ICT as an Enabler to Smart Water Management

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Abstract. Water management in urban areas goes beyond the supply of drinking water or the collection and treatment of waste water. There is a growing interest in the use of Information Communication Technology (ICT), resulting in a large number of new applications that provide access to vast amounts of information generated by the diverse facilities, unthinkable a few years ago, which greatly facilitate the operation, maintenance and management tasks in a context of efficient and sustainable urban development. In this context water management is particularly important, especially when one considers the huge growth in demand in recent years in developed areas where the water footprint is increasing. The proper use of ICTs applied to urban water management allows gathering data to know in real time about supply and demand and put this information in the hands of managers to help them predictively manage demand, or adapt prices based on the demand. Encompassing every aspect related to water management and monitoring in a global platform is known as IWRM (Integrated Water Resources Management). These IWRM systems need a large amount of information to manage, with precision, water systems in urban environments. This information falls under three main headings: generation, transport and consumption; each of them presenting different characteristics thus demanding different treatment solutions. Currently there are numerous initiatives working in the field of ICT applied to water management, some of which will be outlined in this chapter.

Keywords: ICT, smart water management, IWRM, water sensors.

1 New Needs for a New Century

Today we talk about cities of the future and the Smart City concept as a paradigm of good information management to facilitate citizens' lives and the work of those who operate and maintain the facilities that make this welfare possible. The predictions indicate that there will be an increase in the world population, concentrating especially in urban areas and cities in the next twenty years which will mean significant increases in the demand for potable water and waste water generation. Currently, water consumption doubles every twenty years, more than double the rate of human population growth [1]. Major problems affecting water in urban

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management comprise increased demand or obsolete distribution networks. Another important aspect is the influence of climate change which exacerbates weather phenomena, affecting especially big cities. Flexible systems will be needed to adapt to these circumstances and provide resource management at critical times.

For instance, to prevent floods, large volumes of water must be managed in real time to redirect the flow of water and avoid flooding populated areas. Reuse of storm water is also necessary to address periods of shortage, requiring infrastructure for high capacity storage. These situations mean more infrastructure and facilities that require more sophisticated management systems.

The new heterogeneous communication systems in urban environments support new advanced sensing platforms that collect information at multiple points and situations, sometimes requiring decision support systems for processing large volumes of data, and greatly extends the ability to control every detail, and adapt to any requirement that modern urban monitoring demands.

2 Integrated Water Resources Management

According to the Technical Committee of the Global Water Partnership, IWRM is a process that promotes the coordinated development and management of water, soil and other related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems [2]. It is therefore an integrated platform that utilizes the knowledge and participation of all stakeholders and sectors involved, as well as several technological resources and infrastructures, for the management and development of water resources in order to balance the social and economic needs, and achieve a sustainable, responsible and environmentally friendly exploitation of aquatic ecosystems. However, this definition of IWRM is aimed at social, economic and environmental challenges while current water treatment includes other considerations and issues related to current scientific and technological limitations, and the degree of development in infrastructures and services required by modern cities.

From the point of view of ICTs, IWRM can be seen as a set of technologies, services, infrastructures and communications that allow comprehensive management of all aspects of maintenance, infrastructure and control involved in urban water treatment. In this regard, ICTs play a key role by providing the technologies that enable the integrated management system, using existing infrastructures, to operate and grow using new innovations. Given these definitions, IWRM is seen as the solution to perform the following tasks:

- **Stakeholder Participation:** Allows users to know in detail their water use behavior, thus achieving consumption-oriented smart water use while minimizing costs, maximizing efficiency in water use and environmental friendliness, both for industrial and domestic users. This is possible thanks to the "Smart Metering" concept (Automatic Meter Infrastructures), with new devices and meters which allow more comprehensive readings and improved communications between users

and the central management, involving the final step of water distribution, such as housing or industrial buildings.
- **Pollution and Water Quality Control:** A proper management ensures that the best use is made of available water supplies, including protection from pollution, quality tests and control of waste waters.
- **Monitoring for Emergency Prevention and Detection:** Preventing floods and other disasters caused by water, and the ability to react faster to those situations represents a vital aspect in a well-managed city.
- **Economic and Financial Management:** Management of billing, prices and taxes charged on users in relation to water usage.
- **Information Management:** Multisource real time data access, oriented to cloud computing.
- **Smart Water Distribution:** Advanced information management on the status of the water network allows decisions to be made and action to be taken in a faster and more controlled way, dedicating the resources wherever necessary and saving resources where not needed. Includes technologies and concepts such as smart pipes or resource geo-location.

The urban wastewater networks rely heavily on staff for daily management and operational control, and automated tasks are based on legacy polling systems or synchronous communications for monitoring, limiting the interaction with the stations. In recent years, the development of real-time control (RTC), and increased automation and data collection capacity of the sewage networks, have been key factors in contributing to sustainable urban development and greater commitment to the environment. Another need in the modernization of these networks is the adoption of Decision Support Systems (DSS) to allow rapid response to disaster situations.

In many cases, the cities and the entities responsible for water management are still reluctant to implement RTC and DSS systems, mainly due to the difficulty of design and the actual level of development of sensors and communications systems. The establishment of an entire detection, management and control network is complex and expensive. This stage is where ICTs have a key role, providing the tools necessary for installation and communication systems for the infrastructures needed, integrating traditional environmental monitoring stations and new components such as rapidly deployable sensor networks, wireless communications mobile laboratories, geo-location systems for mapping groundwater resources (drinking water and wastewater distribution network, groundwater, etc.) or weather forecasting and climate monitoring systems (primarily for control of early warnings of emergency situations).

Improvements in monitoring and control systems of a city wastewater network enhances the performance and functionality of existing infrastructures, and creating new remote measurement systems increases the capacity for data collection and substantially improves the system's response to critical situations (especially in the detection of toxic substances and suspended solids in water courses, and during heavy rains). The efficiency of the entire system is highly dependent on the communications between the component parts, as well as liaison with the Central Control Station (CCS) and its ability to react automatically to any situation.

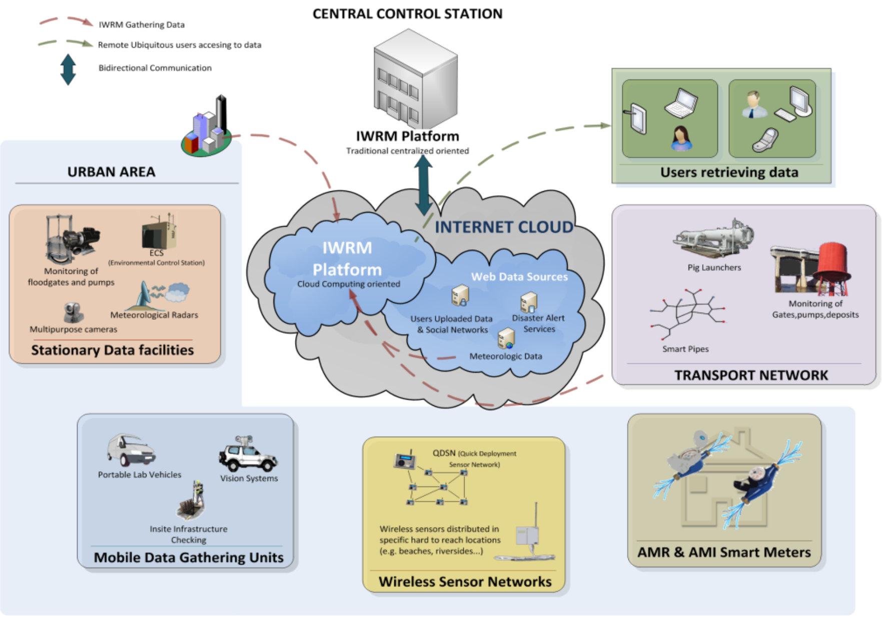

Fig. 1. Involved elements in a modern generic IWRM platform

2.1 *Modern IWRM Platform Structure*

The generic structure of a modern IWRM platform can be seen in Fig. 1, where the different sensor elements report the status and collect data continuously to be sent to the central station through a heterogeneous IP communications network. These sensor elements are grouped into:

- Fixed Stations (ECS, floodgates, meteorological radars, etc) obtaining environmental data such as water quality and pollution parameters and groundwater levels at critical points of the city.
- Mobile units that can be placed on secondary points, reducing the need to install fixed stations, which have cameras and different environmental and water quality sensors.
- Wireless sensor networks, for rapid deployments, which allow monitoring or casual tracking of areas of interest in a fast and reliable way, or fixed in hard to reach areas, such as beaches or riversides.
- Smart Meters (AMR [Automatic Meter Reading], and AMI [Automatic Meter Infrastructure]) installed at water consumption points, which exchange information with the plant, enabling readings to be taken remotely and application of variable tariffs.
- External Suppliers of weather and climatic data, or early warning systems for disasters, which reinforce the data obtained by the sensor networks themselves. Also includes uploaded data by users with private sensor networks, and other data from social networks.

- Sensors distributed throughout the water grid to control water quality parameters, state of gates, pumps, levels, condition of pipelines or enable underground resources geo-location, as well as other distribution network infrastructure control systems.

In the CCS, the management system evaluates the data received and then informs the responsible personnel, or takes decisions on any necessary action. Operators who are physically in the CCS can access all information, both historical and current real time data, and manage the system accordingly. They can also access any of the images required from the network to be used as visual support to help with decision making. Moreover, the web platform provides secure and controlled access to remote clients located outside the CCS, allowing multiple devices (laptops, tablets, and smartphones) ubiquitous access to information, which makes system management even easier for the staff.

2.2 Communication Technologies and Services

To determine which communications model is the most suitable, several factors must be taken into consideration, such as the present communications network, services and rates offered by the operator, the capacity of ECS and CCS, or the requirements from the application using the information.

To link the CCS with the stations, traditionally three architectures have been used to control communications: synchronous, requested by central or asynchronous. However, taking into account the needs of a modern system, none of these models on their own is adequate. IWRM tools must implement a hybrid communications model that supports the three types of communication defined.

Although it is necessary to have regular access to information and to obtain historical records of certain variables, the frequency of communication means that the detection of anomalies or alarms depends on the sampling time planned. If this sampling period is scheduled too often, the network becomes congested with too much information, but if the sampling period is scheduled less frequently, it loses the capacity for early detection of alarms. Therefore, it is also necessary to be able to immediately transmit alarms when the sensors detect a value outside its usual range. In addition, the CSS (or any technical or authorized agent from a remote location) should be able to request a reading of the actual values captured, regardless of the other two methods, so that technicians have the information they need available when necessary.

Regarding the access technology, the deployment of the communication networks has its main problem in the location of the stations, which are usually in remote areas, where it can be very costly, and sometimes even impossible, to lay any cable. Therefore, wireless technologies like WiMAX, WiFi or GPRS are preferred, and chosen depending on capacity requirements of the links and the characteristics of the scenario (depending on the location of the station, factors such as surrounding obstacles, harsh weather conditions or saturation in licensed and free radio bands can severely impair the quality of some links, favoring the choice of GPRS, with less bandwidth capacity but more robust to interference in the channel, or WiMAX, in case of long distance high bandwidth link needs).

With regard to services and added value that can be provided by a modern communications system, the latest trends and technologies that are already being implemented in the exchange and access to information in general should be considered, but focusing in the field of management, control and maintenance platforms for cities, Cloud computing and M2M communications stand out.

The M2M (Machine-to-Machine) communications are defined as the intelligent connection of two devices, through any channel, where the devices are in charge of giving meaning to the information exchanged, for instance, the connection between remote sensors in an ECS and the CCS computer.

Cloud computing is a base technology for smart cities applications. The diversity of communication methods (wireless, fixed network, mobile networks), as well as different data formats, network topologies and architectures, hinder the transmission of information between the different parties involved, ranging from a remote deployed sensor up to the final user's laptop. Moreover, the treatment of such wide and varied information poses new challenges, such as developing the tools for analysis and visualization of information, or addressing security and privacy issues, that represent a priority for data exchange applications. Everything is managed in real time so that the different managers involved may generate an immediate response, establishing appropriate service levels for each situation.

To deal with the management of large volumes of information, along with the changing needs of the cities, it is necessary to have technologies that facilitate the treatment of data and its subsequent homogenization for storage. In this scenario, a Smart City Cloud (cloud-based solutions for smart cities) model provides an intelligent and sustainable end to end platform, based on the deployment of smart sensing and acting systems interacting with the Cloud services, in the areas of energy efficiency and Intelligent Infrastructure, among many others. By using standards in communications and APIs, a number of specifics about sensors, sensor data models, and Web services for sensors can be set to allow devices to be accessible and controllable over the network [3]. Cloud computing advantages can be summarized as:

- Management of large volumes of information.
- Ubiquity of the information: accessible everywhere.
- Agility in the supply and acquisition of new services.
- Innovative technologies evolution.
- Elasticity: adaptable to the needs of the moment.
- Does not require large initial investments.

Developments of cloud platform projects are supported by world renowned companies such as IBM, Cisco or Microsoft. Many other simpler examples and projects of cloud computing can be found around the Internet, handling thousands of data streams, showing the variety of applications and the enormous benefits that cloud computing can provide. Examples include platforms such as Cosm (formerly Pachube), which is used in Japan to monitor radioactive contamination in water in different locations, and where any citizen can participate by sending information.

3 Pollution Control

In the field of water treatment, a major area, which generates a constant flow of information and priority data needed for proper water distribution, is the control of water pollution [4]. The percentage of fresh water available for human use is only about 0.007% of the total water on the planet. This is a vital resource which is becoming increasingly scarce as water pollution renders these resources unusable in the worst case scenario. In addition, poor control of water quality can lead to serious health risks in the affected areas (80% of diseases in developing countries is caused by contaminated water), and discharge of contaminated water into the sea, rivers and lakes seriously affects the ecosystem. Thus the control of water pollution is necessary for sustainable development and maintenance of any water distribution network. The water analysis must be carried out on several fronts:

- Domestic sewage.
- Industrial waste water.
- Agricultural waste water.
- Urban runoff (Storm water).

Concerning storm water treatment, both in urban pipelines (since in modern sewage systems, rain water run through different pipes to wastewater to prevent further contamination of the more pure collected water) and in reservoirs, water must be analyzed, since the measurement of water quality is essential for a water distribution network in a city. Similarly, domestic sewage and water flows resulting from chemical processes and waste in industry and sanitation should be monitored as closely as possible to the possible sources of pollution, and also in water treatment plants that purify the water to decontaminate it before releasing it into the sea (or other large bodies of water), or be used for other applications such as irrigation, and to detect possible toxic or radioactive discharges. The main sources of pollution are industrial toxic waste, leaking sewage networks affecting the drinking water supply, suspended solids, or pollution in the storm water collected. Therefore it is necessary to have adequate tools to analyze the quality of water which in turn are capable of providing the water management platform with all this information in an efficient manner, which allows a continuous monitoring of the water status belonging to different types (sewage, rain water), and allow action to be taken and decisions to be made in real time according to different scenarios. Each type of water requires a different treatment depending on the most affecting pollutants: BOD (Biological Oxygen Demand), pH and suspended solids in domestic sewage; or heavy metals in industry wastewater. Modern sensors are capable of analyzing the water chemistry parameters remotely, and video streams from cameras detect the presence of foreign solids, using artificial vision, thermal imaging and temperature control, in order to differentiate the response depending on the data.

3.1 Fixed Location Control Systems

To do this, ECS (as in Fig. 1) are located at specific points to take these measurements: at the outlet of wastewater treatment plants, industrial parks, urban storm water collection points and other locations of interest. These fixed stations typically have a direct connection to the plant, either by cable or through wireless communication, and also include actuator elements. The stations continuously report the water status sensed to the central management platform, which records and analyzes the data, and can make decisions in real time over the distribution network map, for example to prevent a contaminated water source extending over the distribution network, cutting just the right pipes and minimizing the overall impact on the distribution network.

3.2 Mobile and Portable Control Systems

Another useful tool provided by the new technologies is the ability to monitor inaccessible and distant locations and points of interest, where it is not feasible to have a fixed station. Thus, it is possible to build a network of sensors and cameras (to detect solids in the water stream) in order to capture the essential information during specific situations or for short periods of time when and where necessary, without extra cost on infrastructure and maintenance. This network is composed of wireless nodes with multi-sensors (each sensor can monitor a particular parameter), which communicates with the plant during their task.

For more specialized and accurate measurements on water quality, there are mobile units that have small chemical laboratories where water samples are collected and analyzed and then results are sent to the CCS. Sensor technologies and water quality analyzers are constantly evolving to offer better and more reliable results [5]. All data collected by sensor networks and mobile stations is received and stored in the CSS, where the information is monitored in real time, so the system starts necessary actions reacting to any alarm condition or to take preventive measures.

The CCS has all the necessary tools to process the information automatically. By having a model based on cloud computing, information is processed and accessible from anywhere (authorized by the entity responsible for management) so that technicians can monitor the water quality remotely or set alerts when a parameter surpasses normal limits.

4 Infrastructure Control

The water distribution network is included in the Critical Infrastructure group, since in case of damage it can cause serious physical and economic damage to the operation of a city or state. The deterioration or malfunction of the infrastructure related to the distribution, collection and storage of water could represent, in the worst case, cuts in drinking water for the population, losses of this valuable resource, or even disasters caused by water running outside their usual channels. Examples of the actual amount of water supply of a city or state that is lost through leakage can reach very high values: up to 20% in the municipalities of Canada, 20% in the UK, Spain, Malta and the Czech Republic, 25%, in Rome, and almost 50% in London and Vietnam. [6]

It is therefore essential to perform a constant maintenance and control on the water distribution network.

Traditionally, the maintenance of this infrastructure is costly and inaccurate. The state of a pipeline network is not easy to check, since access to the pipes is problematic if not impossible. This is why fissures or structural damage are often undetectable until leaks are spotted from the outside. Moreover, the process is slow because the technicians have to find and repair the damage manually. Moreover, the discharge of oversized solids can cause partial or complete blockages in pipes, negatively affecting the pressure of the water present therein, in addition to causing supply cuts.

Common methods of control have been based on the monitoring of the infrastructure by technical personnel, leak detection from pipelines outside, or by using the more sophisticated "Pig launchers", also frequently used in gas pipelines. In this case, there are certain locations or access points (called "launchers") to the water streams and pipes, from where devices called “Pigs” (bullet-shaped devices carrying sensors) are inserted, traversing the network to collect information on the state of the interior pipe walls and other structural parameters. At the end of a certain route, the device is removed through one of those spots (this time called "receiver"), and turns over the information stored in the central system for analysis. The drawback of this method is still the time involved while the device to finishes the journey along the pipelines and the data collected is retrieved.

To make things easier for the technicians, at those facilities or locations where it is necessary to check the status of the infrastructure on an occasional or regular basis, but where access is difficult, mobile units, as described in the section on pollution control are introduced as part of the data gathering elements, moving to the indicated locations, and using special cameras to collect the necessary information and transmit video stream in real time to headquarters. They are cameras that can be introduced in pipes and channels, operated by remote control, by both on site technicians and remote technical personnel at the CCS (see Fig. 2).

Other technologies in development are the so called "Smart Pipes" [7]. In this case, and inheriting the concept of monitoring the network of pipes from the inside the Pig Launchers applied, a network of sensors is introduced inside the water pipe network,

Fig. 2. Video Surveillance Interface (left), and remote controlled cameras (right)

capable of real-time reporting on the status of integrity of the walls, leaks and cracks detected, or water pressure and temperature, and always accurately locating the critical spot on an exact map of the network. Thus, the management platform is able to detect, prevent and act much faster and more accurately in the case of damage detected in the infrastructure. Following this methodology of monitoring to detect leaks in the piping, there are also other examples, already being implemented, such as in the Spanish town of Asparrena (Álava) [8], where they have a system based on the division of the network pipes in several areas that are hydraulically independent. Thus, it is possible to measure continuously the flow rate and inlet pressure of each sector. Data is transmitted in real time to the CCS and mobile phones of technicians, allowing immediate action, and has reported promising results, saving 48 million liters of water in 10 months.

5 Smart Metering

The technology that enables automatic capture of consumption information and its integration with the IWRM has been constantly evolving, from AMR systems, through AMIs and on to Smart Water Metering.

However, the current reality does not reflect this, as the vast majority of cities have still not adopted remote reading technologies for water meters. Generally, *mechanical accumulation meters* are used, which provide a single measurement of the accumulated consumption up to a particular moment (absolute values). Obtaining consumption data by the distribution company is carried out by periodic visits by operators to each of the meters in their area, who take a reading of total consumption via a visual inspection of the meter. This is an extremely rudimentary system, which does not allow advanced management of the network due principally to problems such as:

- Human error in meter readings.
- Problems of access in order to read meters.
- Cost of human resources to take meter readings.
- Long intervals between readings for the same meter (in many cases, several months, due to intermediate readings being estimated).

Mistakes or lack of precision when making management decisions for water systems may lead to serious problems for such an important resource, such as cuts in supply to large cities or water wastage, both of which make it vital to eliminate all errors and to obtain precise data cheaply and in real time. In this point, the automation of meter reading has become a necessity for modern cities.

5.1 Evolution on Meter Readings Acquisition

In a first approach to these systems of automatic meter readings (or AMR), the *mechanical accumulation meters* were complemented with a system with datalogger and communication equipment, which allows readings to be taken using portable equipment (*walk-by*) or using vehicles (*drive-by*) which circulate through the streets of a city, scanning the nearby meters. This system eliminates errors in readings and problems of access to meters. It also reduces the costs associated with reading meters and problems of periodicity. The evolution of these systems has been driven by the change from the classic water meters to *pulse water meters*, which register the reading when a certain consumption is reached (for example, every 1L, 10L, etc.), which when combined with the datalogger and transponder system, and used from a vehicle, can provide more accurate water consumption information.

The next step in the automation of meter reading is the elimination of the intermediate vehicle to allow direct communication of readings to the central office using GSM/GPRS communication. However, this is a fairly costly solution due to the expense of using the public network, and is impractical at a residential level due to the high number of meters which need to be monitored. Water companies have evaluated a range of solutions to this problem, such as connecting groups of meters using industrial communication buses (such as M-bus or Modbus) and later via RF, and then communicating with the exterior via a single transmission point per area, thus reducing communication costs considerably. These systems offer the water suppliers instant access to meters, meaning it is then possible not only to take readings, but also to take action on the meter, thus creating a new Advanced Measuring Infrastructure (AMI). This marks a real step forward from the original "one-way" systems towards more advanced "two-way" systems.

Nowadays, AMIs have evolved to a point where they allow real time communication at a much lower cost, through technologies which eliminate, or reduce dramatically, the need of telecommunication providers. The use of private networks allows more frequent access to information without additional cost, which in turn means more effective management of water supplies by staff who now have precise information on how the system is working at all times. This concept, combined with a trend towards the new generation of meters known as *Interval Water Meters*, which allow more precision in taking measurements (they register readings for periods of 15, 30 or 60 minutes instead of registering when a specific volume of water has been used), are opening the path to the use of Smart Water Metering (SWM), whose principal benefits are:

- More frequent billing based on real readings.
- More precise detection of leaks (in both space and time).
- Improvements in measurements and capacity to detect back-flows.
- Contributes to the development of environmental awareness.
- Improvements in control efficiency.
- Option of variable tariffs.

Smart Water Metering is not only a new way to automate readings; it will also help to involve the consumer in water use management. Consumers will be more aware of their own consumption, leading to a more responsible use of water resources. Smart Water Metering contemplates connecting the meter to the Home Area Network

(HAN), and the communication with other domestic devices, meters or consumption displays via Zigbee Smart Energy 2.0, even allowing one to make decisions based on the electricity network load and demand. Additionally, the distributor can offer services to users via their web page. These services will include knowing their residential consumption in real time.

However, all of this leads to a high level of complexity in communications. Currently, the options proposed to deal with this are: the use of private RF technologies, principally over licensed bands reserved for automated meter reading systems, or using other cabled networks, such as the electrical networks. One of the current proposals is to combine electric, gas and water meters and integrate them in Smart Grids and communication through PLC technologies, such as G.hn. For example, in 2009, IBM began a 5-year project for the Enemalta Corporation (EMC) and Water Services Corporation (WSC), Malta's national electricity and water utilities, to create a SmartGrid system to monitor, throughout the country, all water and electricity meters. This project [9] involves changing and updating the meters and their integration in advanced IT applications, allowing remote monitoring, management, meter reading, identification of cuts in service, pre-paid services, localization of leaks and rewards to customers who consume less energy and water, all in real time. Another option for reducing costs is to connect the water meter to the supplier via the consumer's HAN with its domestic access to the internet, offering advantages in terms of billing and additional services, given that most homes now have internet access.

5.2 Smart Water Metering Standardization in Europe

Many governments understand the potential of Smart Metering and its benefits in terms of reducing consumption. The European Union, through its mandate M441 [10], requested to the European standardization organisms (CEN, CENELEC, ETSI) to generate standards to support these technologies. Currently, there is a diverse range of proposals in existence for the standardization of a Smart Metering model, even including a proposal for the standardization of a unified system integrating water, gas and electricity. The Open Metering System Specification (OMS) [11] is the first definition of this type developed by industrial associations (German Gas and Water Industry Association), the KNW and the ZVEI (German Electrical and Electronic Manufacturer's Association). Their objective is to define a complete infrastructure and standardization solution for metering devices. This proposal was presented to the European Committee for Standardization (CEN) with the aim of establishing it as the European standard. Moreover, this proposal includes the standard EN 13757 which deals with the transmission of data between Smart Meters and concentrators.

The OMS establishes an infrastructure of 3 levels for secure communication between the smart meters and the water distributor.

The first level defines communication between the smart meter and the Multi Utility Communication device (MUC), a device which concentrates data from a range of meters (for example, all the meters of an apartment building, or meters for a range

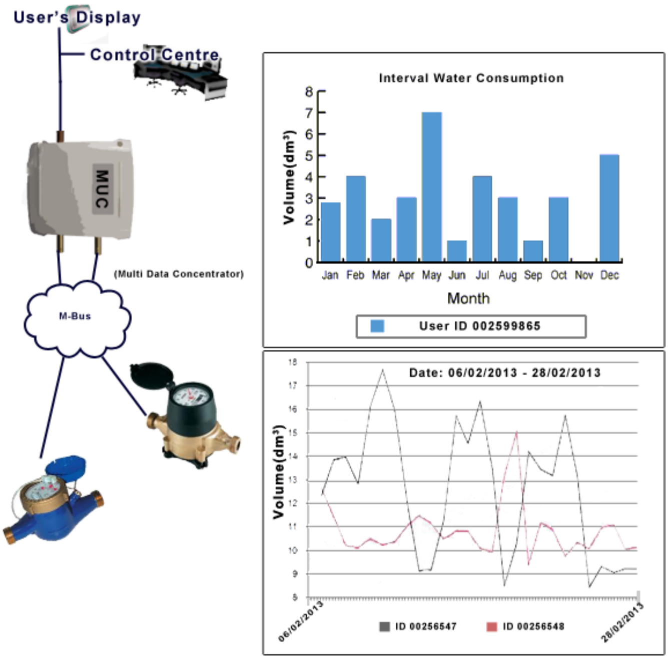

Fig. 3. AMI and AMR smart meters upload water consumption data to the management platform

of resources). This communication is carried out using the standard M-Bus (EN-13757), which supports communication over copper twisted pair or wirelessly (EN 13757-4) over the open VHF bands 868 and 433 MHz, and more recently, the band reserved for gas, water and electricity meters: 169MHz (according to EC DEC/2005/928). This band allows power of up to 250mW, reaching up to 300 meters in urban areas and up to 2 km in rural areas, and battery life of up to 14 years. In other situations the MUC can be integrated with the meter, eliminating the primary sub-network.

The second level constitutes an extension of the first level through repeaters or with the MUC themselves and multi-hop routing protocols. As there is not, as yet, a specified routing protocol, the use of proprietary protocols is permitted.

Finally, the third level establishes communication between the MUC and the office of the distributor via TCP/IP technologies such as DSL, GPRS and PLC.

There is still much work to do for Smart Water Metering to be extensively used, and to show added values to final users (like variable tariffs, or information on water quality, all this being available in real time in the home). However, this technology does have its detractors [12] who point out disadvantages such as:

- Loss of privacy: it is possible to extract information on patterns of use for each consumer.
- Danger of possible monitoring by unauthorized third parties (insurance companies, press, law enforcers, etc.).
- Greater security risks for the network and its meters.

However, these are problems that will be surely solved in time, given that this type of metering has become a must for the future of efficient water management.

6 Monitoring in Emergency Situations and Decision Support Systems

As well as the normal, seasonal management of water networks, there is another important factor that must be considered: emergency situations. For example, continuous rains, or even worse, short bursts of heavy rain, cause breaches of water courses and flooding of crossings, which may cause huge amounts of material damage and even casualties. Early warning systems involve four elements, which need to be supported by governance, coordination mechanisms from national to local levels, and by appropriate infrastructure. These four elements are:

(1) **Risk knowledge:** Risk assessment and mapping will help to set priorities among early warning systems needs and to guide preparations for response and disaster prevention activities.
(2) **Warning service:** Constant monitoring of possible disaster precursors is necessary to generate accurate warnings on time.
(3) **Communication and Dissemination:** Clear and understandable warnings must reach authorities in a fast and reliable way. There are some regulatory barriers to take into account, and these need to be coordinated across many agencies at national to community levels for the system to work.
(4) **Response Capability:** Communities must respect the warning service and should know how to react. Crisis management groups and Decision Support Systems would help with this task.

The Hyogo Framework for Action (HFA) [13] is a 10-year plan (2005 – 2015) adopted by 168 countries of the United Nations in 2005 at the World Disaster Reduction Conference. It is an extremely important reference and deals with risk reduction policies that help countries deal effectively with these disasters to reduce loss of life and material damage. According to the HFA, the starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge. Disaster risks related to weather, water, climate variability and climate change, are addressed in sector development planning and programs as well as in post-disaster situations. At times of disaster, impacts and losses can be substantially reduced if authorities, individuals and communities in hazard-prone areas are well prepared and ready to act and are equipped with the knowledge and capacities for effective disaster management.

6.1 Decision Support Systems

Water management departments usually dispose of some form of crisis management group for critical situations. The main problem they face is the lack of information available to help with decision-making processes. The use of DSS (Decision Support Systems) has an essential role in these cases, and there are currently a number of projects aimed at developing more advanced and intelligent DSS to better deal with this type of event. For example, the *Neptune Project* [14] is a project led by the Centre for Water Systems based at *Exeter University* which is working alongside two leading UK water supply, technology and automation companies: *Yorkshire Water Services* and *United Utilities*. In this project, a DSS is under development that is capable of supporting complex decision making to improve the operation of water supply and distribution systems, coordinating asynchronous information in real time to offer solutions to some of the common problems of water distribution networks. The Decision Support System uses a two-stage approach: data collected from all the sensors is filtered initially by the system to remove all unnecessary information, and the remaining data is presented to the operator using a two-screen approach to aid his analysis of situation and improve risk-based decisions. The first (master) screen displays the current state of the network and the alarm conditions, if any of these are available. The second (slave) screen presents the Neptune-project specific outputs generated by the framework and associated tools. Using this technique together with *Intervention Management* procedures allows fast, reliable action plans to be generated in order to resolve any technical difficulties. *Intervention Management* focuses on designing fully functional impact reduction strategies and incident isolation techniques to be used in the risk-based decision making process. *Intervention Management* is divided into two stages:

- Incident isolation (primary-immediate interventions)
- Impact reduction (alternative interventions)

The first stage forms a situation report, analyzing each event (pump failure, pipe burst, etc.), and presenting possible actions to be taken by an operator using a Decision Support System screen. In the second stage, the possible actions are analyzed, to detect any changes in the system and to find possible better solutions, in order to reduce the impact on customers.

In spite of the advanced development of the DSS used, the problem continues to be a lack of data from sensors or that the data obtained is of poor quality. There is now a genuine need for better, more efficient sensors which need less maintenance and which are smaller and more economical. Advanced sensor and detection systems would allow more precise action on critical situations, avoiding or minimizing their consequences or even preventing them completely.

6.2 Monitoring through Fixed Infrastructure

The essential degree of monitoring in these cases focuses on the installation of cameras and sensors distributed over fixed locations. In cities, it is normal practice to monitor rainfall, floodgates and levels in water channels and tunnels. This monitoring provides valuable information during periods of drought and flood. Real time control and monitoring systems have been around for several decades, but their general implementation in already existing infrastructure is unattractive due to cost issues. However, wireless sensor networks allow a wide range of low cost applications that were not previously possible with cabled networks. Placing these sensors at fixed locations makes it possible to obtain information from a wide range of locations at a greatly reduced cost. For example, in [15] the information from a wireless rainfall sensor network is used to create a flood model that will help to predict possible risks with much greater accuracy than has been possible with other systems. The "*Flood Watch*" system of DHI [16] integrates real-time data and forecast modelling tools seamlessly in a resilient and robust client-server environment that encompasses sophisticated – yet easy to use – tools for data management, monitoring, forecast modelling, decision making and dissemination. The system is often used by regional and local river basin authorities to provide real-time forecasts in areas prone to flooding and to issue early warnings to flood response managers and the public. Within the field of reservoir operation, the system is typically used to forecast inflows and the appropriate release of water. The decision support facilities can be used to assist in developing operational strategies and optimizing power production or water use.

An interesting foresight element in cities prone to flooding is the incorporation of a meteorological radar to the system. This radar would help generate alerts from rain-bearing clouds before the flooding actually takes place. This is the case with the Quebec Urban Community RTC system [17], a management system for residual urban water that operates in real time and which uses distributed sensors, radar generated rainfall predictions, variable optimization algorithms for the resolution of equation systems and monitoring of floodgates and water courses.

Meteorological forecasting and detection through overflow and flood sensors allows affected areas to be evacuated in time to avoid tragedy, and also allows operators to effect counter-measures to re-channel flood waters. An example of this is the use of automated actuators that enable use of the drain system as a linear storage system for rain water, thus avoiding massive dumping of excess rain water into rivers and seas [18,19].

Urban areas close to dams can also dramatically improve the safety by implementing new monitoring technologies, such as the UrbanFlood project set up by the Ijkdijk Foundation in the Netherlands. UrbanFlood [20] is a project to develop intelligent dams that eliminate the need for continuous visual inspection through sensor networks that monitor, among other parameters, pressure in the dams, movements and displacements (using textile optical fiber), and the internal and external temperature. The system transmits values in real time for early prediction of critical situations such as flooding and damage to dams, as well as enabling more effective management and decision making (in the project FloodControl 2015).

Another type of risk situation which requires preventive monitoring is the contamination of water supply to households. Distributed real time monitoring of contaminants and sediments accumulation in water for domestic consumption, as well as quality parameters or the existence of bacteriological contamination (such as Legionnaires disease) allows preventive measures to be taken which are extremely important due to the potential impact on the health of the population. In the USA a range of programs of this type are being launched to allow early warning or even cutting domestic water supplies in the case of contamination of the water network. Blue Box Tool [21] is a good example of a real time water management system for early detection, alert and recovery, that deals with drinking water quality in the public network. This system significantly reduces false alarms, offering a more precise, sensitive and trustworthy service. Water quality is not only a problem in developing countries, the sustainability of European water supplies are also at stake due to factors such as pollution, over-use of resources, damage to aquatic eco-systems, climate change and other safety aspects.

Water contamination affects not only water destined for domestic consumption. Coastal cities which have beautiful beaches as their principal tourist attraction may suffer serious pollution catastrophes which affect their inshore bathing water. COWAMA [22] is a DSS system for these types of waters. It is based on simulation of flow and contamination, possible direct dumping of contaminant materials into the drainage system, water treatment and water outflow into the sea. This system allows the prediction of magnitude and duration of contamination episodes, and is an effective warning system for bathers. Furthermore, this system allows more efficient planning of infrastructure to reduce contamination episodes.

6.3 Monitoring through Mobile Infrastructure

However, there are situations in which it is not possible to maintain fixed monitoring infrastructures. This may be because the variability in the points to be monitored is very high, or due to questions of resources or property. In these situations, monitoring vehicles and rapid deployment sensor networks become vital tools for risk prevention.

Environmental monitoring vehicles have sensors and cameras capable of real time transmission. They can be deployed in areas that are not permanently monitored in order to sense a range of environmental parameters, water quality or even to use their cameras to send real time images of the state of sluices and floodgates, dams and obstructions in water courses, etc. to the central station. This data constitutes an important source of information for the crisis management group, who will then be able to base their decisions on more objective information.

Quick Deployment Sensor Networks (QDSNs) [23] also give huge advantages in critical situations and in environments without sensors or communication infrastructure. While traditional wireless sensor networks require specialized staff to carry out their installation, (pre-planning, coverage studies, network analysis, role assignment, topology design, etc.), quick deployment sensor networks include tools that help in the deployment phase so that a complete network can be set up in a very short time and without technical knowledge of the system. The tools of the QDSN mean that personnel can be sure that the point that they want to monitor has coverage, without the need for any prior planning or post deployment checking. Thus, a network can be set up much more quickly than is possible with other systems, both cabled and wireless. Once the infrastructure has been set up, the personnel will have new, valuable, real time information on the states of flood gates and sluices, flooding, water mixtures, pipes and water courses, pumps, extent of contamination and environmental measurements. Moreover, rapid deployment sensor networks allow the network to be dismantled and set up in a new location quickly and efficiently, allowing data to be collected from different areas around the city in emergency situations in an agile way and with a minimum of personnel.

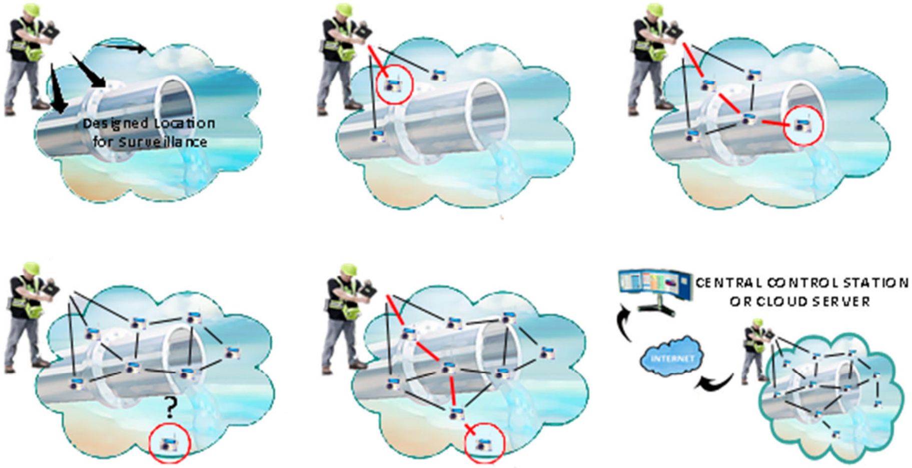

Fig. 4. Quick deployment of a wireless sensor network to collect data in provisional critical locations

7 Conclusion

While there are many challenges faced by smart sensors in the context of water quality monitoring, it is important to remember that sensors themselves are not standalone devices. Instead, they require a wide range of support from ICT, some notion of which has been discussed in this chapter, including data transport and storage, data evaluation and also appropriate presentation. We also see that platforms such as IWRM require a variety of sensor types and supporting technologies in order to accommodate fixed and remote sensing in addition to functions such as smart metering and disaster management: there is no "single-fit" solution for each situation. Thus, it must be recognized that ICT has an important role to play in the monitoring of water quality in order to ensure key objectives are met, including stakeholder participation, pollution and water quality control, monitoring for emergency prevention and detection, economic and financial management, information management and smart water distribution.

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