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D2.2: Smart City Connection topical roadmap

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| **Abstract (for dissemination)** | The Smart City Connection topical roadmap will tackle the importance of the deployment and inclusion of ICT technologies for the connection between Smart City and smart water systems in order to provide real application in the context Smart Technologies and citizenship. The main outcomes are specific analyses and recommendations for policy makers and relevant water stakeholders that can foster Information and Communication Technologies (ICT) for Smart Cities and. This deliverable is the second one of a series of three topical roadmaps which will help in the analysis of key issues regarding the usage ICT based solutions applied to the different water sectors. | | |
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# Executive Summary

Deliverable 2.2 consists in the report of Smart City Connection topical roadmap. The report initially provides a revision of the current technologies that can facilitate the connection between Smart City and smart water systems. That revision has been done following the interests identified within water management community by asking involved stakeholders during WIDEST dissemination actions and also through a survey that has been addressed to relevant stakeholders. The revision provides, from a technological point of view, how the development of ICT can help to the connection between Smart City and Smart Water Networks.

From the revision of the technologies, challenges and issues regarding the development of Smart City connection have been detected and analysed. These challenges and issues can be classified into two groups: a first one linked with technologic issues and challenges; and a second one regarding the actions that each stakeholder should overcome to help the development of Smart City connection. Another important point in this roadmap has been the analysis of the current dominant solutions to advice of the developments, contributions and trends from different vendors and other entities to the field of Smart City connection for water management. A list, with a deep description of the considered as the most dominant and important solutions has been provided together with some of the current trends in which the research community is focusing the new development and transference.

Finally in later sections, the roadmap provides a future vision through the statement of recommendations and actions to be taken for every relevant stakeholder, linking each recommendation to the challenge or issue that it can mitigate. As an example, specific recommendations for best funding and research directions as well as recommended actions to be taken for each specific stakeholder. A five year view of the development of tools for the Smart City connection is also provided, targeting the specific stakeholders that should be involved in executing the mentioned actions.

To understand this document the following deliverables have to be read.

| Number | Title | Description |
|---|---|---|
| 1.1 | Report with IWO definition and implementation | This report focuses on the definition and implementation of the ICT for Water Observatory (IWO). The IWO defines a methodology to collect, analyse and publish in a knowledge base resources from relevant sources of information related to ICT for Water technologies. This report includes the objectives, methodologies, functionalities and structure the IWO is going to offer and support, conforming the inputs of the literature reviews and commercial developments and technology trends analysis. |

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| 1.3 | Reports containing Literature reviews 1st release | This report presents the first iteration of ICT for Water literature review, including ICT4Water cluster projects publications, conference papers, journal papers, books and books chapters, and other reports. The objective of this report is to collect all these sources, and classify each document taking in consideration topics and tags. This information will be uploaded to the different platforms that support the IWO when possible. |
| 1.4 | Reports containing Literature reviews 2nd release | This report presents the second iteration of ICT for Water literature review, including ICT4Water cluster projects publications, conference papers, journal papers, books and books chapters, and other reports. The objective of this report is to collect all these sources, and classify each document taking in consideration topics and tags. This information will be uploaded to the different platforms that support the IWO when possible |

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# 1. Introduction

The objective of Work Package 2 (WP2) is to analyse the keys issues and assimilate information across three major topics: Semantic Interoperability, Smart City Connection and Smart Water Grids. Another objective is to advice about effective implementations of each of the previously noted topics focusing on a holistic approach. The expected outcomes are specific analyses and recommendations for municipalities, decision-makers and interested stakeholders with an overview of the main technical aspects that need to be considered to effectively design and implement each of the topics covered. This will contribute to identify gaps, barriers and bottlenecks on existing regulation blocking innovations and smart technologies and also to enhance the implementation, interoperability and economy.

This deliverable (D2.2: Smart City Connection topical roadmap) is focused in exploring how Information and Communication Technologies (ICT) can be adapted to continuously monitor and diagnose problems, prioritize and manage maintenance issues, use data to optimize all aspects of the urban water management network and analyse how these new developments can be integrated to the Smart City paradigm and the current development of Smart City implementations.

The key ICT technologies that can provide benefits to Smart Cities regarding water management are referred as smart water systems. The OECD defines smart water systems as systems with "*a high degree of automation, rapid response times or the capability to capture information in real-time, the ability to transmit data between remote locations and the data processing facility, and for the data to be interpreted and presented to utilities and end users*" (OECD, 2014). While these systems combine both technical and non-technical innovations, ICTs are increasingly providing novel operational possibilities to urban water managers. In the technical sense, ICT can provide new applications and tools for managing water distribution networks for example, in the non-technical aspect; ICT can integrate consumers as a new element in the supervision of the network.

Moving traditional water management to smart water systems will provide new tools to tackle some of the problems that modern cities are facing and also foster innovative approaches to ensure safe and adequate water provision. The ITU states that this new approach, termed as Smart Water Management (SWM), seeks to promote a sustainable, well-coordinated development and management of water resources through the integration of ICT products, tools and solutions; thus providing the basis for a sustainable approach to water management and consumption (ITU, 2014).

Harnessing the potential of ICTs in cities through the use of SWM can contribute to overcome water related socio-economic, cultural and environmental challenges, as well as to equip cities with technology to mitigate the impacts of climate change.

ICTs are providing Cities lots of tools to improve citizen’s life while improving environmental impact. It is a matter of time that such a basic and essential element for humans, like water, evolve to a piece of the Smart City engine. The Smart Water and Smart City connection is explored in this document by providing a revision of the Technologies for the Development of Smart City and Water Management Connection (Section 2) of the major fields that are part of both Smart Cities and Smart Water Systems.

It is expected that this roadmap together with the other two (D2.1 Semantic Interoperability and Ontologies topical roadmap and D2.3 Smart Water Grid) contribute and inspire future work on WP3 (Overall Roadmap). To this end, during the construction of the current deliverable there have been many interactions with the rest of the partners of the project in order to align, establish and identify common issues and topics. Also, the interaction with stakeholders has been constant, in the first year through informal meetings in conferences and other dissemination actions, and in the second year a survey has been launched to allow stakeholders to provide its views and opinions in a more formal way. This survey has been sent to stakeholders through IWA organisation and it helped to have a wider view of the current dominant solutions, trends, challenges and issues that Smart City connection is facing.

The document is structured as follows: Section 1 provides an introduction to the roadmap and also introduction to Smart City and Smart Water Network concepts. Section 2, provides a review of the technologies for the development of smart city connection regards the water management. Section 3, provides a set of challenges and issues regarding Smart City connection in Water Management community. Section 4, provides a revision of the current dominant solutions in the market and trends that can appear in the future. Section 5, specific recommendations are placed for each implantation/development research direction. Section 6 targets each interested group of stakeholders and recommended actions are proposed. Section 7 concludes the document summarizing the main ideas and recommendations. Section 8 summarizes the results and a discussion of Smart City connection is provided. Section 9 provides the references consulted during the elaboration of this document.

The following subsections provide an introduction to Smart Cities and Smart Water Systems.

## 1.1 Introduction to Smart City

The International Organization for Standardization (ISO) provides up to four definitions for the term "Smart City" in the Joint Technical Committee (JTC) 1 review on the specified topics of Smart Cities (ISO/IEC JTC 1, 2014). One of the definitions accepted by the ISO is the one provided by the general working group of Chinese national smart cities standardization: "*Smart Cities: a new concept and a new model, which applies the new generation of information technologies, such as the Internet of Things, Cloud Computing, Big Data and Space/Geographical Information Integration, to facilitate the planning, construction, management and smart services of cities. Developing Smart Cities can benefit synchronized development, industrialization, informationisation, urbanization and agricultural modernization and sustainability of cities development. The main target for developing Smart Cities is to pursue:*

- *Convenience of the public services;*
- *Delicacy of city management;*
- *Liveability of living environment;*

- *Smartness of infrastructures;*
- *Long-term effectiveness of network security.*"

The term "smart city" was first used in 1994 (Dameri, 2014) and since then, there has been a big evolution of the concept behind that term. According to the "10 Year Rolling Agenda" (Alessi & Saritas, 2013) prepared by the Smart Cities Stakeholder Platform[1], the current objective of Smart Cities is to accelerate investment and the rate of innovation in cities in Europe with the aim of achieving social, economic and environmental objectives. Smart Cities are meant to:

- Increase the quality of life of city-dwellers;
- Enhance the efficiency and competitiveness of the local and EU economy;
- Move towards the sustainability of cities by improving resource efficiency and meeting emission reduction targets.

One key part in the evolution towards the smart city paradigm is the interconnection of all the components that are part of a city (infrastructures, services, etc.) in order to permit the information sharing that will allow better planning and decision making. To this extent, traditionally isolated infrastructures are evolving into highly integrated systems on various scales so as to become "smarter": residential and commercial; district, city and community; and regional and national. Given that water management is a key issue in modern cities, it is understood that the development of Smart Water Management, is a cornerstone for the evolution of Smart Cities.

The European Innovation Partnership on Smart Cities and Communities Strategic Implementation Plan (SIP) was developed to draw both strategic and operational plans that guide all involved entities to work on some prior areas for the Smart City paradigm achievement. The SIP is concentrated on three specific, vertical areas for the time, being:

1. Sustainable Urban Mobility: alternative energies, public transport, efficient logistics, planning.
2. Sustainable Districts and Built Environment: improving the energy efficiency of buildings and districts, increasing the share of renewable energy sources used and the liveability of our communities.
3. Integrated Infrastructures and processes across Energy, ICT and Transport: connecting infrastructure assets to improve the efficiency and sustainability of cities.

[1] The Smart Cities Stakeholder Platform initiated by the European Commission (http://eu-smartcities.eu/) is a physical as well as web-based Platform open to anyone who registers on it. Focus is on identifying and spreading relevant information required by practitioners on technology needs and solutions. The backbone consists of contributions by stakeholders in a bottom-up manner, i.e. owned by the stakeholders. The Platform is one of the two governance bodies of the Smart Cities and Communities EIP

The second vertical area (Sustainable Districts and Built Environment) can also be aligned with urban water management as there are increasing global change pressures, escalating costs and other risks inherent to conventional urban water management that are causing cities to face ever-increasing difficulties in efficiently managing scarcer and less reliable water resources, so a smart water management is needed to overcome this problems within Smart Cities.

The third vertical area (Integrated Infrastructures and processes across Energy, ICT and Transport) can also be aligned with water systems, as they are often overlooked yet are critical components of energy management in smart cities, typically comprising 50 percent of a city's total energy spend[2]. Energy is the largest controllable cost in water/wastewater operations, yet optimizing treatment plants and distribution networks has often been not considered when distributing the up operating funds by cash-strapped municipalities. Once facilities are optimized and designed to gather meaningful and actionable data, municipal leaders can make better and faster decisions about their operations, which can result in up to 30 percent energy savings and up to 15 percent reduction of water losses[3] (EFFINET, 2015).

The OIP (Operational Implementation Plan) includes eight horizontal priority areas that the EIP addresses to achieve the goals of the aforementioned vertical areas:

- Citizen Focus
- Policy & Regulation
- Integrated Planning
- Knowledge Sharing
- Metrics & Indicators
- Open Data
- Standards
- Business, Models, Procurement & Funding

The European Telecommunications Standards Institute (ETSI) already identified a Smart City and water linkage (ETSI, 2013) stating: ”*A city's water distribution and management system must be sound and viable in the long term to maintain its growth and should be equipped with the capacity to be monitored and networked with other critical systems to obtain more sophisticated and granular information on how they are performing and affecting each other. A smart water system is designed to gather meaningful and actionable data about the flow, pressure and distribution of a city's water.*”

[2] http://www.veolia.com/en/veolia-group/profile/challenges/sustainable-cities

[3] http://www.waterworld.com/articles/print/volume-29/issue-12/water-utility-management/smart-water-a-key-building-block-of-the-smart-city-of-the-future.html

## 1.2 Introduction to Smart Water Networks (SWN)

The Swan Forum[4] defines the "Smart Water Network" as that structure of data-driven components which helps operate the "dumb" or data-less physical layer of pipes, pumps, reservoirs, and valves.

Smart Water Networks are a big piece of the current smart water system solutions and they can help to improve the efficiency (Coelho & Andrade-Campos, 2014), longevity (Martyusheva, 2014), and reliability (Di Nardo, Di Natale, Santonastaso, & Venticinque, 2013) of the underlying physical water network by better measuring, collecting, analysing, and acting upon a wide range of network events. This can take shape in different phases of the utility process, such as real-time monitoring[5] and automation, operational readiness, or network planning (Pollino, Caiaffa, Carillo, La Porta, & Sannino, 2015), (Skeens & Ray, 2015), (Kartakis, Abraham, & McCann, 2015), (Mutchek & Williams, 2014).

Key to the success of such a diverse and complex data ecosystem is that data can be used and reused simply and flexibly. Data that is confined or restricted to a single application presents considerably less value for money than multi-purpose data. As exposed in (Coelho & Andrade-Campos, 2014) Smart Water Network components should take into account data compatibility or interoperability in the future to cope with the new challenges faced. This is because they are typically designed as isolated systems, so the connection with Smart Cities would help: i) Smart Water Networks to be connected to other infrastructures and provide to water managers and citizens a modern vision of the water infrastructure; and ii) incorporate to SWANs data from other Smart City components such as Smart Energy Grids, Mobility Entities, Citizen behaviour among others.

According to (Miller & Leinmiller, 2014), the three pillars of Smart Water Networks are:

- Information: making full use of all data produced by a water utility
- Integration: utilizing current ICT systems to maximize previous investments
- Innovation: having the flexibility to meet future challenges

[4] The Smart Water Networks Forum, is a worldwide industry forum promoting the use of data technologies in water networks, making them smarter, more efficient and more sustainable. SWAN members vary from water utilities, technology providers, engineering and consulting firms, academics, and investors. http://www.swan-forum.com/

[5] Real-time data monitoring (RTDM) is a process through which an administrator can review, evaluate and modify the addition, deletion, modification and use of data on software, a database or a system. It enables data administrators to review the overall processes and functions performed on the data in real time, or as it happens, through graphical charts and bars on a central interface/dashboard. Real time is a term used to describe computer systems that update information at the same rate as they receive data.

Through these three pillars, the connection with Smart Cities and Smart Water Networks can contribute to overcome water related socio-economic, cultural and environmental challenges, as well as to equip cities with technology to mitigate the impacts of climate change.

As an example and in relation to the SmartWater4Europe (a European research project in which 21 entities are participating, including water utility companies, technology companies, universities and research centres) the project SWING[6] (Smart Water Innovation Network in the city of BurGos) will set up a management system for water supplies that will provide instantaneous and remote control of the quality of the water, meter readings and the general state of the network.

The solution proposed by this project will integrate, among other technologies, daily remote readings of users' meters, a Geographical Information System (GIS), remote control data, algorithms to forecast demand, a large number of sensors to monitor water quality, and a mathematical model to predict the behaviour of the supply system. This project aims at developing an advanced business management system that will use a 'Business Intelligence' platform capable of detecting faults, blockages or leaks in real time, and locate them,

A Smart Water Network is not simply an individual system that optimizes a network's efficiencies but rather a means of linking together multiple systems within a network to share data across platforms. This way of thinking in the Water Distribution Network as a set of systems that can work independently but that provide a high degree of connectivity (and interoperability) has changed the paradigm, leading to the concept of Systems of Systems (SoS, see Section 2.4) and becoming a suitable tool to foster the Smart City concept, as Smart Energy Grids are doing.

The following sections will explore the current ICT developments that will enable the integration of new Water Management methods to Smart Cities

[6] http://www.acciona.com/news/acciona-agua-implements-a-smart-water-network-in-burgos

# 2. Review of the Technologies for the Development of Smart City Connection

This section provides a revision of the current developments regarding ICT that can foster connection between Smart City and Water Management. It first provides a revision of the integration of smart meters across Europe. The adoption of smart meters is an important aspect as it is the starting point for the application of ICT technologies in the remote part of the distribution network. It has to be taken into consideration that, as in facilities (where data is received and processed) is relatively easy to implant new technologies as ICT infrastructures are more developed. However, Water Distribution Network has not faced a big advance in the integration of electronic elements. So, the adoption of new technologies like Big Data, Cloud Computing can bring more benefits, as the costs of its deployment are not as big as the deployment of Smart Meters or Smart Pumps and Valves, but it also has to be taken into account that without electronic elements that provide such data, analysis and smart management is almost impossible.

## 2.1 Smart Meters

Sensor and monitoring systems are currently providing water utility companies with large amounts of near real-time flows of data. Smart Meters are the evolution of old monitoring systems, when these systems enable a frequent monitoring (less than an hour) and provide two-way communication (that is, the utility can send data to the final consumer through this kind of devices) they are considered part of an Advanced Metering Infrastructure (AMI). It is expected that in the near future the use of Smart Meters provide such a volume of data that the use of Big Data (Section 2.2) approaches will be a must.

More and more utilities are integrating advanced ICT solutions into their operations. And with smart water metering helping to identify and reduce leakages and non-revenue water, the European market could be worth up to $13.4 billion by 2020[7].

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[7] http://www.waterworld.com/articles/wwi/print/volume-26/issue-5/regulars/creative-finance/smart-water-metering-networks-an-intelligent-investment.html

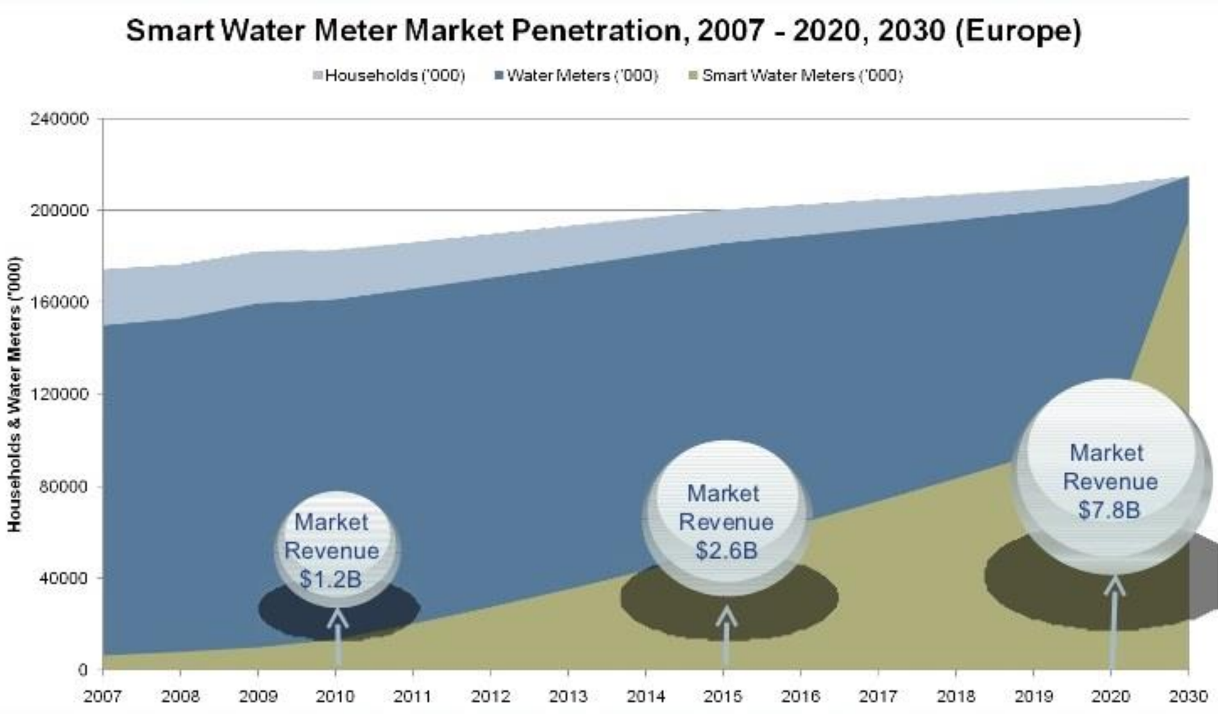


*Figure 1: Smart Water Meter Market Penetration, 2007 - 2020, 2030 (Europe). Source: Frost & Sullivan*

In Europe alone, smart water metering is expected to generate a cumulative investment of $7.8 billion (Figure 1) by 2020[8]. With an improvement of the investment, taking in consideration the strong support provided by government, it is stated that this market should grow further to $13.4 billion over the same period[9]. While initial investments are heavily in smart water meters and installation fees, data and network management will provide most of yearly revenues for the market.

As stated by Pike Research report[10], the strength in this market is found in its ability to offer water utilities specific paths towards operating cost and carbon footprint reduction, while improving service and supply management. These include identifying end point leakage, gaining clarity between leakage, non-revenue water (NRW) and chargeable consumption, establishing consumption patterns and using predictive analytics to regulate supply and setting up adjustable alarm notifications to predict/prevent end point anomalies.

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[8] http://www.waterworld.com/articles/wwi/print/volume-26/issue-5/regulars/creative-finance/smart-water-metering-networks-an-intelligent-investment.html

[9] http://www.palacegroup.co.za/news/40/15/Smart-Water-Meters-Market-Set-for-Growth.html

[10] http://www.navigantresearch.com/wordpress/wp-content/uploads/2010/07/SWAT-10-Executive-Summary.pdf

Water companies need to do big investments, so clear new business opportunities should be discovered. The resulting market environment has yet to witness clear leaders and, like network communications options, demands utilities invest much time to study their options to ensure intelligent investments. In Section 4.1 Dominant Solutions in the market have been identified, and a first observation is that big technology companies have already taken a position to become the domain technology leaders and consolidate tools and standards that can simplify the decision-making process.

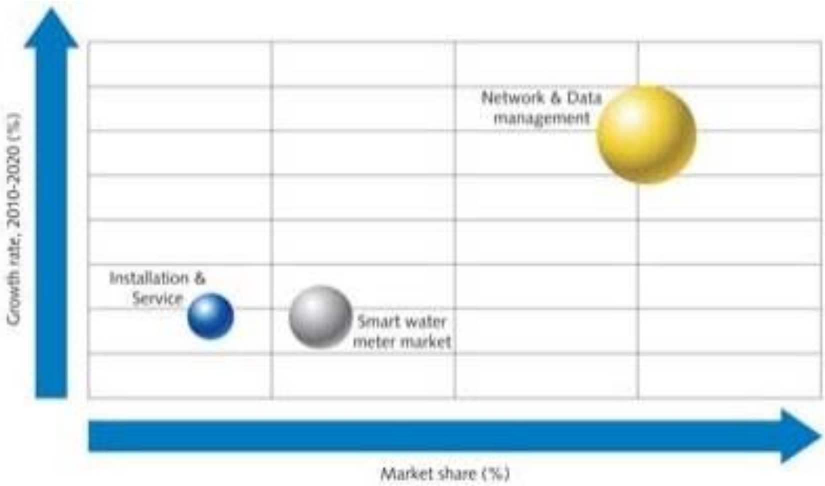


*Figure 2: European market attractiveness by vertical market. Source: waterworld*

As stated previously the predicted cumulative market opportunity in smart water metering of $7.8 billion by 2020 for meter manufacturers, installers and data and network management companies. Of these three segments, however, the largest to represent long-term, sustainable value is data and network management (Figure 2). Once smart water metering is established, further revenue for meter manufacturers and installers will come from timely replacement and upgrading of meters.

At the current moment many countries in the European Union are advancing in the development and installation of Smart Meters and AMI integration, in the following list we enunciate some of the most relevant cases (Osborne Clarke, 2014):

- **United Kingdom:** As reported by the European Parliament (European Parlament, 2014), the UK is one of only three European countries that has more than 31 cities with at least one smart initiative, the others being Italy and France. The UK has set a target to install Smart Meters in every home by the end of 2020. The UK Government, through Innovate UK, has implemented a series of programmes that provide funding directly to cities for investment in smart initiatives. In

January 2013, Innovate UK[11] awarded £24 million to Glasgow, following a competition entered into by 30 UK cities, for investment in smart initiatives. Innovate UK has also launched the 'Future Cities Catapult', funded with up to £50 million over five years. The Catapult will explore ways that public services can be integrated in a smart way to boost the economy and benefit citizens.

- **Germany:** The European Parliament (European Parlament, 2014) places Germany in its third tier of countries ranked by their development of smart cities, meaning only 25-50% of German cities with a population of over 100,000 have at least one smart initiative. As an example, in April 2014, the city of Hamburg signed a memorandum[12] of understanding with Cisco Systems to create a series of pilot projects focusing on smart traffic, smart street lighting, infrastructure sensing and remote citizen services.
- **Spain:** Spain is home to many smart cities. According to research undertaken by the European Parliament (European Parlament, 2014), more than 30 Spanish cities with a population in excess of 100,000 have at least one smart city initiative, making it one of the top three countries in Europe measured by the number of smart city initiatives, alongside Italy and the UK. In 2010 Santander was selected to become Europe's first testing ground for the mass deployment of Smart Sensors. In the last four years, over 12,000 sensors have been deployed throughout the city, measuring a variety of factors, including air pollution, traffic levels, the number of parking spaces and much more.
- **Italy**: Italy is one of the most advanced European countries in terms of smart city initiatives. A report by the European Parliament (European Parlament, 2014) placed Italy in its top tier of countries ranked by the number of smart city initiatives - over 75% of cities in Italy with a population of over 100,000 have at least one smart initiative. Italy is particularly advanced in its deployment of Smart Meters. State utility Enel has installed smart meters for more than 34 million customers, accounting for more than 90% of Italian households (Osborne Clarke, 2014), significantly ahead of the EU requirement for Member States to install smart meters in 80% of households.
- **Belgium:** To date, the development of smart cities in Belgium has been moderate. Research by the European Parliament (European Parlament, 2014) places Belgium in its second tier of countries ranked by smart city initiatives, meaning that 51-75% of its cities with a population over 100,000 have at least one smart city initiative. As the most densely populated country in Europe, with more than 98% of its population living in cities, it ought to rank higher. Change is now afoot. To kick-start development of smart cities, state-owned banking and insurance group Belfius Bank launched in July 2014 a €400 million smart city financing programme, 'Smart Cities & Sustainable

[11] https://www.gov.uk/government/organisations/innovate-uk

[12] https://newsroom.cisco.com/press-release-content?articleId=1414144

Development' (Commission, Bank, Cities, & Cities, 2014), in collaboration with the European Investment Bank (EIB). The programme, capitalised with €200 million from Belfius Bank and €200 million from the EIB, will provide preferential rate loans to municipalities, utilities, or any other organisation providing services to local authorities, for the implementation of mobility, urban development and energy efficiency initiatives in Belgium that can be deemed smart and sustainable.

- **The Netherlands:** The Netherlands is making progress in implementing smart cities. Research by the European Parliament (European Parlament, 2014) places the country in its second tier of European countries that have successfully implemented smart cities, meaning 51-75% of its cities with a population over 100,000 have at least one smart city initiative. In April 2014, the Netherlands announced plans to install 15 million smart meters by 2020 as part of its national roll-out programme (USmartConsumer, 2014). This followed a pilot of 600,000 meters that has been running since 2012. Amsterdam, the country's capital, is furthest ahead in rolling out smart city initiatives. In 2009 the Amsterdam Smart City [13](ASC) programme was established. It is a partnership of businesses, public authorities and research institutions that work together to make the Amsterdam Metropolitan Area a sustainable and more environmentally friendly living environment.
- **France:** France has been very slow to implement smart city initiatives. According to research conducted by the European Parliament (European Parlament, 2014), under half of French cities with a population over 100,000 have at least one smart city initiative, putting it behind many other European countries, including the UK, Spain, Italy, Austria and the Nordic countries. Some 300,000 smart meters have already been installed in pilot projects in Lyon and Tours (Greater Lyon Economic and International Development Delegation, 2014).

It is also worth to note some other initiatives outside the European Union, like for example the initiative taken in Egypt within the utility sector, where two significant and discernible trends are the move towards joint utilities and the use of some form of Automatic Meter Reading (AMR) – often in conjunction with increasingly sophisticated billing systems, tied in with one of CRM (customer relationship management) packages.

The trial involved 2000 installations, including domestic applications, small businesses and hotels. The product on was a combination of the latest electronic metering equipment from the electricity and water sectors.

[13] http://amsterdamsmartcity.com/

Briefly described[14], the system relies on an electricity meter connected to an electronic water meter, which in turn is connected to a flow control valve in the water supply (joint-meters). Readings from both the electricity and water meters are transmitted automatically to the billing system via the electricity power lines. This form of data transfer is used in other systems and is well established as being extremely cost effective. From an end-user point of view a unique device could provide metering information to the supply companies of water and electricity.

## 2.2 Big Data and Data Analytics

Smart Meters are providing more and more data nowadays. However, this flow of data does not comprise Big Data yet. Big Data encompasses much more than the data provided from the Water Distribution Network, as one can integrate data from other domains such as meteorology, economic, citizen behaviour, among others.

In 2012, Gartner[15] provided a definition for Big Data that has been widely accepted through research and industry; it is stated as follows: "*Big data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization.*" Gartner's definition of the 3Vs is still widely used, and in agreement with a consensual definition that states that "*Big Data represents the Information assets characterized by such a High Volume, Velocity and Variety to require specific Technology and Analytical Methods for its transformation into Value*".

Additionally, a new V "Veracity" is added by some organizations to describe it, revisionism challenged by some industry authorities. The 3Vs have been expanded to other complementary characteristics of Big Data:

- Volume: Big Data doesn't sample; it just observes and tracks what happens. This means continuous registering along the whole Water Distribution Network. As an example, the incorporation of IPv6 technologies could lead to (6.5 × 1023) addresses for every square meter of the Earth's surface[16] which implies that a simple measuring for each sensor provides huge volume of data.
- Velocity: Big Data is often available in real-time, for example providing graphs and tables of actual usage and summaries of the data being acquired “right now”.

[14] http://www.metering.com/joint-electricity-and-water-metering-project-in-egypt/

[15] http://www.gartner.com/newsroom/id/1731916

[16] https://technet.microsoft.com/en-us/library/cc781652%28v=ws.10%29.aspx

- Variety: Big Data draws from text, images, audio, video; plus it completes missing pieces through data fusion. For example, linking water data to live videos using computer vision, or adding meteorological data to smart meters to take decisions.
- Machine Learning: Big Data often doesn't ask why and simply detects patterns, this means that incorporating data to Machine Learning models can forecast future states of the Water Distribution Network.

Big Data analytical platforms could manage volume, velocity, variety and machine learning libraries. Sometimes the features are provided by simply storing and viewing the data in a user friendly manner[17], e.g., in a map, huge efficiencies can be gained. Big Data analytics could add predictive models to repair or replace parts of the infrastructure for further optimizing the balance between performance and reliability or even to predict the water consumption in urban areas[18]. They may also prevent man- made disasters, such as sudden drops in water quality, which may not be detected until after they are reported in the media or after the outbreak of a contagious disease.

According to (Brown, 2012) the most attractive advances that Water Management can benefit from Big Data are:

- **Better real-time operations decision-support:** The most immediate and obvious use for Big Data Analytics is in operating the existing infrastructure. Although this requires to provide more communication and information retrieval capabilities to the asset management infrastructure and foster the advancement of the installation of metering infrastructure by water utilities. As this data becomes available, predictive maintenance (IBM, 2015b), leak detection (Kei et al., 2014), and energy optimization (IBM, 2015) can be done using Big Data techniques.
- **Improved customer relationships and communications:** At the same time that data is retrieved from the water distribution infrastructure, smart meters and advanced customer-used devices can be retrieving information about user's water usage. This could lead to a better understanding of how and when water is used by customers and also enable the opportunity to increase the communications and interaction between utilities and government with citizens. The feedback that can be provided to customers, combined with incentives for water use efficiency, offer a more dynamic and effective means of incorporating demand management into utilities resource mix (Gleick, 2013).
- **Stormwater management:** As an example, it is known that trees, can contribute to stormwater management and urban cooling (United States Environmental Protection Agency, 2013) – reducing energy costs and decreasing the amount of urban runoff reaching receiving waters. At the same time, tree planting is often seen as a supplemental benefit rather than a replacement for the traditional

[17] http://www.waterlinedata.com/prod

[18] http://www.wateronline.com/doc/solving-uncertainty-using-big-data-to-predict-urban-water-demand-0001

stormwater infrastructure characterized by pipes and pumps. By monitoring wastewater infrastructure in a Big Data approach one can log and analyse how all the elements of the city can help to improve water treatment and benefit to urban environment. Increasing monitoring and deploying more sensors in the natural environment can provide the necessary data for managers to see that natural systems are reliably doing their part in the urban environment (Boyle et al., 2013).

- **Citizen involvement in infrastructure management:** Through the development of apps, citizens can collaborate to keep the infrastructure in a good state and also citizens can be alerted of the inconveniences of maintenance, such as water distribution disruptions. Web and mobile apps allow government and organizations to receive immediate feedback from citizens including reports of incidents, suggestions, and general comments. For example, a person walking through a park can pull out a smartphone and provide a real-time report on problems or ideas for improvement (Pratt, 2012).
- **Improvement of preparedness and response to flooding:** As stated in (IBM, 2013): "flooding cannot be avoided". However, the human and financial costs of flood events can be mitigated if flood defenses are managed more effectively through accurate early warning systems and alerts. Smarter water management also means data can be collected in real-time from river systems, levees, sensors and weather systems, combined with historical data, and aggregated to generate a unified view of the physical infrastructure. Analytics and advanced weather simulation models can be applied to this data to monitor and predict water flows and floods, monitor emerging threats from flooding, and pinpoint with greater accuracy potential areas at risk. The city of Rio the Janeiro in collaboration with IBM, developed the intelligent operations centre[19]. They implemented a platform to integrate all of the data derived from city's management of urban watersheds including, both the man - made and the natural infrastructure that supports the water distribution network.

Some other examples from (Washington, 2012):

- **The role model sewer system in South Bend**: The city of South Bend in Indiana started using IBM's Intelligent Operations[20] in 2012 to mitigate sewer overflows. This project's integration of hundreds of sensors was unique in the world and many (Smart Cities) are now looking to South Bend, Indiana as an example for improving their own sewer systems. The results of the system[21] have been remarkable: the system has saved roughly $100 million by not having to enlarge the sewers pipeline infrastructure and saved around $60 million in fines with better insights that prevented waste water overflows in rivers.

[19] http://www.fastcompany.com/1712443/building-smarter-favela-ibm-signs-rio

[20] http://www-03.ibm.com/software/products/en/intelligent-operations-center

[21] https://www.ci.south-bend.in.us/government/content/csonet

- **Water conservation in California**: In large agricultural areas such as in California, rainfall and water are extremely important as the area is known for drought. These drought conditions not only affect agricultural businesses, but also the citizens and thereby the other related businesses in the area. Silicon Valley has looked into Big Data technologies to conserve water in the region[22]. A one-year pilot was started to deliver a Software as a Service (SaaS) tool to residents to empower them with the capabilities to crunch data and provide themselves and others with feedback and tips for cutting their water consumption. The pilot was funded by the California Water Foundation[23] and its basis had its origin from an independent study that shows that when participants received information about comparing water consumption to neighbourhood averages, their usage would decrease by 5% on average. This effort is part of a whole package to reduce the water usage by 20% state wide.
- **Leak Detection:** Another company (Leak Defense[24]) has developed a water leakage device for consumers similar to a smoke detector. The device is installed at the central intake pipe of a residential home to detect the inflow of water. Whenever there are irregularities, like a running toilet, the device can alert the homeowner from a distance with its Wi-Fi connection (ACE Private Risk Services, 2015).
- **Storm Flood Map** The National Hurricane Center[25] (NHC) used Big Data approach for providing advanced warning and detailed information about the emergencies in case of hurricanes and storms. To this end, they launched the Storm Flood Map in 2014 (National Hurricane Center, 2014). Within 60 minutes of a hurricane warning, the new interactive map will provide detailed graphics of land and river systems, water infrastructure and flooding information. The public and first responders never have had this type of critical information before and it could potentially help save lives. The NHC plans to further develop the tool and is working towards implementation by embedding it in Google Maps.

## 2.3 Internet of Things (IoT) and Cyber-Physical Systems (CPS)

Robots, intelligent buildings, implantable medical devices, cars that drive themselves – these are all examples of Cyber-Physical Systems (CPS). Today, CPS can be found in such diverse industries as aerospace, automotive, energy, healthcare, manufacturing, infrastructure, consumer electronics, and communications. Everyday life is becoming increasingly dependent on CPS – in some cases with dramatic improvements. Cyber-Physical Systems or “smart” systems are co-engineered interacting

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[22] http://www.metering.com/smart-water-meters-california-utilities-prefer-apps-to-big-data/

[23] http://waterfoundation.net/about-us/

[24] http://leakdefensesystem.com/

[25] http://www.nhc.noaa.gov/

networks of physical and computational components (NIST, 2015). CPS are starting to be part, not only of Smart Cities, but also of all world cities. As an example, Donosti (Spain) has incorporated a driverless vehicle in its transportation network[26].

Some of these CPS interact with the world thanks to the sensing capabilities of devices that are connected to the Internet. These devices have decreased its size and price thanks to the advances in electronics. They are referred as 'Internet of Things' or IoT devices as due to its size can be embedded to almost anything to provide connectivity. The IoT describes a network of physical objects embedded with electronics, software, sensors, and connectivity that allows the exchange of data with multiple entities and other connected devices.

The focus of IoT is often more on sensing and connectivity, compared with CPS, which puts more emphasis on reliability, security, and system control. The use of such technologies will enable cities and communities to get 'smarter' – that is, improve services, promote economic growth, and enhance quality of life.

One critical issue of the deployment of IoT networks is the connectivity among its components. In the U.S. the appropriate solution for this kind of devices (such as smart meters, data loggers, etc.) is low power RF (LPRF) communication using a Sub-1 GHz mesh network. However, depending of the country and the nature of the grid, a wireless solution might not be the best choice, for example in Spain or France where wired narrowband Orthogonal Frequency-Division Multiplexing (OFDM) Power Line Communication (PLC) technologies are used. There is no connectivity solution that fits all deployments. Making the IoT real requires a larger portfolio that can go from wired to wireless and sometimes combined together.

IoT has a huge potential applicability in Smart Cities and Water Management Systems.

At the lowest communication level, the appearance on scene of new methods and technologies (Monnier, 2014) enabled the use of electronical devices for monitoring and transmitting data in almost any part of the Water Distribution System.

Another example of application is the use of smart meters in household environments. Thanks to the use of such devices, it is possible to deliver useful power consumption information into the home through an in-home display or a gateway. This information allows consumers to adapt resources behaviour and lower utility bills. So in essence, smart meters are becoming smart sensors that communicate both ways, inside and outside homes and buildings, connected to each other in a mesh network while reporting essential resource consumption data to utilities. Regarding the connectivity issue, in the U.S. the IEEE 802.15.4 2.4 GHz ZigBee standard is being used in combination with Smart Energy application profile. Other

[26] http://www.citymobil2.eu/en/

countries such as the U.K. or Japan are evaluating Sub-1 GHz RF or PLC solutions for greater reach or a combination implementation with both hybrid RF and PLC,

For meter vendors, the move to the smart meter has a big impact on the meter topology. On top of the metrology piece that measures energy consumption, flow rate or water pressure, several radios or PLC solutions are now integrated onto the meters. Sometimes, pre-payment and Near Field Communication (NFC) functions are also implemented. The needs of host microcontrollers (MCUs) are changing, which require them to have greater memory size and more connectivity and security options to carry the communication protocol.

Additionally, the MCU on a smart meter needs to support advanced functions like dynamic pricing/demand response, remote connect and disconnect, network security, over-the-air downloads and post-installation upgrades so utility providers don't have to send out technicians to each meter.

Research communities have devoted efforts for fostering Architectures and Protocols for IoT in Water Management and Smart Cities (Zanella, Bui, Castellani, Vangelista, & Zorzi, 2014), (Jin, Gubbi, Marusic, & Palaniswami, 2014) and (Robles et al., 2015). For example, in (Sheng et al., 2013) the authors provide a review of the IETF (Internet Engineering Task Force[27]) standards for IoT. Below we summarize some of the standards that undoubtedly will contribute to Smart Cities connection:

- IEEE 802.15.4: IEEE 802.15.4 is a radio technology standard for low-power and low-data rate applications with a radio coverage of only a few meters. The standard has been developed within the IEEE 802.15 Personal Area Network (PAN) Working Group. Because of its designated nature as low power and low complexity, an increasing number of IoT devices have been built as IEEE 802.15.4-compliant devices. Moreover, many well-known standardization organizations are also active in developing low-power protocol stacks based on IEEE 802.15.4, such as WirelessHART[28] and ZigBee[29].
- 6LoWPAN: Since the beginning of the IETF research on IoT related technologies, IPv6 has been selected as the only choice to enable wireless communication. Its key features, such as universality, extensibility, and stability, have attracted a lot of attention and may become the de facto solution for future Internet technology. In order to enable IP connectivity in resource constrained sensor networks, the IPv6 over Low-Power WPAN (6LowPAN) Working Group has

[27] The Internet Engineering Task Force (IETF) develops and promotes voluntary Internet standards, in particular the standards that comprise the Internet protocol suite (TCP/IP). It is an open standards organization, with no formal membership or membership requirements. All participants and managers are volunteers, though their work is usually funded by their employers or sponsors.

[28] http://en.hartcomm.org/main_article/wirelesshart.html

[29] http://www.zigbee.org/what-is-zigbee/

been established and works on protocol optimization of IPv6 over networks using IEEE 802.15.4. Specifically, the 6LoWPAN protocol discusses how to apply IPv6 to the MAC and PHY layers of IEEE 802.15.4.

- RPL (Routing Protocol for LLN[30]): RPL responds to the necessity of constructing routing protocols for LLNs. Based on this kind of networks requirements, the RFC 6551 introduces two kinds of quantitative metrics: node metrics, including node state, node energy, and hop count, and link metrics, including throughput, latency, link reliability, expected transmission count (ETC), and link colour object. In order to assist dynamic routing, nodes can select path(s) based on the quantitative metrics to achieve the defined objective. The RoLL (IETF Routing over Lossy and Low-Power Networks working group) developed this routing protocol RPL supports three kinds of traffic flow: point-to-point (between devices inside the LLN), point-to-multipoint (from a central control point to a subset of devices inside the LLN), and multipoint-to-point (from devices inside the LLN toward a central control point). RPL is a distance-vector routing protocol, in which nodes construct a destination-oriented acyclic graph (DODAG) by exchanging distance vectors and root with a controller.
- CoAP: The Constrained Application Protocol (CoAP) specified by the IETF CoRE Working Group, is a specialized web transfer protocol for resource constrained nodes and networks. CoAP conforms to the REST[31] style. It abstracts all the objects in the network as resources. Each resource corresponds to a unique Universal Resource Identifier (URI) from which the resources can be operated stateless, including GET, PUT, POST, DELETE, and so on.
  Strictly speaking, CoAP is not an HTTP compression protocol. On one hand, CoAP realizes a subset of HTTP functions and is optimized for constrained environments. On the other hand, it offers features such as built-in resource discovery, multicast support, and asynchronous message exchange.

There also exist other standards from other Standardization entities such as MQTT that is part of the OSASIS[32] Standard since 2014. MQTT is a machine-to-machine (M2M)/"Internet of Things" connectivity protocol. It was designed as an extremely lightweight publish/subscribe messaging transport. It is useful for connections with remote locations where a small code footprint is required and/or network bandwidth is at a premium. For example, it has been used in sensors communicating to a broker via satellite link, over occasional dial-up connections with healthcare providers, and in a range of home automation and

[30] Lossy and Lowpower Networks (LLNs)

[31] http://www.ics.uci.edu/~fielding/pubs/dissertation/rest_arch_style.htm

[32] OASIS is a non-profit consortium that drives the development, convergence and adoption of open standards for the global information society. (https://www.oasis-open.org)

small device scenarios. It is also ideal for mobile applications because of its small size, low power usage, minimised data packets, and efficient distribution of information to one or many receivers.
These standards facilitate the communications between IoT elements. These mentioned elements have gained a lot of attention thanks to the appearance of Open Hardware platforms such as RaspberryPi or Arduino. These platforms allow users to implement architectures using tiny, cheap and highly customizable pieces of hardware and build in a very easy manner. At the same time, the openness of its design make very easy to provide a final prototype without having to spend time and money worrying about the electronic part. The openness also helped in the development of operating systems that already incorporate standard protocols, this is the case of Contiki[33], TinyOS[34], FreeRTOS[35], Riot[36], and OpenWSN[37].

At the other part of the IoT communication there exist servers capable of reading the data provided by IoT elements and provide useful information to the user. These servers is the endpoint where the final user work and are commonly referred as “IoT platforms”. Generally speaking, an IoT platform provides a comprehensive set of generic application independent functionalities which can be used to build IoT applications. Although there is a wide range of different services and functionalities existing IoT platforms offer, the most common ones are:

- **Connectivity & normalization:** harmonizes the inherent dispersion of protocols and data formats of the connected devices and services.
- **Device management:** ensures the connected “things” are working properly, seamlessly running patches and updates for software and applications running on the device or edge gateways.
- **Database:** offers a scalable storage solution.
- **Processing & action management:** allows to define rule-based event-action-triggers.
- **Analytics:** Integrates some sort of analytic tools to extract information from the collected data.
- **Visualization:** includes data visualization tools.

Below we list of some of the most well-known IoT platforms, focusing on open implementations:

- Kaa[38]: Kaa is a production-ready, multi-purpose platform for building complete end-to-end IoT solutions, connected applications, and smart products. The Kaa platform provides an open,

[33] http://www.contiki-os.org/

[34] http://tinyos.stanford.edu/tinyos-wiki/index.php/TinyOS_Documentation_Wiki

[35] http://www.freertos.org/

[36] https://www.riot-os.org/

[37] https://openwsn.atlassian.net/wiki/pages/viewpage.action?pageId=688187

[38] http://www.kaaproject.org/smart-energy/

feature-rich toolkit for the IoT product development and thus dramatically reduces associated cost, risks, and time-to-market. For a quick start, Kaa offers a set of out-of-the-box enterprise-grade IoT features that can be easily plugged in and used to implement a large majority of the IoT use cases.

- Temboo[39]: Temboo is an IoT platform that provides a software stack with pre-built processes that handle common aspects of IoT applications – monitoring, data logging, notifications, remote control, and more. Temboo has a prebuilt system that can sense the water levels in a tank, and call the administrator when water levels are too low and allows to remotely refill from a reserve.
- Fiware[40]: The FIWARE platform provides a rather simple yet powerful set of APIs (Application Programming Interfaces) that ease the development of Smart Applications in multiple vertical sectors. The specifications of these APIs are public and royalty-free. Besides, an open source reference implementation of each of the FIWARE components is publicly available so that multiple FIWARE providers can emerge faster in the market with a low-cost proposition.

There are already IoT solutions that address water sustainability in cities. One example is the project that teamed AT&T, IBM and Mueller Water Products[41].

This partnership combines Echologics sensors[42] and sound technology from Mueller Water Products with AT&T's LTE wireless network to detect water pressure, temperature and leaks in urban water systems. The IBM Water Management Center helps aggregate the water data, providing a complete view of past, present and future performance.

The enhanced water management solution put forth by these companies was part of NIST's Global City Teams Challenge (NIST, 2015), an initiative to advance the deployment of IoT technologies within smart city environments. It enables cities to track information on the condition of their fire hydrants, underground pipes, and drainage systems.

## 2.4 Systems of Systems

The traditional approach of Water and City management is under a constant change. Tools like Big Data, Data Mining, IoT, Cloud Computing and many other ICT paradigms are providing new features to managers. We have seen an explosion in the adaptation of new isolated systems that manage the

[39] https://temboo.com/iot-applications

[40] https://www.fiware.org/2016/03/08/iot-fiware-along-the-revolution-of-smart-digital-services/

[41] http://www.sustainablebrands.com/news_and_views/ict_big_data/brynn_mcnally/iot_technology_helping_att_ibm_revolutionize_city_water_ma

[42] http://www.echologics.com/

resources of a utility, industry or even in citizens' homes. Thanks to the standardization of communications with the Internet Protocol, these systems have de ability of share all data and features to almost any other device or person in the world. The growing overall complexity of systems has triggered a paradigm shift and the need to enhance the classical view of Complex System Engineering towards System of Systems (SoS) Engineering. System of Systems describes the large scale integration of many independent self-contained systems to satisfy global needs or multi-system requests (European Commission, 2012).

The term SoS has arisen from the systems engineering community and reflects the interest in concepts and developments such as smart grids, integrated supply chains, collaborative enterprises, and next-generation air traffic management.

As defined in (Samad & Parisini, 2011), a SoS is built of components that are themselves systems. But the term gains specificity with two properties that the whole must possess for it to be considered a SoS:

- **Operational independence of components:** The component systems fulfil valid purposes in their own right and continue to operate to fulfil those purposes if disassembled from the overall system; and
- **Managerial independence of components:** The component systems are managed (at least in part) for their own purposes rather than the purposes of the whole.

As explained in (Cheng & Sun, 2013), from the perspective of urban structure, a city is a combination of interactive elements, such as the economic structure, social structure, and spatial structure. From a technical perspective, a city is a complex system composed of multi-field, multiclass, multilevel, and multidirectional heterogeneous subsystems for collaboratively processing different types of massive data in different areas. According to this definition, a Smart City can be considered a System of Systems.

Communication between systems has gained a lot of attention, as it is a crucial issue to take into account not only for the feasibility for physical connectivity but also for the semantics and syntax of the relying data. To Machine to Machine (M2M) communication techniques have been revised and the following subsection provides a review.

### 2.4.1 Machine to Machine (M2M)

M2M communications can be defined as a system in which individual devices capture data on events, and relay that data through a network (wired, wireless or hybrid) to an application (software program) that translates the captured data into meaningful information.

This concept is closely coupled to the idea of IoT[43][44], as Internet has become the de facto protocol for data transmission. However M2M is also an enabler for future Intelligent Systems, as it is not necessary that all data is published to Internet, but a central system orchestrator can talk to every component in the SoS architecture.

As an example[45], one can think in a M2M solution that provides remote communication with a Programmable Logic Controller (PLC) without the presence of an on-site technician. The operator can monitor and control an individual device or group of devices through a panel interface. This solution can also allow a technician to do PLC programming over the air to the remote M2M device. There is no need for a technician to go out to site to do a program change. The PLC can be configured to send data on a time interval, on an alarm event, when the storage buffer limits are reached, or when it is manually polled. Event and alarm data is transmitted to the central system simultaneously. Communications can also be set to live mode which will show real time data as the site changes.

Another example, at a remote pumping station engineers might want to monitor the temperature of three different bearings, a motor's load and its run time, the flow rate of the water and its turbidity. Retrieving this data is a simple matter of adding the appropriate data-logging hardware and one or more communications options. When the data is collected, the software can then convert this raw information into reports, each formatted appropriately for the intended user. For instance a maintenance engineer would look at current temperatures and total run times; a process engineer would focus on flow rates and volume, while an environmental scientist would check the turbidity.

Once the data is transferred to the central server, it is integrated with data from other pumping stations to produce management level reports and to update business systems.

One can imagine more similar scenarios[46] for every aspect of a water industry's and Smart Cities assets and it is clear that the relation with Big Data approaches is near as the amount of data involved is potentially massive. M2M communications mean that collecting that data, even in real time, is simple and affordable; the storage of the largest amounts of data is virtually free and there exist a lot of software suites that can help Water Managers to take better and more informed decision. For example, M2M technologies could help reduce global GHG emissions by 9.1 billion metric tons by 2020, equivalent to

[43] https://m2m.telefonica.com/blog/smart-water-the-smart-way-to-distribute-treat-and-supply-water

[44] http://www.koretelematics.com/blog/can-m2m/iot-safeguard-the-worlds-most-sacred-resource-water

[45] http://www.engineerlive.com/content/m2m-communications-brings-sophistication-water-industry

[46] http://www.environmentalleader.com/2014/06/13/qualcomm-ch2m-hill-cincinnati-develop-m2m-water-management-system/

18.6 percent of global GHG emissions in 2011[47]. These software suites powerful enough to mine that data, analyse it, highlight relationships within it and provide operators with the information they need to predict the behaviour of the complex systems that the data represents, so optimising performance. The ability of incorporating this kind of communication technologies within Urban Water Distribution Systems will be crucial for Smart City connection.

## 2.5 Cloud Computing

Web-based software services, more commonly called cloud computing or Software as a Service (SaaS), are being implemented globally by users in virtually all types of organizations, including manufacturing, government, services, retail, and water utilities. Cloud software services are bringing about rapid and diverse changes to how a water utility operates and how data is used. As new systems often require new technology resources to operate and support, utilities are finding cloud computing to be a viable alternative to investing in additional hardware. Cloud-based or SaaS platforms share several major characteristics:

- Quick to deploy
- No hardware to purchase
- Experts maintain the system so utilities can focus on their core competency
- Automatically implemented software updates
- Rapid elasticity or expansion as utility's needs change
- Subscription pricing provides a pay-as-you go option

These characteristics allow organizations to rapidly build IT resources through cloud-based software services, making it easier and less costly to adapt to changing utility requirements. The emergence of cloud-based services, however, has been met by a lack of thorough understanding of how this new model compares to the traditional in-house IT model, and how a utility might rationalize its costs and benefits. To assist utilities in evaluating this new solution for managing their operations, a brief overview of both of these topics is presented, along with information on the benefits of Advanced Metering Analytics (AMA) and planning for a transition to the cloud.

Big ICT companies such as Microsoft are collaborating with other companies as Ecolab to use cloud-based computing and the Internet of Things (IoT)[48] to help industries worldwide find solutions to the problem of water scarcity.

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[47] http://www.environmentalleader.com/2013/02/26/internet-of-things-can-cut-emissions-19-report-finds/

[48] https://blogs.microsoft.com/transform/2016/04/04/ecolab-and-microsoft-team-to-face-water-shortage-challenges/#sm.00014qp2ok2dxcowxzt20iaqhaiae

The evolution from a utility-centric system to a cloud-based, provider-managed solution, means utilities can enhance their entire meter reading operation, including staffing and skills requirements, to drive decisions on how to best allocate staff and use the additional data to proactively manage their operations and customer relationships.

A case in point is the Smarter Sustainable Dubuque research project[49] in Dubuque, USA, which uses cloud services provided by IBM -- services available to other cities as well -- to leverage apps that help residents and businesses to monitor their use of water and electricity. Having a cloud will streamline the move to more coordinated efficiency applications.

In another example, the Smart Santander (Telefonica, 2013) project in northern Spain, the country's major telecom supplier Telefonica, among other entities, has helped the city of Santander (population 180,000) to streamline functions such as sanitation and city maintenance. Not only are tasks like rubbish collection automated; citizens help speed the process with real-time feedback.

Most cities on limited budgets simply can't produce anything like this on their own; and by using cloud services, they support providers who in turn profit from offering the same sophisticated services to other organizations. Economies of scale help spur demand.

The market of cloud services providers isn’t monopolized by one supplier or type of supplier. Nevertheless, from telecom providers to research umbrella groups, sources of cloud services are diversifying fast.

For instance, a project called ClouT[50], funded by the European Commission and the National Institute of Information and Communications Technology of Japan, combines the resources of France's CEA-Leti research institute with a variety of other institutions and vendors to create smart-city solutions using IoT technologies such as sensors and smartphones along with cloud computing.

## 2.6 Geographic Information Systems (GIS) and Spatial Data Infrastructures (SDI)

A city, by definition, is a geographic entity and hence using Geographic Information Systems (GIS) as one of the key SoS for a city would help any of the actors involved in the Smart City development at all stages – planning, design, engineering, construction, asset management, operations and development, managing outage situations and during emergencies.

A GIS based framework can track a set of indicators including total energy use, water demand, waste produced, rain water volume or even the quantity of freshwater lost due to leakages. Various energy or water conservation strategies can be recombined and modelled to show the immediate carbon or water

[49] http://www.cityofdubuque.org/1348/Smarter-Water

[50] http://clout-project.eu/

footprint, as well as initial development costs or ongoing maintenance and management costs of a the current Urban Water Distribution Network for any point in the future.

GIS is also being increasingly used in the construction of Smart, Green Buildings as GIS easily interfaces with (Building Information Modelling) BIM solutions. Latest developments in 3D GIS and Indoor GIS allow creation of intelligent and interactive digital city models that makes it easy for the city planners to create "what-if" scenarios. This helps them in understanding short and long term impact of various planning decision they take.

GIS integrates hardware, software and data for capturing, managing, analysing and displaying all forms of geographically referenced information for a city. GIS technology allows a city to view, query and understand data in many ways. This is very coupled with the new technologies presented in this document, as when Big Data, IoT, M2M, SoS and Cloud systems are fully integrated in Smart Cities, GIS will provide a lot of potential, having different sources of powerful information ready for managers and citizens. For example, one could simulate and integrate data from heavy storms and then provide data to avoid floods and advance resources for emergency city states[51].

It is very easy to see relationships, patterns and trends in the form of GIS-based maps, reports and charts. GIS helps answer questions and solve problems. When viewed in the context of geography, a city's data is quickly understood and easily shared. GIS technology can be integrated into any enterprise information system framework of a city.

GIS has the unique ability to:

- Integrate data from multiple sources
- Present them visually using geography as a common element of these various data sources
- Help understand patterns and relationships between these data elements
- Informed decision making enabled by this would be very helpful while converting existing cities to smart cities or while developing new green-field smart cities

Apart from enabling cities to be more efficient and "green", GIS can play a critical role in enabling government interface where citizens can share grievances, comment on the status of city infrastructure and understand the corrective measure taken by the city authorities. Citizens can also access the city master plans and share their views on the proposed development activities.

While GIS can be used in many areas of a Smart City, Water Management can benefit of unique capabilities of GIS. Water resource assessment and management are inherently geographical activities requiring the handling of multiple forms of spatial data. Various combinations of GIS and simulation models will be required to improve our knowledge in these areas. GIS offer powerful new tools for the

[51] http://www.esri.com/industries/water-resources/flood-management

collection, storage, management, and display of map related information, whereas simulation models can provide decision- makers with interactive analysis tools for understanding the physical system and judging how management actions might affect that system.

GIS has played a major role in the development of distributed hydrologic models and in improving the understanding of the spatial aspects of the distribution and movement of water in landscapes. It has also greatly influenced the study of the impact of land use on water resources. The management of water resources requires a wide range of spatial data, from hydrography and water distribution and collection systems, representing the status of water resources, to phenomena influencing the quality and movement of water such as terrain, climate, soils, and land use.

For example, for a full ICT-oriented management, it is required an infrastructure that allows the integration of heterogeneous geographical information and sensor networks into a common technological ground. In this context 3D city models will play an increasingly important role in our daily lives and become an essential part of the modern city information infrastructure (Spatial Data Infrastructure - SDI).

# 3. Summary and analysis of the major challenges and issues

Urbanization is already a humanity challenge per se, according to (Koop & van Leeuwen, 2016) urbanization will continue in both the more developed and the less developed regions so that, by 2050, with nearly 90 per cent of the increase concentrated in Asia and Africa. At the same time, the proportion of the world's population living in urban areas is expected to increase, reaching 66 per cent by 2050 (United Nations, 2014).

In today's increasingly global and interconnected world, over half of the world's population (54 per cent) lives in urban areas although there is still substantial variability in the levels of urbanization across countries. The coming decades will bring further profound changes to the size and spatial distribution of the global population. The continuing urbanization and overall growth of the world's population is projected to add 2.5 billion (Koop & van Leeuwen, 2016).

Cities concentrate people and resources in a very small room. Currently people live in about 2% of the land surface on Earth and in this part of the earth there is the 60–80 % of the energy consumption and 75% of global $CO_2$ emissions. Close to half of the world's urban dwellers reside in relatively small settlements of less than 500,000 inhabitants, while only around one in eight live in the 28 mega-cities with more than 10 million inhabitants (United Nations, 2014).

Currently, cities infrastructures' are not prepared to handle the expected future demand and big investments are to be made. For example it has been estimated that the investments on global infrastructure between now and 2030 need to increase by nearly 60 % from the US$ 36 trillion spent on infrastructure over the past 18 years (Dobbs et al., 2013).

Water goals have big costs but also big returns. Conservative estimates of global investments in a post-2015 water for sustainable development and growth agenda have been estimated (United Nations University, 2013). Between 1.8 and 2.5 % of the annual global GDP is needed for implementation of water-related sustainable development goals. This would also generate a minimum US$ 3108 billion in additional economic, environmental and social benefits, i.e. a net annual benefit of US$ 734 billion.

In many countries, awareness of the urban challenges is low. Nevertheless, there are developments which cannot be ignored:

- The UN (United Nations, 2014) estimates that in 2025 about 2 billion people will have an absolute water shortage and that two-thirds of the world population will be affected by water scarcity. Estimates for 2030 assume 40 % more demand for water than is actually available (2030 Water Resources Group, 2015).
- The world population growth and immigration will take place mainly in cities (United Nations, 2014).

- Many cities lie in high-risk areas (United Nations, 2014). It is estimated that two-thirds of the world's largest cities will be vulnerable to rising sea levels. At the same time, many delta cities suffer from severe land subsidence
- Adequate sanitation remains a challenge for 2.5 billion people and lack of improvement will continue to lead to mortality, particularly among children (Prüss-Üstün, Bos, Gore, & Bartram, 2008).

Sustainable water management can be considered also a major challenge. This is why many organizations (World Economic Forum, 2015) have identified water-related risks as global issues in terms of both probability and impact. Included in the report there are also other Water and Smart Cities risks: Extreme weather events (e.g. floods, storms, etc.), Failure of urban planning, Water crises, Breakdown of critical information infrastructure and networks, Massive and widespread misuse of technologies (e.g. artificial intelligence, geo-engineering, etc.).

The specific challenges and issues related to Smart Cities and Water are showed in the next section these challenges have been identified thanks to the revision on technologies from Section 2 but also its been asked among stakeholders which of these challenges and issues are more relevant and also if any other can be taken under consideration. The following subsection collects all the challenges and issues.

## 3.1 Challenges and Issues regarding Smart Cities and Water Management

Although there is sustainable opportunities of ICTs use in SWM, global development in this area has been under investigation[52] and there are already some issues and challenges identified (OECD, 2014), (Hamdy, 2015). It has to be noted that most of the challenges and issues are not technical, apart from securisation and anonimisation issues (that always are a threat), most of the problems encountered for the development of the Smart City connection with Smart Water Networks are political, standardization and budget issues that have to be solved among the stakeholders involved in the development of the Smart City paradigm. Table 1: Issues regarding Smart City and Water Management connection and Table 2: Challenges regarding Smart City and Water Management connection provide a brief description of each issue and challenge identified during the revision of the technologies involved in Smart City and Water Management connection.

Also a key issue to overcome is the increase of awareness among customers and citizens of the current pressure put over natural resources, and target these technological developments as a tool for mitigating and relaxing this pressure. Consciousness raising and habit changing should be important goals to reach.

[52]https://www.linkedin.com/pulse/challenges-water-waste-climate-change-cities-kees-van-leeuwen?trk=prof-post

| Issue | Description |
| --- | --- |
| **Lack of standardization** | In spite of the efforts carried out by ITU in this field, there still need for further standardization. Standardization maintains integrity, and adherence ensures that there is compatibility, interoperability, and certain level of quality. Therefore reduction of risks (UN-Water, 2015). It is a wider problem and it has been under a deep analysis in Deliverable 2.1: Semantic Interoperability and Ontologies topical roadmap. |
| **Lack of policies** | Generally in most Countries there is no coherent multi-sectors and or multi-stakeholder coordinated policy on water management and /or conservation. For those Countries, it is needed to have an integrated policy formulation approach that integrates different governmental sectors, NGOs, CBOs, Academia, and the private sector for the success and adoption of water resources management policies on the national and regional level (UN-Water, 2015). |
| **Lack of awareness** | Awareness, proper education as well dissemination are essential for proper water resources management. Many Countries are not necessary conscious on the role of ITCs can play in water management or of it is usefulness, with little attention on how ICTs can act as an enabler of SWM on large scale. |
| **Old existing infrastructure** | Retrofitting existing water infrastructure creates challenges in terms of how to adapt existing infrastructures with new technologies at least cost for the community in order to meet current and emerging demands |
| **Leakages in urban water supply networks** | Water losses are an inevitable part of the public water supply infrastructure. For economic and technical reasons, water losses cannot be entirely eliminated. The urban water infrastructure is vulnerable owing to deterioration with age, damage from excavations or overloading. Currently, water leakage rates are not subject to any regulation other than management decisions taken by utility suppliers (European Environment Agency, 2015). |

| Issue | Description |
|---|---|
| **Aged accounting systems** | As it has been already exposed, current water distribution networks are very old. Some of them were built in early 1900s, and the range of materials used for these constructions go from concrete to wood. Accounting systems, as part of the water distribution network, also are very aged despite the fact that these systems have been under permanent updating (due to the fact that they are the only metering device used to bill the final user). However, the technology for accounting is from the past century and its logging strategy is based on human reads and estimations. To adopt new billing strategies, increase the accuracy of accounting and provide a more detailed information to the user accounting systems must adopt ICT and provide these new features. |
| **Lack of trained operators** | As explained in (Shea & Patten, n.d.), a significant percentage of existing certified drinking water and wastewater operators and managers are approaching retirement age, while at the same time there is a lack of trained and knowledgeable replacement operators for entry level positions. Moreover, the inclusion of ICT in water management increases the knowledge required for operators to manage and maintain the infrastructure. Moreover if we add the new complex Smart City paradigm, it is required for the operators to have a wide expertise ranging from water domain to technologic and ICT knowledge. |
| **Changing regulations** | Governments have the water market under constant changes, in one hand it is crucial to develop a more vibrant and competitive market. However, in the other hand, it can block the adaption of innovations due to the fear to face normative unfulfilment. |
| **Lack of investments** | Within the current economic situation across Europe, there are not major investments in research and development of such smart water systems. There should exist specific actions providing enough budget to prove that smart water networks are a good solution for economic, energetic and environmental problems and also show that with good business plans, the ROI is viable. |
| **Value for money** | There exists no clear vision of how Smart City and water connection will transform the inherent value in money. Business plans and similar initiatives should be proposed from specific stakeholder's side, for example exploiting related services or using data to provide more accurate products. |

*Table 1: Issues regarding Smart City and Water Management connection*

| Challenge | Description |
|---|---|
| **Smarter Cities** | Cities require a long-term framing of their sectorial challenges into a proactive and coherent Urban Agenda to maximize the co-benefits and to minimize their cost. We need smarter cities:<br>• Smarter cities are cities with a coherent long-term social, economic and ecological agenda.<br>• Smarter cities are water-wise cities that integrate their sectorial agendas on water, wastewater, energy, solid waste, transport, ICT, climate adaptation and nature into a forward-looking, coherent Urban Agenda to maximize co-benefits and to minimize the cost.<br>• Smarter cities implement a circular economy, focus on social innovation and, last but not least, greatly improve on governance. |
| **Smart goals** | Cities should develop a cohesive set of long-term objectives that should be Smart:<br>• Specific (target a specific area for improvement),<br>• Measurable (quantify or at least suggest an indicator of progress),<br>• Assignable (specify who will do it),<br>• Realistic (state what results can realistically be achieved, given available resources),<br>• Time-related (specify when the result(s) can be achieved). |
| **Proper ICTs governance** | Lack of ICTs governance impacts investments as well as prevents stable coordinated and comprehensive planning to address future requirements and proper integration (Water Governance Facility, 2012). |

| Challenge | Description |
|---|---|
| **Open Data** | All entities involved in water environment should see Open Data as a positive aspect to integrate in their systems. As data becomes available to the whole community; new procedures, algorithms, systems, etc. can be discovered and shared among the research and industry community which ultimately can result in improvements available by the whole water community. Actions can be initiated by legal regulations (like in USA or in Europe) adopting Open Data policies that promote and ensure easy access to data so that they can be used as often and widely as possible. For example in Europe Open Data[53] initiatives are starting to make an impact in respect to both public sector information, and scientific data, while the Research Data Alliance[54] has been established to accelerate and facilitate research data sharing and exchange at the global level. Also open access to different data sources can help to take decisions at a higher level and foster the decision taking. |
| **Open Source** | The open-source model, or collaborative development from multiple independent sources, generates an increasingly more diverse scope of design perspective than any one company is capable of developing and sustaining long term. A report by the Standish Group[55] states that adoption of open-source software models has resulted in savings of about $60 billion per year to consumers. The benefits of developing software in a collaborative manner goes beyond the economical aspect, as it has been demonstrated that open source development allows to share knowledge, adapt innovation faster, maintain projects non lucrative, increase the interoperability among software systems, and many other advantages (Lakhani & Von Hippel, 2003). |

[53] https://ec.europa.eu/digital-single-market/node/70

[54] http://rd-alliance.org/about.html

[55] www.freesoftwaremagazine.com/community_posts/creating_wealth_free_software

| Challenge | Description |
| --- | --- |
| **Real-Time Data Integration** | One specific capability that can quickly provide economic benefits to utilities is transforming real-time data into valuable information for faster decision-making in areas of the utility outside of the control room. Monitoring real-time data improves maintenance procedures because the system is automatically generating information as events occur. Using an advanced GIS system to send crews to the exact spot of the incident also cuts labour costs. Utilities can dramatically decrease the time between when an incident occurs and when the problem is fixed, thus reducing the risk and the cost associated with that event. |
| **Accurately Forecasting Demand** | Utilities rely on historical data to create a demand curve so they can properly adjust their production to ensure they are operating at peak efficiency. But by using an AMI system, that process can be automated so pumping regimens can be adapted to more accurately fit the demand. AMI still is not as widely used in the water industry as it is in the energy industry, although its ability to streamline demand curves to set more accurate thresholds will undoubtedly be one of the main pieces of the puzzle that will help utilities optimize their production and operations in the future. |
| **Improving Transparency in Water Services** | A recent report[56] states that in average European directly uses approximately 130 litres of water per day. A better access to data on water supply and treatment may help Europe use this precious resource more efficiently |

[56] http://www.eea.europa.eu/highlights/improving-transparency-in-water-services

| Challenge | Description |
|---|---|
| **Physical security of water supply networks** | Over the last two decades, as well as within the ongoing process of the evaluation of the Drinking Water Directive (98/83 EC) article 10, quality assurance of treatment equipment and materials has been a major concern and remains an unsolved legislative issue. Article 10 does require Members States to ensure the hygienic safety of materials and products in contact with drinking water and thus it is of very high relevance for consumers' health protection. But its implementation on a supra-national level (all Members States) does also require common agreements on market aspects for the free trading of drinking water products within the EU. A real functioning legislative framework covering both requirements for a high standard of consumer health protection, and free movement of goods, does not exist so far.<br><br>Security measures based on ICT such as lighting, the presence of closed circuit television (CCTV), computer based vision, sensor based alarms can increase the security of water infrastructures. If these infrastructures are also linked with other security measures in other systems it can benefit to the overall security of the City. |

| Challenge | Description |
|---|---|
| **Cybersecurity** | As its been described how Smart Water Networks can provide great benefits using technological advancements in automation, but sometimes these advancements also generate security problems, that weren't present in the pre ICT infrastructure. One of the major challenges regarding cybersecurity is often left to the discretion of the utility's Information Technology (IT) department. IT personnel are well versed at securing business systems against cyber threats, installing software patches, updating virus definitions.<br><br>In recent years, ICT technology has been associated with vulnerabilities in the "back doors" into their systems. An example can be the Stuxnet[57] virus, an extremely intelligent piece of malware that was transmitted via USB. The virus was programmed to look for a very specific type of programmable logic controller (PLC) on a specific plant floor running a specific type of procedure. If it didn't find it, it would lie dormant. When it did find it — in this case at an Iranian uranium enrichment facility — it sped up the plant's centrifuges to the point of early failure. Nearly a thousand centrifuges failed before the virus was discovered.<br><br>It is mandatory to keep the security of smart systems up to date and against cyber threats and viruses. An ICT infrastructure that is easily hackable or attackable will not succeed in the future. |
| **The value proposition** | The value of the connection of water networks with Smart City has to be increased and also shown to the involved stakeholders. There are already many benefits with great value so it is also important to highlight the value components of water monitoring and key benefits of online monitoring, including water and energy savings, increased network visibility, prevention of damages and early detection of network issues (SWAN Forum, 2012). The connection with smart city is a plus, and it can add more value by relating data from other sources like energy or transportation. |

[57] http://www.waterworld.com/articles/print/volume-28/issue-4/editorial-features/water-and-wastewater-cyber-security-strengthening-the-chain.html

| Challenge | Description |
|---|---|
| **Information about water quality and properties** | As the adoption of smart meters grow, the information available at utilities side will be more relevant regarding quality and other important water properties (such as origin, water footprint, etc.). Within this Smart City connection, this information should be spread among all City components, ranging from governance entities to citizens. This could increase the awareness and provide new business models regarding water usage. |
| **Recommendations for water saving based on water usage patterns** | At the costumer side (including industries) smart meters can provide useful information about water usage. This can be a good point for utilities to provide very specific recommendations about client's water usage and therefore provide recommendations for saving water.<br>At a more high level, taking all city water usage can also be important for implanting water saving strategies and implant new taxes (or even dynamic taxes) depending on the current state of urban water levels and environmental conditions (for example droughts or floods). |
| **Advices during natural disasters and threats in critical infrastructures** | Disasters and threats can be fight in the future with more detailed information, but also the threads of important information can be improved, providing real-time information about infrastructures among entities in charge of facing disasters but also providing recommendations to citizens accurately depending of the zones and the risk involved. |
| **Integrated DSS across Smart City systems** | Provide tools for the integrate decision taking such as Decision Support System that integrates data from different domains out of water. This could also help to the integration of water-energy decisions. |

*Table 2: Challenges regarding Smart City and Water Management connection*

# 4. Summary and analysis of the dominant solutions and trends

At the current moment some governmental agencies are fostering the Smart Water management through public initiatives and partnerships with large ICT companies. Some examples are:

- **@qua Thematic Network**: @qua is under the CIP-ICT PSP[58] Programme of the European Commission. The ICT Policy Support Programme (ICT PSP) under the Competitiveness and Innovation Programme (CIP) aims at stimulating innovation and competitiveness through the wider uptake and best use of ICT by citizens, governments and businesses, particularly Small and Medium-sized Enterprises. The approach is based on leveraging innovation in response to growing societal demands.

  In his programme frame of ICT Policy Support Programme (ICT PSP) 2011, the General Direction Information Society (DG INFSO) of the European Commission has launched a new theme network dedicated to Innovation Communication Technologies for water management. This domain represents a sector which the European Union wishes to develop during the next 10 years and it's contemplated in different initiatives of the Digital Agenda for Europe 2020 which will allow at the same time improving the user's services quality and developing a sustainable management of resources. These objectives will be achieved with the improvement of already available technologies, adaptation of the existing solutions and the identification of R&D axes to work on the next years.

  The theme network @qua it is being coordinated by the Nice-Sophia Antipolis University and integrated by 17 partners from 10 different countries of the European Union.

  @qua Innovation Network gathers thus ICT and water services leading actors from SME to majors, research entities developing competences in both sectors, local and regional authorities directly responsible for water policy and water management. Partners have developed significant expertise about the interface of ICT and water and at the same time, covering the full spectrum of the water related domain.

  Its main aims are:

  - providing a forum to exchange and to share expertise in deploying innovative ICT solutions for water management;
  - studying feasibility of standardized ICT solutions and interoperability in the field of water management across the EU;
  - developing specifications and guidelines according to a jointly defined "level of sharing" among representatives of professional sectors.

[58] http://ec.europa.eu/information_society/activities/ict_psp/about/index_en.htm

The main focus of @qua is on gathering and sharing experiences on how to overcome barriers to the introduction of ICT solutions for innovative water management and on how to ensure their wider uptake and best use. Partners have the ambition to develop and to promote the interoperability principle and the use of common standards in the water industry.

In a holistic and consistent approach, @qua addresses all the issues of the water management from resources to societal changes, using a wide range of ICT solutions: data acquisition, numerical modelling, real-time monitoring and field operation management.

@qua instigates working groups, workshops and exchanges with the aim of creating the necessary conditions and consensus on action plans, standards and specifications in view to ensure the widest future replication and co-deployment of innovative solutions. @qua provides guidance for ICT-enabled solutions and their roll-out and will highlight the remaining obstacles to be overcome.

Results and outcomes are available in the public domain and widely disseminated through various media.

The network has the ambition to become the core-group of an international association focused on standards definition and promotion.

- **The World Bank – Thirsty Energy initiative:** At the energy/water nexus, the Thirsty Energy initiative[59] of the World Bank aims to help countries begin the process of co-managing their electric and water planning. This initiative aims to address the interconnection between energy and water head-on by providing countries with 'assessment tools and management frameworks' to help governments 'coordinate decision-making' when planning for future energy and water infrastructure.

  It does so by preparing countries for an uncertain future by:

  - Identifying synergies and quantifying trade-offs between energy development plans and water use
  - Piloting cross-sectoral planning to ensure sustainability of energy and water investments
  - Designing assessment tools and resource management frameworks to help governments coordinate decision-making and enhance sustainable development;
  - Providing capacity building and knowledge transfer.

  Thirsty Energy demonstrates the importance of combined energy and water management approaches through demand-based work in several countries; and tailors approaches depending on the available resources, modelling experience, and institutional and political realities of a country. To

[59] http://www.worldbank.org/en/topic/sustainabledevelopment/brief/water-energy-nexus

ensure client ownership and successful integrated planning, Thirsty Energy focuses on building the capacity of relevant stakeholders and leveraging existing efforts and knowledge.

- **AT&T and Environmental Defense Fund – WaterMAPP:** Environmental Defense Fund (EDF), AT&T and the Global Environmental Management Institute (GEMI) have developed a set of tools and resources that can help organizations build their own program to reduce water and energy use in buildings—and save money in the process.

  The EDF-GEMI Water Management Application[60] (WaterMAPP) is an Excel-based, multi-tabbed spreadsheet with two primary components:

  - The Water Scorecard helps you assess your company's water efficiency and can be used to create visibility for water performance at facilities. The Water Scorecard Guide offers an overview of the score card concept, calculations used by AT&T in developing their first scorecard, and provides detailed information about how you could develop your own scorecard.
  - The Water Efficiency Calculator estimates water and financial savings from cooling tower or free-air cooling improvements — key data for making the water-efficiency investment business case.

  The WaterMAPP provides decision-support tools when considering various change scenarios.

- **U.S. Environmental Protection Agency – WaterSense:** WaterSense[61] helps people save water with a product label and tips for saving water indoors and out. Products bearing the WaterSense label have been independently certified to perform well; help save water, energy, and money; and encourage innovation in manufacturing.

  WaterSense partners with manufacturers, retailers and distributors, and utilities to bring WaterSense labelled products to the marketplace and make it easy to purchase high-performing, water-efficient products. WaterSense also partners with professional certifying organizations to promote water-efficient landscape irrigation practices. Since the program's inception in 2006, WaterSense has helped consumers save a cumulative 1.1 trillion gallons of water and more than $21.7 billion in water and energy bills.

[60] http://gemi.org/EDFGEMIwaterMAPP/

[61] https://www3.epa.gov/watersense/

WaterSense program grants certification labels to products that meet its water conservation standards; such products range from bathroom fixtures to sprinkler systems.

- **Global Water Tool (GWT) - World Business Council for Sustainable Development (WBCSD):** The Global Water Tool[62] is a free, publicly available resource for identifying corporate water risks and opportunities which provides easy access to and analysis of critical data. It includes a workbook (data input, inventory by site, key reporting indicators, metrics calculations), a mapping function to plot sites with datasets, and Google Earth interface for spatial viewing.

  By comparing locations with the best available water, sanitation, population and biodiversity information on a country and watershed basis, including sub-basin data, the tool allows to answer the following questions:

  - How many of companies' sites are in extremely water-scarce areas? Which sites are at greatest risk? How that will change in the future?
  - How much of companies' total production is generated from companies' most at risk sites?
  - How many of companies' employees live in countries that lack access to improved water and sanitation?
  - How many of companies' suppliers are in water scarce areas now and will be in 2025?

  Users can quickly map their locations and water use data against water, sanitation, population and biodiversity datasets and stress indicators on a country and watershed basis, with future outlook, and in turn assess risks related to their global operations, supply chains, new projects and prioritize action.

  The key benefits are:

  - Understand water use/needs of operations in relation to local externalities (including staff presence, industrial use and supply chain, water consumption and efficiency) to make informed decisions
  - Perform a first level screening through maps or charts capturing key water performance and risk indicators of water consumption, efficiency and intensity. These metrics can then be used for communication with internal and external stakeholders and reporting under corporate disclosure initiatives like the Global Reporting Initiative, CDP Water, Bloomberg and Dow Jones Sustainability Index.

[62] http://www.wbcsd.org/work-program/sector-projects/water/global-water-tool.aspx

## 4.1 Dominant Solutions

This section collects the current tools and products present in the market from different vendors for the management of water in urban, industrial and agricultural environments.

### 4.1.1 IBM – Intelligent Water

IBM Intelligent Water[63] software delivers smarter water management through insights from data to help utilities manage pressure, detect leaks, reduce water consumption, mitigate sewer overflow, and better manage their water infrastructure, assets and operations. This software uses advanced data management, visualization, correlation and collaboration technologies to transform the vast amounts of disparate data received from various devices (including metering systems), assets, systems and stakeholders into actionable information that can guide executive and operational decision-making. Intelligent Water is a water management platform that enhances infrastructure visibility to deliver an advanced level of situational awareness, event and incident management, informed decision-making and collaboration among stakeholders.

IBM Intelligent Water provides the following benefits:

- Includes the Intelligent Operations for Water component, which provides extensive visibility and situational awareness spanning water and wastewater operations. This helps improve decision-making, enhance efficiency and reduce risk.
- Includes the Water Efficiency Analytic component, which helps mitigate non-revenue water through pressure optimization and pipe failure prediction.
- Turns data from smart meters into opportunities for recapturing revenue and detecting fraud.
- Delivers insights from big data and smart devices to help operators improve irrigation, flood management and sewer overflows.
- Takes advantage of flexible deployment options by offering multiple deployment models.

IBM Intelligent Water is available in a variety of deployment options. The software can reside in a data centre. For utilities and cities with limited IT infrastructure or resources that prefer a subscription service model, the solution is also available on the IBM SmartCloud, which is a Cloud Computing (Section 2.5) platform that allows the software to run in the Cloud.

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[63] http://www-03.ibm.com/software/products/en/intelligentwater

Examples and real cases:

- China, which is on the verge of building smarter cities, has smarter water or hydropower as a key area of this initiative. Founded in 1998, Chengdu SimuTech Incorporated (referred to as SimuTech) is a high-tech certification enterprise in the IT industry. SimuTech is focused on Product Lifecycle Management (PLM) but does not have an integration platform for all the silos in a hydropower facility to interact with each other.

  By combining the IBM Smarter Water solution and SimuTech's industry solutions, SimuTech provides a "smarter hydropower" system to users. By using IBM Intelligent Operations for Water, SimuTech can build a reliable platform to enhance the value of its hydropower solution. Intelligent operations at a hydropower plant can provide decision support on several levels by using a dashboard. These levels extend from the planning phase of hydropower operations to monitoring the state of the reservoir (water levels, silting and more), energy production and beyond. Such decision support can help SimuTech determine when and how much water to discharge from the reservoir. The SimuTech solution is one of several others at the intersection of the water and energy domains that are commonly referred to as the "water-energy nexus."

- In the Netherlands Digital Delta has initiated a breakthrough innovation program in collaboration with Rijkswaterstaat (Dutch Ministry for Water), local water authority Delfland, Deltares Science Institute and the University of Delft. The goal is to harness insights from big data to transform flood control and management of the Dutch water system.

  At Digital Delta's core is an intelligent, cloud-based system that is built on IBM Intelligent Water software and the Smarter Water Resource Management solution and that includes consulting expertise. The new management system is expected to address concerns that range from the quality of drinking water to the increasing frequency and impact of extreme weather-related events to the risk of floods and droughts. With better integrated information, water authorities believe they can prevent more disasters and environmental degradation, while reducing the cost of managing water by up to 15 percent.

- Rio de Janeiro added new capabilities to further improve the city's emergency response system, and give citizens access to information that will help them better manage their daily lives.

  The city included new automated alert system that notifies city officials and emergency personnel when changes occur in the flood and landslide forecast for the city of Rio de Janeiro. As opposed to a previous system in which notifications were manually relayed, the new alert system is expected to drastically reduce the reaction times to emergency situations by using instantaneous mobile communications, including automated email notifications and instant messaging, to reach emergency personnel and citizens.

### 4.1.2 Siemens – Smart Water Platform

Siemens Smart Water Platform[64] is a proven, scalable and rapidly-deployed application platform that bridges the gap between IT and Operations, empowering water utilities to take control of rapidly-growing smart grid data volumes by quickly converting data into actionable information.

Siemens Smart Water Platform provides a proven, reliable and cost-effective solution to help utilities and cities start solving your water challenges today and across their network over the long term. The Smart Water Platform combines EnergyIP Core Platform[65] functionality with integration and an ever-growing portfolio of customizable apps. The platform seamlessly integrates with new or existing metering system, providing actionable data to help address issues before they become problems, providing new ways to engage customers and strengthen relationships, and most importantly allowing utilities to generate a more predictable revenue stream.

Examples and real cases:

- Burbank, California, is a forward-thinking media and entertainment-oriented city that requires 21st century infrastructure and technology. Home to three major movie production studios, Burbank is a high-tech city by nature and very dependent on consistent, high-quality electric and water delivery. Burbank Water and Power (BWP) provides 45,000 residences and 6,000 businesses with water and electricity. Since 1913 it has been entrusted to deliver safe, reliable and affordable public services to Burbank's citizens and business owners. In 2008, the mid-sized, community-owned utility embarked on a comprehensive Smart Grid initiative. The grid's foundation, a meter data management system (MDMS) with robust meter-to-cash capabilities, was chosen and implemented with expertise from Siemens.
- JEA is the eighth-largest community-owned electric and water utility in America, currently serving more than 417,000 electric and 305,000 water meters in Jacksonville, FL and parts of three adjacent counties. JEA sought to increase the level of benefits it was realizing from the implementation of its Advanced Metering Infrastructure (AMI) network and following an extensive business case development process, JEA decided to implement EnergyIP to support its electric and water meters. The implementation included a centralized usage data repository; equipment, asset and administrative data storage; and automated data, asset, and service management processes and

64 http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/smart-metering/emeter/Documents/SmartWater_iPDF.pdf

65 http://w3.siemens.com/smartgrid/global/en/products-systems-solutions/software-solutions/emeter/pages/energyip.aspx

tools to enable utility business process improvements. EnergyIP is integrated with JEA's existing legacy CIS, mobile WMS, OMS, GIS, asset management, and distribution planning systems.

- City of Fort Collins Utilities is a municipal electric and water utility serving over 65,000 homes and businesses in Colorado. It operates and maintains the electric system facilities which are nearly all underground. In addition, it installs and maintains the city's streetlight system. Through the Advanced Meter Fort Collins Project, Fort Collins Utilities upgraded its old mechanical, electric and water meters in homes, schools, and businesses throughout the community with electronic devices enabling two-way digital communication between the meter and the utility. The upgraded infrastructure has allowed the City of Fort Collins to provide more timely customer service solutions, use information to maintain high system reliability, and make utility operations even more cost-effective. The project is funded through the Department of Energy (DOE).

### 4.1.3 Schneider Electrics - StruxureWare for Water

Schneider Electric

StruxureWare[66] for Water provides full visibility into the complete water supply, collection, and treatment system while delivering process control and energy efficiency from field to enterprise. It permits to control, operate, and optimize the water and wastewater infrastructure from field to enterprise level. Utilities can reach operational excellence across the full water cycle while reducing energy consumption and total cost of ownership.

It is an open, scalable, and easy tool to incorporate into third-party and legacy systems, StruxureWare for Water transforms - in real-time and from shop floor to top floor - the massive amount of data into meaningful information to all stakeholders enabling the utility to make informed decision and take decisive action.

It provides a solution for the following challenges:

- Supply cleaner water via aged infrastructures without increasing costs
- Balance reduced government spending on infrastructure investment with increased regulation
- Control energy impact on environmental and financial performance
- Manage the water scarcity linked to growing urbanization and climate changes

It provides the following benefits:

[66] http://www2.schneider-electric.com/sites/corporate/en/solutions/struxureware/suites/water.page

- Increase operational efficiency by up to 25%: integrates all process control in the water or wastewater infrastructure - from electrical distribution and motor and pump control, to chemical and biological treatment, safety, and energy monitoring. By combining real-time water network data, historical analyses and hydraulic modelling, StruxureWare for Water helps reduce operation costs and service interruptions while maintaining consistent water pressure and improving water quality.
- Reduce energy consumption by up to 30%: StruxureWare for Water optimizes energy efficiency up to 30 percent by combining energy and process control data which allows operations and energy managers to work together to optimize process demands and energy consumption. In addition, it provides visibility into enterprise and network performance, displays all measurement data and KPIs in real time, analyses results over time, and identifies areas for improvement.

The StruxureWare for Water suite consists of the following software applications:

- Resource Advisor: tracks and manages the enterprise's energy and carbon costs
- Network Operation: improves water management and decision making by combining real-time water network data, historical condition analysis, and hydraulic modelling
- Energy Operation: transforms data into essential energy information and reduces operating cost
- Plant Operation: combines energy and process data to get visibility into plant asset performance to identify areas for improvement
- Asset Operation/GIS: manages and maps all network assets in powerful geographic information systems (GIS)
- Power Monitoring Expert: collects and organizes data from the enterprise's electrical network
- SCADA Expert: manages the water network based on telemetry systems that transform data into useful information
- Process Expert: integrates application control and supervision into a single environment
- Security Expert: protects people, facilities, and assets

### 4.1.4 TaKaDu

TaKaDu[67] was an early adopter of the IoT (Internet of Things) concept, aiming to create an easy-to-implement cloud-based SaaS (software-as-a-service) solution, which could analyse and process the raw data measured by sensors in the water networks. TaKaDu uses big data analytics, based on sophisticated statistical algorithms, to provide in-depth visibility, real-time detection and quick insights into every, and any, type of “event”. This includes - identifying leaks before they turn into large bursts - detecting changes and trends in water pressure, anomalous usage patterns, supply interruptions, water quality issues, identifying faults in meters, valves and other assets - telemetry issues and data availability - spotting water theft, and automatic early warning of operational issues, like open valves and zone breaches. The aim of TaKaDu is to deliver tangible water and energy savings while helping utilities improve their managerial processes and customers’ satisfaction, delivering a faster response time.

### 4.1.5 Microsoft – City Next

The Microsoft CityNext[68] initiative was created to help empower city staff and citizens to be their best. Through Microsoft CityNext, Microsoft partners offer city solutions that can help solve pressing challenges and support the goals and aspirations of health, government, and public safety organizations.

Microsoft CityNext energy and water solutions connect cloud, Big Data, mobile, and social technologies to help citizens, businesses, and governments create innovative, energy- and water-efficient solutions.

- Energy and Water
- Carbon Management
- Energy Management and Analytics
- Smart Grids
- Water and Wastewater Management

[67] http://media.wix.com/ugd/05a510_aee2a841f2794248b93634236355c3ad.pdf

[68] http://enterprise.microsoft.com/en-us/industries/citynext/

Examples and real cases:

- **Smart Grids in Issy-les-Moulineaux, France**: A consortium of utilities, building owners, software leaders, green-tech start-ups, and other companies launched IssyGrid. It's a bold experiment to see what happens when home owners and building owners have real-time data on their energy usage. The result: they reduce their consumption - and their energy bills - by 10 percent to 20 percent.

### 4.1.6 Tata - Intelligent Urban Exchange (IUX)

IUX[69] is a modular, pre-integrated software solution sold to partners and systems integrators, telecom service providers, large engineering firms and city operations and maintenance service providers - to help cities accelerate their smart city programs, easily and cost-effectively, enabling them to achieve greater levels of social, economic and environmental sustainability.

The IUX platform, built for Big Data, collects and analyses data from multiple sources (e.g. flow, pressure, and level sensors and SCADA, meter data management, water management, Geographic Information (GIS), enterprise, and Leak Detection (LDS) systems) for real-time insights and next step recommendations. It provides a common platform across multiple domains (e.g. transportation, water with additional domains to be added) for a unified urban vision and shared intelligence.

IUX permits all city systems and entities to connect among them, providing the ability to connect a wide range of devices, sensors and APIs, and applications. Tata Consultancy Services (TCS) opens up the IUX platform for partners to develop customer applications that can be used in addition to prebuilt IUX use cases for ultimate flexibility and faster time to market. The IUX's Advanced Analytics Engine (AAE) provides the capability for partners to deploy their own custom analytics models quickly and efficiently with little to no programming required. It delivers advanced analytical capabilities for all available real time and historical city data, adding value to city open data.

IUX also incorporates domain-specific data models for Intelligent Water Management and Non-Revenue Water (NRW) Reduction Performance Management with pre-built use cases designed to solve real water

[69] http://www.tcs.com/digital-software-solutions/Pages/Intelligent-Urban-Exchange.aspx

conservation challenges and deliver real results including Opex savings, Capex reduction and reliable water delivery.

Through IUX Platform APIs, this solution enables city transportation integrators and partners to develop custom applications on top of IUX platform services and resources.

The benefits are:

- Comprehensive analysis, advanced situational awareness, forecasts, 'what-if' analysis and goal based performance monitoring
- Reduction of NRW Levels and prediction of NRW loss and losses mitigation
- Enhancement of the decision making
- Maximization of the effectiveness of planned initiatives
- Reduction of leakage impacts
- Prediction of pipe failure and prioritization of preventive maintenance

It also helps at improving operations and reducing costs by offering:

- Support offline and real time integration across fragmented systems
- Improve maintenance operations
- Predict failures
- Optimize Repair Opex
- Optimize Network Rehabilitation Capex
- Reduce capital expenses with as-a-Service subscription pricing
- Reduce IT infrastructure allocation with cloud based applications accessible online or on mobile devices

The TCS IUX Intelligent Utilities solution was designed specifically for water utilities, water networks and city partners. Only TCS offers:

- Industry solutions: Our customized solutions, created by water planning experts incorporate the latest technologies and wisdom from TCS' world class R&D.
- Faster Deployment: IUX's open standards platform enables faster implementation and integration with existing systems. The out-of-the-box Intelligent Utilities Application with pre-built use cases accelerate smart water deployments.
- Lower cost of ownership: IUX's modular, architecture lets you buy only what you need now with the option to add capabilities later. The common, scalable IUX Platform extends economically across multiple domains such as water and transportation for collaborative city initiatives.
- Simplified business and engagement models: IUX offers As-a-Service subscription pricing. It's cloud-based with applications that are accessible online or on mobile devices.

### 4.1.7 Oracle – Solutions for Water Utilities

ORACLE®

Oracle offers a suite of solutions and tools for Water Utilities[70]. Among these solutions there are included the following:

- Leak Detection, Outage Isolation, and Planned Shutdown Management Tool: Oracle Utilities Smart Water Network Management provides comprehensive valve operations management, from planning and modelling through execution and analysis. Harnessing the solution's automated valve operations tool and study mode, water utilities can automate and improve emergency response, process and network efficiency, and safety.

  This tool helps to improve the coordination and accuracy of valve operations for maintenance and emergency restoration. The Oracle's network model and valve operations management tool enables operators to record valve control actions electronically via interaction with the map for real-time execution or in study mode for planning.

  Among the main benefits of the tool include the isolation of breaks to improve emergency response, to this end it provides:

  - Speed leak identification in water main segments, including loops, branches, and dead ends, via improved network modelling
  - Quickly contain leaks and bursts via automating isolation plan requests and valve control
  - Understand valve operation impact through the use of private study modes to examine scenarios concurrently
  - Extend valve reliability and pipe lifecycle by suggesting ideal operation plans
  - Eliminate water hammer, back siphoning and back pressure during restoration

  It also helps to improve pipeline operations and crew performance for planned and unplanned shutdowns, to this end it provides:

  - Streamline preplanning of large distribution valve operations sequences in study environments and real-time models.
  - For planned maintenance shutdowns, determine impacted customers and fire hydrants to allow proactive notifications

[70] http://www.oracle.com/us/industries/utilities/039809.htm

- Boost crew performance via step-by-step instructions for opening, closing, and tagging devices.
- Model the network in real time to assess contingency and land-use plans to account for breaks and emergency services

- Smart Meter Advanced Analytics for Water: this tool, Oracle proposes advanced analytics through the deployment of smart meters (Oracle, 2015). With this tool water utilities can extend their reach all the way from generation to the end customer. With smart water grids, utilities can now understand in detail how each piece of the network is stressed, connected and contributing to overall performance. The analytic tool based on Big Data techniques provides:
    - Business-relevant tools for exploration and visualization of data.
    - Relevant tools for both deep and rapid ad hoc analysis of the data.
    - Capabilities to operationalize advanced analytics to be run on a daily basis on the live data.
    - Support of data scientists familiar with both smart grid data and analytical tools to help the utility to develop and adapt the most reliable analytical algorithms.

### 4.1.8 Trimble - Trimble Unity Version 3.0

Trimble Unity[71] is a cloud-based, (GIS) centric software-as-a-service (SaaS) solution for smart water management. Version 3.0 includes new features and workflows and also offers an App Builder and new integration capabilities to simplify connecting mobile workers with maps and data from back office enterprise systems.

Trimble Unity offers a unified cloud-based and mobile collaboration platform for smart water mapping and work management to water, wastewater, stormwater and environmental water industry customers. The software is designed to automate a variety of workflows through individual "apps" that enable utilities to monitor real-time operations, deploy smart meters, assess the condition of assets, repair leaks to reduce NRW, and locate and map critical infrastructure using Trimble high-accuracy Global Navigation Satellite System (GNSS) mapping technologies. Trimble Unity can be deployed to assist utilities in reducing spills and environmental damage, extending the life of aging assets and enabling improved worker safety and productivity. These benefits enable utilities to address many of the significant challenges they are facing due to water shortages, flooding, budget constraints and environmental regulations.

[71] www.trimblewater.com/unity.html

The new version includes a variety of apps with enhanced features for automating and streamlining common water, wastewater and stormwater asset management activities and monitoring field operations. Customers are now able to use the included App Builder to create and customize their own apps, workflows and data collection forms to improve their organization's existing business processes. Version 3.0 adds new administration capabilities for managing mobile and office user roles, access rights and available apps. The product also includes new integration capabilities for allowing customers to connect Trimble Unity with their existing third-party back office customer service and asset management systems and provide a single GIS-centric field solution across their entire workforce.

Trimble Unity leverages the Esri ArcGIS technology across the product providing support for Esri GIS mapping in the office and field. Trimble Unity is available on iPhones, iPads, and Windows and Android smartphones and tablets as well as on Trimble rugged, high-accuracy mobile mapping devices.

The new version of Trimble Unity provides:

- New App Builder and Administration. Customers and partners can build custom apps, workflows and data collection forms with the new App Builder. A simple wizard-based tool walks users with admin roles through the app configuration process, allowing the configuration of GIS data, basemaps, workflows and data collection forms. Forms are built using a drag and drop form builder tool supporting various data formats and business rules.
- Smart Outage Tracing. Identify and locate valves that are to be shut off to isolate a water main break quickly. The feature also includes the capability to skip valves that are inaccessible or inoperable. The valves, hydrants and affected customers can also be retrieved and included in the workflow.
- Work Management Enhancements. Dispatch multiple work orders or jobs at once from either the work list or the map. Supervisors and dispatchers can filter and prioritize the work, then batch dispatch multiple work orders based on spatial location, scheduled date, or priority.
- Work Order Integration. Extend the work order in Trimble Unity to include additional information from third-party systems. The information can then be accessible by the field technicians using the mobile application when performing the work. Work order extensions can include customer information, meter read history, or any other information required to complete the work in the field and is not available in the GIS.
- Work Order Tracking. Track work related information including capturing labour, equipment and material usage for cost tracking. This feature can be used to configure capturing work completion codes or any list of work related information.
- Asset Work History. View the history of all forms collected on a particular asset in the GIS. Users using the Trimble Unity Web application can tap on any asset and quickly access the history of all forms collected on that asset.
- Workflow Notifications. Easily access workflow actions to quickly progress work through the configured workflow, avoiding additional clicks. Notifications are now displayed on the mobile application when new work assignments are downloaded.

- Mobile Offline. Mobile workers can use Trimble Unity on their Android, iOS and Windows mobile and tablet devices when disconnected from a wireless data network and synchronize automatically when a wireless connection is available.

### 4.1.9 OSISoft – PI System

The PI System connects sensor-based data, operations and the people who rely on data to manage process efficiency, asset health, quality and resource management. The PI System works through server-based technology and allows data to be instantly accessible to users wherever they are. As a result, you achieve end to end operational visibility.

The PI System comprises:

- PI Interfaces
    - OSISoft has developed over 400 standard interfaces to real time data sources such as OPC, RDBMS, ModBus, SCADA, OLEDB, etc.
    - PI Interfaces temporarily buffer data and then translate diverse communication protocols and collection intervals so data speak a common language.
- PI Server: Its server is very scalable being able to manage vast amount of data:
    - Collect large volumes of sub-second data
    - Store up to 20 million streams of high fidelity data
    - Provides operational context to raw data streams.
    - Organizes data by asset topology so that data retrieval is more intuitive to users across the enterprise.
    - The PI Server also includes, auto-event capture, streaming, asset-based analytics, notifications and performance monitoring tools
- PI Tools: the system also provides tools to visualize and share data and information in order to be able to take more informed decisions. PI Client Tools address visualization and analysis needs of stakeholders across the organization and include
    - Graphical displays
    - Automated analysis and reporting spreadsheets
    - Web-based, ad hoc trending that can be visualized on multiple devices

In OSISoft webpage one can find some examples of PI system applications is cities worldwide:

- Yorkshire Water provides clean water and wastewater treatment services to 4.7 million people and 130,000 businesses in Northern England, delivering its services via 65,600 kilometres of pipelines. The company also manages 650 water storage facilities, 2,250 pumping stations and 86 wastewater treatment facilities. The geographic spread of this network includes both hilly and flat territories and the company draws water from both groundwater and river sources.

Yorkshire Water uses the OSISoft PI System to help support its planned growth, because it allows the utility to view its assets in an integrated way, supporting continuous improvement of operations as a whole. After implementing the PI System Yorkshire Water realized an Enterprise Agreement would help them realize even more benefits. The PI System acts as a central translator for a wide range of device languages and protocols while providing a highly scalable infrastructure. The Enterprise Agreement provided additional support and resources for the Yorkshire Water thus furthering the deployment of the PI System, providing Yorkshire Water with a true, enterprise-wide, infrastructure. Yorkshire Water was able to quickly integrate its existing assets into the system—which includes nearly 60 technologies from more than 40 vendors.

- The City of Calgary provides safe, reliable, drinking water to over 1 million residents in Calgary, Canada and local regional customers. With its vast network of pipes, water mains, plants, reservoirs, and pump stations, City of Calgary draws, cleans, treats, and delivers water to meet its customers' water demands. The utility also manages the collection, treatment, and safe discharge of wastewater. Providing these services is deeply connected to the region's watershed. City of Calgary had been using the PI System to collect real-time data about the status and performance of its entire water treatment and distribution network, including five water and wastewater treatment facilities and more than 200 distributed field devices. City of Calgary decided to expand its PI System to monitor the watershed that feeds the municipal water system and capture information such as river water heights, reservoir water heights, flow rates, and rainfall. This new data allowed City of Calgary to monitor the watershed in real-time and better predict potential floods. Today, City of Calgary operations, maintenance, engineering, planning and enterprise users can see precisely how much water is in the system from river to reservoir to pipe to sewer using their PI System analysis and visualization tools.

#### 4.1.10 Visenti - Pipe Network Product Suite

Visenti provides a set of products in its software product suite to prevent the rate of pipe network failures and disruption and help in the achievement of normal operation. According to the needs of pipe network operators that face significant challenges in operating their complex and aging infrastructure efficiently, Visenti's product suite allows pipe network operators to reduce the pipe failure rate, improve efficiency, save time and money. The suite of software products are:

- LeakIntel™: this system identifies the pressure transients generated by potential pipe breakage and localizes the event to the faulty pipe with high likelihood.
- PascalView™: it provides on-line multi-frequency pressure data management, analytics and alerts that are critical for adequate and reliable pressure management in pipe networks.
- DataIntel™: it is the Visenti's data analytics solution, and it mines through the data supplied by a variety of sensors installed on water systems. It provides a wide range of real-time analytical capabilities to monitor, detect and notify on anomalies related to pressure variations, night flow, water quality issues, demand fluctuations and consumer-level Non-Revenue-Water (NRW) tracking for revenue protection.
- OHMView™: is an Online Hydraulic Modelling Simulator that allows utilities to run operational simulations and analyse impacts of field operations before they are carried out.

From this revision one can extract that there is a huge development in water management products ranging from very specific solutions like the ones provided by Oracle but also, there are already products developed from the Smart City point of view like the one provided by Tata. It also relevant that such big companies like Microsoft, IBM, Siemens, etc. have products for water management, this is proof of the potential gap in the market and the big necessities for such solutions.

However, there is still some deficiencies as for example the lack of openness of these products. This can be a future issue, as for example small villages or small neighbourhoods and communities cant affords such big developments. Moreover, the connection between systems can be a problem, and the use of standards should be increased so for example different products can be used from a central system without any interoperability problem. The example of OSISoft with the PI system approach in a Smart City view would really help to the integration of water management in cities.

In the other hand it has to be noted that all these products already incorporate the newest and cutting edge technologies such as Cloud Computing, Big Data, etc. As it has already been explained, at facility side it is relatively easy and affordable to adapt such technological changes as ICT infrastructures are up to date. However, there are no products that can help to overcome the technological development in water infrastructures. This can be also a problem in the future, as we have seen that technologically all stakeholders are ready (even costumers who hold very advanced devices in their day to day life), but the water infrastructure lacks of proper investments to finish this technologic change.

These future problems and views have been addressed in further sections by means of recommendations for each stakeholder.

## 4.2 Trends

This section collects a set of trends that stakeholders consider as relevant for the development of the connection of smart water systems and Smart City. These trends have been identified through the development of WIDEST project, in informal meetings in dissemination actions and meetings and also through stakeholders opinions expressed in the survey distributed in second year. These trends (Table 3) are important points in the development of technologies that should to receive special attention in the coming years.

| Trend | Description |
|---|---|
| **Progress on the integration with data and services from other sectors with common objectives** | It has been explained how OSISoft PI System can be used as a proxy among standards from different vendors. In a more general and higher layer, and taking into account all the subsystems that can be integrated in the Smart City (transportation, energy, gas, water, etc.) it is mandatory, that before all standards converge to a single one unique stack, a piece of software or product can provide this proxy functionality and act as a middleware among systems. |
| **Smart metering and dynamic billing** | One of the most promising features regarding the use of smart meters, is to be able to dynamically account the amount of water that a customer is consuming in a real-time frequency. This means that the utility can know the instant consume of a costumer and therefore (by means of aggregation) know the total instantaneous consumption. This could lead to dynamic pricing of water and instantaneous billing (or even periodic by providing water just in contracted periods of time). |
| **Integrated use of smart water meters** | The described Smart Water Network is composed of smart meters, but a coordinated operation strategy has to be designed. This is, apart from installing smart meters, the unified management of all smart meters across the water distribution network has to be assured. |
| **Network modelling which now needs a rethink if it is to be useful in the future** | With such changes in cities and water networks, the common model of distribution has to be rethought and see if it can be useful in the future, or perhaps other models have to be adopted (such as the Smart Water Grid, see deliverable 2.3: Smart Water Grid topical roadmap) |

| Trend | Description |
|---|---|
| **Integration with mobile technology** | Nowadays consumers handle high sophisticated and computationally very capable devices in their hands the most part of the day. Bringing the control of home water assets or providing real-time and up to date about their consumption can benefit both utilities and consumers who can increase the awareness about consumption, detect leaks or missuses in daily habits. |
| **Citizens does not get yet enough direct benefits from Smart Water Networks and Smart City connection** | Applications have to be provided to consumers, who can have a better impression of such changes through interesting applications which can really solve day to day problems or even provide interesting services. This will go through the implementation of Open Data standards and the development of accessible applications such as mobile apps or web applications. |
| **Real time control of the water consumption** | At consumer, utility and municipality side, the Smart Water Network has to provide real-time information that leads to a real-time control depending on the consumption, but also taking into account other parameters. This can be very valuable in cases of drought, floods or emergency city states. |

*Table 3: Trends in Smart City connection*

# 5. Specific recommendations for the best funding and research directions

This section collects some specific recommendations for the best funding and research directions. Table 4 contains a set of recommendations with its description and the challenge or issue that the recommended action addresses. Challenges and issues have been identified from Section 2: Review of the Technologies for the Development of Smart City Connection and have been presented in Table 2: Challenges regarding Smart City and Water Management connection.

| Description | Recommendations | Challenge/issue addressed |
|---|---|---|
| **Dynamic Billing** | • Implant new sensing devices<br>• Implant new accounting systems<br>• Trial runs of such billing strategies to gradually check the acceptance among clients | • Lack of policies<br>• Lack of awareness<br>• Aged accounting systems<br>• Value for money<br>• Smarter Cities<br>• Real-Time Data Integration<br>• Water-Energy nexus |
| **Water-Energy Nexus** | • Standardize communication interfaces<br>• Provide common Semantic tools for full interoperability among domains<br>• Develop methods and models capable of multi-objective optimization<br>• Increase the awareness among the citizens | • Value for money<br>• Lack of standardization<br>• Lack of awareness<br>• Lack of investments<br>• Value for money<br>• Smarter Cities |

| Description | Recommendations | Challenge/issue addressed |
|---|---|---|
| **Integration with mobile technology** | • Incentive data openness, so developers can provide application in common software repositories | • Lack of awareness<br>• Smarter Cities<br>• Real-Time Data Integration<br>• Value for money<br>• Improving Transparency in Water Services<br>• Information about water quality and properties<br>• Recommendations for water saving based on water usage patterns<br>• Advices during natural disasters and threats in critical infrastructures<br>• Integrated DSS |
| **Real time control of the water consumption** | • Provide useful applications to citizens to control water consumption<br>• Implant new technologies regarding smart meters<br>• Construct ICT infrastructures capable of processing huge amount of data | • Real-Time Data Integration<br>• Smarter Cities<br>• Lack of awareness<br>• Value for money |

*Table 4: Specific recommendations for the best funding and research directions*

# 6. Recommended actions to be taken for each of the targeted stakeholders to implant the innovations

A varied set of target groups and actors are considered in the context of the application of ICT for Water Management (European Commission, 2015). These include:

- Water entities, including those that treat water and/or waste-water, water supply and distribution system (WDS) operators, etc.
- Governments and other types of policy-making or influential organisations, including:
    - Municipalities
    - Water authorities/regulators (e.g., River Basin Authorities, OFWAT in the UK)
    - Environmental authorities
    - Non-Governmental Organisations (NGOs)
- Customers
    - Individual customers
    - Groups of customers (e.g., blocks of flats, suburbs, hotels, etc.)
    - Industry end-users
    - Agriculture end-users

One of the first recommendations for implanting the innovations is the coordination and synergies among these different stakeholders. It has been highlighted as one of the main challenges (European Commission, 2015) and, at the same time, opportunities in the sector. The rest of recommendations are listed in Table 5.

| Recommendation | Stakeholder | Challenge/issue addressed |
|---|---|---|
| • Foster the development and usage of semantic technologies such as ontologies for the syntactic and semantic interoperability among systems within Smart City | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities | • Lack of standardization |

| Recommendation | Stakeholder | Challenge/issue addressed |
|---|---|---|
| • Increase the awareness at regulatory level by acquiring opinions form experts in water domain and ICT, for example building expert groups for advising municipalities, governments and European entities<br>• Provide a long term regulatory strategy and advice relevant stakeholders about the adoption of smart technologies | • Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs) | • Lack of policies<br>• Changing regulations |
| • Increase the awareness at customer level by disseminating actions | • Municipalities<br>• Environmental authorities<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | • Lack of awareness |
| • Incentive the adoption of new technologies by supporting research projects.<br>• Facilitate by means of economic incentives the implantation of new assets<br>• Use the data provided by smart meters to target the most important parts of the water distribution network to update | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | • Old existing infrastructure<br>• Leakages in urban water supply networks<br>• Aged accounting systems |

| Recommendation | Stakeholder | Challenge/issue addressed |
| --- | --- | --- |
| • Include water and ICT studies in technical professional formations<br>• Incentive the specialization of workers by means of technology dedicated courses | • Water entities | • Lack of trained operators |
| • Provide business plans for the development of new technologies in water distribution networks and the connection with Smart City | • Water entities<br>• Municipalities<br>• Water authorities/regulators | • Value for money<br>• The value proposition |
| • Integration of accurate models capable of providing real-time information<br>• Integration of demand forecasting models<br>• Provide semantic tools to assure interoperability among systems<br>• Increase the development of Decision Support Systems for facilitate the decision making processes | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities | • Real-Time Data Integration<br>• Accurately Forecasting Demand<br>• Recommendations for water saving based on water usage patterns |

| Recommendation | Stakeholder | Challenge/issue addressed |
|---|---|---|
| • Provide backup communication networks for Smart City sub-systems connection<br>• Increase the cross-domain data sharing<br>• Provide tools for all stakeholders (including citizens) to get notifications (specific devices or mobile applications) | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | • Advices during natural disasters and threats in critical infrastructures |
| • Incentive the adoption of Open Data standards to be able to provide information in a transparent and up to date manner<br>• Provide the data using common standards<br>• Contextualize the information by means of semantic tools such as ontologies, schemas and taxonomies | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | • Improving Transparency in Water Services<br>• Information about water quality and properties |
| • Adopt common policies to reduce the damage to a critical infrastructure, its destruction or disruption by natural disasters, terrorism, criminal activity or malicious behaviour in case of attack<br>• Follow security standards in software development and implantation | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities | • Physical security of water supply networks<br>• Cybersecurity |

*Table 5: Recommended actions to be taken for each of the targeted stakeholders to implant the innovations*

# 7. Conclusions and Recommendations

As seen in Section 2: Review of the Technologies for the Development of Smart City Connection, there are still some challenges and issues that need to be addressed before the achievement of Smart City connection and smart water systems. However, there already exist solutions form major ICT vendors that go in that direction and can help in the development of such connection. Another point derived from the number products provided by ICT vendors is that there exist an interest for this kind of technology providers and thus is an empirical fact that the gap in the market exists.

Stakeholders think that citizens are mature enough to assimilate such changes, this has been certified by the answers to the survey done in the second year of WIDEST project. However, dissemination has to be done to increase the awareness and pilot plans have to be executed before a major deployment. These pilot plans can be made in areas where the acceptance is more or less assured (e.g. taking into consideration socioeconomic demographic indicators).

Table 6 summarises the actions to be taken within a stage of action. The stages are tied to short-term actions (to be taken within the following year), mid-term actions (to be taken within the next 2-3 years) and long-term actions (to be taken within the next 5 years). Also these actions are tied to some stakeholders, as not all recommendations should be taken for each stakeholder.

| Recommendations | Stakeholder | Stage |
|---|---|---|
| Provide technologic tools for the intercommunication of information among systems within Smart City | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities | Short-term |
| Disseminate guidelines and best practices in the development of smart water systems developments to reduce the costs of innovation and minimize the probabilities of failure. | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities | Short-term |
| Achieve semantic and syntactic interoperability for the provision of interfaces and date | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities | Short-term |

| Recommendations | Stakeholder | Stage |
|---|---|---|
| Provide Open Data interfaces to foster the use of data among different domains | • Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs) | Short-term |
| Establish regulations for the use of citizen data and assure the anonymization | • Municipalities<br>• Water authorities/regulators | Short-term |
| Provide a legal framework for the use of Smart Meters and guarantee the proper use of the information gathered | • Municipalities<br>• Water authorities/regulators | Short-term |
| Develop a strategic common plan by means of regulations and policies for the application of dynamic prizes in water consumption | • Water entities<br>• Municipalities<br>• Water authorities/regulators | Mid-term |
| Disseminate the use and application of Smart City and water related technologies and advances to increase the awareness among citizens | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | Mid-term |

| Recommendations | Stakeholder | Stage |
|---|---|---|
| Disseminate the energy saving results among stakeholders and citizens achieved thanks to the use of Smart Water Networks within Smart Cities | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | Mid-term |
| Execute pilot plans on dynamic pricing among selected sections of population | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | Mid-term |
| Execute pilot plans on emergency and disasters | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | Mid-term |

| Recommendations | Stakeholder | Stage |
|---|---|---|
| Execute pilot plans on advanced information about water infrastructure among Smart City users (smartphone applications, advanced in-home devices, web applications, etc.) | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | Mid-term |
| Deploy the final application of Smart City and water infrastructure connection | • Water entities<br>• Municipalities<br>• Water authorities/regulators<br>• Environmental authorities<br>• Non-Governmental Organisations (NGOs)<br>• Individual customers<br>• Groups of customers<br>• Industry end-users<br>• Agriculture end-users | Long-term |

*Table 6: Recommendations to be taken in the future*

# 8. General summary

The current Deliverable is the Smart City Connection topical roadmap which intention is to analyse the current state of the technologies that can permit the connection between smart water systems and Smart Cities, identify the barriers and challenges of the adoption of such technologies and provide a vision for the future while providing relevant recommendations for involved stakeholders in the field.

To analyse the barriers present in the adoption of such technologies this document first provide a revision of the technologies that can facilitate this connection. This revision has been done by targeting the most promising technologies by querying both the current literature and also the involved stakeholders through personal informal meetings and a specific survey distributed by electronic mail. The results of this revision can be found in Section 2.

Later, in Section 3 an analysis of the main challenges and issues identified during the revision of the technologies (Section 2) is provided. These challenges and issues can be divided into two groups: a first group which is focused in technological barriers and challenges regarding the development of Smart Water and Smart City connection; and a second group of regulatory/educational challenges and issues that all stakeholders can contribute to overcome. These challenges and issues have been used later in the document to identify possible actions and recommendations for the future.

In Section 4, an analysis of the main solutions present in Water Management community is provided. Included in this analysis there exist public initiatives that can foster the development of smart water systems and Smart City, but also private initiatives, most of them provided as products. One thing that has to be highlighted is the presence of major ICT vendors in this market. This confirms the potential gap in this market and the interest of the ICT companies. Also the trends that will help to cope with the barriers have been identified, especially these technologic trends/ideas that deserve a special attention in near future.

The rest of the roadmap is devoted to the identification of actions to be taken in the future. Section 5 targets some of the best research directions to be funded, which can help in the development of Smart City and Smart Water tools for Water Management community. Later in Section 6 recommended actions for each stakeholder are provided, these recommendations are linked to the challenges and issues that each action helps to solve while each stakeholder that is involved in the execution of the action is also identified. The roadmap concludes in Section 7 providing a 5 year vision of the actions to be taken in the future for each stakeholder.

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