole and from the individual components of the Waternomics project.

1.3 Relationship with other Activities in the Project

WATERNOMICS is organized in eight different WPs as shown in Figure 1.

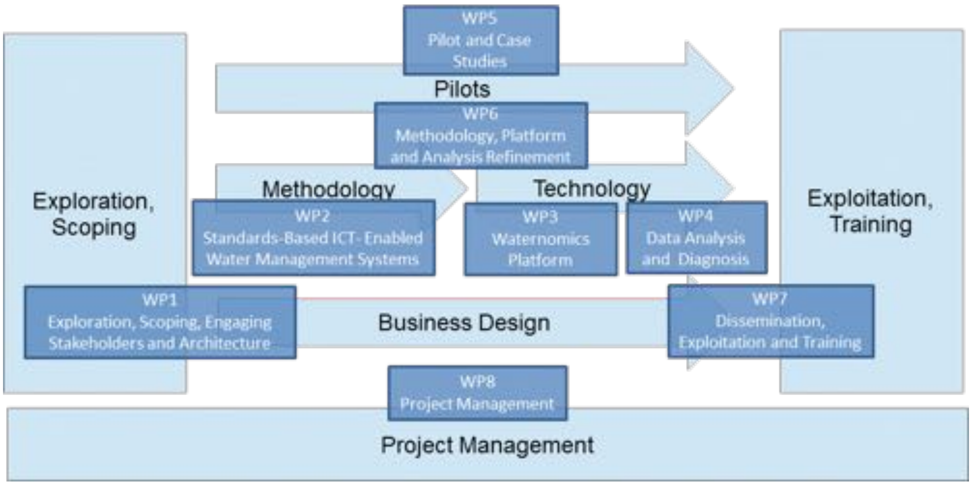

Figure 1 : WATERNOMICS WP structure.

WP6 has been active in the last months of the project, from M28 to M36, and it aimed to refine the projects results with the pilot activities and feedbacks before being made available for exploitation and training (WP7). The links between WP6 / D6.2 and other activities in the project are outlined in Figure 2.

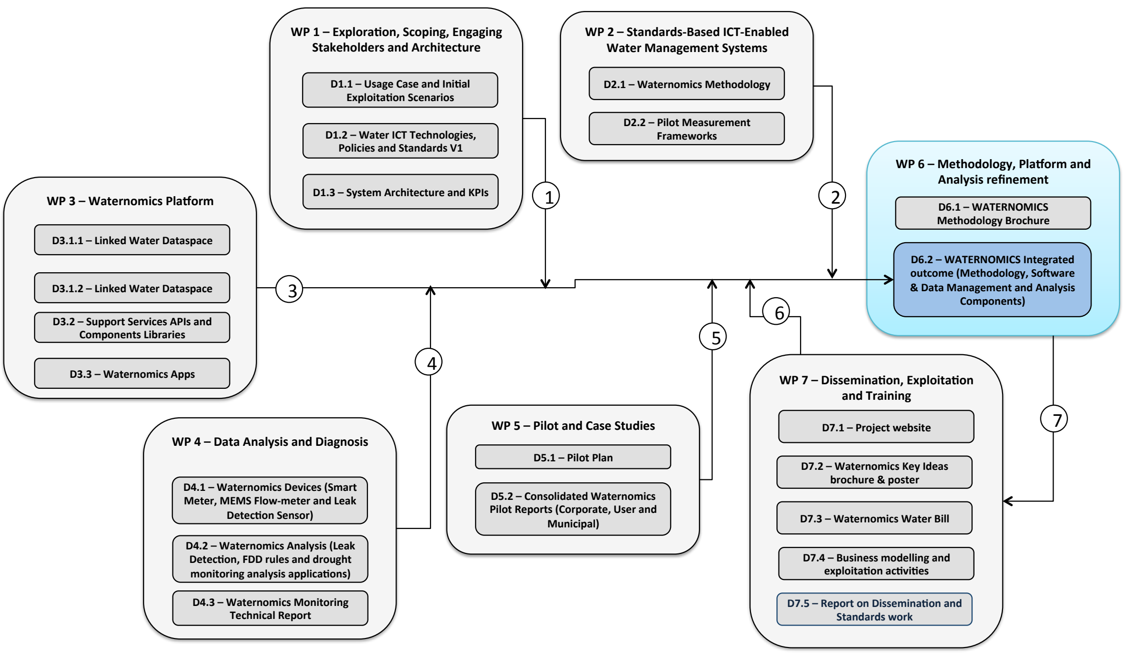

Figure 2: Relationships between D6.2 and other activities in Waternomics

Figure 2 shows the interdependencies and relationships between WPs as they relate to WP6 and Deliverable D6.2 and we can summarize as follows:

Link 1 – From WP1, its stakeholder workshops and D1.1, D1.2 and D1.3, WP6 received the project scenarios, information related to sensing technologies, the overall architecture, KPIs particular to delivering water efficiency for the targeted groups and user needs. The scenarios are the basis for the economic validation of the project results.

Link 2 – From WP2 the WP6 received the first draft of the project standard – based methodology. The developed methodology is refined through the pilot sites feedbacks.

Link 3 – From WP3 the WP6 received the overall Applications Platform. It is refined with the pilot sites feedback in order to achieve the final version. The Application Platform is an aggregator element of all project results.

Link 4 – From WP4, initial information related to leak detection, fault detection and data analysis are considered and refined to achieve the final version.

Link 5 – From WP5, operational feedbacks, governance aspects, physical infrastructure data and consumption data observed in applying the Water Efficiency Measures (WEMs) are the basis for the refinement and improvement of the Waternomics methodology.

Link 6 & 7 – WP7 is directly connected to the WP6 outputs. Indeed the results from WP6 are exploited and disseminated through the WP7 activities and the WP6 training documents help in doing this.

1.4 Document Outline

The remainder of this document is organised as follows:

Section 2 summarizes the Waternomics methodology framework, the activities and methods to implement each phase, a particular focus is made on the lessons learnt from the pilot sites and on the validation of the methodology. Section 2 is divided into three sub-sections:

- Section 2.1 summarizes definitions, ideation & process of the Methodology
- Section 2.2 describes the lesson learnt from the pilot sites
- Section 2.3 describes the validation of the Waternomics methodology and the final version

Section 3 describes the lessons learnt from each pilot site about the application of the Waternomics Application Platform and a particular focus is made on the validation of the Waternomics Platform and the final version. Section 3 is divided into two sub-sections:

- Section 3.1 describes the overall lessons leaned from each pilot sites (experience from pilots)
- Section 3.2 describes the final version of the Waternomics Platform

Section 4 presents information aggregated about the other Waternomics outputs: Rule based FDD, model based FDD, Data management, leakage detection and flow meters. Section 4 is organized into four sub-sections:

- Section 4.1 presents a mapping of data management plan developed within the Waternomics project
- Section 4.2 provides an analysis of fault detection methods developed within the project (rule based and model based FDD) and presents their final version.
- Section 4.3 presents an analysis and the updated version of the leakage detection method and sensors developed within the project
- Section 4.4 describes several operational conducted to adjust the sensors hardware and software to implement the data transmission system within the Waternomics project

Section 5 provides conclusions related to the Waternomics integrated outcomes, future steps to implement in order to achieve the market exploitation.

2 Waternomics Methodology final report

The Waternomics Methodology is a project outcome and it provides a set of knowledge, tools and references related to water efficiency and water management to help the different end-users targeted by the project in implementing a water management plan. Use of the developed methodology provides a standard-based pathway that can lead to both organizational change (management procedures) and individual change (behaviour change) and serve as a manual or guideline on how to get started.

Already from the beginning of the project, one of the main points was how to create a simple and effective guideline for users in order to obtain a change in behaviour against the waste of water resources. To meet that need it was a deliberate choice to develop a "standards-based" methodology. In this way, it is possible to align with concepts and terminology that high replication-potential decision makers are already familiar with. As is often the case, frameworks and methodologies are general so that they can be adopted, adapted and applied to a wide range of stakeholders.

The proposed Methodology has been applied in the four Waternomics pilot sites and each pilot manager has followed it in order to create a water management plan, implement WEMs and assess the results. Also a visual graphic of the methodology has been introduced through the Trello Board application in order to assist implementation and eliminate the potential gap between overarching procedural steps and the actions required to accomplish them.

In the following subsections will be presented the final version of the Methodology that comes out after a feedbacks loop from the pilots experience.

2.1 Summary of the methodology

The methodology introduced in the earlier deliverable D2.1_"WATERNOMICS Methodology" is targeted to fill the gap in the water sector where not many standards are available for implementing a WMP. The methodology provides a basis for water management improvement and effectively shows how different standards, also taken from energy sector, can drive organizations and households to use water more efficiently.

To meet this need the methodology proposes a method resulting in an effective combination of existing water and energy related standards (ISO 50001, IPMVP, ISO 50002 and ISO 14046).

A knowledge base of the methodology has been founded on the ISO 50001 processes, Plan-Do-Check-Act cycle and the integration of all the other standards criteria represents a novelty. This knowledge base contributes to better understanding and implementing water management system, since it starts from the relationship between the scientifically recognized ISO 50001, the Plan-Do-Check-Act cycle, which underpins all the standards for systems management. Added to the PDCA cycle is an initial "Assess" phase. Because end-users may be less aware of water efficiency, water scarcity and how/why it affects them, the Assess Phase in the Waternomics methodology is a deliberate attempt to engage and educate the end-users.

Processes within the WATERNOMICS methodology are designed to adapt to organizations of any size and take you from initiating a water management program to monitoring the performance of the actions taken through five phases (Figure 3).

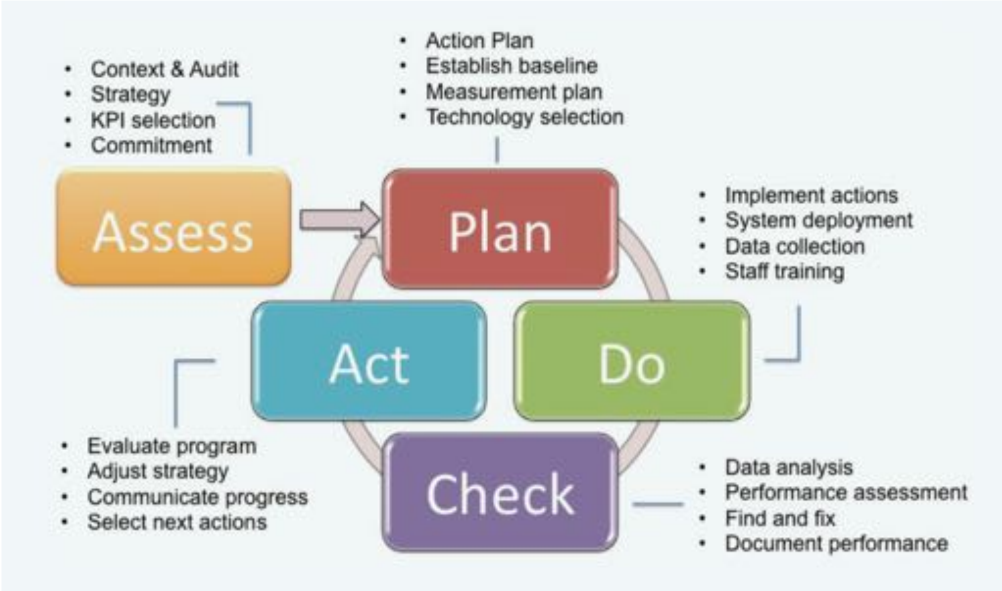

Figure 3: Waternomics Methodology Phases

Assess: Determine whether or not an end-user or decision maker should engage in the construct of a water management program, take water efficiency measures and/or implement a water information system. Establish the baseline, objectives, targets and action plans necessary to deliver results in accordance with opportunities to improve water consumption.

Plan: Establish the baseline, objectives, targets and action plans necessary to deliver results in accordance with opportunities to improve water consumption.

Do: Implement the water management action plans.

Check: Monitor and measure processes and the key characteristics of its operations that determine energy performance against the water objectives.

Act: Take actions to continually improve water performance.

The model is universal and can be applied for all type of organizations, as well as in service sectors. The proposed methodology can serve as a basis for national and international certifications for water excellence.

2.2 Overall lesson learnt (experience from the pilots)

The developed methodology has been applied in the four Waternomics pilot sites in order to test it in different environments and with different end-users.

Each of the four pilot sites is managed at a project level by a WATERNOMICS consortium partner. Due the fact that the proposed methodology was in an experimental phase, basically it was led by a pilot manager in each of the four pilot sites.

Table 1 describes the consortium partner assigned to each pilot site and the nominated representative from the partner organisation. The pilot site managers work closely with representatives from the permanent staff at each of the pilot sites to ensure the successful implementation of the WATERNOMICS methodology phases and the achievement of the pilot specific objectives.

Table 1 - Waternomics Pilot managers

Pilot Site	Consortium Partner	Nominated Representative
Linate Airport, Italy	R2M	Domenico Perfido
Thermi, Greece	Thermi	Christos Kouroupetroglou
NUI Galway, Ireland	NUIG	Louise Hannon
Coláiste na Coiribe, Galway, Ireland	NUIG	Louise Hannon

This approach helps us in applying each single phase of the standard-based methodology, assess the results, promote water awareness among the different users and carrying out the overall Waternomics plan and water management system (WMS).

The first issue to overcome in all the pilot sites was to have a common guideline for implementing the Waternomics project; what we have thought about was to develop a common methodology. The idea was fine and the application in the pilot environments just gave us confirmation about this.

Lesson Learnt 1:

When more and different environments are involved in a project the Waternomics methodology provides a common background, a way to follow, and what's more it gives the opportunity to compare the results.

Moreover, the standard based approach of the methodology is well accepted especially in the public or private company environments. Indeed, it gives credibility to the methodology and its phases and it helps in complying with the most recent standards related to the water footprint. Both Irish and Italian pilot sites are now on the right way to be compliant with ISO 14046 and ISO 50001 Standards and this helps the organizations in promoting their environmental responsibility, best practices and in reduce their water consumption. At a household level (Thermi pilot) the importance of being compliant with standards becomes secondary, and greater importance is given to the possibility of being able to actually save the water resource.

Lesson Learnt 2:

A standard-based approach helps in implementing a WMS and it is well accepted in public and private company environments because it helps to be compliant with EU directives and ISO standards. It also gives actionable steps to follow in order to improve or establish a water management system.

The second issue we have overcome is how to apply the methodology in a real case. It can be difficult for people who are not yet introduced to standards or do not have a good knowledge of standards, technologies, etc. This could result in a methodology that is not properly applied, in this case the risk is that the methodology might not be as effective as expect for achieving the specific objectives.

To avoid this problem the Waternomics methodology is made of five phases and those phases are broken into a series of activities and these activities can be considered a method to conduct each phase. Moreover, we also have introduced different methods to conduct specific activities to capture a baseline, conduct a water audit, determine strategy and so on (see D2.1_Waternomics Methodology) and the novelty is that we have coupled our methodology with a web based management tool the "Trello Board".

The Waternomics methodology TRELLO Board is a user-friendly way to both engage the users and make them follow the methodology phases.

Through Trello board, the pilot managers and the project team had the possibility to apply the methodology in each of the different pilot sites and it results to be a good method to share ideas, document, progress, problems solutions and to check at every moment what is the next action to implement in order to apply the Water Efficiency Measures (WEMs). In this way, the Trello tool has promoted knowledge sharing and dissemination within the project team as well as the progress tracking and actions prompting.

The Trello board has been managed and experimented by the project team and we found it as a key idea for the methodology market exploitation.

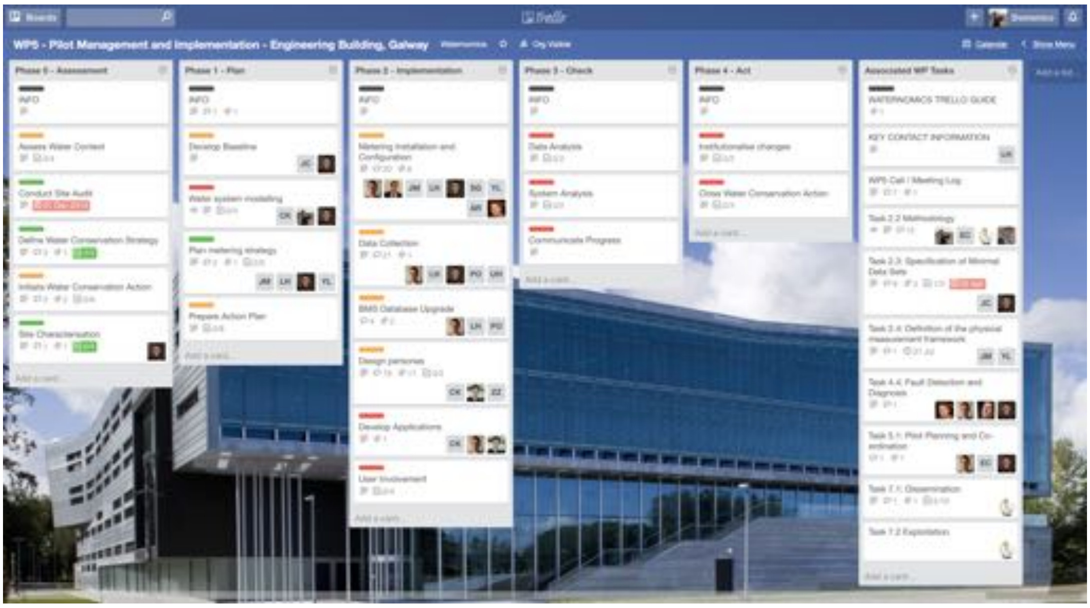

Figure 4: Waternomics Methodology TRELLO Board

Lesson Learnt 3:

A methodology may be as exhaustive as possible when listing the actions to be implemented, but without the accompanying tools will always be difficult to apply it to the real case. Through use of the Waternomics Methodology TRELLO Board, an organization can better ensure that a water management program is performed in a consistent way and have relevant information captured and communicated all in one place.

Certainly, there have been some problems in the implementation phase, however, they have been analysed and have contributed in the methodology improvement.
As for example, ordinary problems encountered in each pilot site are:
- obtain information from end users on their water consumption
- get the updated plans of the water network

These issues have been solved with physical surveys and the implementation of awareness questionnaires developed "ad hoc" for the end-users.

On the other side, the compliance of the operational asset of the methodology with well-recognized ISO standards results in very detailed phases in a certain sense that are suitable to be tested in different environments with clear steps to follow and actions to implement. This results in few changes in our methodology framework. However, we have introduced a Water audit - “Phase 0” - to better understand the real needs of the end-users. We have merged many aspects taken from the energy sector with the water one and by implementing the methodology some aspects have been reviewed and readapted.
As for example the Phase 2 “DO”, at the beginning, included the validation as part of the activities to be conducted, however, we recognized that these validation activities have to be targeted not only to the meters installed (equipment) but also to the data gathered from them. Problems such as data integrity and accuracy, calibration of the meters and sensors have persistently caused issues and delays during the project development. For this reason, the activity of data verification became a separate activity placed within the ‘Do’ phase of the Waternomics methodology.
In addition, in the Phase 1 “PLAN”, at the beginning, was included the Baseline development. We recognized that there might be a requirement for baselining of usage data also in the Phase 2 “DO” as information may not be available until after new metering has been installed and not possible in earlier Phase 1.
From the pilot sites experience all the other methodology Phases and actions are well planned and placed and they don’t need changes.

Lesson Learnt 4:

The standards background gives a solid structure to the Waternomics Methodology. This results in the necessity to introduce very little changes. In addition, what we can understand is that a methodology is helpful but also the directives of a water manager (in our case the pilot managers) are necessary to comply with each single phase/action.

The standard approach gives the possibility to include in the methodology new standards to comply with organizations needs and governance. The D7.5 _ “Report on Standard Work” will show in detail how in implementing the Waternomics methodology the pilot sites executed many of the aspects that comply with new standards, e.g. water aspects of ISO 14001:2015 – Environmental Management Systems.

In general, we can conclude by saying that the methodology is a starting point for implementing a WMS and the Waternomics team and pilot managers find it very useful to achieve the pilot specific objectives. Moreover, it can lead to obtain a water consumption reduction excellence certification by being compliant with the most recent EU directives.

2.3 Validation of the methodology and final version

The pilot results show that the Waternomics Methodology helped with setting priorities, selecting technologies, planning the work and aligning stakeholders and partners. While the pilot environment does not fully reflect a commercial business setting, it can be concluded that the Waternomics Methodology lowers the barrier for organisations to purchase and install a smart water system. It functions like a guide or manual and increases the efficiency of the investment an organisation makes for adopting a smart water system.

A smart water system is complex and touches many organisational units and business processes. External consultants can help organisations with defining a proper strategy for adopting a smart water system, selecting the right technology and offer support and guidance during the implementation of the system. Linking a consultancy agency with a technology provider enables a new value proposition where the Waternomics Information Platform can be

offered on a Smart Water as a Service (SWaaS) basis to industrial customers. The consultancy company manages the customer interface and the technology provider delivers and manages the required technology. Within the Waternomics consortium, partners Ultra-4, a technology provider, and R2M-Solution, a consultancy agency, are investigating collaborative post-project exploitation of the Waternomics Platform and Methodology on a SWaaS basis, targeting at industries and public buildings in southern Europe.

For the Waternomics methodology to remain relevant, it needs to stay aligned with the further development of the Waternomics Platform and adopt relevant newly developed tools and techniques that become available on the market.

The final version of the Waternomics Methodology includes in itself the feedbacks from the pilot sites. However, as described in the previous section, the standard-based approach assures a strong background. The result is that no many changes are needed due the consolidate ISO 50001 structure. The pilots case studies clearly show also the utility of the first Audit phase "ASSESS" which aim is to engage the end-users in checking if a real WMS is necessary in their organization. A detailed description of the five phases of the Methodology is provided in D2.1_ Waternomics Methodology and in the following we will present again a short overview, with user friendly images, each single phase and the corresponding actions to be taken to comply with the pilots' feedback. In red colour are pointed out the changes resulted from the pilots feedback.

The five phases are consolidated; each single phase contains in itself the action that needs to be taken from the end-users in order to reach the specific objectives and each one should happen in the right order as shown in the Figure 5 below.

What we have to point out is that the methodology process is a cyclic loop, so the last phase is strictly connected with the first one. This because such a thing helps organizations in applying effective Water Efficiency Measures and establishing an efficient WMS compliant with the organizations' needs.

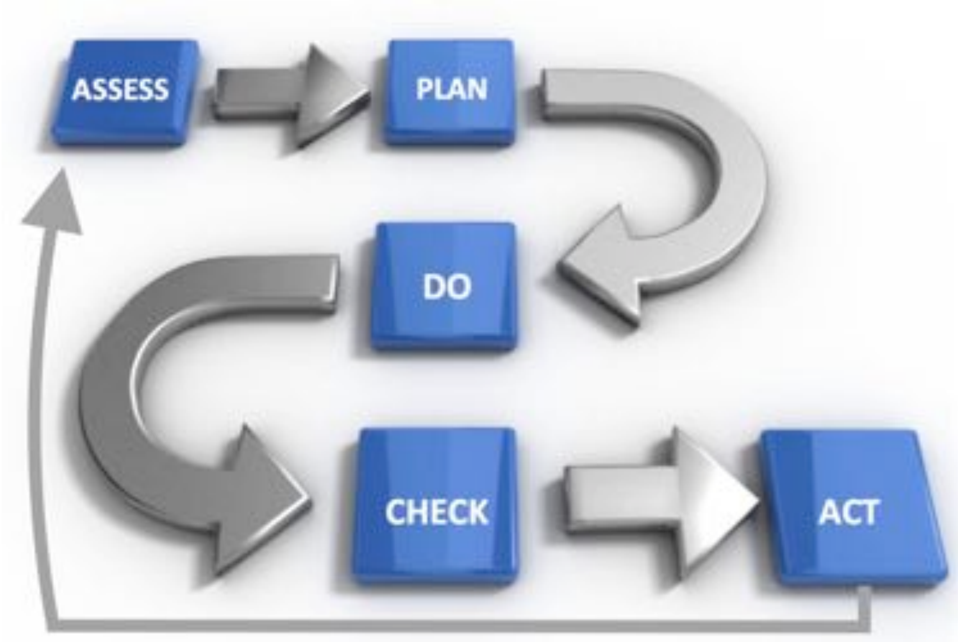

Figure 5: Waternomics Methodology stream

In a further detailing of Figure 5, Figures 6 - 10 provide an intuitive view of the methodology.

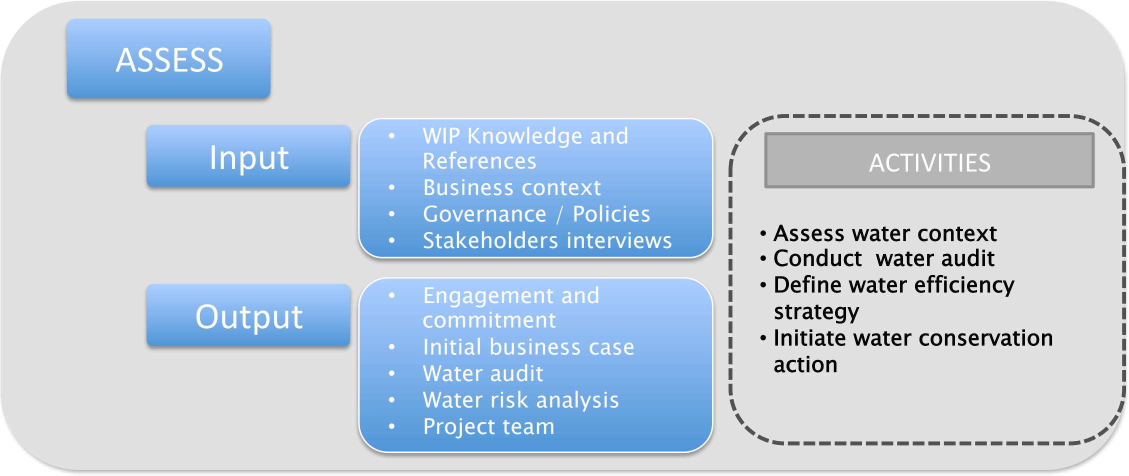

Figure 6: Phase 0 - ASSESS

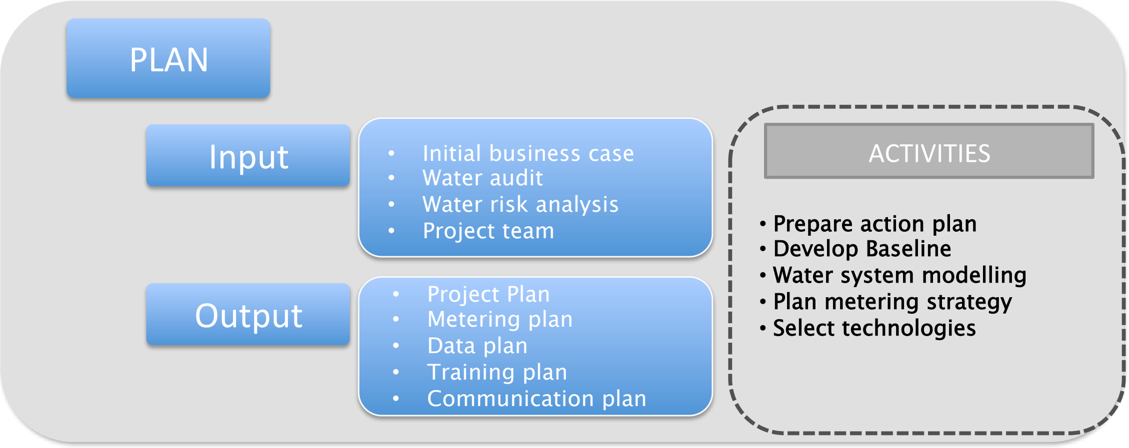

Figure 7: Phase 1 - PLAN

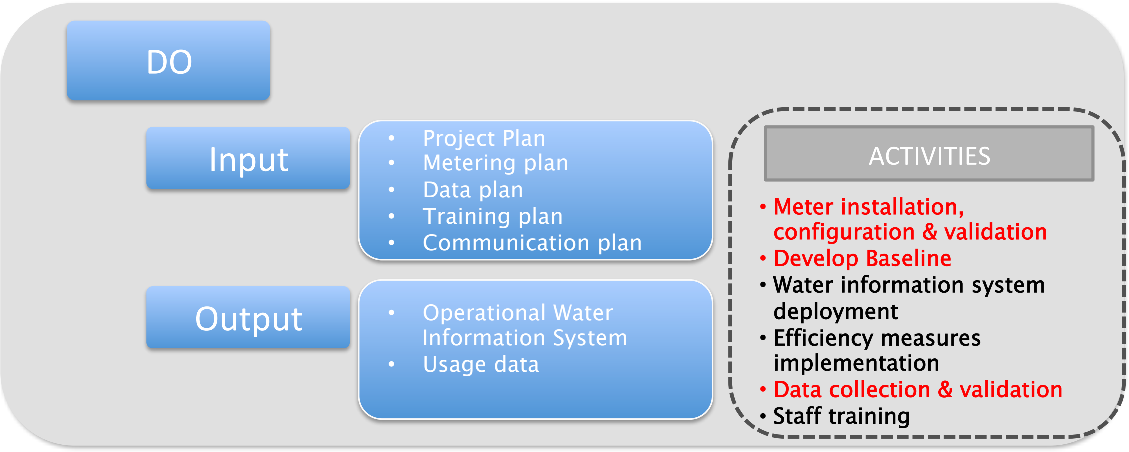

Figure 8: Phase 2 – DO (reviewed with pilots sites' feedbacks)

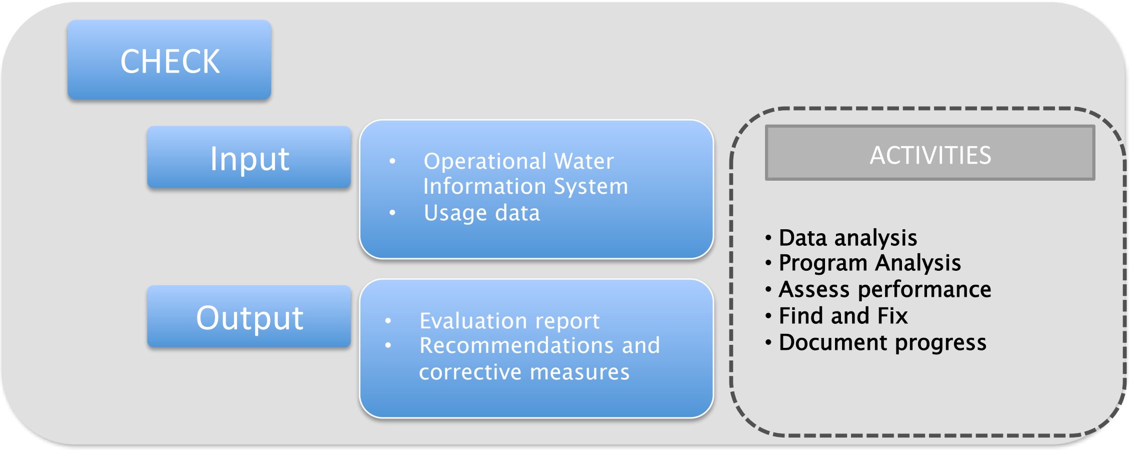

Figure 9: Phase 3: CHECK

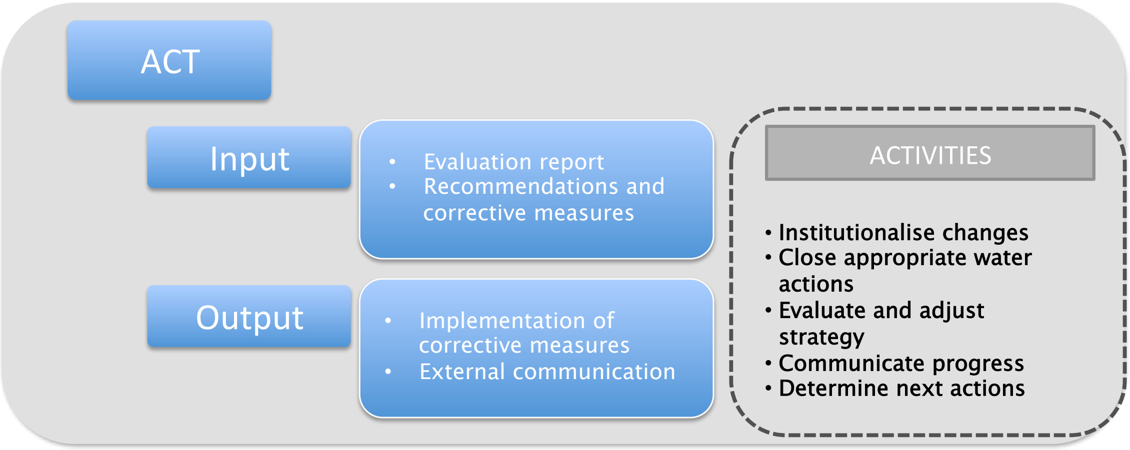

Figure 10: Phase 4: ACT

In the overall Waternomics project, the most important phase was the deployment of the Phase 2 "DO". Indeed, this phase executes previous planning activities and begins the data collection for charting and analysis in the following "CHECK" and "ACT" steps.

During the executing process in all the pilot sites, we realized that activities such as Data collection and validation are a crucial aspect that should not be underestimated in the implementation phase because from this data we will understand the real water resource savings obtained. In order to preserve the integrity of data gathered from each single pilot sites, activities like quality assurance and quality control coupled with the calibration activities of the meters were performed repeatedly during the course of the project.

In details, activities like quality assurance have been performed by comparing the data gathered from the meters with the existing baseline (data available before the data collection begins). While quality control activities have been implemented during and after data collection with direct staff observation during site visits, conference calls, or regular and frequent reviews of data reports to identify inconsistencies, extreme values or invalid codes. In deploying the quality control more useful has been the comparison between data measured in different periods in each single pilot site. These activities lead actions like Find and Fix, calibration of the meters, improvement of the hardware installation manuals.

Figure 11 shows a full view of the final version of Waternomics methodology. In specific, the activities, desired outcome, and related standards are shown for each phase, while for further details about the methodology please refer to the D6.1_ Methodology Brochure.

Figure 11: Final version of Waternomics Standard-based Methodology

3 Final Waternomics Platform

3.1 Overall lesson learnt (experience from the pilots)

One of the key concepts introduced in the Waternomics applications platform (WApP) was the concept of the applications marketplace where you can find and create your own application to fit your needs. The idea was based on existing paradigms especially on the mobile domain and helped in creating an ecosystem of applications able to provide personalized information to different types of users from domestic to corporate. Users in all pilot sites received the idea quite warmly and did not express difficulties in understanding it. They were able to understand form the first time entering the Waternomics applications platform its purpose, how to find and use applications.

Part of the applications platform is the idea of the app builder which allows users to combine different components in order to create their own applications based on their own needs. When presented to users of all types it was well received and appreciated. However, creating an application for a specific user needs requires some planning and designing and learning effort from the user. It requires a certain degree of familiarity with the components available and how to configure them. In general, the app builder was appreciated for its potential but within the scope of the pilot only very few users attempted to create a new application for their specific needs. Most of the applications were designed and developed by consortium members providing pilot management services.

Users' difficulty of remembering and being able to configure different components to create applications led to the creation of an additional application from the existing ones focusing on providing help to users on how to create their own applications. This application was called video-tutorials and was guiding users through a series of short videos on how to configure different components needed to create their own applications (see Appendix A). However, the effort required in planning and designing such apps was still a hindering factor for user creating their own apps.

Another problem hindering users' ability to realize the full potential of the platform and its applications was the lack of data from all sensors installed. In Linate for example the delay in installation of some sensors could not provide the overall picture of DMA6 and the terminal area as expected. Therefore, the applications developed could not give the expected overview of the consumption in these areas. In Thermi, where the number of sensors installed per household was much smaller it was much easier to understand their usefulness. In NUIG the consistency and validity of data provided by sensors help in understanding easier the value of the applications and their usefulness.

In addition to the validity and availability of data a very important aspect noted during the feedback cycles from all pilots was the representation of data in applications. Details such the labels used, the colours and the structure of different elements used, the labels for the controls provided by the application were all very significant details for the users to understand and engage with the platform. This difference in presentations was accommodated to a point where the configurations of the Waternomics applications platform were allowed for a consistent representation among people belonging to the same user group and pilot. For example, domestic users liked the ability to see metaphors for their consumption where managerial and technical stuff at Linate and NUIG though it was unnecessary. Linate requested to customize the overall statistics to show two different costs for the amount of water where in NUIG, managers requested to see information about CO_2 emissions from the energy used to get the water from its sources. All these differences between user groups and pilot sites confirmed once more that the choice to include all of them under a common applications platform similar to existing applications ecosystems because it enabled the necessary customizations and personalization features to meet all different user requirements.

Although personalization was indeed appreciated by users, the general User Interface (UI) and the experience on the platform was a significant factor in improving their engagement. In particular, the initial design of the UI had some visual inconsistencies that were not hindering its functionality but were reducing the appeal factor of the platform in overall. During the pilot implementation, a redesign and restructuring of the most important components took place. As a result, most of the applications developed for users were updated accordingly. This redesign received a positive feedback from users in all pilot sites which was followed by an increase in interest.

Figure 12: Example of application design before UI redesign

Figure 12: Example of application design after UI redesign

However, this increase in interest and positive feedback were not enough to keep users engaged and returning often to the platform. A common comment coming from all different user groups in all pilot sites was that water management was just one of their obligations between many others. Therefore, keeping track of their consumption wasn't that important for them in order to check their consumption on a daily or even weekly basis. In order to tackle this low engagement problem, we interviewed users from all pilot sites and identified that regardless of their profile, all of them were checking their emails on a daily basis. Managers and technicians in Linate and NUIG were doing so as part of their job and domestic users were doing so as part of their everyday routines. Having identified a common path to their daily routines we designed and released an app that users could configure to get daily, weekly and monthly digest emails

with a very simple short text informing them of their consumption metering in selected meters or group of meters.

This application was initially intended to target social media and publish posts or tweets to personal timelines. However, a lot of the users were not daily users of social media and on the other hand filtering algorithms would possibly affect the outcome as they might hide some of the posts created by the platform applications. Therefore, the application was decided to change to an application sending those short reports through emails that was a common part of daily routines of all types of users. Another concern raised with the use of social media to publish and inform about water consumption was the privacy that such a process might violate. Although it was explained that such posts would remain private for the users only, many of them, especially in corporate environments, expressed their concern. Emails were thought to be more private than social media and similar concerns were not raised.

Finally, another important aspect appreciated by users in all pilot sites apart from the periodic digest emails were the applications that offered to users a kind of “peace of mind” service. In particular, the application titled “Goal setter” enabled users to set a number of rules to get personalized notifications. This allowed them to set up rules to get notifications for unexpected large amounts of consumption and gave them a peace of mind that whenever something was going wrong they can get notified by the system through email which was their most preferred communication channel. This, once again, demonstrates the fact that monitoring applications providing information about consumption to specific points are useful but not easy to integrate into daily routines of users. People did not find it easy to visit often the platform so such services allowed them to utilize the monitoring applications without having to visit them regularly.

3.2 Validation of the Waternomics Platform and final version

The pilot results show that the Waternomics Information Platform generates value for end-users in many different forms. All pilots show an increased awareness of water usage and an increased knowledge level about water availability and consumption by the involved participants. For the airport and the schools having a smart water system is a way to differentiate from competition and strengthen their brand image. Reduction of water consumption is not a main driver, possibly because of the low price of drinking water. Furthermore, each pilot has its own set of benefits and drivers for adopting a smart water system.

Table 2 - Perceived value of Waternomics Smart Water System

Perceived value by end-user	Linate	NUI Galway	CnaC	Thermi
Control over water network	X			X
Efficient maintenance scheduling	X	X		
Simulation	X			X
Decision support	X			
Fair billing	X			X
Increased awareness	X	X	X	X
Education about water management	X	X	X	X
Reputation	X	X	X	
Cost reduction	X			X
Reduction energy consumption	X			
Reduction water consumption	X			X

Discussions with external stakeholders also show a wide diversity of drivers for adopting smart water systems. The Dutch Ministry of Defence is interested in reducing the water and energy footprint of their field bases. Their main driver for reducing water consumption is to decrease

logistical movements since all drinking water is currently delivered through air or road transport, often in a hostile environment. Another important factor is that most conflict areas where the Dutch military operates, are located in dry regions, like Mali or Iraq, who already suffer from drought.

In a second case, we talked to Simaxx, a provider of smart building solutions, who collects all available data from an office building and uses this data to generate recommendations for building management. Key drivers are reducing operational costs while maintaining a good level of comfort for the inhabitants of the building. A pilot has been defined to investigate how the Waternomics platform complements with the Simaxx platform. Water sensors and adapter software will be linked to Simaxx platform and the Waternomics dashboard application and public display application will be ported onto the Simaxx platform. This way, smart water services will be integrated in a smart building service, offering building managers a single point of entry for managing the energy efficiency and comfort levels of their building.

Project deliverable D1.1 - "Usage Case and Exploitation Scenarios" identifies three target markets for the Waternomics Information System. In the next section the impact of the findings on perceived value on the business strategies, is discussed shortly for each of these markets.

1 Corporate users: With an increasing focus on sustainability and the environmental footprint of companies, businesses can benefit from smart water systems in multiple ways. To control and manage their water usage and network a smart water system can be obtained on a transaction basis or as a managed service. Using a company's real data for simulations and support for strategic investment decisions, smart water system can be offered as part of a long-term consultancy service, where sustainability experts help a company with increasing water and energy efficiency. Adoption rate for smart water services will be highest when bundled with other smart building services and especially with smart energy services.
2 *Municipalities and water utilities:* Water utilities benefit from a smart water system by reducing their operational costs due to a more efficient management of their water distribution network, and by reducing the number of disputes with clients because of more accurate billing. Also, real-time local metering data can be used for educational, awareness campaigns or promotional activities targeted at their customers. Metering and billing can be offered as a managed service to water utilities as already is done by a broad range of service providers. To reduce resistance against the installation of smart water meters amongst their end-users, utilities should consider providing free value added services for their customers, letting them share the benefits.
3 *Domestic users:* When targeting smart water systems directly to domestic users, three things need to be considered. Currently, the consumer market is flooded with smart devices, for example thermostats, electricity meters or smoke alarms. To have consumers adopt a smart water system, it should integrate with existing smart solutions which are already longer on the market. An interview with a representative from Toon, the provider of in-home energy displays, stated that adding support for water related information is on their 2017 product roadmap. Smart water products or services should be user-centred and fit in a smart home context. Next to that, implementing a smart water system in a house gives the house-owner the opportunity to regain ownership of its water consumption data. It doesn't make sense to have two smart water meters installed next to each other so it would be more efficient to provide water utilities access to the households' water metering data via the house-owners smart water system. This is an opportunity for private household data vault solution providers such as HelloData. Finally, the most valued features for households seem to be control over their water consumption and network, e.g. alerts upon leakages or open taps, and water saving tips and challenges. This would be offered best on a subscription basis, bundled with other related smart home services like energy services or security services.

In terms of potential concepts to be followed in providing such services to end-users, in all cases, is the idea of the applications marketplace where users can find applications best fitting

their needs is one that can have a significant impact. People are already familiar with the concept and providing an ecosystem of applications for bundled services including water, energy, security, etc. can lead to easier adoption of such solutions from end-users in all cases. Moreover, such an architecture allows device vendors to easily open their hardware to be used in combination with others by third party developers.

To this extensibility, factor solutions such as the app builder provided in the Waternomics platform can help in specific user cases. Most users would like to have ready to use applications so that they don't deal with configuring and setting them up. However, consultancy service providers to corporate users and water utilities personal will probably find the ability to design their own custom applications interesting and valuable.

Finally, another key point to be taken from the Waternomics experience is to provide services and applications that are able to link the information provided in the platform with existing daily routines. Either this is a display in the bathroom or an app that sends an email on a daily basis people need to have often and prominent triggers to remind them of the available information and actions they can take. This way the applications provided will gradually weave into daily routines of users and become even more useful.

4 Other WATERNOMICS Outcomes

4.1 Data Management and Analysis

One of the main outcomes of the Waternomics project is the Linked Water Dataspace. The dataspace has been realised as part of WP3 in terms of the design and implementation of an overall architecture from water sensors to end-user applications. The overall system architecture contains three main layers: the hardware, the data, and the software, as shown in Figure 13. WP3 results are centred on the data and software layers:

- **Linked Water Dataspace** [fully detailed in D3.1.1 and D3.1.2]: A dataspace is an emerging information management approach used to tackle heterogeneous data sources that support requirements such as standardization, enrichment, and linking of data in an incremental manner. The Linked Water Dataspace is a collection of water datasets along with a set of services that supports the dataspace. The dataspace is designed to be an incremental view of how water datasets join the computational space targeted by applications. In contrast to the classical one-time integration of datasets that causes a significant overhead, the Linked Water Dataspace adopts a pay-as-you-go paradigm. Water datasets join the space in an incremental manner: the more interfaces they expose, the more links they provide, and the more linked dataspace services they support, the more integrated into the dataspace they become.

- **Support Services and Applications** [fully detailed in D3.2 and D3.3 respectively]:
    - **Support Services:** Selecting, designing and implementing such support services, APIs and component libraries is an important step towards developing end-users' applications using data from the Waternomics information platform. In the Waternomics vision support services, APIs and component libraries are key elements needed for effective analytics to drive decision making: e.g., querying, entity management, and water usage analytics to raise user awareness of water consumption.
    - **Applications**: Applications are the actual points of interaction of users with the data kept in the Waternomics Information Platform. In total deliverable D3.3 presented 20 applications developed targeting 19 different user groups in the 4 pilot sites. In some cases, applications are described in families where more than one actual application instance is deployed to be tailored to individual user groups and their needs. Dashboard application is such an example where users create as many dashboard applications as they like to fit their needs. This means that the actual individual application instances deployed is much higher than 20 and quite dynamic as a number since the same application is deployed multiple times for different user groups or even for the same user based on his/her individual needs as it has been discussed in Section 0.

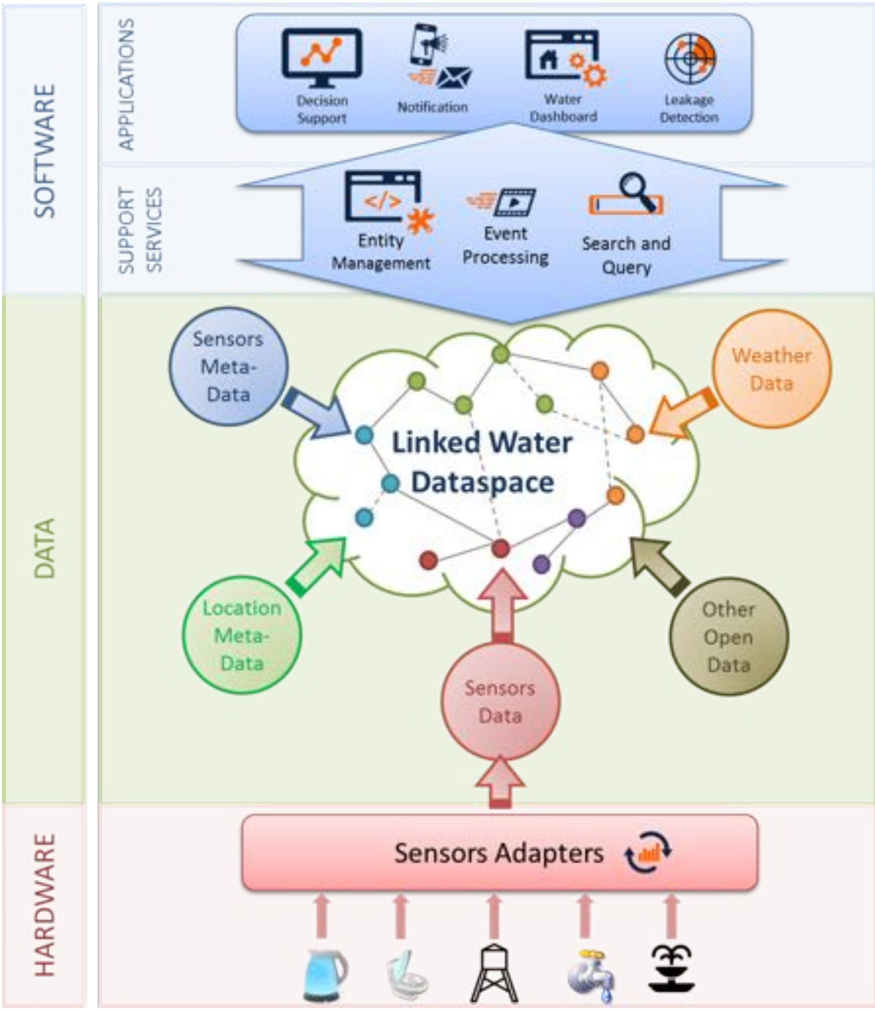

Figure 13: System Architecture [Available in Section 5 of D3.1.1]

An overview of the data collected for each Work Package, Task and Pilot is made in Appendix B The overview shows the reference name of the data set, the mandatory Metadata (if any), data set specific Metadata, and a dataset description. It furthermore sets out a reference to existing standards in the topic area governing its data collection, aggregation, storage and how the data will be shared. It also mentions archiving and preservation intentions. This in order to allow a handover or some continuity of the Waternomics insights and systems at the pilot sites when the project ends.

4.1.1 Overall lesson learnt (experience from the pilots)

4.1.1.1 Lessons Learnt from Real-time Data Management

The real-time data management takes place in the Waternomics project as a part of the Linked Water Dataspace. The Waternomics architecture adopts a Lambda paradigm that handles, in parallel, data-in-motion and data-at-rest. The data-in-motion part connects the data that comes from the sensors with the adapters and the processing Spark jobs at the core of the dataspace, where most of the aggregation takes place. A part of the realtime data management is the ingestion of aggregated streams from the Spark jobs into the Druid storage which plays the role of a serving layer through queries.

The following lessons can be compiled from dealing with the real-time data in Waternomics:

1. The Loosely Coupled Paradigm
    - It has been effective at the design and development phase to use a loosely coupled model that depends on a distribution middleware. Data is exchanged through topics or queues in the middleware, and applications and services play the roles of consumers and/or producers. That removes dependencies between parties and helps efficient development and maintenance.
2. The Lambda Architecture
    - It is important to account for two types of data: data-in-motion and data-at-rest. In Waternomics for example, different pilots have different types of data. Some of it can or must be processed in batch processes. Some has to be in real-time. The architecture shall support both batch and realtime and shall not try to force a realtime pipeline into a batch one, or the other way around. Both types can be integrated if possible at various stages, and be served in a transparent way to users through a homogeneous query mechanism.
3. Sensor Data
    - It proves effective and efficient that sensors play the role of clients which push data into an HTTP Restful API provided by the dataspace. The main advantage comes from the standardization through Web protocols. HTTP in its native form was sufficient for the pilots, but other protocols such MQTT and Web Sockets can be used for high rates.
    - Sensor programming and maintenance is a challenge. It is very important that sensor programmers handle exceptions and account for various types of possible faults. Auto-restart and memory management can also be used to improve reliability. Remote access and maintenance of sensors can be very critical especially in pilots where it is difficult to reach the sensors often as in residential settings. Plug-and-play sensors are the ideal goal for future projects where the cost to program and maintain the sensors is minimized.
4. Archiving
    - It is useful and maybe necessary to archive close-to-raw data. Although the end point of the Lambda architecture stores aggregated versions of the data, it was useful to store close-to-raw version, either to reconstruct data in the case of failure, or to allow new forms of analysis that was un-envisioned previously and which need granular data.
5. Time and Time Zones
    - It is important to handle timestamps and time zones carefully from early stages of the data pipeline. In Waternomics for instance, the four pilots exist in three European countries, which have up to three time zones. If a query is interested in an overall picture of the data, or if the user exists in a country different from where the data was originated, timestamps should fully support time zones. Wrong time zones can result in data being considered out-of-window for realtime processing and thus be lost.
6. Processing data-on-the fly vs. store-and-query cultures
    - The store-and-query culture is more common between developers and users. Nonetheless, with the proliferation of new sources of data, processing data on-the-fly and detecting only that of interest in realtime, without storage in many cases, can be challenging as a paradigm (aka. event processing) to understand by some developers or users. That can happen mostly in points of interoperability

where services by two different parties have to talk to each other. It can be useful to clarify the two different paradigms and have domain and technical discussions within a team or between teams to maximize the benefits of both paradigms.

4.1.1.2 Lessons Learnt from Historical Data Management

The management of historical data in the Waternomics project is also supported as a part of the Linked Water Dataspace. Similar to the data-in-motion part, the data-at-rest part processes the historical data that is collected from sensors with the adapters over time. The majority is data processing is performed through batch jobs. First step in batch jobs is downloading data from Web-based and local files. Second step involves rejection of incorrect data and aggregation of correct. Last step of batch processing is the ingestion of this aggregated data from the into the Druid storage through schedule jobs.

The following lessons can be compiled from dealing with the real-time data in Waternomics:

1. Batch layer of the Lambda Architecture
   - A key part of our implementation of the Lambda architecture is its batch layer, under the umbrella of historical data management. While realtime pipeline primarily focuses of immediate available of sensors data, the batch processes ensure that data accumulated over time is checked for data quality issues and re-indexed in the database. Therefore, it is important to align both aspects of the Lambda architecture in a seamless way. Our DRUID based implementation allowed us to achieve it successfully with very few difficulties.
2. Processing Sensor Data in Bulk
   - The batch process typically deals with large databases and files that need to be made available for querying. Therefore, the batch process needs to be deployed on servers that are capable of in-memory processing with large datasets. We experienced specific challenges when processing data collected over 1 year by Building Management System in the Galway pilot. In this case, the batch processes were carefully designed to minimize the possible of memory overflow.
   - To reduce the need large data transfer over network, the batch processes were implemented within a single server which also hosted the Historical node of DRUID. This approach allowed us to process and store multiple datasets locally.
3. Frequency of Batch Processing
   - As the sensor data accumulates over time it is necessary to also update the historical data accordingly. In this sense, the batch processes need to be scheduled for timely updates. A major challenge in this respect is the timing for batch processes which can depend on the sources sensors their associated real-time processes. We found out the scheduling the batch processes out of the office hours allowed us more bandwidth in terms of network and server capacity. However, there were some challenges in synchronizing the batch processes with when the data for sources was made available in-time due to network issues at the pilot sites. Programming appropriate exception handling and notifications was important in such cases.
4. Data Quality Issues
   - A major challenge in batch processing the data quality issues which include but are not limited to incorrect file formats, incorrect timestamps, unusual water usage values, multiple and conflicting values, and missing data. Specifically, in terms of the timestamps, the different time zones for pilot sites in different

countries posed a challenge, as well as the time changes due to the Daylight Savings Time.

4.1.1.3 Lessons Learnt from Catalog Service

A key support service for the Linked Water Dataspace was the catalog service. This service provided support for all processes that were concerned with data-in-motion and data-at-rest. The catalog services server a crucial role in providing information services over data that is part of the dataspace. Primarily it provided search, browse, and query services over descriptions of datasets and data sources.

The following lessons can be compiled from dealing with the real-time data in Waternomics:

1. Organization of data sources and datasets
   - At a basic level the catalog can list the entire datasets or data source that constitute the Linked Water Dataspace; however, so form of systematic organization can help in both browsing and queries. In the respect, we have organized the datasets according to the pilot sites in Waternomics dataspace. Further support for browsing includes tagging, dataset format, etc.
2. Queries over entities and metadata
   - Allows programmable access to the catalog services in very important since in facilitate applications over dataspace. A key lesson here is to enable queries over dataset descriptions as well as the entities contained in the datasets. Therefore, the catalog service served a canonical source for identifiers for entities in the Linked Water Dataspace and it provided metadata in machine readable formats.
3. Access control
   - Limiting access to dataset descriptions and entities to the authorized users only was also a critical aspect of the catalog services. In this regard, we used individual user accounts to manage access. This also enables site specific management of users and their datasets. As a further step, this access control in catalog also allowed us to manage queries over the DRUID by resolving access level of queries from the catalog services.
4. Change management
   - Keeping provenance of changes to datasets, entities, and their descriptions is also necessary. In our catalog services, each update to dataset metadata was recording accordingly to be viewed later on by users, thus allowing tracking of changes over time. This becomes especially useful as the catalog services starts to include and describe openly available datasets which are not in direct control on the dataspace managers.

4.1.2 Validation of the Data Management and final version

The Waternomics Data Management Platform (DMP) is designed specifically for collecting, storing and analysing water consumption related data. As such, the Waternomics DMP differs from existing water DMP's from which the majority is designed specifically for water utilities. Examples of such water DMP's are IBM's Intelligent Water software, Aquarius Time-Series products from Aquatic or Siemens Smart Water Platform who focus on topics such as non-revenue water, pressure optimization and pipe failure prediction and offer modules for supporting business processes like asset management, customer billing or customer support.

The unique selling points of Waternomics DMP are threefold:

1. The Waternomics data taxonomy provides clear definitions on the data sources, data categories and use cases specifically for the end-user domain. Adding new data sources requires minimal effort because standardised adapters for data sets are available and the data taxonomy supports al kind of water applications, domestic as well as industrial.
2. Waternomics DMP already supports multiple open data sets like the dataset from Waterfootprint.org, which is used to show users their water consumption in new and more engaging ways, EDO drought data which is used to alert users about drought periods in their region, and open calendar data sets which provide context information such as public holidays, weekends and school terms, which are required to, for example, analyse water usage in working vs. non-working days.
3. The Lambda architecture ensures scalability of the Waternomics DMP. The used technologies, such as Spark, Kafka and Druid are similar to the. technologies that companies such as Netflix, eBay, or Twitter are using for their (big) data analytics.

A DMP in itself doesn't generate value. Only when a DMP is linked to Key Performance Indicators and business objectives and the DMP creates insight in *why* something happens and actionable information is generated, its real value is unlocked. From the pilots and the interviews with external stakeholders, it can be concluded that Waternomics DMP generates the most value in domestic environments and in industrial environments, specifically at industries who consume large amounts of water in their operations. Waternomics DMP can be used for the delivery of smart water services by municipalities to their citizens. Because the DMP manages entities and data flows on-demand, a pay-as-you-go (PAYG) revenue model would fit perfectly in this domain.

For Waternomics DMP to work in office buildings the DMP should be able to work together seamlessly with existing building information systems.

4.2 Fault detection and diagnosis (FDD)

The fault detection and diagnosis (FDD) developments as part of the Waternomics Project are well described in Project Deliverables D4.2 – Waternomics Analysis (leak detection, FDD rules, and drought monitoring analysis applications) and D4.3 - Waternomics Monitoring Technical Report: Documentation of WP4 technical work.

FDD is a measurement science that brings automation to the process of

- detecting faults in physical systems
- diagnosing their causes

D4.2 outlines the development of model-based FDD for use at the Linate Pilot Site and rule-based FDD system at the NUIG Pilot Site and D4.3 present further details of the testing, monitoring and analysis of the FDD applications at the Pilots sites. The following subsection describe the lessons learnt from the pilot sites and the refinement of the FDD methods.

4.2.1 Rule based FDD

An FDD methodology to monitor the residence time of potable water within the water network of the NUIG Pilot Site was developed as part of the Waternomics Project. The issue of extended water residence time negatively effecting the quality of potable water at the NUIG Pilot Site was identified in the course of stakeholder interviews documented in Project Deliverable D1.3 System Architecture and KPIs. The generalised FDD methodology to automate the identification

of issues with residence time on potable water was first presented in D4.2 as an idealised decision tree and later in D4.3 as rule-based FDD for each of 5 sub-systems in the NUIG Pilot Site potable water network. In M32, the developed rule-based FDD was released as a Waternomics platform Building Managers Dashboard Application (i.e. Retention Time Observer Application) providing alerts of issues and recommending remedial action.

4.2.1.1 Overall lesson learnt (experience from the pilots)

Since its release in M32, a total of 141 potential faults have been detected by the Retention Time Observer Application.

Figure 14: Retention Time Observer Application Statistics M36

A dedicated training session regarding the rule-based FDD and the associated application developed for the NUIG pilot site was held by the NUIG Waternomics Team in M33. The application was previously introduced to the NUIG Building Management team as part of a Building Manager Dashboard Training Session in M32.

Figure 15: Waternomics Rule-based FDD Application Training Underway at NUIG

The training session generated a significant discussion regarding potential to further refine the parameters adopted for the rules and it was agreed that a physical water network model will be constructed at the NUIG Pilot Site to study the degradation of water quality over time and allow the refinement of the rules. This work will be progressed after completion of the Waternomics Project in support of an automation of remedial measures required to address identified faults.

The feedback from the NUIG Pilot Site Building Manager regarding the FDD Methodology and its application was very positive and the receipt of email notifications of detected faults and recommended remedial action was found to be very useful.

As described in D4.3, it was found that the frequency of fault alert notifications must be carefully considered i.e. the rule-based FDD System for the Potable Water Retention Time Observer is designed to alert Building Managers of a fault when simple remedial action is possible i.e. before a situation becomes critical. Overwhelming recipients with notifications of potential faults was found to be counterproductive leading to a potential disregarding of fault alert messages. The Building Manager at the Engineering Building agreed that a single fault alert notification in the morning period is the most suitable approach.

Despite the positive feedback regarding the Rule-based FDD system and the acknowledgement that the system fully satisfies the KPI identified in D1.3, the email fault alert notifications fail to translate into Manager Dashboard Logins and interaction with the managers' dashboard platform applications (combined total for two pilot sites in Galway) recording a total of 47 logins from Galway as registered by Google analytics for the period 01 September 2016 (M32) to 01 January 2017 (M36).

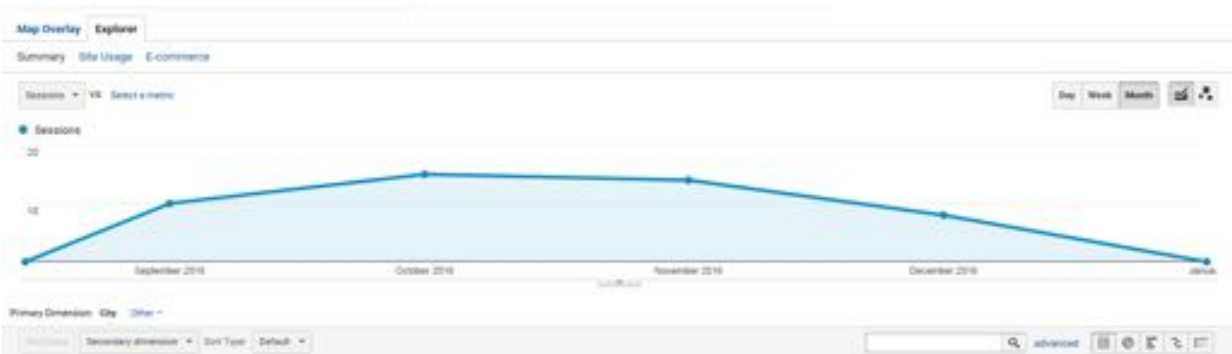

Figure 16: Managers Dashboard Application Logins Galway Pilots M32 – M36

It is likely that the email fault notification message with remedial action instructions that is generated by the applied rule based FDD system is sufficient for Building Management professionals to complete necessary tasks without further investigation.

Figure 17: Example of Email Fault Notification from Rule-based FDD Application

4.2.1.2 Validation of the RULE BASED FDD and final version

The rule-based FDD alert history is stored on the analytics platform and is available through the dashboard application.

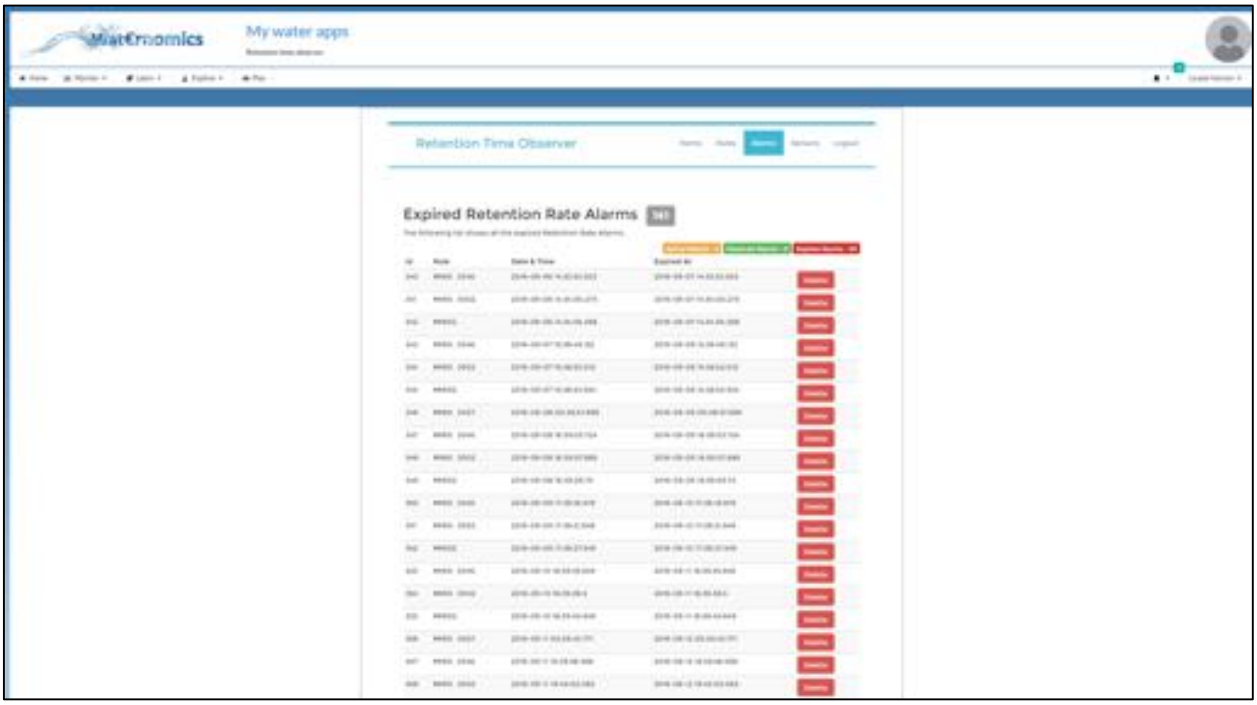

Figure 18: Example of Rule-based FDD Application Alarm History

Rule based FDD is more suitable for buildings with less complex water networks, like single houses or office buildings, because of the growing complexity of the rule set when the number of variables increases. Another reason for rule based FDD to be more suitable for less complex water distribution networks is because rule sets cannot be re-used for other buildings and need to be designed again for each new instance.

It is technically possible to automate actions upon notifications from the FDD but it raises some legal issues. If third parties can interfere with a supplier's system, the supplier may not be willing to fix problems under their warranty. It is expected that legal issues will be resolved in the near future and smart building systems will directly interfere with the systems in a building by changing set-points, opening/closing valves etc.

4.2.2 Model based FDD – refinement and outcomes

The model based FDD method developed within the Waternomics project is detailed in the deliverable D4.2 and the test results are fully detailed in the D4.3. The method is based on the analysis of both pressure and flow variations produced by leakage in the Water Distribution System (WDS). For this reason, this technique differs from the others that we can find in the literature because it is not based on the transient analysis of the pressure waves but on the comparison of real pressure and flow data with their estimation using the simulation of the mathematical network model.

The methodology proposed is derived from the energy sector and it is composed of 5 phases described in Figure 19 below.

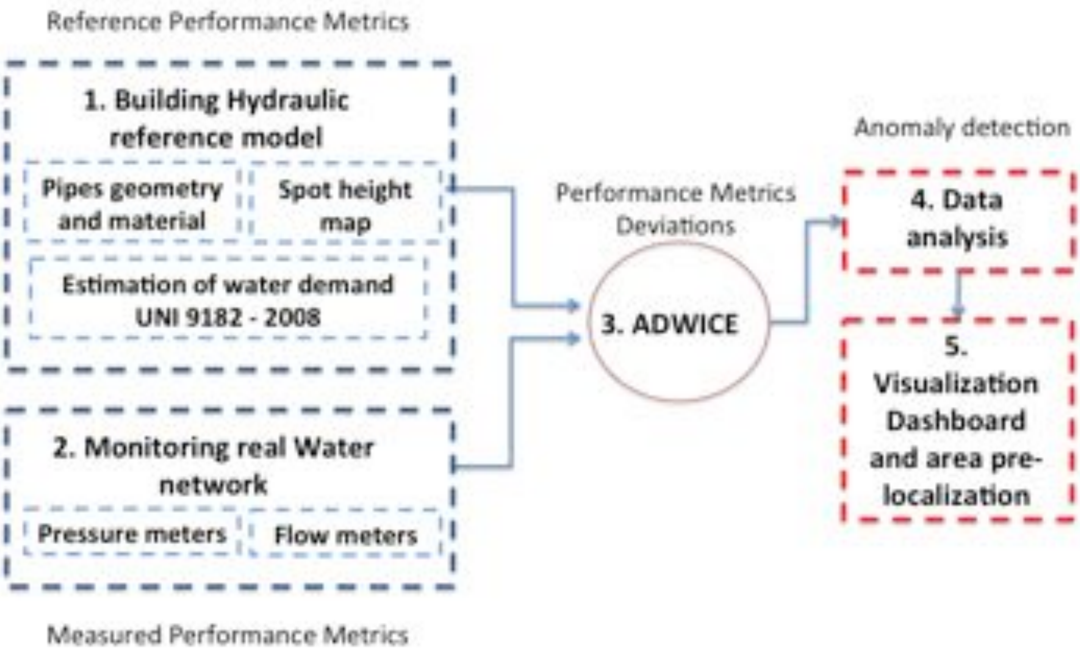

Figure 19: Waternomics Model Based FDD Methodology

The automated FDD is suitable for large water networks and the Linate pilot water network match this characteristic due the fact that the WDS has an extension of about 10 Km.
The FDD method coupled with the Decision Support System (DSS) developed with the cooperation of another European project (IceWater) and fully detailed in D4.2, D4.3 and D5.2, is intended to give the opportunity to the decision makers to simulate different operational scenarios with their water network without having technical knowledge about water and hydraulic simulation model and check how the water network is working. A guideline of the DSS tool is available in the Appendix C.

Figure 20: DSS component developed in the Explore section of the Platform

The following sections are intended to show the refinement of the model based FDD method and the real test performed in the Linate airport water network.

4.2.2.1 Overall lessons learnt (experience from the pilots)

As described in the D4.2, whichever water network we consider, “the leakages exist; and they have to be localized and measured” (B. Brunone et al. - 2008).
This problem is more enforced when we have to face cases in which large water networks are implied and where, due the many variables coming into play, it could be very difficult to detect anomalies or fault in the system with rule-based or approaches that require deeper knowledge of the system dynamics.

For this reason, the Linate water network is found to be highly suitable for the application of the model-based FDD method rather than the water networks of the other three Waternomics pilot sites.

The Model-Based FDD method also needs a considerable amount of data gathered from the meters to perform the training phase of the ADWICE algorithm to work effectively at detection time. For this reason, at the delivery time of the deliverables D4.2 and D4.3 (M30 and M32), due to the fact that the installation phase in Linate pilot was still going on, the historical data which are used to train the anomaly detection algorithm have not been obtained by the measuring instruments but from a mathematical simulation of the loss in the water network through an EPANET model of the water network itself.

However, the results obtained really convinced the Linate Mangers and the operational staff. The FDD application was integrated in the Waternomics Applications Platform and received a very positive feedback. The ability to know the operational phase of the water network in real time by changing the inputs in the Epanet hydraulic model (size of the pipes, roughness, water demand patterns, etc.) thanks the Decisional Support System (DSS) and the ability to perform the fault detection also by receiving email notifications of detected faults was found to be very useful.

Positive feedbacks was also received from external stakeholders (Water Utilities) that have joined the Waternomics workshop held in Thermi in October 2015.

Basically, starting from the early test results of the FDD method, the need for an efficient Water Management System (WMS) is strongly felt both the internal Waternomics partner (SEA) and external stakeholders as they see the possibility to implement the fault detection in the water

network at an early stage as an essential ability to manage the water resource in a sustainable way by avoiding both the waste of the natural resource and the waste of money.

4.2.2.2 Validation of the Model-Based FDD and final version

In earlier deliverables (D4.2 and D4.3) we have described how we simulated link flow and node pressure to generate data used both for training and testing (i.e. discovering anomalies). The next step is to use real sensor data stored in the Waternomics dataspace and process them to feed the anomaly detection algorithm for fault detection.

The model-based FDD algorithm has been implemented and deployed in the server hosting the DSS. The input to the anomaly detection algorithm is fetched from the Waternomics dataspace through a Python script that aggregates sensor data on a daily basis, fuses them is a feature vector and calls ADWICE to perform anomaly detection on that vector. The output of the algorithm, which is essentially a bit which assumes the value 1 if an anomalous condition is detected and 0 otherwise, is sent for display in the Waternomics platform or sent by email (Figure 21).

Figure 21: Implementation of the ADWICE in the Linate setting

The sensor data gathered in the Waternomics dataspace is, however, pretty limited to perform a complete and comprehensive training and test cycle. The first flow sensors have been installed in the Linate network as early as September 2016, with the following ones being added incrementally. The pressure sensors have been installed starting from October 2016. In both cases, a calibration procedure had to be performed to provide accurate data. In total, about two months of complete data were acquired at the time of writing of this deliverable.

Since a long period is required to gather enough data to capture the typical behaviour of the system and create a normality model of a system that is likely going to show seasonal variations. For this reason, the first step was to evaluate the results of applying anomaly detection on real sensor data using the model built with simulated data. The results have shown that a divergence is present when evaluating it with the available data (e.g. a lot of anomalies are raised) indicating that either the Epanet model of the network needs to be revised to reflect the real operating conditions of the water network and the algorithm needs to be fine-tuned on its internal settings (tolerance gap, number and order of the features etc..) to better calibrate its accuracy. In order to do so, however, a larger amount of real data is required.

We have also discovered that the real sensor data fetched from the dataspace was not always reliable (some values were out of scale). To deal with this the data pre-processor has also been programmed to replace the wrong or missing values with appropriate values. These can be zero values or averages on recent historical readings.

With the methodology, we proposed, by having few months of real data, one can refine the overall FDD method by training on simulated data and testing on real data; by reiterating the revision of the model, training and detection phase until little-to-no outliners are detected one can be ready to deploy the model based FDD to give outcomes on real data from then on.

In the longer term, when at least one year of data is collected, one can abandon the simulated model, retrain the FDD and use the real sensor data to perform both training and validation.

For model-based FDD, a model of the building's water distribution network and water applications needs to be generated before the system can analyse actual performance versus measured performance. Developing the model is a major task and the quality of the model defines the efficiency and accuracy of the FDD. Advantage is that with model-based FDD the analytical software can be re-used, only the models need to be created for each new building. This makes replication of the FDD algorithms for other buildings easier and more cost effective. Model-based FDD is suitable because of its ability to handle large numbers of variables efficiently, more suitable for environments with complex water distribution networks like industries, airports or hospitals.

4.3 Leakage detection, refinement and outcomes

Since the last reporting in D4.3, the following activities have been carried out in order to refine the acoustic leakage method developed within the Waternomics project:

1. Improvement of the information flow sensor – server – analysis
2. Collection of data in household A during 6 months
3. Replication of system in household B for two months
4. Analysis of new results

The leakage method developed is a novelty in the water leakage detection sector. Due the early experimental stage, it was decided to test it first in household environments in Delft, rather than from the Thermi pilot site of the Waternomics project.

4.3.1 Information flow & lesson learned from pilots

In previous reports (D4.2 and D4.3) the information flow of the leakage detection method, including sound recordings, FTP server storage, and analyses were presented. It was demonstrated that the method performed satisfactorily for the lab setup and that it was ready for the household experimentation. The first experiments in the household A, however, revealed that the use of an FTP server to store the recordings was adding an extra complexity to the data management, in particular because such FTP server was localised in the lab. This situation implied different shortcuts in the data collection.

In order to improve the situation, it was decided to skip the data transfer to the FTP server, and, instead, to access directly the information of the Raspberry Pi platform and transfer the data to the local PC where the fingerprinting software was installed. To this end, a procedure in Python was developed, which grabs the information from the Raspberry Pi platform, synchronise it with a local PC folder and then runs the algorithms of the audio fingerprinting. The option to send the data to the Waternomics platform was unaffected. A diagram that depicts the new information flow is summarised below in Figure 22.

Figure 22: Information flow; from the installed Raspberry Pi to the Weaved platform, where after the data is sent to the Waternomics platform

The code works as expected. However, some improvements can still be made, including a routine to alert that either the sensor or the server is offline and to handle an exception error that occurs when the file size is too small (see details below).

The new system was tested in two households, namely A (previously reported), and B, a new site.

4.3.1.1 First pilot test: Collection of data in household A for 6 months

The same household for which the analysis was carried out, reported in D4.3, was used for several months. This household in Delft is a 3-floor, family house where two children and two adults live. The house has two toilets, one kitchen tap, one bathtub, one shower, two faucets, one washing machine and one dishwasher. At the moment of edition of this document, a total of 2583 wav files were produced. As in the previous stage, the length of the files were fixed to 30 sec, giving a file size of 5.76 MB each. The frequency of the recordings started from every 30 minutes, and it was varied according to the house occupancy and availability for experiments. Figure 23 shows the number of collected files in this period.

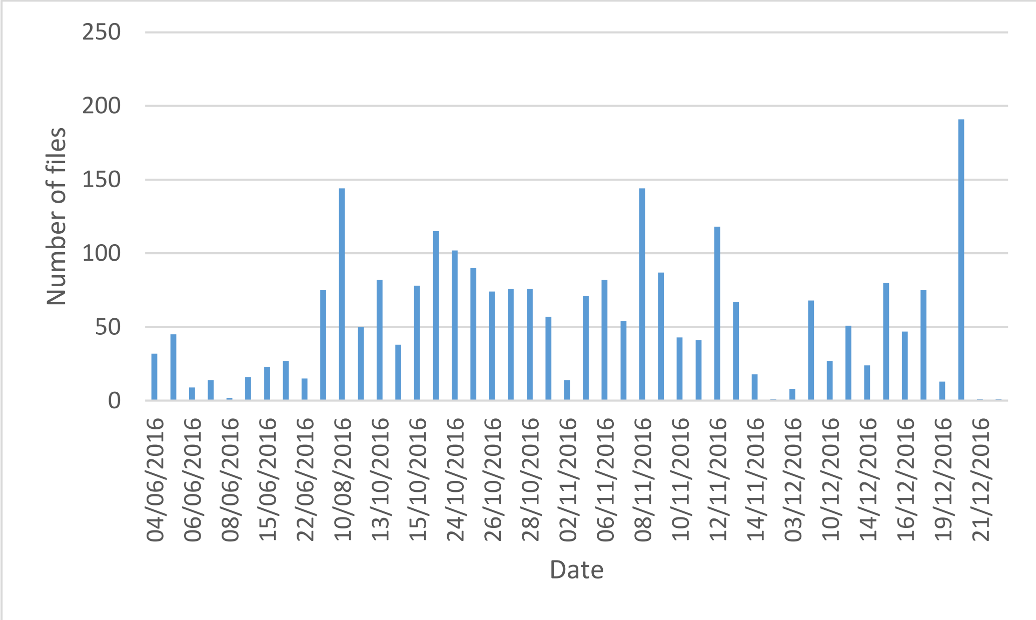

Figure 23: Number of collected files in the period between June and December 2016

4.3.1.2 Second pilot test: Replication of system in household B

In order to test the functioning of the whole system in other working conditions, a new household (B) in The Hague was selected. It corresponds to an apartment where two persons live. The apartment contains a kitchen with water tap and dishwasher, one bathroom with tap, bathtub and shower, and a room that includes a tap, a washing machine and a toilet. Next to this, the automatic heating device uses water to heat the house.

4.3.2 Validation of the leakage detection method and analysis of new results

At the moment of edition of this document, a total of 3255 wav files were produced in a period of two months. As in household A, the length of the files was 5.76MB each. On the contrary to household A, where different data collection frequencies were used, in household B this frequency was set as 5 minutes.

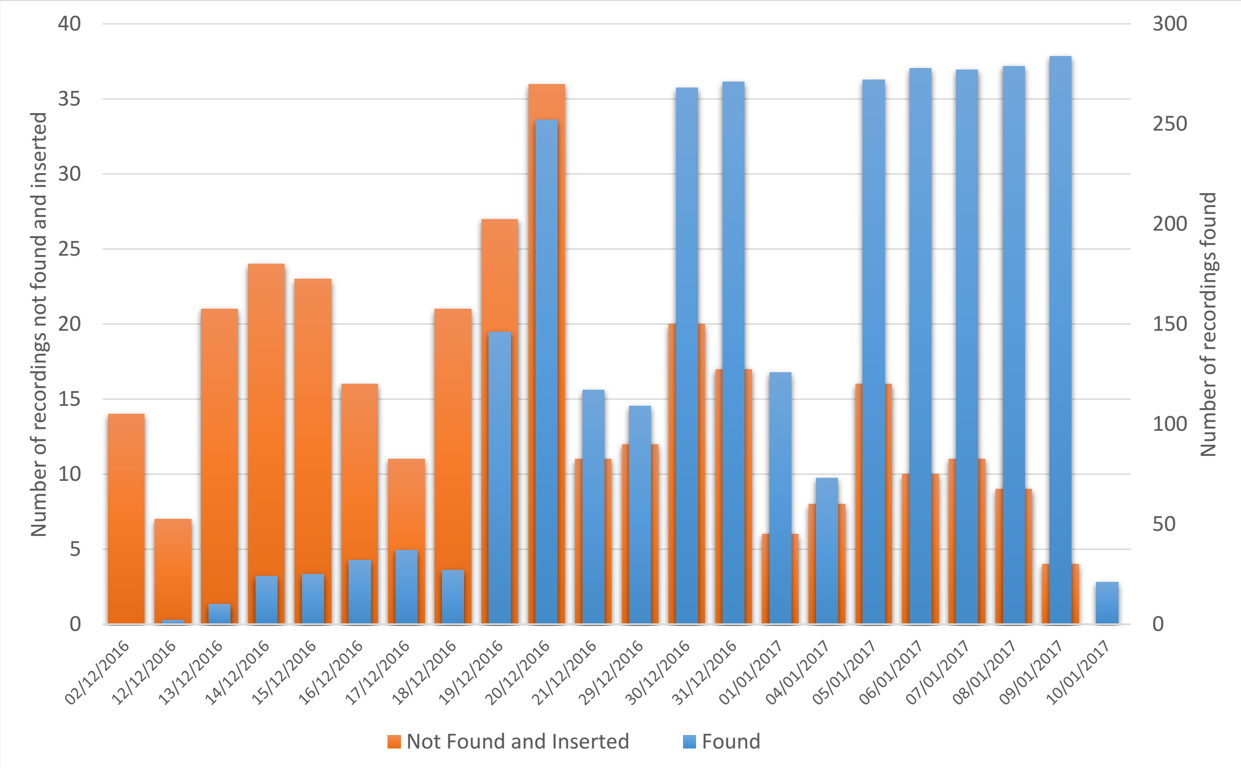

Figure 24 Results of fingerprinting method ran in feed mode for household B

As in the case of household A, the first part of the recording period was used by the fingerprinting algorithm to populate its database (feed mode, Figure 24). This is, the majority of files in the first week were not found and inserted. In addition, towards the end of the period, the majority of files were found in the database. Approximately 30% of the files recorded in the first half of the period were not found and inserted, whereas this percentage dropped to 5% for the second half of the period. These results are in agreement to those obtained in household A. This shows that, although it was not possible to test with real leaks in either house, after a period of training time, the sound fingerprint detection of unusual patterns occurring in the water network, including leaks, is possible.

4.3.2.1 Additional experiments

During the analysis of all previous experiments, interesting facts were observed, such as the potential of the fingerprinting method as a possible way to monitor domestic water uses. This new use could have interesting applications such as characterising water consumption by appliance, profiling water use and estimating accurate water demand patterns for improved network designs. In order to explore this potential, which is in addition to the scope of the originally planned method, a new experiment was conducted. The objective of the experiment was to corroborate that the fingerprinting software operating in detection mode can detect the recordings taken manually at home for possible combinations of water demand at different points. The method used was the following:

1. With a clean database, run ALD software in feed mode using the files taken manually (with informative filenames).

2. Run the ALD software in detection mode for the files recorded by the sensor.

The hypothesis to test is that a file containing a signal of a water demand point will be identified, by labelling its title with the corresponding informative filename.

The files taken manually in the original household used different combinations of the water demand points shown in Table 3.

Table 3 - Water demand points used for the manual files

	Num	Water point
Ground floor	1	Toilet0
	2	Faucet0
	3	FaucetK
	4	Dishmachine
	5	GardenHose
First floor	6	Shower
	7	Faucet1
	8	Bathtub
	9	Toilet1
	10	Faucet_small
Second floor	11	Wash_machine

The (self-explanatory) filenames are demonstrated in Table 4 below.

Table 4 - Self-explanatory filenames of the different combinations of water demand points

BathShower_03-10-2016_20-33.wav
Bathtub.wav
Bathtube_03-10-2016_20-28.wav
BathtubeShowerGarden_03-10-2016_20-32.wav
BathtubeShowerToilet_03-10-2016_20-35.wav
BathtubeShowerTwoFaucets_03-10-2016_20-30.wav
BathtubeShowerTwoFaucetsGarden_03-10-2016_20-31.wav
DishMachine.wav
Faucet0.wav
Faucet1.wav
FaucetK.wav
HalfBathtubeHalfBathtubeShower_03-10-2016_23-32.wav
HalfBathtubeHalfKitchen_03-10-2016_23-21.wav
kitchen_03-10-2016_20-41.wav
Shower.wav
ShowerHighestTap.wav
ShowerToilet_03-10-2016_20-36.wav
Toilet0.wav
Toilet1.wav
WashingMachine.wav

A first experimental stage with 1848 files was made, in which the fingerprinting software was run in detection mode and adding an additional "silence" file, corresponding to the file Silence_12-11-2016_04-00.wav. The following table was obtained.

Table 5 - Obtained result of detecting the silence files

Status	Found
Row Labels	**Count of FileName**
ihe01_2016-11-12_04-00.wav	950
kitchen_03-10-2016_20-41	2
Grand Total	**952**

As it can be seen, the kitchen tap was identified two times, whereas the silence file was recognised 950 times. Although more appliances were expected to be detected, the fact that the noise file was identified so many times is a good indication, because, as stated above, an important number of files were recorded during the night.

The same experiment was repeated, now in feed mode. Interestingly, more files from Table 4 were identified, in the proportion shown in the graph below.

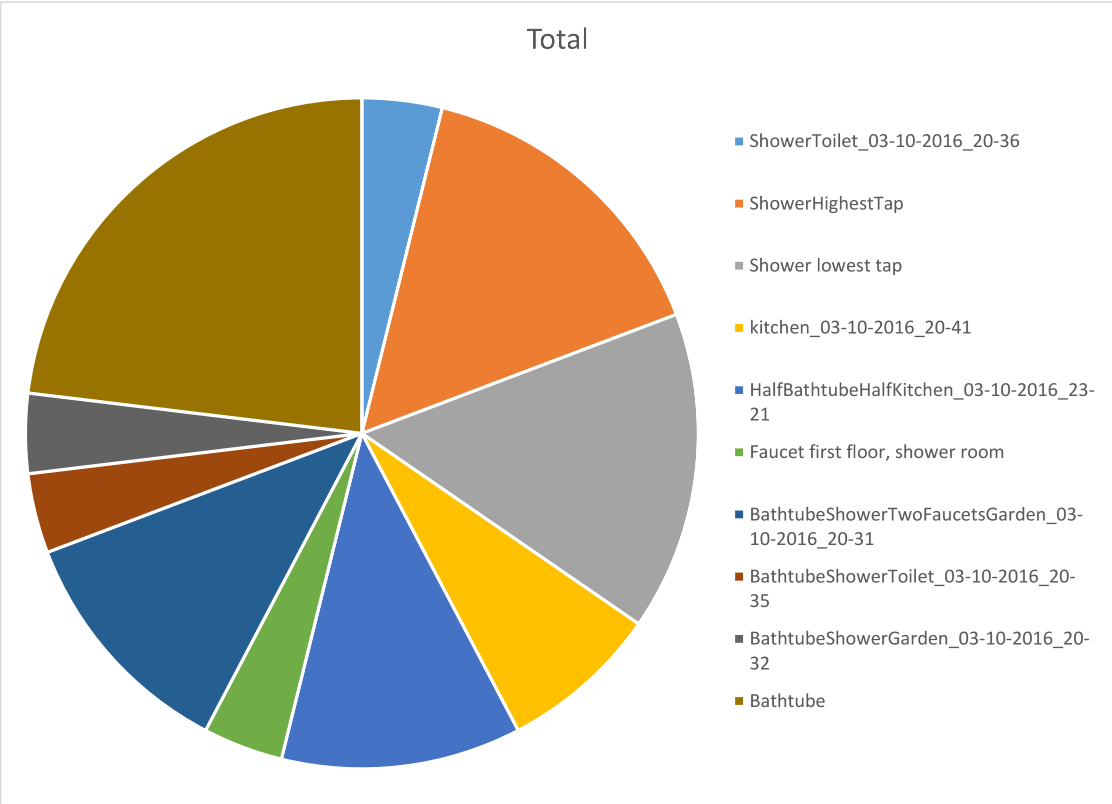

Figure 25 Identified files during feed mode

It must be noted that a file called ihe01_2016-10-13_11-40.wav was identified 1040 times, while it did not correspond to the silence file. A possible explanation is that in the month of October a new gas meter was installed, which could have created interference in the collection of signals. The moment a wav file with this new signal was added to the database, without any informative name, the fingerprinting software started identifying many signals like these. It is worth noting also that in the month of November the heater started functioning, adding additional noise to the signals. Unfortunately, no proper logs for the exact dates of functioning are available.

The same experiment was made but now changing the threshold for building the fingerprinting tables in the databases (please refer to D4.2). In the previous experiments this threshold was set to 4. Recall that if the fingerprinting software finds *Threshold* number of matches in each table, then file is eligible to be selected. If there are many, then it reports them all, sorted by the threshold values. If Threshold=25 it means exact match (the same file, basically). 2: almost all is recognised as match; 3: about 60% similarity. 5: almost as strict as the exact match. As 4 seemed to be OK after several experiments, it was fixed so far as a result of the laboratory tests for leak detection. However, the sensitivity of this threshold is important to analyse. The results for th=3 is shown in the figure below. Note that it only accounts for 13 files. The rest of the files appeared to be as background noise as in the previous exercise. The same exercise was repeated for th=2 and more than 80% of the files were recognised already as a match in the initial training period of two days, which implies that a large amount of detections would actually be false alarms.

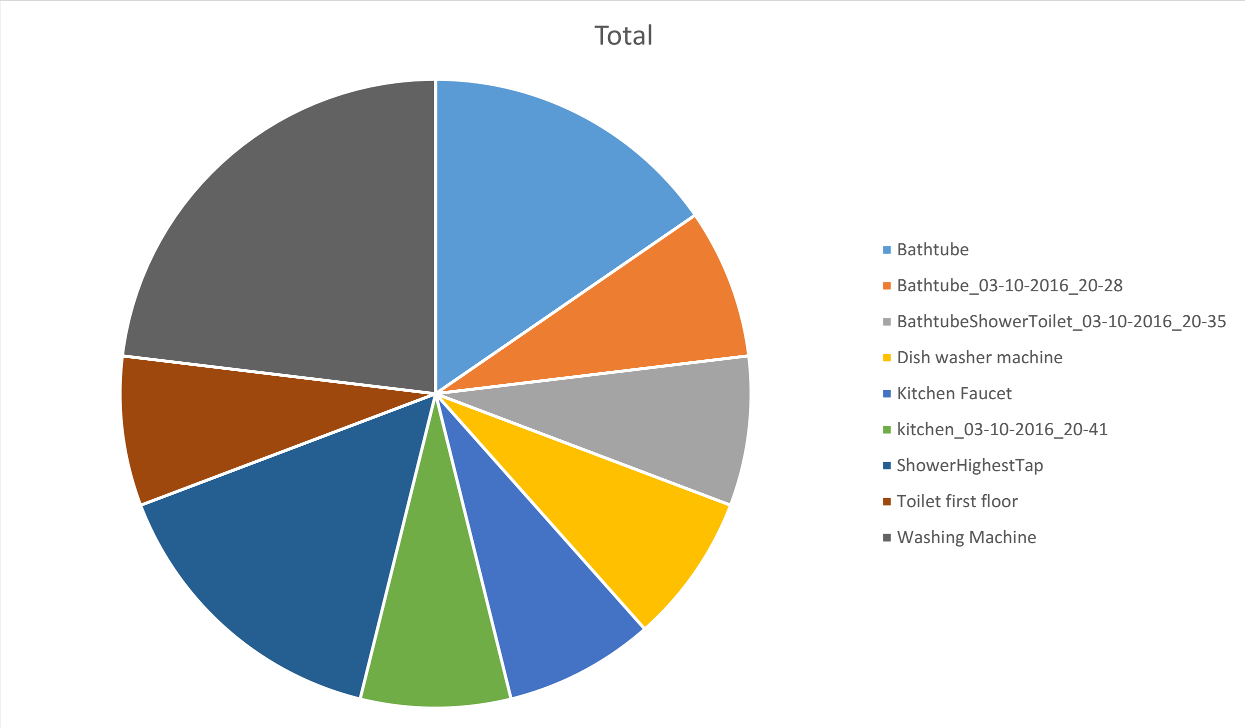

Figure 26 Identified files during feed mode, when using threshold number 3, for a total of 1713 files

Another parameter to consider is the length of the file to be analysed. In the previous experiments, this was set to 15 seconds. The procedure consisted on feeding an empty fingerprinting database using the files in Table 4, then running the software in detection mode with a particular amount of seconds to be analysed for each of the 1713 files collected for this analysis and store the detection results. The exercise was repeated for analysed file lengths of 5, 10, 15, 20 and 25 seconds. The result showed that the amount of recognised files is not higher than the 15% of the total, and that this performance is similar for different lengths of analysis.

As a general conclusion, automatic acoustic leak detection method for households has been developed with both hardware (sensor) and software (fingerprinting). Results in the lab and in test houses show promising results, as the capacity to detect unusual behaviour in water pipes sounds is proven, provided enough period of training. In addition, an unforeseen potential use of the technology is the detection of water uses, which could have implications for demand profiling, better estimates of demand and improved design of piped networks.

The work initiated in this project is to be continued with extended R&D in cooperation with SME partner VTEC. The performance of the method in buildings different from households will be analysed, such as in the NUIG engineering building.

4.4 Flow meters

In Waternomics two types of flow meters have been installed in the pilots from partners within the consortium. The first is the mini water meter and the second is an ultrasonic flow meter. For both types a short introduction will be given.

Mini water meters

A typical domestic Waternomics Platform for domestic application consists of several mini water meters which are connected to a data acquisition device (BBB) for data collection and transmitting to the cloud. Figure 27 shows the schematic of a typical domestic Waternomics Platform. A mini water meter is easily coupled to the household water network to measure the water usage of the cold water, boiler and dish washer. Then, it is connected to a BBB. To realize wireless transmission, WiFi or LAN technology is utilized.

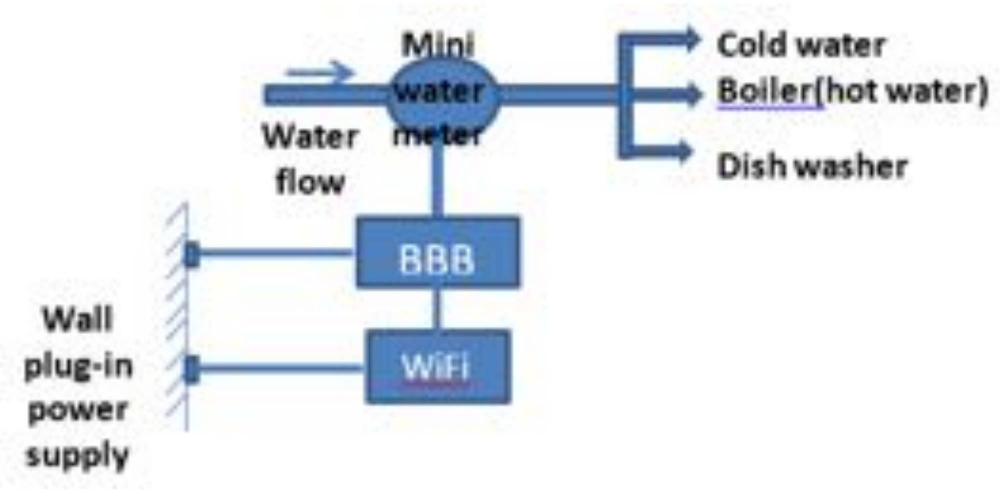

Figure 27. Typical setup for a domestic water flow measurement system

There will be multiple sensors connected to one transmitter box for a household. For example, there could be several sensors installed in the kitchen for measuring the water use from dish washer, cold water and hot water. Then multiple sensors can be connected to one sensor box and then transmit data to one transmitter box.

Ultrasonic flow meters

The ultrasonic flowmeters supplied by VTEC offer a minimally invasive metering solution for mid-range pipe sizes with installation costs significantly lower than those associated with retrofitting inline solutions to existing pipes. In addition, the ultrasonic flowmeter does not result in any down time for the existing water system during installation. The wall-mounted design and easy to read digital display of the meter facilitates its installation in the publicly accessible areas of NUIG pilot site and was considered to be consistent with the its ethos of the building as a teaching tool. Data transfer can be facilitated by Ethernet point to point connection with data transfer and short term storage provided at each meter by a BeagleBone Black Board.

Table 6 shows the suitable technology selection for the NUIG (Engineering building) pilot.

Table 6 - Ultra sonic flowmeter

Typology	Photo	Main characteristics
Ultrasonic flowmeter		It is cost effectiveness and easy installation. The pair of transducers is clamp-on type so it is unnecessary to make any penetration on the pipe. And the main controller is well-designed for data collection and for further transmission. It is recommended to use for measuring the main supply

		water.
Data acquisition device and wireless data transmission *(BeagleBone Black Board)*		The data acquisition platform is to use BeagleBone Black (BBB), a very smart and cost-effective single-board computer.

The picture below shows the proposed transfer of data from the pilot sites NUIG and Coláiste na Coiribe to the Waternomics platform (*Figure 28*). The ultrasonic meters at NUIG have a wired connected via BeagleBone Black process (also wired) to the NUIG data communication system. The electromagnetic meters at Coláiste na Coiribe also have a wired connection to the proposed Building Management System at the School.

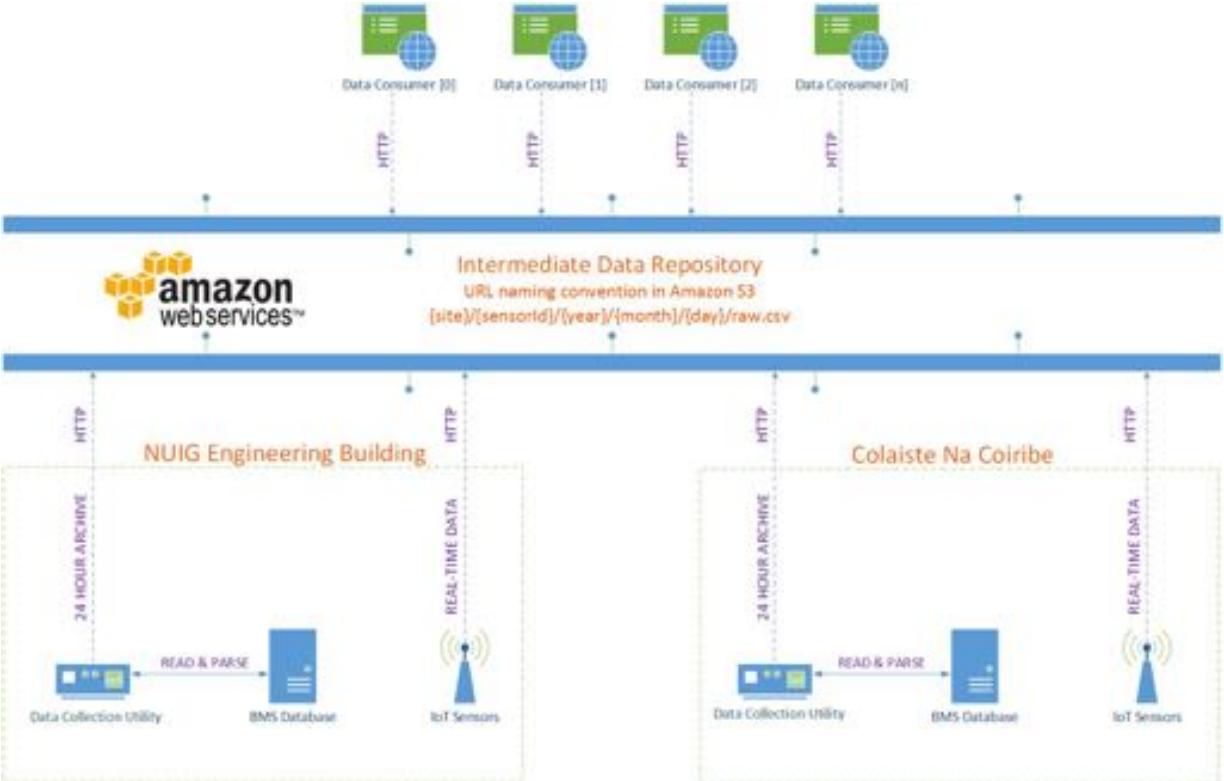

Figure 28. Wireless Sensor box to Transmitter box via LAN

4.4.1 Overall lessons learnt (experience from the pilots)

The Waternomics pilots have been extremely useful to get experience for the development, the installation/maintenance as well as the regulatory aspects.

In the project the sensors system has been developed for scratch. This means that the initial phase test has been done for the functional aspects of the devices in a controlled environment. After transfer of the sensor systems to the pilots sites a lot of practical problems have come up and have been addressed as good as possible.

<u>Thermi pilot</u>

The Thermi pilot is a domestic pilot with the sensor systems installed in homes. Problems that have been encountered are related to visual aspects of the products, the Internet infrastructure,

the components of the systems, time differences, updating of the software, controlled remote operation of the devices. Due to the very good cooperation of the participants and a close cooperation between VTEC, NUIG and Ultra4 and no regulatory issues the problems could be solved in a practical way. In the following table an overview of problems is given

Issue Ref.	Date	Unit Reference			Brief Description of Issue
		House	BBB	Sensor	
1	5-2-2016	H01	both	all	The software of the BBBs in the first test house needed to be updated to send data to dataspace
2	17-2-2016	H01, H22	both	all	BBBs sending data to dataspace without timestamp
3	29-2-2016	5 houses	all	all	Stability issues. Sensors stop sending data after some time
4	3-3-2016	some houses	some	all	Some BBBs even in the same house exhibit different behaviour. One sending and the other not sending data
5	24-3-2016	H20, H02, H22 and others	all	all	Complaints from owners that internet speed is significantly reduced when connecting the BBBs
6	24-3-2016	All	all	all	Change in data sending frequency led to requiring change in the data to be sent. Flow should be changed now to volume.
7	8-4-2016	All	all	all	Large number in consumption registered from sensors that started sending data
8	17-2-2016	All	all	all	Need for remote update mechanism identified
9	18-4-2016	All	all	all	Stability issues. Sensors stop sending data after some time
10	12-5-2016	All	all	all	Double measurements registered for sensors connected in the third place of the transmitter box
11	12-5-2016	All	all	all	Bad wiring. Sensors connected to the first place were sending data as if connected to the third place for the transmitter box
12	1-6-2016	All	all	all	Memory leak identified in U4 offices BBBs local logger script
13	30-5-2016	H04 and H07	all	all	BBBs seem to shut down shortly after plugging them in

NUIG Engineering Building

Similar problems are encountered in this pilot with the completeness of the testing during the development but the problems that appeared during the installation have been different. In this case the solving of the problems has to be addressed in cooperation with the maintenance team of NUIG, again problems have been addressed and mostly solved in close cooperation between VTEC and NUIG. An overview of the problems encountered is given in the following table:

Issue Ref.	Date	Unit Reference			Brief Description of Issue
		Sensor	Controller	Unit Type	
1	12-10-2015	USF_08		Grey Water West CWS top up (CWS7_US)	Not working repositioned transducers numerous times removed insulation fully around pipe
2	18-12-2015	USF_10		Complete CWS (Cold Water Service) (MR.WM.002_CW_US)	no data on the cloud since 18/12/15. Saujan working on meter for Kafka, said data may be lost (22/12/15)

3	6-1-2016	USF_04		Male Showers/Sinks (CWS) (ENG-G004) (CWS3_US)	Issue with dates fixed with NTP server. Past data labelled with wrong dates, a number of different days labelled with the same dates. Cut off value for velocity set to 0.03m/s had been 0. Recording ok now
4	11-12-2015	USF_05		Zinc (CWS) (CWS4_US)	Flow recorded through the night. Could not zero the meter on 21/12/15 because of bad signal on meter. Signal seems to worsen since 11/12/15 but variable. Since 29/12/15 no data on cloud
5	12/3/0205	USF_06		Lab (CWS) (ENG-G034) (CWS5_US)	Restarted on 3/12/15 as no data recorded previously. Flashes negatively values on display. Data recording, although less data since 29/12/15
6	6-1-2016	USF_07		Grey water East CWS top up (CSW6_US)	Some flow recorded when it is know there is no flow (noise)
7	6-1-2016	USF_08		Grey Water West CWS top up (CWS7_US)	Wasn't working since 12/10/15. Repositioned transducers and removed insulation on 14/12/15, got a good signal. Since 29/12/15 bad signal again
8	6-1-2016	USF_09		Complete DHW (Domestic hot Water) (CWS8_US)	Some flow recorded when it is know there is no flow (noise)
9	6-1-2016	USF_03		Female Showers/Sinks (CWS) (ENG-G036) (CWS9_US)	Meter working and showing data on website but no data on cloud since 29/12/15
10	18-1-2016	USF_10		Complete CWS (Cold Water Service) (MR.WM.002_CW_US)	no data stored
11	18-1-2016	USF_04		Male Showers/Sinks (CWS) (ENG-G004) (CWS3_US)	data stored vtec cloud
12	18-1-2016	USF_05		Zinc (CWS) (CWS4_US)	no data stored
13	18-1-2016	USF_06		Lab (CWS) (ENG-G034) (CWS5_US)	data stored vtec cloud
14	18-1-2016	USF_07		Grey water East CWS top up (CSW6_US)	data stored vtec cloud
15	18-1-2016	USF_08		Grey Water West CWS top up (CWS7_US)	data stored vtec cloud *H Bad signal
16	18-1-2016	USF_09		Complete DHW (Domestic hot Water)	data stored vtec cloud

				(CWS8_US)	
17	18-1-2016	USF_03		Female Showers/Sinks (CWS) (ENG-G036) (CWS9_US)	no data stored
18	1-2-2016	USF_04		Male Showers/Sinks (CWS) (ENG-G004) (CWS3_US)	Flow recorded when it is known there is no flow.
19	1-2-2016	USF_05		Zinc (CWS) (CWS4_US)	Flow recorded through the night. Could not zero the meter on 21/12/15 because of bad signal on meter. Signal seems to worsen since 11/12/15 but variable. Flow recorded when it is known there is no flow.
20	1-2-2016	USF_06		Lab (CWS) (ENG-G034) (CWS5_US)	Flow recorded when it is known there is no flow. Flashes negatively values on display. Sometimes displaying error signal 'I' on downloaded data, but not on physical meter.
21	1-2-2016	USF_07		Grey water East CWS top up (CSW6_US)	Flow recorded when it is known there is no flow
22	1-2-2016	USF_08		Grey Water West CWS top up (CWS7_US)	Wasn't working since 12/10/15. Repositioned transducers and removed insulation on 14/12/15, got a good signal. Since 29/12/15 bad signal again. Flow recorded when it is known there is no flow.
23	1-2-2016	USF_09		Complete DHW (Domestic hot Water) (CWS8_US)	Flow recorded when it is known there is no flow
24	1-2-2016	USF_03		Female Showers/Sinks (CWS) (ENG-G036) (CWS9_US)	Flow recorded when it is known there is no flow
25	8-2-2016	USF_04		Male Showers/Sinks (CWS) (ENG-G004) (CWS3_US)	DateTime 2 hours ahead of local time
26	8-2-2016	USF_05		Zinc (CWS) (CWS4_US)	Bad signal *H
27	8-2-2016	USF_08		Grey Water West CWS top up (CWS7_US)	Mounting method change to N, *R signal again.
28	8-2-2016				(mounting method defaults to V after power outage)
29	8-2-2016	USF_09		Complete DHW (Domestic hot Water) (CWS8_US)	DateTime 2 hours ahead of local time
30	8-2-2016	USF_03		Female Showers/Sinks (CWS) (ENG-G036) (CWS9_US)	No data since 19/1/16. BBB hard reset, after noticed offline.
31	2-6-2016	USF_10		Complete CWS	Flow recorded by USF when

				(Cold Water Service) (MR.WM.002_CW_US)	there is no actual flow - 14% error from inline water meter
32	2-6-2016	USF_04		Male Showers/Sinks (CWS) (ENG-G004) (CWS3_US)	Flow recorded by USF when there is no actual flow
33	2-6-2016	USF_06		Lab (CWS) (ENG-G034) (CWS5_US)	Flow recorded by USF when there is no flow, a lot of noise when no flow, 50% error (underpredicting volume)
34	2-6-2016	USF_07		Grey water East CWS top up (CSW6_US)	DateTime 1 hour behind of local time on sql database data and Flow recorded by USF when there is no flow
35	2-6-2016	USF_08		Grey Water West CWS top up (CWS7_US)	DateTime 1 hour behind of local time on sql database data and Flow recorded by USF when there is no flow
36	2-6-2016	USF_09		Complete DHW (Domestic hot Water) (CWS8_US)	Flow recorded by USF when there is no actual flow
37	2-6-2016	USF_03		Female Showers/Sinks (CWS) (ENG-G036) (CWS9_US)	Issues with data transfer partly solved by using ntp server/Flow recorded by USF when there is no actual flow

Problems are related to installation, calibration, read-out, time differences, connection to proprietary databases, etc.

Linate

R2M and VTEC have spent significant time on the transfer of knowledge for the installation and required modifications of the sensors systems. Major difference for these installations is the addition of batteries and GPRS for the remote and independent operation of the USF sensors.

This and the position of the sensors in the Linate Airport proved to be difficult to get them operational. The issues encountered in this pilot are listed below.

Issue Ref.	Date**	Unit Reference			Location	Brief Description of Issue
		Sensor	Controller	Unit Type		
1	November 2015	MW3 (portable meter - data saved locally)	BBB	USF	Administrative offices. The meters measures the water input of the administrative building	the BBB not works properly, the measurement frequency is unstable and the time / data are inconsistent
2	February / March 2016	MW3 (normal USF meter)	BBB	USF	RCT pumping station. The meters measures 1 water input of the aerostation	the BBB not works properly, the measurement frequency is unstable and the time / data are inconsistent
3	February / march 2016	R1	BBB	USF	RCT well	the BBB stops to work and to send data
4	February /	R2	BBB	USF	DeMONTIS well	the BBB stops to

	march 2016					work and to send data
5	February / march 2016	M1	BBB	USF	Merci area (DM6)	the BBB stops to work and to send data
6	February / march 2016	MW4	BBB	USF	RCT pumping station. The meter measures 1 water input of the aerostation	the BBB stops to work and to send data

Update: 11-10-2016

Update: 31-01-2017
Several firmware for the BBB have been released and tested from VTEC, now two USF meters work and transmit data to the Waternomics data-space.

As a general conclusion, the pilots have given us considerable information about the requirements for the different operating environments. The requirements for the maturity of the development are much more significant for a pilot with a lot of regulations like in Linate Airport than in Thermi for the installation in the households. In the households, the impact on the daily living is much more important because of the influence on the Internet speed and visual appearance.

4.4.2 Validation of the Flow meters and final version

The flow meters have been validated in separate environments. We have executed tests at the private lab of Waterbedrijf Groningen, after that we have setup trials in different buildings in Eindhoven like the Videolab (whole building and specific domestic areas like kitchen and pantries). Furthermore, the sensors, both Ultrasonic and miniwater meters have been used in a Smart Home environment in Eindhoven as well as in Alkmaar.
Above that we did a calibration in cooperation with Brabant Water at a school, called the Rooi Pannen. These results have been reported in deliverable D4.3.
The final validation has been done in the pilots as described in the previous section.
Several manuals have been prepared during the project and these have summarised in the Appendix document (Appendices D – E – F).

The findings in the pilots and previous tests have resulted in a number of products and business initiatives.

VTEC offers now the Ultrasonic Flowmeter and also the miniwater meter both coupled with BBB as a product (flyer can be found in the appendix – Appendix D-E-F). The selling price for the US Flow meter is, dependent on the volumes, around 1000 €. The mini water meter is offered in combination with a subscription for monitoring the Daily life of elderly people with the possibility to create an alarm when deviations from normal life are detected. The target selling price for the mini water meter for this application is 25€ and a subscription of 3€/month. The product is marketed under the name Yourlifebeacon. New projects, (S-Clusiv and a cooperation between BM-Change, VTEC and Simaxx) are initiated for monitoring the efficient use of energy in buildings where water usage is an additional parameter to be considered.

The IoT platform is the technical basis for a new company, ISENSIT, focusing on the fitness and health of workers. For this application, the IOT platform has been extended with other sensors like accelerometers, gyroscopes, temperature, humidity etc.
VTEC is also involved in a new project, SMART SYSTEMS, where the IOT platform is offered as a fieldlab for other parties to accelerate their business development by having a fast complete technical/commercial infrastructure to bring their specific, differentiated product to the market.

5 Conclusions

This report points out the Waternomics outcomes. The results as a whole represent an integrated system through which every kind of organization can achieve the goal of increasing water awareness and reducing its water consumption.

In detail this report has outlined the following:

- ***Methodology:*** It's a novel aspect in the water sector and the tools, references and best practices gathered from the application in the project pilot sites. It details a useful guideline to assist organizations in the construction and implementation of water management programs and the execution of water efficiency measures. The final methodology presented consists of five phases: Assess, Plan, Do, Check, Act. The methodology is based on standards so that the approach overall has a higher likelihood of adoption, uptake and replication. Also a user friendly visualization mode of the methodology is presented: the Waternomics methodology Trello Board. It consists in a web based management tool that replicates the methodology phases to help the end-users in the implementation of WEMs. U4 and R2M are working together to explore the possibility to introduce the Methodology as a service in the market to help organizations to be compliant with existing and new standards.
- ***Waternomics Application Platform (WApP)*:** In order to implement a WMS and WEMs it's important to make users aware of their water consumption. Only this knowledge can lead to a change of users' behaviour and can increase their awareness of the importance of safeguarding water resources. This is the objective of the Waternomics project and we can define the WApP the tool through which Waternomics achieves this objective. The Platform is targeted to different end-users and it is customizable to meet all the different users' needs. Moreover, the WApP offers a unique and easy way to understand the water consumption through comparisons, metaphors and user-friendly graphs. The execution of the WApP in the four pilot sites leads to an effective improvement of the platform and the final version really is able to address all the users' requests and their necessities of water consumption knowledge. U4 and R2M are working together to explore the possibility to introduce the WApP merged with the Methodology as a service in the market to help organizations to implement a smart water system.
- ***Data management and analysis:*** A Data Management Platform (DMP) has been developed, refined with the pilots' feedback and implemented to support the overall Waternomics project. In order to allow a handover and the exploitation of both the Waternomics activities and outcomes this work also presents a detailed Data Management Plan.
- ***Fault detection and diagnosis:*** NUIG pilot test results of the rule-based fault detection for too long retention time, show the effective working of the application and its notification system. In the same time Linate test results of the model-based fault detection and diagnosis algorithm on Linate airport water-system model data, for some real scenarios simulated, show that the method works well. The algorithm provides higher accuracy when detecting localized leakages than with multiple leakages at the same time. However, the Model-based FDD need more effort to improve the leakage localization and it should be integrated in the Waternomics Application Platform. In consideration of the positive feedback from the Linate airport operator and external stakeholders, R2M is going to invest more effort and research to introduce this FDD method in the market.
- ***Acoustic Leakage detection:*** test results of the newly developed acoustic detection method in some households in the Netherlands showed that the methods works relatively well but more effort needs to be spent in order to introduce it in the market. This has been taken up in post-project exploitation activities.
- ***Flow meters*:** this work demonstrated that in deploying a new generation of flow meters a lot of problem have to be faced in the real pilot test field. However, all the problems

encountered lead to an improvement of both the hardware and the software. Every step forward is a step closer to the commercialization of the product. This is clear also by considering the great amount of guideline / troubleshooting materials developed for future clients.

Now that the Waternomics outcomes are assessed, implemented for the first time in the project pilot activities which include domestic, municipal and corporate settings, and improved with the lessons learnt from the pilot tests; the Waternomics overall system can be one step and contribution in the development of a Smart Water Management System that lead to increase users' awareness regarding their water consumption and so to an overall behaviour change.

Some aspects of the outcomes (such as leakage detection and FDD) need further effort to meet in the best way the market needs but the future plans of some of the Waternomics consortium partners are working in this way by exploring new market opportunities and new funded projects in order to increase the technology readiness and maturity levels.

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