SMART WATER GRID

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Abstract

The total availability of water resources is currently under stress due to climatic changes, and continuous increase in water demand linked to the global population increase. A Smart Water Grid (SWG) is a two-way real time network with sensors and devices that continuously and remotely monitor the water distribution system. Smart water meters can monitor many different parameters such as pressure, quality, flow rates, temperature, and others.

A review of the benefits of Smart Water Grids is presented in the context of water conservation and efficient management of scarce water resources. The pros and cons of a Smart Water Grid are discussed in the context of aging infrastructure. Current distribution systems have large leakage rates. Locating leaks, missing, and/or illegal connections can lead to increase in revenue. Updating or replacing parts of the current infrastructure can be very expensive. SWG cannot substitute for basic water infrastructure. However, these costs could eventually be offset by savings obtained from their implementation. Setbacks include higher costs and a lack of economic incentives. In some cases, a lack of public awareness resulted in negative public opinion. Some citizens might be concerned with health problems and ailments associated with wireless transmission of data.

The reliability of quantity and quality of water at the source is also discussed in relation to the network vulnerabilities. The interface of Smart Water Grids with natural systems such as rivers, lakes, and reservoirs is also a key component of a “smart” approach to the use of water resources. These natural components are subjected to climate variability and single events can disrupt daily operations. Floods, droughts, and disasters such as typhoons and forest fires can affect the water quality at the source. Robust systems should have alternative supply sources when facing scarcity of resources or changes in water quality/contamination. Deep understanding of the network vulnerability and preparedness for disaster prevention may also contribute to the “smart” reputation of water distribution systems.

Several projects worldwide have implemented Smart Water Grids into their water distribution systems and have seen promising results. These meters helped to monitor many variables, decrease water losses as well as promote water conservation.

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I. Introduction

Current water infrastructure is aging and deteriorating. Water networks are vast and consist of various components (pipe segments, pumps, valves, etc). These components vary in age, and material type. As they age their performance and efficiency decrease, making them prone to failures and leaks. Because water networks are so vast and hard to access, some municipalities may not have a complete inventory of their assets, or be aware of any leaks in the systems. In these hard economic times, funding is very limited, which sets water infrastructure lower on a priority list. However, postponing maintenance on water infrastructure sometimes results in significant component failures and main breaks that can cause other damage or disruptions. In addition, lost water does not bring revenue and exacerbates water scarcity problems.

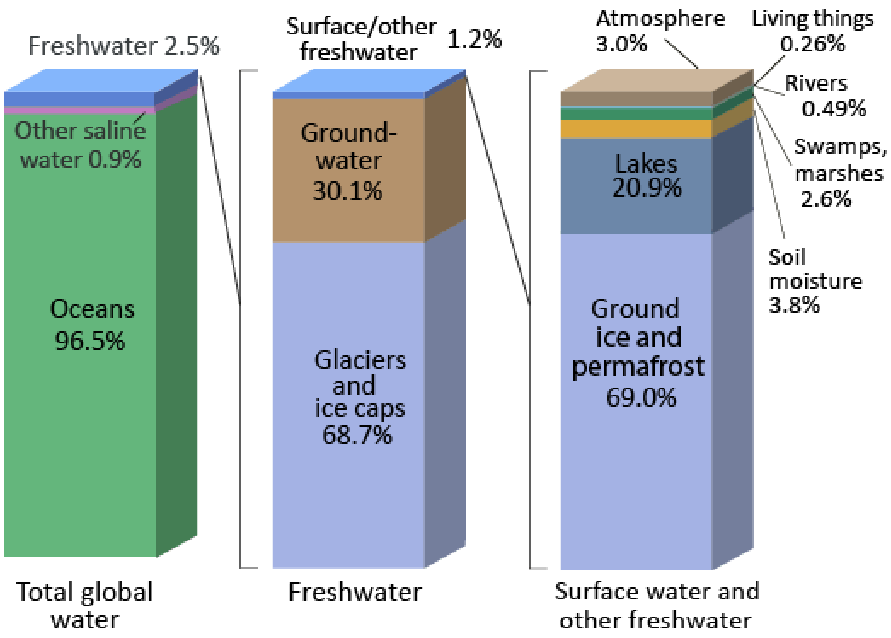
One solution to meet those problems is implementing Smart Water Grids as a tool to help manage our water distribution networks. Smart Water Grid is a two-way network with sensors, measurements and control devices. The components of the system integrated within the network, which remotely and continuously monitor and diagnose problems. This will provide utilities with real time data and status of the system, and help locate leaks in the system. As a result, this will promote water conservation and energy.

The purpose of this report is to perform literature review of information available regarding Smart Water Grid technology. The objectives of this technical report are outlined as follows: (1) discuss current water, energy demand, consumption, and current state of water infrastructure; (2) describe Smart Water Grid and its components; review other monitoring methods; discuss advantages, disadvantages, and vulnerability of smart water grid networks; (3) lastly, present several case studies where this technology has been implemented.

1.1. Water Demand and Consumption

Water is an essential resource to all of nature to be able to sustain life and plays many important roles. Water is an important element in Earth’s climate. Water comes in three states: gaseous, liquid, and frozen. In its liquid state, water meets our basic demands for plants, animals, and humans. The runoff from precipitation feeds our ecosystems and recharges our water availability.

Water vapor in the atmosphere feeds precipitation, and is responsible for Earth's temperature. In solid (frozen) state, water helps to cool the Earth by reflecting solar radiation. In addition, frozen water serves as water storage for warmer seasons when the demand is higher. Water also affects the intensity and variability in the climate, and extreme events such as droughts and floods. Its abundance, spatial and timely delivery has also an effect on society and ecology. Water plays an important role in the World's Economy as well. Water is needed for agriculture, forestry, mining, energy extraction and production, manufacturing, and public water supply. Even though the Earth's surface is covered with 71 percent water, and 96.5 percent of total volume is stored in oceans, only 2.5 percent of the total volume is considered fresh. **Figure 1** below shows a diagram with Earth's water distribution. It is important to understand that not all of the freshwater is available for consumption. Not all of the groundwater is accessible and some of the freshwater remains in the frozen form. With only 2.5 percent of total volume of Earth's water available for consumption, it is important to practice water conservation and help maintain and meet water quality and availability needs.



Source: Igor Shiklomanov's chapter "World fresh water resources" in Peter H. Gleick (editor), 1993, Water in Crisis: A Guide to the World's Fresh Water Resources.
NOTE: Numbers are rounded, so percent summations may not add to 100.

Figure 1: Distribution of Earth's Water (USGS, 2014)

Population continues to grow, increasing energy and water demands. Over 1.4 billion people live near rivers. The use of water exceeds minimum recharge levels, which leads to desiccation of rivers and depletion of groundwater (Human Development Report, 2006). There is also a worldwide increase of freshwater demand of 64 million cubic meters per year (UN-Water, 2012). According to the United Nations report (2014), urban population is expected to increase by 2.5 billion by 2050. However, this increase is expected in developing countries, while urban population in developed countries is expected to remain fairly constant (UN-Water, 2012). These large increases in population in urban areas increase water demands and the need for a reliable water infrastructure. **Figure 2** shows total water withdrawn in US for different usage categories. This report is prepared by USGS for data collected every five years. The next report will be available later in 2014 with 2010 withdrawals information. This figure shows that most of water is withdrawn for irrigation and thermoelectric purposes. The withdrawals volumes vary from year to year.

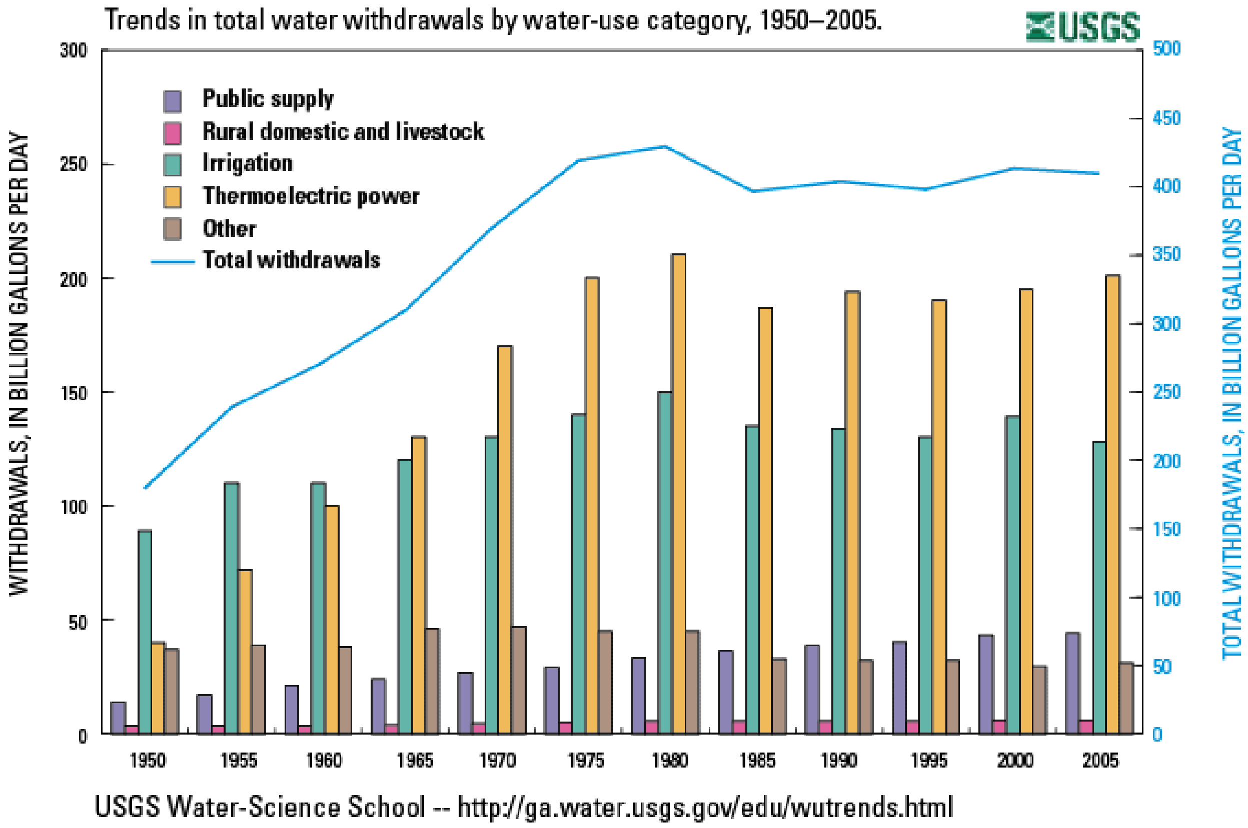
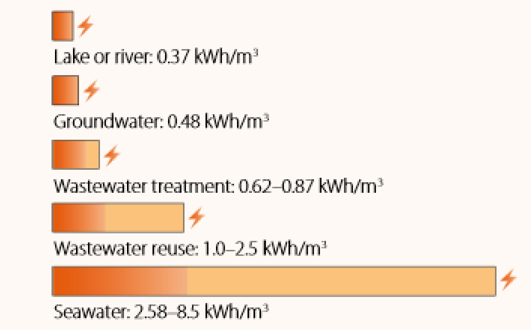


Figure 2: Water withdrawals in United States (Kenny et al, 2009)

Public water supply is water withdrawn by city and local municipalities to provide water to homes, businesses, industries, etc. As the population grows, so is the water demand and it can be seen in the **Figure 2**. However, it is interesting to see that starting 1980, the overall water withdrawal levels have remained fairly constants. This shows great efforts in water conservation practices and improvements in efficiencies over the years.

Thermal power is responsible for approximately 80 percent of global energy production. As shown on **Figure 2**, thermoelectric power energy production is the largest water user in US, which is also seen in other developed countries. In developing countries, the agricultural sector withdrawal is generally higher than the power sector. According to the World Bank as reported by WWDR (2014), 5 to 30 percent of the total operating cost of water and wastewater utilities is electric consumption. In some developing countries, energy consumption for such utilities may be as high as 40 percent. Some countries obtain their water through desalination processes, which accounts for 0.4 percent of the global electricity consumption (75.2 TWh/year). Depending on the water and energy source, it would require 0.37 kWh to 8.5 kWh to provide one cubic meter of potable water. **Figure 3** shows a diagram of various sources required to provide one cubic meter of water that is safe for human consumption. Water and energy consumptions are linked as water is required for many types of power generation. Water and energy conservation in both developed and developing countries can be achieved through implementation of water conservation, planning, and management tools.



Note: This diagram does not incorporate critical elements such as the distance the water is transported or the level of efficiency, which vary greatly from site to site.
Source: WBSCD (2009, fig. 5, p. 14, based on source cited therein).

Figure 3: Amount of energy required to provide one cubic meter of potable water from various water sources (WWDR, 2014)

Water availability is also an important part of agricultural sector. Water is required for irrigation to provide food for increasing population around the world. The US Drought Monitor was established in 1999. It is organized by the National Oceanic and Atmospheric Administration (NOAA), US Department of Agriculture (USDA), and the National Drought Mitigation Center (NDMC). US Drought monitor presents weekly maps of drought conditions in US[1]. These conditions are determined using climatic, hydrologic, and soil condition measurements from more than 350 sources around the US. Current drought conditions in some areas, such as California, became worse compared to drought conditions one year ago (**Figure 4**). California State has been experiencing drought conditions, which resulted in many fields to become fallow due to the lack of water for irrigation. Consequently, it results in higher rates of unemployment and decrease in overall production of food, which ultimately impacts the economy. Similar trends can be seen around the World. Some developing countries may lack the funding and resources to build irrigation infrastructure. By promoting energy and water conservation tools and technologies, water and energy consumption can be stretched to accommodate increasing populations and needs.

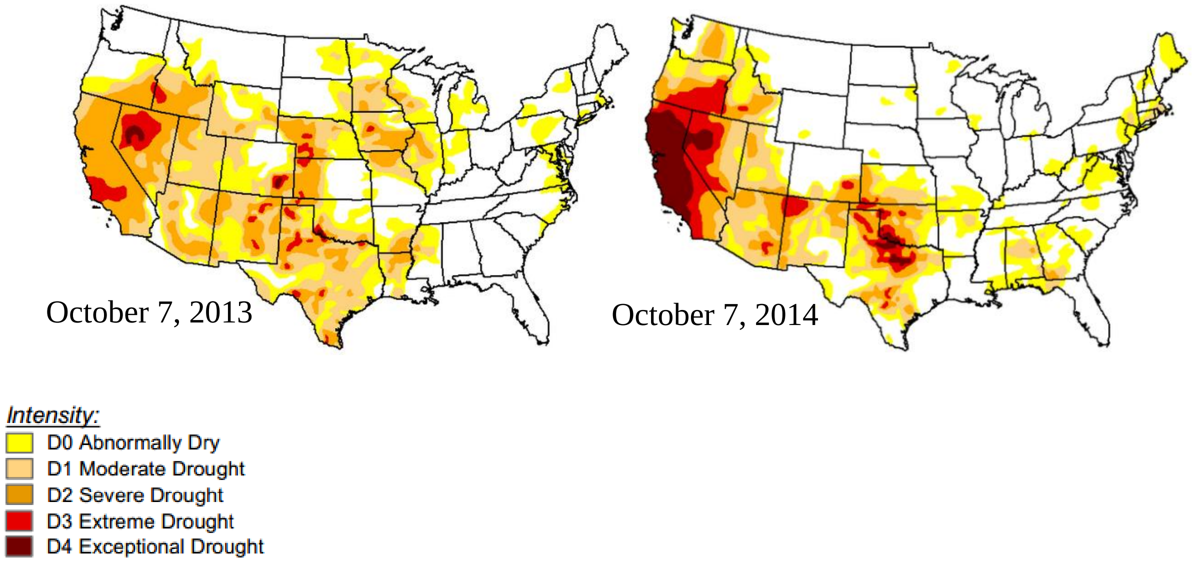


Figure 4: US Drought Conditions comparison (US Drought Monitor).

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[1] For more information and drought maps, go to the following website: http://droughtmonitor.unl.edu/

1.2. Water Infrastructure

Folkman et al. (2012) conducted a survey in 2011 of utilities across United States and Canada to obtain information on water main failures and supply systems. From 1,051 surveys that were mailed to US and Canadian water utilities, 188 utilities responded to a basic survey, with 47 responding to a detailed survey. Based on the information received, the authors estimated that there are 264 people served for each mile of water main. In 2007, US EPA reported that there are approximately 880,000 miles of distribution pipes. According to US Census population clock, current United States population is approximately 318 million people. Using the estimate of 264 people served per mile of water main, the approximate length of distribution pipes is 1.2 million miles. The actual inventory may be larger because municipalities might not have a very good asset management system, and the survey was based on approximately 10% of the total miles of pipe used in the United States. There is a need to fill a data gap in water resources as it creates a political disadvantage for careful decision making regarding water and its role in socio-economic development (WWDR, 2014).

The current water infrastructure of many countries is aging and continues to deteriorate. The age of water infrastructure can date back to the earlier 19th century. Twenty four percent of pipes are between 40 and 80 years old (EPA, 2007). As reported by IBM (2013), the average age of US and Canada water mains is 47 years: 47% is between 20-50 years old, 22% is greater than 50 years old. Water infrastructure is made of multiple components some of which are pipes, pumps, reservoirs, gates, and valves. All of the system components age and wear out with usage. Water quality, age, corrosion protection, loads, and service pressures are some of the things that affect the overall life expectancy of the system components, and their failure rate.

According to UNESCO (2009), some distribution systems have leakage rates of 50 percent. Some of the big challenges related to maintenance include awareness, problem location, and funding. Since water distribution networks are so vast, it is hard to know where the leaks are located. Finding leaks is very important. However, the pipes are buried under streets and sidewalks making them hard to access.

According to the USGS, water systems in the US experience 240,000 water main breaks annually, which results in 1.7 trillion gallons of water loss every year (Symmonds, 2012).

American Society of Civil Engineers presents a report card for America’s infrastructure. Drinking water and wastewater infrastructure received a grade of D (ASCE, 2013). When drinking water infrastructure fails, it can create water disruptions, impediments to emergency response, and damage to other infrastructure such as roadways (ASCE, 2013). In addition, emergency failures can cause farther disruptions to transportation.

Table 1 presents a water balance prepared by the American Water Works Association (AWWA, 2012). It shows a breakdown of revenue and non-revenue water. Apparent losses are the hardest to control. Real losses are mostly contributed to leaks within the system that can be mitigated.

Table 1: Water Balance Table (AWWA, 2012)

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	Revenue Water
			Billed Un-metered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	Non Revenue Water
			Unbilled Un-metered Consumption	
	Water Losses	Apparent Losses (Commercial Losses)	Unauthorized Consumption	
			Customer Meter Inaccuracies	
			Systematic Data Handling Errors	
		Real Losses (Physical Losses)	Leakage in Transmission and Distribution Mains	
			Storage Leaks and Overflow from Water Storage Tanks	
			Service Connections Leaks up to the Meter	

Table 2 was prepared by based on a survey that asked utilities to list five most common causes of main breaks (US EPA, 2007). As reported from the responses, material type and deterioration are the most common causes of water main failure. This shows that pipes and components deteriorate with time and need replacement. Some causes of failure listed in the table can be addressed through assessment and maintenance to prevent and/or eliminate impending or possible failures. For example, 25 percent of utilities reported that main breaks occurred due to construction or utility digging, which can be eliminated through asset management inventory and

proper communication with utilities. Most utilities encourage people and other utilities to "call before you dig" to avoid damage to not only for water pipelines, but also gas pipelines.

Table 2: Causes of main breaks (US EPA, 2007)

Causes of Main Breaks	Percent of utilities reporting
Materials/deterioration	55
Weak joints	35
Earth movement or settling	30
Freezing	30
Internal corrosion	25
Corrosive soils	25
Construction or utility digging	25
Stray DC current	20
Seasonal changes in water temperature	15
Heavy traffic load	10
Tidal influences	5
Changes in system pressure	5
Water hammer	5
Air entrapment	5

The aging infrastructure and leakage problem is seen all around the world. Utilities lose between 10 to 60 percent of water that they pump to consumers. For example, average leak rates in Latin America and China are 35 and 20 percent respectively (IBM, 2013). The Telegraph (2012) reported that United Kingdom loses 3.4 billion liters of water annually. As population numbers rise, leaking pipes contribute to overall water loss and scarcity. According to WWDR (2014), approximately US $103 billion per year is needed to finance water, sanitation, and wastewater treatment through 2015 in developing countries. As their urban population increases, so is the demand for reliable water infrastructure to deliver potable water to its consumers. Water resource is a valuable asset and plays a very important role in economy and climate. Climate change adds another stress to the overall water availability. Therefore, it is crucial that water waste and leaks are minimized as much as possible.

II. Smart Water Grid

As technology is advancing, new tools and techniques can be implemented to help electric, gas, and water grids run more efficiently. There are several existing water infrastructure monitoring methods: Automated Meter Reading (AMR), Advanced Metering Infrastructure (AMI), and

Supervisory Control And Data Acquisition (SCADA). These methods are described in section 2.1 below. A smart water grid is another innovative way to monitor water distribution networks. **Figure 5** shows a sketch of a smart water grid as presented by Sensus. Sensus is a utility infrastructure company that provides technology, tools, services, software and smart meter systems for electric, gas, and water utilities.

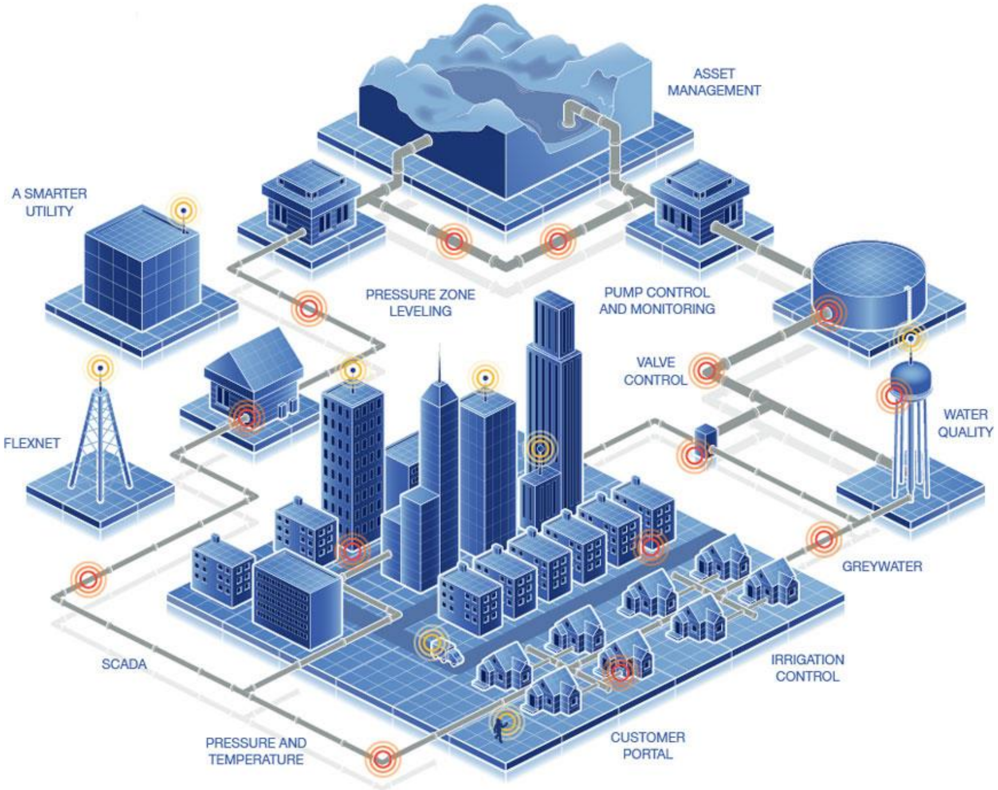
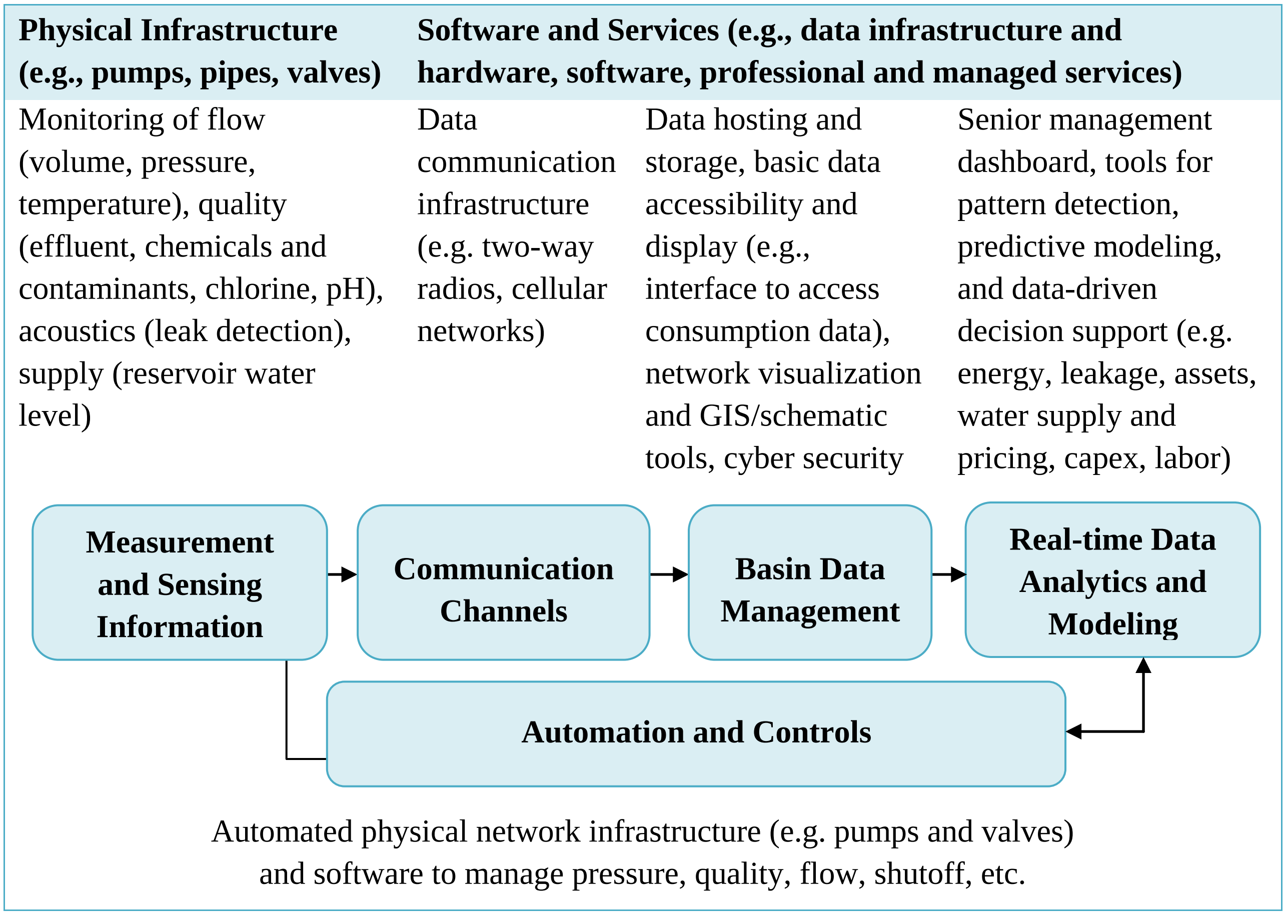


Figure 5: Smart Water Grid Diagram (AquaSense, Sensus, 2013)

Smart water grid consists of a two-way real time network with field sensors, measurement and control devices that remotely and continuously monitor and diagnose problems in the water system. Smart water meters can monitor some key parameters such as flow, pressure, temperature, quality, consumption, and energy usage. The information gathered by these meters is wirelessly transmitted to a tower, which then transmits this information to a utility company, or other central location. Sensus developed FlexNet^{TM} technology, which is designed specifically for smart grid applications. Smart water meters communicate information several times a day. With smart water meter technology, utilities are able to see real time consumption and performance of the distribution system. Based on the information obtained from smart meters, utilities can further help analyze data and identify unusual patterns or changes in the network. As a result, this would help prevent impending failures, and decrease response time to occurred failures.

Sections 2.3 and 2.4 describe advantages and disadvantages associated with smart water grid technology. In order to obtain full benefits and be prepared for a variety of vulnerabilities, a wide spectrum of technology needs to be implemented. Many of these technologies are available today, while others may require more research and development. **Figure 6** shows a sketch by Sensus (2012a) that shows different components needed for a comprehensive smart water network solution.



Physical Infrastructure (e.g., pumps, pipes, valves)	Software and Services (e.g., data infrastructure and hardware, software, professional and managed services)		
Monitoring of flow (volume, pressure, temperature), quality (effluent, chemicals and contaminants, chlorine, pH), acoustics (leak detection), supply (reservoir water level)	Data communication infrastructure (e.g. two-way radios, cellular networks)	Data hosting and storage, basic data accessibility and display (e.g., interface to access consumption data), network visualization and GIS/schematic tools, cyber security	Senior management dashboard, tools for pattern detection, predictive modeling, and data-driven decision support (e.g. energy, leakage, assets, water supply and pricing, capex, labor)

Automated physical network infrastructure (e.g. pumps and valves) and software to manage pressure, quality, flow, shutoff, etc.

Figure 6: Smart meter network solution (Sensus, 2012a).

Sensus (2012a) summarized this solution into five layers. First layer is a set of measurement and sensing devices (e.g. electromagnetic or acoustic). They collect data and help detect any abnormalities within the system. Second layer consists of communication channels. They wirelessly and continuously gather information from first layer (measurement and sensing devices). They are two-way communication devices that can also execute actions on those devices (i.e. valve shut off). Once the data is collected, it needs to be analyzed and presented in an articulate manner. This is the role of the third layer – basic data management software. Its goal is to present data via different visualization tools such as GIS, spreadsheets, and graphing tools. Customer information systems can also be part of this data management software. Forth layer is a real-time data analysis and modeling software. Its purpose is to enable utilities to draw conclusions and gain information based on the collected data. It will be a central source of evaluation of economic value of smart water networks. This software will aid personnel in detecting patterns to determine false alarms versus genuine concerns. In return, this will aid utilities to responds effectively and proactively to any future scenarios. The last layer of smart water network solution, which ties with communication channel in the second layer, is automation and control tools. The goal is to enable utilities remotely and automatically conduct measurements and managements of devices in the network. Many utilities utilize SCADA systems, which can be tied with smart water grids to further enhance and improve control of water distribution networks.

Smart Water Research Group held the Smart Water Grid International Conferences in 2013 at Incheon University, South Korea. Some of the abstracts are presented in **Appendix A** at the end of the report.

2.1. System/Network Monitoring Methods

Just like any other network or system, water distribution networks require operation, maintenance, and personnel. The utilities keep track of residential and industrial usage through water meters, which may be located inside or outside the building. Older water meters are analog and require local utility personnel to obtain the reading. Most municipalities are required to take a meter reading once every two years. In those situations, trained personnel stops by a residence and records a water usage reading.

2.1.1. Automated Meter Reading (AMR)

Automated Meter Reading (AMR) is a method of obtaining water meter readings through radio-transmitted signals. Manufacturers developed encoder registers that produce electronic output for radio transmitters and other data logging devices. This method is faster and less invasive compared to traditional data collection described above. Using AMR technology, utility personnel can walk or drive by residences to collect water usage readings. Depending on the municipality, these readings may be taken twice a year. The collected information includes the serial number of the meter and the volume of water consumed. According to United Utilities, the meter can detect if the water is being used continuously, which will indicate a presence of the leak in the system. In this situation, they would notify the residents, and help avoid unexpectedly high bills.

2.1.2. Advanced Metering Infrastructure (AMI)

AMR technology was improved to help optimize water distribution networks including sewer and combined sewer system. Advanced Metering Infrastructure (AMI) is system that remotely and continuously collects and transmits information to various parties. Electric Power Research Institute (EPRI) describes this advanced metering infrastructure. AMI can be implemented for electric, gas, and water networks. The meters transmit electric, gas, water information through an available network. Some examples are Broadband over Power Line (BPL), Power Line Communications (PLC), Fixed Radio Frequency (RF), and other public networks such as landline or cellular networks. The information is received by Meter Data Management System (MDMS) that is responsible for data storage and analysis. EPRI (2007) says that AMI hardware costs have been declining over the years. The average hardware cost of meter was approximately 76 US dollars in 2005 through 2006. The capital costs associated with installation of communication infrastructure ranged from 125 to 150 US dollars per meter.

2.1.3. Supervisory Control And Data Acquisition (SCADA)

Supervisory Control And Data Acquisition (SCADA) is a computer-controlled system that helps to monitor and control processes. SCADA systems acquire information from remote devices such as pumps, valves, transmitters, and others. The Host software system can communicate and control these devices remotely. SCADA Host platform are equipped with displays, alarms, and can store received information (Schneider Electric, 2012). SCADA systems are commonly used in industrial processes such as manufacturing, transportation, energy management, building automation, and other fields where real time operational data can be used to make decisions. Because these processes are different and require their own unique solutions, SCADA systems are catered to specific markets. It is important to understand that SCADA systems require human interaction as personnel will be controlling and monitoring processes. This will require training and certain skill sets.

SCADA systems consist of four levels of components/communication: field instrumentation, PLCs/RTUs, Comms/Telemetry, and SCADA Host (**Figure 7**). Field instrumentation is an important component of any system. In many industrial processes, the instrumentation is automated which reduces the response time to any operation changes or abnormal events. However, automated or advanced instrumentation requires appropriate knowledge and training. In many cases, such as oil and gas industry, the field instrumentation must be designed for the location and surrounding area in which it will be placed. Environmental conditions must also be considered, as instrumentation must still be performing in harsh environments. In some cases, the designed instrumentation requires casing, which increases costs for the future maintenance. Another important requirement is compliance with electromagnetic compatibility (EMC) standards. The designed equipment must not produce negative effects on the environment or other electrical devices.

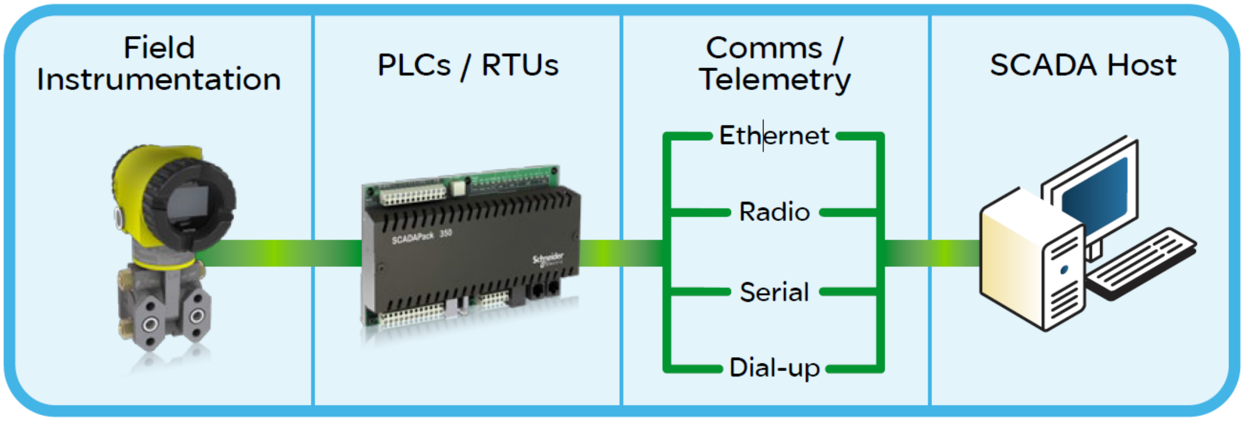


Figure 7: SCADA System Overview (Schneider Electric, 2012).

One of the advantages of SCADA is the ability to control and activate devices remotely. This is done using programmable logic controllers (PLCs) and remote telemetry units (RTUs) (Schneider Electric, 2012). Originally, PLCs and RTUs were different devices, but with current advances in technology, they are now almost the same. Field instruments are connected to the RTU, which relays information to the SCADA host without processing this information or controlling the devices. The instrumentation is controlled using PLCs. Nowadays, RTU operate similarly to PLCs with added control programming capabilities. It is also important to keep in mind the environmental conditions as PLCs/RTUs may need to be located near the instrumentation.

The remote communication network is a crucial component and defines how successful is a SCADA system. The field instrumentation and PLCs/RTUs are located in the field, while SCADA host is located in the office or control center. The remote communication network must be able to transmit gathered information and control the instrumentation in response to any operation changes. Advances in technology help improve this communication network. Cellular or radio devices are examples of communication types. However, these types can still experience failures. Schneider Electric (2012) also points out that the protocols have changed over the years and may pose some complications. Different manufactures used to have proprietary sets of protocols for their instrumentation. This would mean that the customer would be tied to a given manufacturer. Most oil and gas manufacturers use a single protocol called MODBUS while still have the ability to add proprietary elements orientated towards a particular customer and their needs. This helped to improve communication and flow of information. More recently, the industry is working on developing a standard by developing a non-proprietary protocol called Distributed Network Protocol (DNP). This protocol has not acquired a broad appeal as most manufacturers are still reliant and heavily use MODBUS protocols. However, as manufacturers will become more familiar with benefits of having a non-proprietary protocols, it may become more accepted and used.

The last component of the SCADA system is the SCADA host software, which consists of graphical displays, alarms, and trends. Traditionally, this information was available to operators, engineers, and technicians. Currently, other branches of businesses require real time access to this information **(Figure 8)**. These groups include but not limited to accounting, maintenance management, material purchasing, and customers (Schneider Electric, 2012). This network and large database requires trained personnel to perform maintenance and monitor data interface and access.

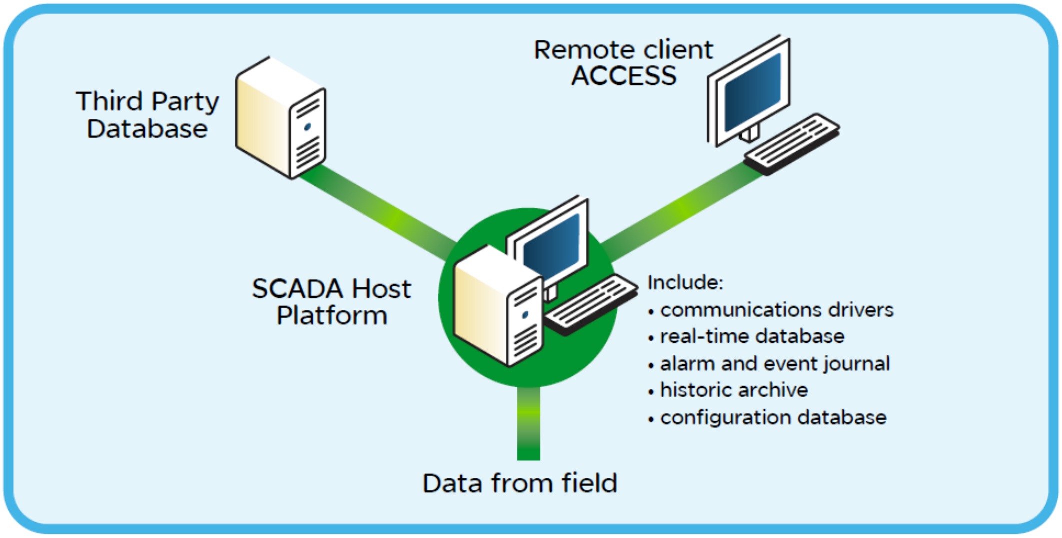


Figure 8: SCADA Host schematic.

With advances in technology, SCADA host communication software has improved. It utilizes 'drivers' that are integrated within the SCADA host, compared to previously used hybrid PLCs or RTUs which were external to SCADA platform. These modern 'drivers' are made of different protocols that communicate remotely with PLCs and RTUs. SCADA host software is able to handle thousands of changes a second while still complying with standard database interfacing. These standards are Open Database Connectivity (ODBC) and Object Linking and Embedding for Databases (OLE DB) which are required for third-party access to the information. SCADA host software is also equipped with remote client access to allow operation and monitoring even while the user is mobile or changing locations.

As was stated earlier, SCADA systems were isolated to technical workers and engineers. With increase in information demand for other branches, an issue of security arises. The information is transferred remotely to the SCADA host. According to Schneider Electric (2012), there have been many attacks on the SCADA systems. Security issues are not concentrated around the SCADA system itself. The whole network is vulnerable as communication devices are located in the field and may be easily compromised by a trespasser. This would require fences, surveillance cameras, and/or personnel. More precaution would need to be taken with access to SCADA host to make sure that viruses cannot be transferred with things like a USB drive. There are documentations that emphasize SCADA security in procedures and practices.

Smart Water Grids are SCADA and AMI systems, where information is gathered from sensors within the distribution network, which is then transmitted to a central location.

2.2. Advantages

Some of the advantages of smart water grids are better understanding and analysis of the water networks, leak detection, water conservation, and water quality monitoring. Implementing smart water grid technology will allow the utility companies to build a complete meter database. Having a detailed meter grid should help to pinpoint the locations of water leaks. The utility companies may discover missing and/or illegal connections. In addition, companies would know the quantity of water being used and lost in the system. Smart meters can use statistical methods, based on the data collected, to evaluate the performance of the metering system. The improved monitoring of the metering system and faster response to impending failures will improve the overall efficiency and, hopefully decrease costs of water distribution networks.

Hinchman et al. (2012) explain that utility companies would be able to receive this data from meters several times a day compared to several times a year. This pool of data will yield a better mass balance of the system, which will allow for a more detailed analysis and a better understanding of the water distribution network (Schlenger, 2013).

2.2.1. Water Conservation

Water is lost due to leaks, unmetered consumption, and meter inaccuracies. Municipalities may not be aware of occurring leaks, which may last from months to years. An average time length of underground leaks is two or more years (SWAN, 2012). This lifespan can be reduced with continuous monitoring with smart water grids. The utilities will be receiving real-time information several times a day. This will help to identify leaks in the system before a large volume of water is lost, or a significant damage occurred. According to UN-Water (2012), there is an increase of freshwater demand of 64 million cubic meters per year in addition to the irrigation demand. In addition to the increase in water demand, climate change adds more stress to the total water availability. As water demand increases on limited resources, the water prices will increase as well. Therefore, it is important to practice water conservation to lessen the environmental and conservation concerns. At some point, the pressure for increased efficiency of water consumption systems will favor the development of smart water grids.

Energy and water conservation can make a big difference if residents pay attention to their water and energy consumption. On average, a person uses 80 to 100 gallons of water daily (Krishnamurthy, n.d.). An annual water use of an average residence is 100,000 gallons. The largest use of household water is contributed to flushing toilets. Showers and baths usage is the second largest. Newer showers, faucets, and toilets limit the flow of water per minute, and many local governments encourage installation of such amenities. Residents are also encouraged by their municipalities to water lawns only several times a week and at certain time of the day. Evenings are better for watering, as less water is being evaporated and lost. In addition to water conservation, household utility bills would be lower.

Another major water loss is leaking faucets. According to IBM (2013), a faucet that drips once every second wastes 2,700 gallons of water annually. Leaky faucets are an easy to fix and can help to conserve water and lower utility bills. What might seem like a harmless leak, might add up to a large volume of water lost.

2.2.2. Energy Conservation

Hinchman et al. (2012) discuss how smart grids can lower energy costs and conserve water. The energy costs can be reduced by reducing the amount of water needed to be pumped or treated. Water conservation would be achieved by reducing the volume of water lost within distriabution networks. Reports indicate that energy is the second highest cost to most water companies, after manpower (SWAN, 2012). Depending on the utility, the energy costs can represent 25 to 30 percent of utility’s operation and maintenance costs, and even as high as 60 to 70 percent of operating expenses. This energy goes towards treating and moving water. Knowing the quantity of water needed, and accounting for any loses, the utilities can produce less water. This will be reflected in lower energy costs as well as in water conservation.

Leaks in the system also decrease service water pressure. As a results, more energy is required to pump water to consumers. This increase in pressure exacerbates the severity of the leak, which means more water and energy is lost. In addition, inner pipe walls can be coated with biofilm or tuberculation that increase frictional resistance, slowing water down, and requiring more service pressure to compensate for these loses. Smart water meters will be able to measure pressure along the water network. Any unusual pressure changes or significant pressure losses will warn the utility. Furthermore, the utilities can remotely control pressure within the system reducing pipe deterioration. This will help save energy and water in the long run.

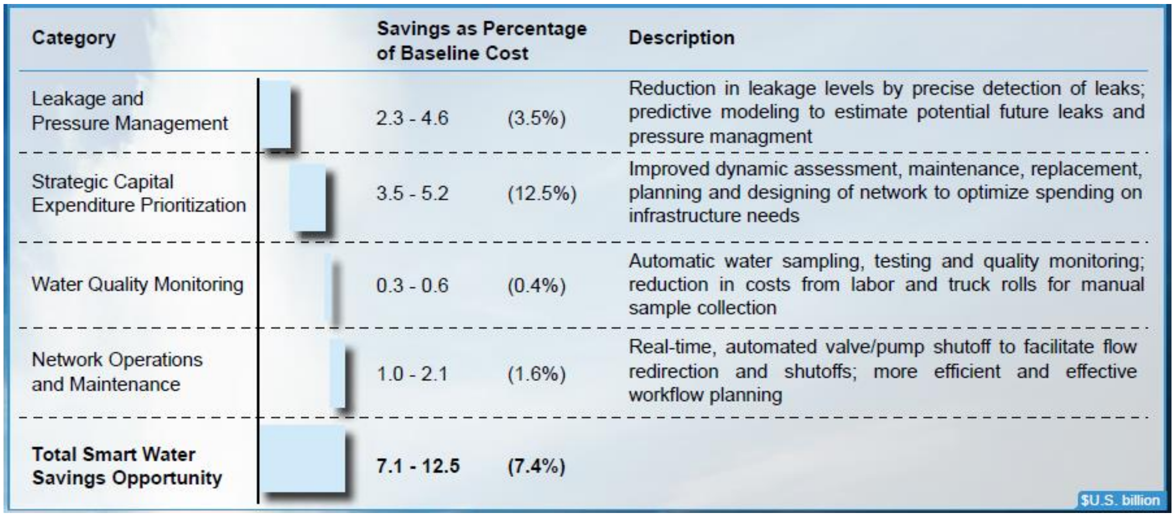
2.2.3. Network Visibility and Damage Prevention/Reduction

The spatial distribution of sensor through the network will help to visualize and monitor its current conditions. This will help utilities to understand water networks and their performance. The ability to see information in real time will help utilities to see any impending or occurring failures. Some leaks grow with time, which can be identified in the system. Real time data will help to identify leaks in the system before major failure occurs. Some water main breaks are sudden, and cause road damage, flooding, and traffic disruptions. If unexpected failure occurred, the system can warn the utilities, which will decrease the response time. The goal is to be able to control valves remotely. In cases of water main breaks, the utility will be able to shut the water off in the system to prevent flooding, further damage, and water loss.

Water exiting water treatment plant may be clean and meeting quality standards. However, water quality can degrade as it flows through distribution system to consumers. Disinfectant depletion or residual, contaminant intrusion from pressure differential or pipe work, biofilm, corrosion, and bioterrorism are some of the factors that affect water quality in the network. Smart water grids will be equipped with water quality monitoring sensors and can alert utilities with potential problems or changes in water quality. Currently, if there is a suspicion of contamination, water quality is tested at the tap. Twenty percent of average water quality monitoring cost is attributed to sample collection (Sensus, 2012a). These costs can be reduced through remote sensing and monitoring. Smart water meters will be transmitting data several times a day. This will allow utilities to ensure there is no contamination present in the system. In addition, water quality standards change. Smart water grids will not only enable utilities to monitor water quality within the network, but help efficiently isolate contaminated water before it gets to consumers. For example, valves can be shut off remotely to avoid further displacement of contaminated water within the water distribution network. Continuous water sampling throughout water distribution system can provide more knowledge on how water quality changes as it flows from water treatment facility to consumers. Monitoring and meeting water quality standards will also help reduce fees for water companies.

2.2.4. Financial Benefits

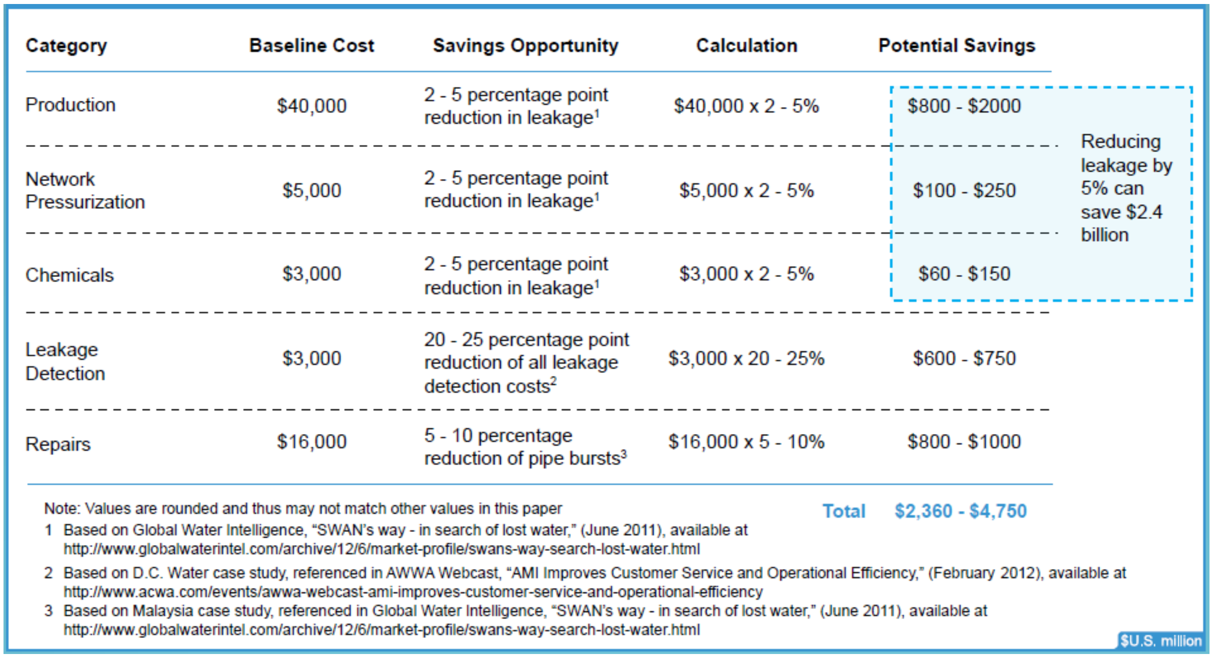
Even though smart water infrastructure has a large upfront cost, it will yield large monetary savings associated with water and energy conservation, reduction in operational inefficiencies and other expenditures. **Figure 9** and **Figure 10** show global savings associated with smart water grid implementation, as reported by Sensus (2012a). These savings would then be used to reinvest in network upgrades, or can be reflected in lower rates to consumers. Sensus (2012a) estimates that 7.1 to 12.5 billion dollars can be saved globally by utilities via implementing smart water technology solutions. They describe that savings would result in improved network assessments, planning, and monitoring. This is not surprising because improvement in monitoring will increase the knowledge of the state of water distribution systems. Timely monitoring will help to reduce the amount of water lost and prevent impending failures. A large amount of savings can results from leak detection associated with pressure managements, leak detection, production, repairs, and chemicals needed to treat water (**Figure 10**).



Category	Savings as Percentage of Baseline Cost		Description
Leakage and Pressure Management	2.3 - 4.6	(3.5%)	Reduction in leakage levels by precise detection of leaks; predictive modeling to estimate potential future leaks and pressure managment
Strategic Capital Expenditure Prioritization	3.5 - 5.2	(12.5%)	Improved dynamic assessment, maintenance, replacement, planning and designing of network to optimize spending on infrastructure needs
Water Quality Monitoring	0.3 - 0.6	(0.4%)	Automatic water sampling, testing and quality monitoring; reduction in costs from labor and truck rolls for manual sample collection
Network Operations and Maintenance	1.0 - 2.1	(1.6%)	Real-time, automated valve/pump shutoff to facilitate flow redirection and shutoffs; more efficient and effective workflow planning
Total Smart Water Savings Opportunity	**7.1 - 12.5**	**(7.4%)**	

$U.S. billion

Figure 9: Summary of global savings associated with smart water grid implementation (Sensus, 2012a).



Category	Baseline Cost	Savings Opportunity	Calculation	Potential Savings
Production	$40,000	2 - 5 percentage point reduction in leakage[1]	$40,000 x 2 - 5%	$800 - $2000
Network Pressurization	$5,000	2 - 5 percentage point reduction in leakage[1]	$5,000 x 2 - 5%	$100 - $250
Chemicals	$3,000	2 - 5 percentage point reduction in leakage[1]	$3,000 x 2 - 5%	$60 - $150
Leakage Detection	$3,000	20 - 25 percentage point reduction of all leakage detection costs[2]	$3,000 x 20 - 25%	$600 - $750
Repairs	$16,000	5 - 10 percentage reduction of pipe bursts[3]	$16,000 x 5 - 10%	$800 - $1000
			Total	$2,360 - $4,750

Reducing leakage by 5% can save $2.4 billion

Note: Values are rounded and thus may not match other values in this paper

1 Based on Global Water Intelligence, "SWAN's way - in search of lost water," (June 2011), available at http://www.globalwaterintel.com/archive/12/6/market-profile/swans-way-search-lost-water.html

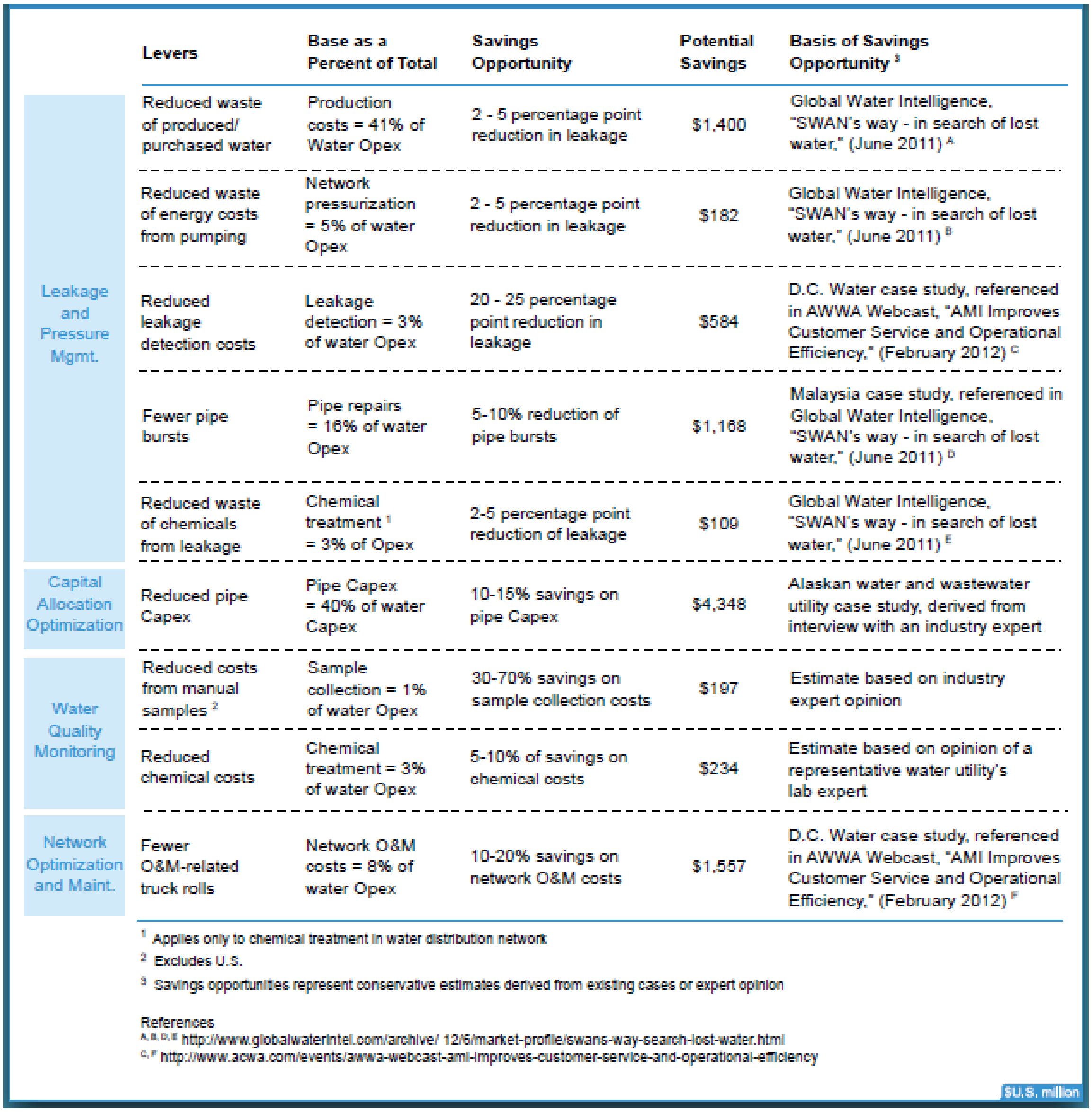
2 Based on D.C. Water case study, referenced in AWWA Webcast, "AMI Improves Customer Service and Operational Efficiency," (February 2012), available at http://www.acwa.com/events/awwa-webcast-ami-improves-customer-service-and-operational-efficiency

3 Based on Malaysia case study, referenced in Global Water Intelligence, "SWAN's way - in search of lost water," (June 2011), available at http://www.globalwaterintel.com/archive/12/6/market-profile/swans-way-search-lost-water.html

$U.S. million

Figure 10: Monetary savings associated with leakage and pressure management (Sensus, 2012a).

Figure 11 summarizes and shows four largest opportunities for monetary savings and performance improvements for utilities. However, all four opportunities are interrelated. For example, improvement in pressure management and leakage detection (assuming the leaks are fixed), reduces the cost of producing and treating water, cost of chemicals, capital expenditures. Optimizing leak detection and pressure management can reduce cost associate with operation and even improve life expectancy of the pipe. Presence of leaks and high pressures within the system can results in pipe busts. Even though these numbers seems optimistic, there are challenges associated with leaked water. A survey was performed to identify most significant challenges. The responses were based on the number of times a given challenge was selected as first, second, and third. Out of 182 responses, 139 utilities stated that the most significant challenge for their business from leaked water is wasted energy costs. Second most significant challenge was wasted water treatment costs (126 out 182 responses). Misdirected network repair and maintenance activities were the third most significant challenge (122 out 182 responses).



	Levers	Base as a Percent of Total	Savings Opportunity	Potential Savings	Basis of Savings Opportunity [3]
Leakage and Pressure Mgmt.	Reduced waste of produced/ purchased water	Production costs = 41% of Water Opex	2 - 5 percentage point reduction in leakage	$1,400	Global Water Intelligence, "SWAN's way - in search of lost water," (June 2011) [A]
	Reduced waste of energy costs from pumping	Network pressurization = 5% of water Opex	2 - 5 percentage point reduction in leakage	$182	Global Water Intelligence, "SWAN's way - in search of lost water," (June 2011) [B]
	Reduced leakage detection costs	Leakage detection = 3% of water Opex	20 - 25 percentage point reduction in leakage	$584	D.C. Water case study, referenced in AWWA Webcast, "AMI Improves Customer Service and Operational Efficiency," (February 2012) [C]
	Fewer pipe bursts	Pipe repairs = 16% of water Opex	5-10% reduction of pipe bursts	$1,168	Malaysia case study, referenced in Global Water Intelligence, "SWAN's way - in search of lost water," (June 2011) [D]
	Reduced waste of chemicals from leakage	Chemical treatment [1] = 3% of Opex	2-5 percentage point reduction of leakage	$109	Global Water Intelligence, "SWAN's way - in search of lost water," (June 2011) [E]
Capital Allocation Optimization	Reduced pipe Capex	Pipe Capex = 40% of water Capex	10-15% savings on pipe Capex	$4,348	Alaskan water and wastewater utility case study, derived from interview with an industry expert
Water Quality Monitoring	Reduced costs from manual samples [2]	Sample collection = 1% of water Opex	30-70% savings on sample collection costs	$197	Estimate based on industry expert opinion
	Reduced chemical costs	Chemical treatment = 3% of water Opex	5-10% of savings on chemical costs	$234	Estimate based on opinion of a representative water utility's lab expert
Network Optimization and Maint.	Fewer O&M-related truck rolls	Network O&M costs = 8% of water Opex	10-20% savings on network O&M costs	$1,557	D.C. Water case study, referenced in AWWA Webcast, "AMI Improves Customer Service and Operational Efficiency," (February 2012) [F]

[1] Applies only to chemical treatment in water distribution network

[2] Excludes U.S.

[3] Savings opportunities represent conservative estimates derived from existing cases or expert opinion

References
[A, B, D, E] http://www.globalwaterintel.com/archive/ 12/6/market-profile/swans-way-search-lost-water.html
[C, F] http://www.acwa.com/events/awwa-webcast-ami-improves-customer-service-and-operational-efficiency

$U.S. million

Figure 11: Largest opportunities to improve performance (Sensus, 2012a).

2.2.5. Additional Benefits

Besides benefits listed above, efficiency of the system can improve customer service. Wireless data transmission eliminates the need for service personnel to enter residential property to obtain meter reading. Utilities can notice unusually patterns or continuous consumption, which may indicate leaks within the system. This can help consumers reduce water usage and costs by fixing those leaks. The customer will also be able to see their water usage and potentially practice water conservation. Symmonds and Hill (2013) state that consumers, who chose electronic billing and data presentation, were more actively reducing water consumption, in some instances as high as 30 percent.

Having large database will help utilities to build a good asset management system. Many utilities may not be aware of their full inventory and relevant information such as pipe age, type of material, location, and others characteristics. Installing smart water meters will help them initiate or improve asset management process. They may find illegal or missing connections. Knowing pipe and component connections will help to integrate this information with GIS tools. Integrating networks with GIS tools will help to see failures in real time and decrease utilities' response time. Furthermore, a good asset management system will help prioritize maintenance and operations. For example, different pipe segment and component may be older and experience larger loading conditions, which increase their risks of failure. According to Sensus (2012a) improved asset management can reduce capital expenditures by 10 to 15 percent, which can results in global savings of 3.5 to 5 billion dollars.

Natural disasters can disrupt water distribution. This technology needs to be prepared for a variety of things that can compromise its performance. This is discussed in more detail in the next section. When designed properly, the utilities should be able to see in real-time any disruptions. This will help utilities to remotely control the situation and direct their efforts to locations that need maintenance. Again, this will reduce the response time to failures, increase efficiency in repair, and thereby improving customer service.

Another challenge with water availability is its increasing scarcity. Many areas are faced with drought conditions. During periods of drought, utilities enforce short-term restrictions on residents, for example lawn watering. This may be hard to enforce, as not all residents may practice this water conservation method. In some areas, water over-use has not been addressed. Depending on the areas, watering urban landscapes can be more than 50 percent of the total household water consumption in the summer months (Mutchek and Williams, 2014). However, this depends on the geographical location. For example, a residential house in Las Vegas can use 100 gallons of water per day for outdoor uses, compared to 21 gallons in Atlanta, or 9 gallons in Seattle (Mutchek and Williams, 2014). Providing customers with real-time information can have a greater influence on their water usage and helping them find ways to cut down on water consumption. Smart water meters are a long-term solution to water scarcity. Resulting water conservation can lessen challenges associated with drought.

Furthermore, smart water meters can be implemented for irrigation systems. Smart irrigation meters and sensors can monitor soil moisture and temperature to determine the optimum time to water crops. This will help to conserve water but avoiding overwatering plants and reducing water losses to evaporation.

2.3. Setbacks and Disadvantages

There are several setbacks associated with implementing smart water grids. The disadvantages are discussed in more detail in the following sections. Besides the lack of funding and incentives provided by the federal government to implement this technology, the cost to update current infrastructure and implement this technology is high. Another setback is the lack of public awareness about this technology and water conservation. This can be linked to a lack of effort to get the community involved. However, this might be eliminated by providing citizens with more information regarding water conservation and smart water grids. Information can be provided on the internet and by mail. Community events are also a good place to provide citizens with this information.

Another setback associated with the public is a potentially negative opinion towards this technology. This negative opinion can be traced back to a feeling of government’s invasion and control. Some citizens might not want meters to be installed on their property and to record their water usage. The public needs to be open-minded and learn about the advantages and disadvantages of this technology. Manual reading of flow meters can cause problems with access of individuals on private property. Wireless transmission of data is usually safe, but may be subject to claims that the devices cause health problems and physical ailments. Nevertheless, this can be the subject of fierce opposition and verbal advocacy at public presentations. Smart water grid technology development combined with public awareness can reduce those risks. Some of other disadvantages are hard access of the infrastructure, and uncertainty of the extent to which disasters can affect the grid.

2.3.1. High Costs and Lack of Incentives

Sufficient funding is needed to upgrade existing infrastructure and to implement smart water grid technology. The total cost of replacing aging water infrastructure in industrial countries may be as high as 200 million US dollars per year, as was estimated by the World Business Council for Sustainable Development (UNESCO, 2009). In addition, dams, dikes, waterways, and other water structures require maintenance. UNESCO (2009) lists sources of funding for water utilities. In industrial countries, the three main sources of funding are user tariffs, public expenditure, and external aid. In developing countries, the funding comes from taxation, service charges, and occasionally from donor assistance.

It would cost more than one trillion US dollars to bring US water supply and sewage infrastructure up to the state-of-the-art standards. The US Environmental Protection Agency (EPA) conducted a survey of the current drinking water infrastructure (Berst, 2013). The survey showed the need for 384 billion dollars to improve the current drinking water infrastructure through 2030. The improvements are needed in distribution and transmission, treatment, storage, and source systems. In their survey, EPA does not mention upgrading old meters to smart meters. If the smart water grid technology is implemented, it may save money in the end. It is also important to consider that a smart water grid cannot replace the basic infrastructure. The infrastructure must be present and must be functioning in order to obtain full benefits of this technology. The smart water grid technology requires more research to maximize the capacity of the system. However, if smart water grids are implemented, utility companies can have large annual global savings as high as 12 billion dollars (Sensus, 2013; Sensus, 2012a). This money could then be allocated towards the improvement and maintenance of the current infrastructure.

In sluggish economic times, funding for water infrastructure can be even more limited. Hinchman et al. (2012) discuss monetary incentives in the US and report that companies producing advanced water technology do not get any incentives from the federal government to enter and invest in this market. Symmonds (2012) also reported that the federal government does not provide a large enough economic stimulus for water infrastructure projects due to other competing demands. In reality, the federal government gave some funding through the Smart Grid Investment Grant Program geared to accelerate and promote smart grid technologies for the nation’s electric distribution systems. The federal government provided this program with 3.4

billion of US dollars. However, if smart water grid gains more popularity and insight, the federal government might provide similar funding or incentives for those companies. Some of the incentives can be provided in the form of grants and loans, and may eventually be part of an economic stimulus package on infrastructure. However, consumers might see increases in water costs from their utilities.

Mutchek and Williams (2014) add that lack of funding is associated with institutional and political legacies. Traditionally water utilities want to deliver water to consumers at the lowest cost. Water infrastructure is mainly located underground, which inadvertently lowers the priority of improving water infrastructure ("out of sight, out of mind"). Smart water technology requires a high upfront cost, which will not have an immediate return on investment. Many water utilities lack the funding or incentives to pay this cost. Water utilities may be reluctant to try to convince residents of the need to implement this technology, as this will be partially funded at their expense through higher water prices. Furthermore, board members that vote on water prices are elected by citizens' popular vote. Increases in water prices are viewed negatively by voters, who will less likely vote for members that favor increases in water tariffs.

Mutchek and Williams (2014) also explain that there is a lack of incentives to innovate water infrastructure. Water resource is viewed as something that is given and needs to be distributed at lowest cost, where as energy, like electricity, is something that needs to be produced. As with any technology or product, the benefits must outweigh the costs. As was mentioned before, smart water grids have high initial costs, thus making them undesirable. Its payback or return periods may be large or hard to quantify. Longer return periods imply longer periods of increased water prices to consumers. Smaller utilities have smaller investment capabilities. Property owners that pay utility bills may perform upgrades to decrease their expenditures, but the resulting expense may be reflected in higher tenant monthly rental costs.

Even though smart water meters may help pinpoint leak in the distribution system, it will be hard to access and repair those leaks. Water infrastructure is located under other infrastructure like roads, behind walls, underground, which will cause inconvenience to residents or require professional repair that can be expensive. It may take several years for residents of lower water bills for a customer to gain the money invested in repairing those leaks. The leak repair may need to be postponed to align with other repairs activities to reduce costs. For example, pipe replacements will be schedules during road repavement projects. The authors state that benefits can be obtained and more recognized when a smart water grid reaches a certain size.

Chicago Department of Water Management implemented a plan to replace aging water infrastructure. This department delivers almost one billion gallons of fresh water to its consumers (ASCE, 2013). The water mains in Chicago are over 100 years old. The city used various financial pathways to finance pipe replacement: rate increases, fees, cutting payroll. This allowed them to invest 225 million dollars a year to upgrade the water system and sewers. Even though the department succeeded in financing these projects, some people lost their jobs and the water rates went up. Hard economic times make rate increases undesirable, and the unemployment rates increase due to payroll cuts. It is hard to meet everyone's needs and some sacrifices need to be made. With increase in water rates, utilities may consider compensating residents for their great efforts of water conservation.

One negative effect associated with automation is decreased number of jobs available for people. With smart water meters and frequent data transmission, utilities will have large volumes of data. It is only useful if it is well organized and well maintained.

2.3.2. Frequency Limits and Exposure

One of the negative public opinions associated with Smart Water Grid technology arises from the data transmission, which utilizes radio frequency (RF). Public is concerned with exposure to those frequencies, that may pose adverse health effects. Federal Communications Commission (FCC) has developed guidelines and standards for recommended safe limits of human exposure to RF. The Institute of Electrical and Electronics Engineers (IEEE) and National Council on Radiation Protection and Measurements (NCRP) provided recommendations, which have been implemented by FCC, on permissible RF exposures limits regarding field strength and power density (Sensus, n.d.). There are also specific absorption rate (SAR) limits (within close proximity to the body) specified by American National Standards Institute (ANSI) and IEEE. Exposure to high levels of RF, causes body temperature to increase and it may reach hazardous levels.

The exposure to the RF also depends on the distance to the source, and it is usually expressed as power density. Power density is power per unit area. For example, if you double the distance to the RF device, power density decreases by a factor of four. Smart water meters would be located on the outside of the house and transmit data less than one minute per day (Sensus, n.d.). **Table 3** below shows a comparison of power density for various devices utilized RF.

According to PG&E and Sensus, smart meters transmit very weak radio signals, similar to baby monitors, microwave ovens, or cell phones. **Figure 12** shows also a diagram of various devices and their frequency in Hertz. PG&E reports that having smart meter at a residence for 1,000 years would expose a person to radio frequency equivalent to one month to typical cell phone usage.

Table 3: Power Density in Microwatts per square centimeter ($\mu W/cm^2$).

Power Density for Smart Water Grid Meters:

Adjacent to a gas SmartMeter$^{\text{TM}}$ (1 foot)	0.00166
Adjacent to an electric SmartMeter$^{\text{TM}}$ (10 feet)	0.1
Adjacent to an electric SmartMeter$^{\text{TM}}$ (1 foot)	8.8

Power Density for other commonly used wireless devices:

Microwave oven nearby (1 meter)	10
Wi-Fi wireless router, laptop computers, cyber cafes, etc maximum (~1 m for laptops, 2-5 meters for access points)	10-20
Cell phones (at head)	30-10,000
Walkie-Talkies (at head)	500-42,000

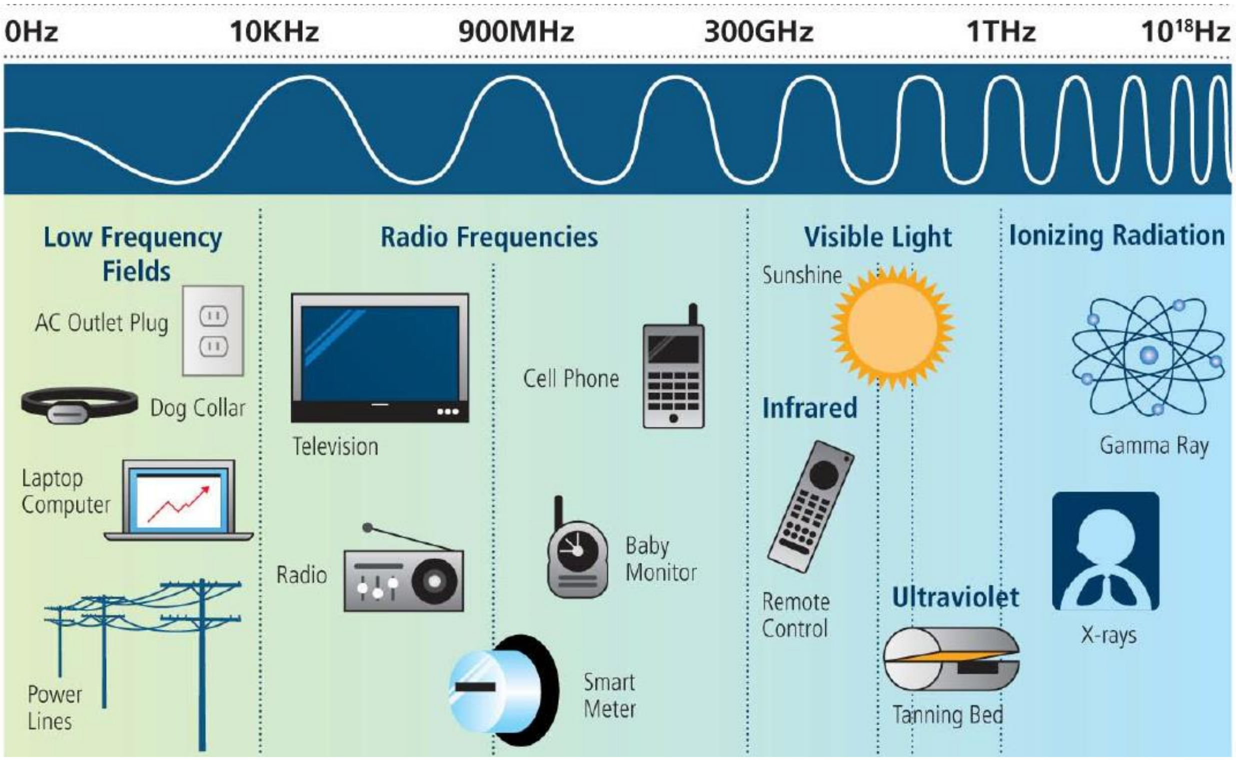


Figure 12: Frequency in Hertz (Silver Spring Networks, 2011)

American Cancer Society (ACS) (2012) also talks about smart meters and their exposure. Smart water meters would be located on the outside of the house creating a barrier between people and RF. The RF emitted from these meters is less than of a typical cell phone. While smart meters emit RF and pose potential risk of harm, the actual risk of this occurring is extremely low. They further explain that the emitted RF waves would be similar to FM radio, microwaves, heat (non-ionizing radiation). Non-ionizing radiation means that the frequency does not have enough energy to damage the DNA in the cells. Ionizing types of radiation (UV light, x-rays, gamma rays, etc) can damage the chemical bonds in the DNA (**Figure 12**). Prolong exposure to ionizing radiation can lead to cancer. ACS (2012) explains that smart meter technology is new and has very little direct research and data on the possible negative health effects from RF emitted from these devices. A lot of research has been done on cell phones. The research saw negative impacts on human cells in lab dishes, but it is not yet clear if it can cause or promote tumor growth. This is an active area of research, and based on the research data available, the link between RF and cancer is not clear. Some people relative RF exposure to tinnitus, headaches, dizziness, and other ailments. Experts suggest keeping RF devices (such as cell phones) at least 3 to 4 inches away to minimize risks. Smart meters would be located at a much greater distance, reducing the risks even further. If residents strongly oppose installation of smart meters on their property, the utility company should be able to opt them out from having them installed. As the meters are installed, organizations should perform research and collect data to determine if there is a negative impact from RF radiation.

Tell et al. (2012) performed a study on analyzing radio frequency exposure associate with Itron smart meters. Based on their results, the RF fields complied with FCC exposure limits. The RF frequency associated with smart meters was found to be two orders of magnitude, or more, to be below FCC levels for general public. For more information on this study, please refer to a copy of this paper in the **Appendix B** at the end of this report.

2.3.3. Other Disadvantages

The concept of smart water grids has been around for years, but its implementation is very slow. This is due to the lack of understanding business case, funding, political support, and adequate products and solutions (Sensus, 2012a). **Figure 13** shows the summary of barriers as obtained from surveying different utilities. Eighty-nice percent saw strong business case but lacked funding to install smart meters. Sixty-five percent of utilities responded that there is a lack of business case to support these solutions. Those who answered that business case was "significantly" or "very significantly" not compelling explained that benefits were not high enough to justify the investment, and the overall cost of investment (smart meters, communication infrastructure, sensors) was too high. The utilities were concerned that the return on investment was hard to quantify. A strong business case is especially important for small utility companies.

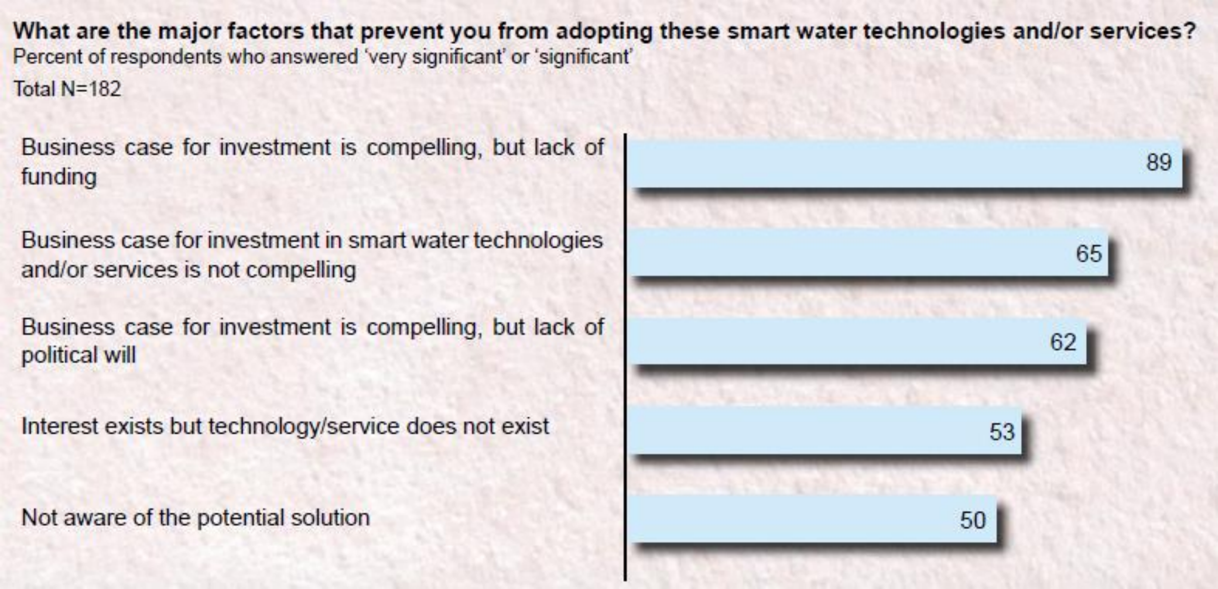


Figure 13: Major factors that prevent utilities from adopting smart water technologies (Sensus, 2012a).

Another common reason among utilities was the lack of political support to implement smart water networks. The responses expressed the need for a leader (within the organization) who would be technology orientated and would support these solutions. Externally, other leaders (city council members) need to be open minded and educated on available technology and overall picture of the water distribution systems. Utilities need to build a strong business case to gain political support. This may be more important in areas that are faced with water scarcity problems.

Sensus (2012a) also summarizes that utilities are concerned with a lack of integrated solutions within smart water technologies. Utilities expressed a need to have an international standard for such devices. Different vendors provide different systems that may not work well with others. Small utilities also expressed the need for smart water technology to be user-friendly, because they have a limited number of staff and lack of capacity to train multiple operators.

2.4. Network Vulnerability

Julien and Martyusheva (2013) discuss how smart water grid networks can be vulnerable to natural events. While smart water grids clearly emphasize water quantity aspects, another important aspect of water distribution systems deals with water quality. The quality of the water can be affected by changes in water quality and quantity at the sources, and by possible accidental water plant releases of "below standard" water treatment batches. The water quality at the source can also be affected by natural cycles in floods and droughts. Low flows and warm temperatures may favor algae growth, low dissolved oxygen, salinity problems, fish kill, odors, etc. Floods may on the other hand bring large concentrations of sediments, accidental industrial releases, etc. In terms of water quality at the source, smart water grids should be prepared for the worst possible scenarios. For instance, the water quality of reservoirs is normally very stable and dependable. Solely rely on this source of water could yield to consequences damaging the "smart" reputation of water grids. If the systems shut down because of unexpected circumstances, the public opinion may turn against the proponents of smart systems.

Unusually high sediment concentrations can be observed in South Korea during major storms and typhoons. An (2012) studied the impact of typhoons on the distribution and propagation of interflows carrying large concentration of clay particles in Imha Dam. The reservoir waters became heavily silted and highly turbid for several months after typhoons Maemi and Rusa. These high water turbidity problems could be attributed to thermal stratification during the summer months and very large floods from typhoons as shown in **Figure 14**.

Figure 14: Discharge of highly turbid water during Typhoon Ewiniar downstream of Soyang Reservoir in 2006 (An, 2012)

These high turbidity waters could persist for months and caused tremendous problems in the reliability of water sources. In the context of smart water grids, it is important to consider alternative sources of water during some potentially critical times of the year. These time periods are usually associated with extreme flow conditions, either very high flows or very low flows. These natural events are subjected to climate variability and single events can disrupt normal operations for extended periods of time. Some anthropogenic or industrial activities as well as extreme climatic conditions can have devastating consequences.

Robust systems may have alternative supply sources when facing scarcity of resources or changes in water quality/contamination. For instance, semi-arid areas impacted by forest fires can see the water quality at the source deteriorate greatly for several years. It is important to develop strategic relationships in such cases. Perhaps the water sources can be exchanged with groundwater users for a certain period of time. Other users may not mind using water with a different water quality. After all, thorough understating of the network vulnerability can lead to “smarter” distribution systems. The ability to prepare scenarios for disaster prevention may also positively contribute to the “smart” reputation of water distribution systems.

2.4.1. Forest Fires

Forest fires can greatly impact water quality. Depending on the burn severity, most of the vegetation is removed and exposes the soil. In high burn severity areas, soils can form a hydrophobic layer. In the rainfall event, the water does not infiltrate; the soil is eroded and carried downstream into a reservoir or stream, which serve as water sources for local areas. The sediment and ash in the water influence not only aesthetics but also the taste, which is undesirable by consumers. Large sediment concentrations also may affect overall design and storage capacity of hydraulic structures downstream.

To date, Hayman fire is the largest wildfire in Colorado that occurred in the summer of 2002. The fire burned 138,114 acres of land. The wildfire burned area around Cheesman reservoir, which stores water for supply for Denver area. Forest Service was implementing various types of hillslope treatments to help reduce erosion and delivery of sediment to the reservoir, which may travel further down into South Platte River. According to Colorado State Forest Service (CSFS), 26 municipal water storage facilities were shut down due to fire and post-fire impacts in 2002

Colorado fire season. Post fire effects due to the Hayman fire impacted source water quality for more than five years after the fire.

Fourmile Canyon wildfire occurred in Boulder County, Colorado in 2010 (**Figure 15**). This fire burned approximately 6,181 acres, which is 23 percent of the Fourmile Creek watershed (USGS, 2012). A drinking water treatment plant withdraws water from Fourmile creek. Water treatment plants typically prefer the turbidity to be less than 20 nephelometric turbidity units (NTU). Based on the data collected, spring snowmelt and summer thunderstorms transported the most sediment and increased turbidity beyond the acceptable threshold. Similar can be seen in other water quality parameters shown in **Figure 16** below. Summer season is also the higher time period for water demand. As described in USGS (2012), besides affecting the water aesthetics, increased sediment loading shortens reservoir lifetimes, higher treatment requirements, larger volumes of sludge, which all attribute to increase in maintenance and operational costs. Algal blooms, undesirable taste and odor can be attributed to increase nutrient loading (increase in nitrogen). Results presented in **Figure 16** also showed increased levels of dissolved organic carbon (DOC). Elevated concentration of DOC help form unwanted by-products such as chloroform and trihalomethanes. The sources of water located downstream of the burn areas require monitoring, temporary diversion of water or change of the source.

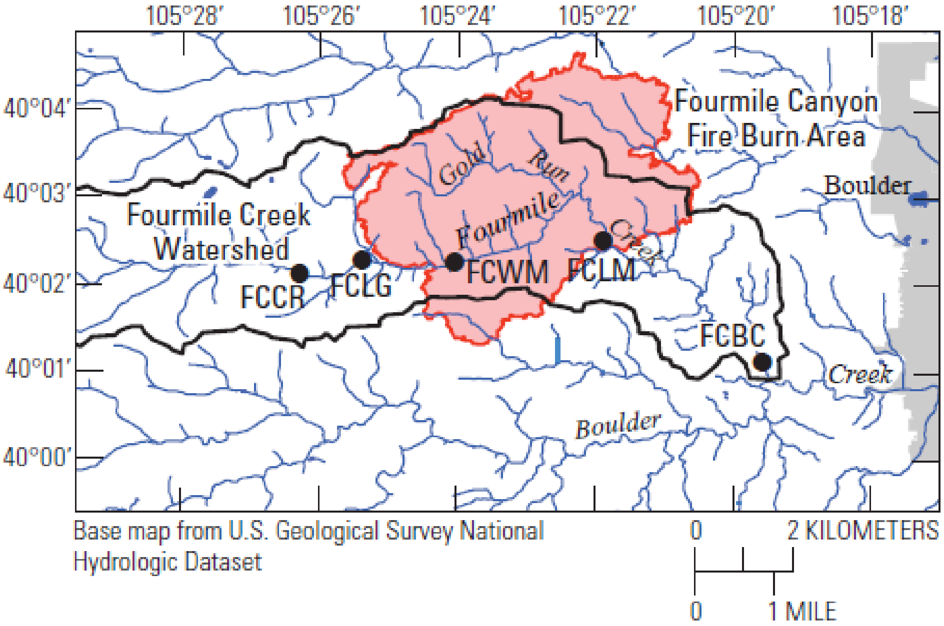


Figure 15: Fourmile Canyon burn area (USGS, 2012)

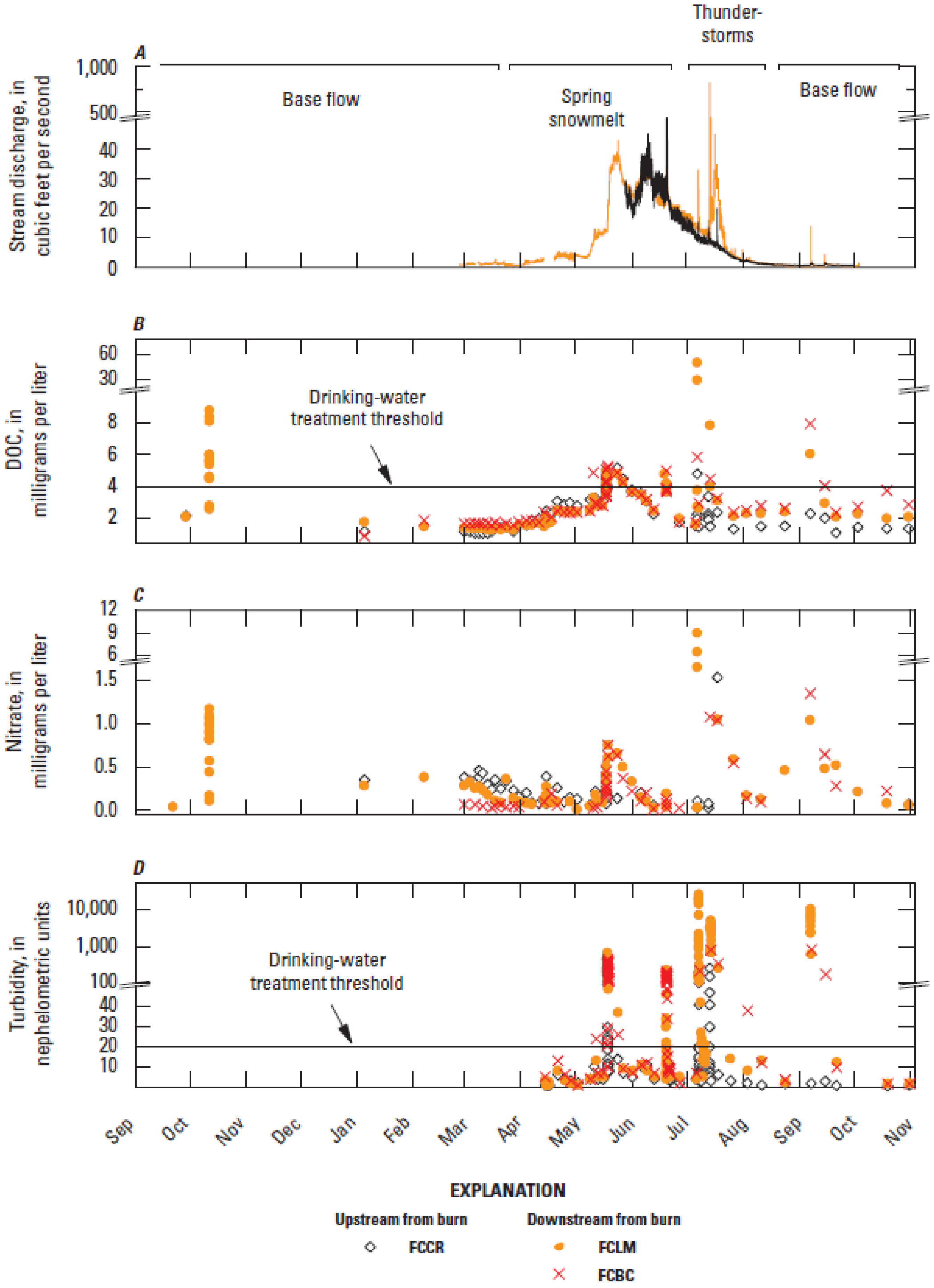


Figure 16: Water quality characteristics measured in Fourmile Creek, CO in 2010-2011 at three monitoring stations.

2.4.2. Other Vulnerabilities

T0 further maintain the intelligent reputation of the smart water grid systems, they need to be prepared for a wide range of vulnerabilities. The communication and data transmission is done using wireless technology. It is important to make sure that there is no data interference with data collection and transmission. Depending on the size of the distribution network, there may be limitations associated with distance between meters transmitted information and towers receiving this information. The number of towers may need to be increased to accommodate these large distances and ensure proper data transmission. The systems also need to be prepared to handle power outages as this may affect flow of information, billing, and monitoring. This may require generators, or presence of analog meters in the distribution network. As was mentioned earlier, the meter, and communication devices become vulnerable due to their surroundings. Animals, trespassers, and inclement weather can jeopardize system performance. Understanding how the information is flowing within the system, may help to find potential vulnerabilities and secure the network. It is also important to protect the system not only on the outside, but also on the inside. The system may become compromised due to untrained personnel, people without permitted access, viruses transferred to a computer through email, USB drive, and others. This will require proper training of the system and teaching personnel about security and risks, and provide limited access to the control room.

2.5. Other Considerations

Human interaction is a key component of the Smart Water Grid system. The personnel need to know how the software works and how to interpret the information it presents. The personnel needs to observe the information presented and look for any irregularities. The system will display alarms, but it is the job of the personnel to understand what it means and take necessary action.

The Smart Water Grid needs to be designed based on the water distribution system, which are different for every location. The networks may be large or small depending on the location. This will also dictate the location of the central system and receivers within the network as the signal may be limited by distance. In the rural areas, the individual smart meters would be spread out across large distances. The larger the network and the number of its components, the more maintenance and operation it will require, increasing capital and operational costs. Therefore, the receivers need to be placed optimally and accordingly to communicate with meters, receive and transmit the information. Similarly, in the large urban areas the information and communication needs to be successful even with the farthest points on the grid. Additional challenge in urban areas is the data transmission and interference.

The Smart Water Grid is not a standalone system and cannot replace basic infrastructure. It is a tool to help utilities monitor and maintain water distribution networks. Therefore, it is important the water infrastructure is functioning. ASCE (2013) reported a grade of the drinking water infrastructure and wastewater to be a D. Even though the quality of the drinking water is high, the overall state of the infrastructure is very poor. It would cost more than one trillion of US dollars over several decades to replace every pipe in the system (ASCE, 2013). In order to determine which pipes need replacement or maintenance, utilities must have a good inventory of their assets. Utilities may run into problems regarding lack of information of where the pipes are located, their age, and material. It will take time to create a detailed network of the system. Having this information availability will help utilities to keep up with the infrastructure and maybe have scheduled assessments, and respond faster to any irregularities or problems.

There are different tools that utilities can use to help them further monitor water distribution networks. Condition assessment is an important part of the determination of the pipe condition. There are different technologies available to inspect pipes and determine leak location. Proper condition assessment tools and techniques can help determine if the pipe needs repair or replacement. Utilities can also perform water audits to help obtain a water balance. This goes back to **Table 1** presented by American Water Works Association. Calculating infrastructure leakage index (ILI) can help to classify the condition of the infrastructure and provide some considerations. ILI is a dimensionless ratio between the current annual real losses (CARL) and the unavoidable annual real losses (UARL). However, it is important to understand how these tools calculate those parameters/ratio, and their assumptions, as it is not a true representation of the condition. Those tools have been developed as simple means to quickly evaluate network performance. The goal is to utilize smart meter information to help find and reduce those losses, and create a detailed database of the system. EPA and AWWA provide some helpful resources and guidelines for conditions assessment, performance indicators, and others to help monitor water distribution networks.

III. Case Studies

Several projects worldwide have implemented Smart Water Grid technology and have seen promising results. There are several case studies presented below from Malta, Miami-Dade parks, South Bend in Indiana, Mumbai India, and Panama City, Florida.

Malta Islands

The Republic of Malta is located in southeastern part of Europe. Malta's population is approximately 400,000 people. It is a popular tourist destination, which has approximately 1.4 million visitors every year. Malta is one of the world's smallest and most densely populated countries. It consists of several islands in the Mediterranean Sea. These Maltese islands are surrounded by seawater. The drinking water is obtained from an aquifer and desalination processes. Three desalination plants provide more than half of Malta's water supply. Water Service Corporation (WSC) is a company that supplies water to Malta's residents. According to Water Services Corporation, about 17 million cubic meters of water were produced by three reverse osmosis plants in Malta in 2006-2007. The cost to desalinate water for consumption is 75 percent of their total electric costs, while their energy comes from imported fossil fuels. Enemalta is an energy company that works closely with WSC.

In 1995, the Infrastructure Leakage Index (ILI) was calculated to be over 10. The leakage amount was at 3,900 cubic meters per hour. WSC worked towards reducing the amount of water lost. By 2012, the ILI dropped to 2.3, and the leakage amount was decreased to 496 cubic meters per hour. This was achieved through water pressure management, active leakage location, and repairs. Another losses associated with loss of revenue are apparent losses, which are associated with meter-under-registration, errors in billing, or theft of water. Based on the studies done in Malta, meter under-registration was the largest contributor to apparent losses.

In response to increasing water, energy demand, prices, and water scarcity Enemalta and WSC formed a private limited liability company in 2010 called Automated Revenue Management

Services (ARMS) Ltd (IBM, 2012). Their purpose it handle all aspects of customer relations and all billing functions for both companies.

To improve network efficiency and conservation, the nation of Malta partnered with International Business Machines (IBM) Corporation and Itron, Inc. to create first national smart utility grid for both electric and water infrastructure. In regards to water infrastructure, WSC aimed at reducing their apparent losses. The total approximate cost of the project was 88 million US dollars. The project set to replace 250,000 analog electric meters, and more than 100,000 water meters. As of May 2014, the WSC successfully installed 120,000 Itron smart water meters. WSC signed an additional contract for another 33,000 smart water meters (Itron Inc, 2014). In addition, their reverse osmosis plants are installing SCADA system to help them monitor and optimize desalination processes. Considering all of the facts presented above, Malta can obtain numerous benefits from this technology. The smart meters will help to map the water distribution network to monitor usage and help find leaks, or illegal connections. This will help to reduce their energy and water treatment costs in the future as losses are reduces.

WSC management describe that smart meters provide a variety of additional functions compared to old analog meters. They monitor active and reactive energy consumption, export and import (if consumers have renewable energy), and quality of supply. The utility can remotely disconnect and reconnect circuit breakers. Voltage interruptions, variations, or fraud attempts can also be seen by these meters through self-diagnostic functionalities.

The collected data must be interpreted and analyzed. This is the purpose of the data concentrators, which communicate with devices through PLC. They gather information from the meters such as loads, consumptions, service quality, etc. These data concentrators can also issue commands back to the meters. The next piece of the system is the Automated Meter Management system (AMM), which is responsible for collecting data from data concentrators. It can also give commands directly to the meters such as activate/deactivate circuit breakers. Its main purpose is to make sure that the information that being sent is delivered securely, in timely manner, and to the right recipient. The last, and most intelligent component, is Metering Data Management (MDM). It stores all of the information received from the meters. Once all of the meters are installed, Enemalta will be receiving 25,000 times more data. MDM would then aggregate, validate this information, estimate any missing information. Finally, it would provide this information to other users. The information is used for billing, energy balance, identify any fraud attempts, and analyze loads on the substations.

These smart meters operate on batteries. Meters can be located in hard to reach places. To maximize the useful life of the battery, functionalities must be optimized and prioritized. Water meters in Malta transmit information every four hours. According to ARMS Ltd. (2010), smart meters transmit information on 169-868 MHz frequency, and should not pose any health risks, or affect radio and Wi-Fi capabilities. The goal is to use gathered information to improve management of water distribution networks and improve service to customers. The information can also help identify undersized or oversized meters. They can inform customers if there is a leak in their system. Furthermore, the meters can capture and transmit information related to pressure, and water quality.

Due to the implementation of these meters, partly attributed to successful partnership with IBM, Enemalta and WSC has a greater knowledge on the performance of their networks and behavior of the customers. This will continue improving their services to the customers, move towards a sustainable water systems, and contribute to the energy efficiency and environmental targets set by Malta.

In 2013, Water Service Corporation received an Engineering Excellence Award for its efforts to reduce water losses and increases in efficiency in reverse osmosis water treatment plants (WSC, 2013). Due to their efforts, it led to reduction of CO_2 emissions by 26,000 tonnes per year. Consequently, water prices were able to remain stable.

Miami-Dade County Parks

Miami-Dade County Parks are one of the largest and diverse parks in US. They collaborated with IBM to help track and monitor consumption. Jack Kardys, the director at Miami-Dade county Parks, is very pleased with this project. The parks are aware of leaking pipes, but the time to find leak locations and responds to those problems is very slow. The Miami-Dade parks pump approximately 360 million gallons of water per year, which costs about five million US dollars. They have a combined water and sewer system. They installed Smart Water meters that communicate data to a central location, which shows any irregularities in water usage. The response time to any unusual water usages is much smaller. They anticipate one million US dollars worth of savings once this project is completed and deployed. The savings would then go towards the community and programs at the parks, such as learn to swim program. It costs one million dollars every summer to manage 12 pools and teach 10,000 kids to swim. They also have an after school program, which costs them 400,000 US dollars per year. This project will help to practice water conservation, improve their water usage efficiency, improve maintenance and response time, and use their savings to provide more services for the kids in the community.

South Bend, Indiana

South Bend, Indiana also worked with IBM to implement their Intelligent Water software platform to help improve their wastewater management. The city has a combined sewer overflow system. During high precipitation events, sewer water may overflow (wet weather flow) and be discharged into a nearby river, or stream. By implementing this platform, South Bend was able to reduce their wet weather overflows by 23 percent, and reduce their dry weather overflows from 27 to one percent. This also helped to avoid 120 million US dollars of infrastructure investments, and 600,000 US dollars of government fees associated with sewer discharge.

Mumbai, India

Mumbai is India’s largest city with a population of 13 million people. Itron meters were installed in the system that supplied tap water to half of the city’s residents. By implementing these smart meters, there was a 50 percent decrease in water losses (Itron Inc, 2013). The city was able to identify leak locations as well as promote water conservation. This project exceeded the target’s goals and provided a higher quality water network. Other case studies done by this company can be found on the Itron, Inc website.

Panama City, Florida

Panama City, Florida utilized Sensus technology to improve its water grid. They upgraded approximately 25,000 existing water meters with zero-lead Sensus iPERL^{TM} residential and OMNI^{TM} commercial meters. This was initiated after a water audit showed that 20 percent of the water was unaccounted for in the system (Sensus, 2012b). After implementation, they were able to better track and account for this lost water. In addition, this technology helped improve customer service, efficiency, and improve the ability to keep up with regulatory requirements.

IV. Conclusions

This technical report presented a literature review of information researched regarding Smart Water Grids. The summaries for each objective are summarized below. The objectives of this technical report were: (1) discuss current water, energy demand, consumption, and current state of water infrastructure; (2) describe Smart Water Grid and its components; review other monitoring methods; discuss advantages, disadvantages, and vulnerability of smart water grid networks; (3) lastly, present several case studies where this technology has been implemented.

(1) There is a worldwide increase in freshwater demand as population in urban areas and developing countries continues to increase. Climatic conditions, extreme events, and drought affect overall water availability. Many areas, such as California, are experiencing drought conditions, increasing water demand, and the need for water conservation. In addition, the infrastructure delivering water to public is aging and deteriorating. Water networks are diverse, made up of various components, and span long distances. Most of the water infrastructure is buried, which makes it challenging to inspect. Especially in hard economic times, pipe maintenance and replacement is set aside. When there are leaks in the system, municipalities may not be aware of them, and it is difficult to locate leaks in the system. It requires trained personnel to go out in the field and perform condition assessment. In some cases, it is hard to predict impeding failures until it is too late. Water main breaks can cause disruptions and damage to road and/or other property and structure. The response to these failures takes time as municipalities become aware of the situation.

(2) Smart water grid can help monitor water distribution systems. Smart water grid consists of a two-way wireless communication network. The water distribution system would be equipped with smart meters that can measure a variety of system characteristics some of which are flow, pressure, and water quality. The information from the meters is wirelessly transmitted to the central location for display and analysis. One of the advantages of this technology is the increased volume of data that can be used to further gain knowledge on system performance. Compared to older approaches, the information will be received several times a day. The workers would be observing system

performance and watch for any irregularities. If such irregularities were to occur (e.g. main break), the response time would be greatly reduced as this information is transmitted in real time. Real time information can also be used to identify leaks within the system. This can help reduce water waste. Knowing water consumption demand, the utilities can adjust their water treatment processes to meet those demands and promote water conservation. In return, water conservation can be reflected in lower energy costs, as large percentage of operating expenses is attributed to water treatment and distribution to consumers.

The smart water grid system requires human interaction, as personnel response and takes necessary actions. Furthermore, this system cannot replace the basic infrastructure. The system can help to obtain a detailed mass balance, locate leaks or problems within the system, reduce response time to failures, find missing or illegal connections; it may even be improved to help monitor water quality. However, one of the main disadvantages is the initial cost to implement these systems is large. In hard economic times it is hard to find funding. In addition, consumers are opposing increase in water tariffs. Besides the lack of funding, some utilities find lack of business case to implement smart water grids to their water distribution networks. Utilities want to make sure that they can obtain an appropriate return on their investments. There is a need to increase awareness of aging and deteriorating water infrastructure and possible technologies. Some people have negative opinions regarding smart water grids, as it brings issues of government invasion, and negative health effects associated with radio frequency. Research has been done to measure radiofrequency exposure associated with smart water metering infrastructure. The results are consistent among different agencies and authors. The radiofrequency emitted by smart meters is below limits imposed by US Federal Communication Commission.

Smart water grid systems need to be prepared for a wide range of vulnerabilities. These vulnerabilities arise from the surroundings and may come from within the system. The integrity and performance of meters and communication devices can be compromised due to the outside conditions, trespassers, or animals. Severe weather, extreme events, or power outage can disrupt information flow. The central locations must also have an appropriate security system to allow trained personnel only. The viruses can also be introduced into the system using a USB drive. Being prepared for the potential vulnerability will ensure a better performance of the system, better customer service, and maintain “smart” reputation of this technology.

(3) Based on the case studies presented in this report, smart water grid has a lot of benefits and potential to help improve monitoring of water distribution systems. The technology industry can learn from implemented projects, learn about vulnerabilities, and improve the technology for future development projects. As industries gather more data, they can study the systems and watch for any negative impacts the technology may have.

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Appendix A

The Smart Water Grid International Conference 2013. Abstracts

SMART WATER GRIDS AS A SOLUTION TO PROTECT WATER RESOURCES AND THE QUALITY OF WATER BODIES

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Keywords: Energy Conservation; Smart Water Grid; Water Consumption.

ABSTRACT

Customer's expectations regarding Smart Drinking Water and Smart Waste Water revolve around 4 major challenges for which Smart Water Grids bring an added-value solution:

1. Preserve the health, security and quality of life of citizens,
2. Minimize adverse environmental impacts
3. Optimize operations to reduce operational expenditures
4. Manage and preserve assets and optimize investments

In France, network water losses average 25%, and there is a growing pressure on the water resource. 6 billion m^3 are abstracted every year by local governments. Water distribution networks (about 856,000 km) loose an average of 25% of water, with some peaks at 40% in some locations. A water distribution network should not exceed a leakage rate of 15%. Improving the network technical yield thus preserves the water resource.

Smart Drinking Water

Along a value chain spanning the water resource, production, transport, distribution, and customer management, the challenges of Smart Drinking Water can be summarized as follows:

- Operational performance: optimizing works planning, reduce losses and accidents, reinforce crisis management capability, analyze network events in real time (leakages, breaks,...),
- Environment: preserve the water resource by reducing leakages, monitor water quality in real time, and insure regulatory compliance,
- Optimization of expenditures: optimize returns on assets and equipment, manage operational and capital expenditures,
- Information & Governance: engage inhabitants, promote water service quality, improve community knowledge base, and report on performance.

The benefits can be described as follows:

- Visualize the state of the drinking water network at a glance,
- Target and prioritize works on the field,
- Improve network technical yield and preserve resources.

Smart Waste Water

Urbanization and major weather events have strong impacts on the environment.
Extreme weather events induce 50% of river pollution. Urbanization increases flood risks. The survey of natural water flows in France shows that periods of low water over the last 40 years are increasing in duration and severity (source: www.onema.fr/dossier-secheresse-2011). In France, artificialized areas have increased by over 40% in 20 years (source: Ministry of Ecology and Sustainable Development (MEDD) study, 2011)

The challenges of Smart Waste Water can be summarized as follows:

- Protect water bodies and inhabitants
    - Control flood risk by limiting overflows in urbanized areas using the storage capacity of the waste water system,
    - Reduce extremely polluting overflows in water bodies (responsible for 50% of river pollution).
- Manage systems in an efficient way
    - Anticipate and manage crises,
    - Optimize operation costs through automated management of sewers and anticipative and dynamic management of waste water treatment plants during rainfalls,
    - Reduce investments needs by using the storage capacity of the sewage network.

Smart Waste Water brings the following benefits:

- Synthetic and detailed visualization of a waste water system,
- Global visualization of parameters affecting the waste water system (weather, hydrology, hydraulics,...),
- Detailed visualization of assets (sewer networks, reservoirs, flood-protection assets,...),
- Anticipation of flows and water volumes at key points of the waste water network,
- Dynamic instructions to reduce overflows and discharges in the environment.

From Smart Water to Smart Energy

Energy costs represent a little over 25% of water production operational expenditures and about 20% for waste water treatment.

Smart Water applications can be extended to the control of energy costs that is a fundamental component of water and waste water operational expenditures.

There are 3 possibilities to valorize flexibility in Smart Energy Management:

- Adjustment: on-demand increase or decrease of electricity consumption, with an important reactivity to correct forecasting errors,
- Load-shedding: stop or reduce electricity consumption on demand to avoid peak consumption at agreed conditions,

Profiling: optimize the consumption profile of one or several sites according to electricity tariffs.

WATER MANAGEMENT POLICY OF MONGOLIA

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Keywords: Water Resource; Surface Water; Water Management.

ABSTRACT

According to the 40 years study, Mongolian water resource 608 000 million m^3 and 34 600 million m^3 of it is rivers, 500 000 million m^3 is lake, 62 900 million m^3 is glaciers, 10 800 million m^3 is groundwater. Water resource distribution is unevenly and it is depend on water quality, components, location, ecological regions, and geological structure. The 70% of surface water is forms in higher part of Altai, Khangai, Kentii, Khuvsgul and Great Khyangan's Mountains which are 30% of Mongolian total territory. The water resource divided in to three drainages, Arctic Ocean basin, Pacific Ocean basin and Central Asian Internal Drainage basin. The 17 bigger rivers and their tributaries originated from these drainage basins and most of it flows into neighbor countries.

In Mongolia, total water use and water demand is 500 million m^3. The 30.5% of total population use water from centralized water supply chain, 35.8% is from portable water service, 24.6% is from wells, 9.1% is from springs and rivers. Level of water use is different, for example, people who live in apartments connected with engineering supply chain in cities and settled areas use 230-350 liter water in a day, otherwise people who live in countryside or ger areas use 5-10 liter water a day. Water use has trend of increasing year by year and further, improving sufficient of the water supply chain, sewerage; ensuring sustainable of farming and agriculture; irrigating the pastureland and agriculture areas; determining the development of food, mining, industrial and renewable energy sectors will be main factor of development.

Due to the climate change, evaporation will be increased by 39-66 mm in 2020, 50-72 mm in 2050, 106-193 mm in 2080; melting of glaciers will be increased because of increasing air temperature, for example 50 m ice will be potentially melt in 2040, 100 m in 2050-2060. According to the state inventory of surface water in 2007, totally 5121 river registered, from them 887 dried out; Also 2096 springs of total 9340 and 1166 lakes of total 3732 dried out. It indicates that even though water use and water demand is relatively small, but water resource, quality is degrading because of climate change and farming.

In national level, control on water use did not developed and related laws, regulations, integrated data, monitoring system are not completed. Due to it, creating data base, monitoring and managing water use is inconvenience. Mongolia is one of the water resource scarcity countries and small amount of the resource is distributed unevenly; monitoring and management is insufficient; related laws and regulations are not developed enough; level of water supply is lower; sufficiency of sewerage and treatment and it capacity is not enough, capacity building is lack. Therefore it is required to solve the problems.

ICT BASED WATER PLANNING AND MANAGEMENT FOR EFFICIENT WATER SUPPLY IN NEPAL

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Keywords: Managerial Decision Making; Operational Management; Tactical Management; Strategic Management; Layer Model.

ABSTRACT

Lying between the two most populous countries of India and China, Nepal covers a thin expanse of the eastern half of the Hindu-Kush Himalayas along India's northeastern border near Bhutan. It is a nation of rich biodiversity and vast natural resource wealth—especially water—with more than 6,000 rivers cutting across numerous microclimates, from the high peaks, glaciers, and incised valleys of the High Himalayas (including Mt. Everest) to the tropical broadleaf and coniferous forests of the Middle Mountains and the savanna and grasslands of Terai. These rivers have total drainage area of 191000 sq. km, out of which 74% lies in Nepal alone. There are 33 rivers having their drainage areas exceeding 1000 sq. km. Drainage density expressing the closeness of spacing of channels is about 0.3 per square km. If this natural resource is properly harnessed, it could generate hydropower; provide water for irrigation, industrial uses and supply water for domestic purposes. More than 2000 glaciers lakes are identified in the Himalayan region where more than 20 are highly vulnerable. In addition, unprecedented rainfall (>100mm/day), flooding, landslides, draught in the winter, water pollution and increase of water borne diseases are the major risk in this region. Only about 80% of the country's population has access to basic water supply and only 43 % of the whole population has sanitation facility (Sanitation & Hygiene Master Plan, 2011).

Nepal is rich in fresh water recourses having approximately 225 billion tons of water available annually in which only 15 billion tons is used for agriculture 96%, industry 1%, and municipal use 3%. Though, the availability of excessive quantity of water, country cannot fulfill the 280 Million Liter Day (MLD) urban water demands of capital city (Kathmandu Valley) only. Out of the total demand of the valley, the current supply system supplies 140 MLD only even though the history of piped water supply system development in Nepal dates back to 1895 A.D.

Effective water management is very important to overcome the water supply problems. Nevertheless, the situation of such water supply management problems can be improved with the use of Smart Technology. The use of such technology focuses towards Information & Communication Technology (ICT)-enabled solutions for integrated water resources management (IWRM) which includes Innovative demand management systems, decision support system and data management. The technology simultaneously focuses on operations, operational management, tactical management and strategic management. Hence, it helps to reduce peak period water distribution load, saves the consumer water and empowers end users with real time information. Moreover, it increases awareness and stimulates behavioral changes, controls over unnecessary leakage and protects the scarce water resources as well as reduces CO2 emission.

Table 1. Climatic Conditions of Nepal

Ecological Belt	Climate	Average Annual Precipitation	Mean Annual Temperature
Mountain	Arctic/ Alpine	Snow/150mm-200mm	<3–10 degree centigrade
Hill	Cool/warm Temperate	275 mm-2300 mm	10–20 degree centigrade
Terai	Sub-tropical	1100 mm- 3000 mm	20–25 degree centigrade

Source: National Water Plan, 2005

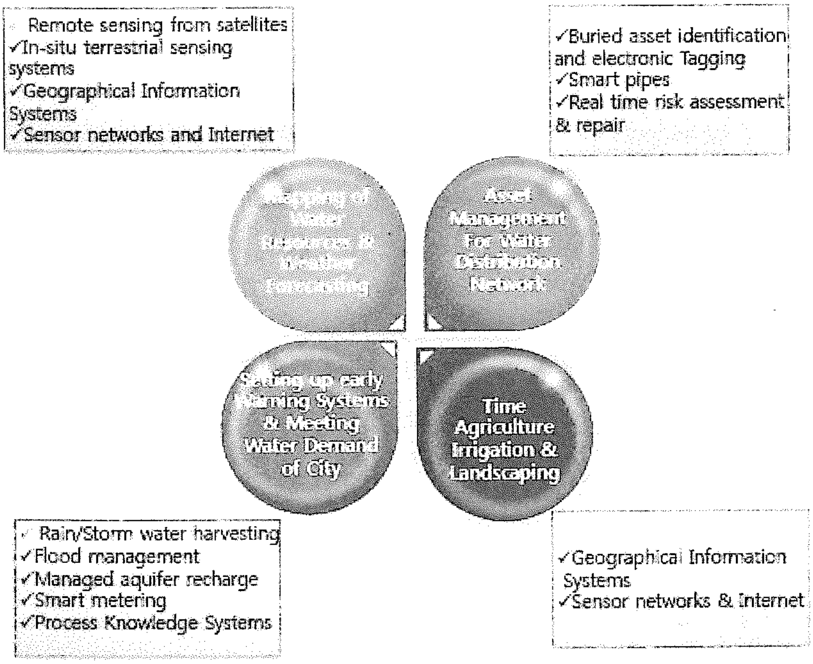

Figure 1. Conceptual Framework: Smart Water Management

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SMART MANAGEMENT OF THE WATER URBAN CYCLE

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Keywords: Real-Time Monitoring; Decision Support; Flood Prevention; Public information; Demand prediction; Water reuse; Asset Management; AMR.

ABSTRACT

Aguas Municipalizadas de Alicante, AMAEM, is the company in charge of managing the urban water cycle in Alicante and several neighbour towns: San Vicente, Sant Joan, Petrer, Monforte and El Campello. More specifically, AMAEM provides the water distribution service in all of them, and is responsible for the sewage service in Alicante, Sant Joan and Monforte. The population served amounts to 750,000 inhabitants, supplied by a 2,000 km water distribution network and 700 km of sewage drains. AMAEM is a public-private-partnership shared by the town council (50%) and the AGBAR Group (50%). AMAEM is an example of successful PPP for the World Bank.

The company develops and makes intensive use of available ICT solutions to run the services and to optimize its assets with partners such as Aqualogy or Ondeo Systems in an environment where traditional strategies prevail. This stake in added value technologies is reflected in the involvement of the Company in the @qua consortium. We shall briefly describe some of the projects developed and implemented by AMAEM for the management of the Urban Water Cycle, classified in four lines

Public Administration Smart Synergies

- iCAP: Online System for Water Quality Control in extensive Regional Networks
- SIPAID: Smart Flood Early Response Management: Integrated System for flood prevention, decision making speeding-up for all the actors concerned

Smart Citizen Information:

- Spot Billing: Onsite instant billing to guarantee the client access to the complete invoice: alternate solution to both traditional and Internet invoicing
- Augmented Reality Mobile Information of City Works Progress: Multi-platform integrated solution to provide updated information on planned and ongoing urban works to citizens, in order to minimize impact.
- Cowama/iBeach/Smart Panels: Integrated and Real Time Monitoring System to Protect the Quality of Bathing Waters and public communication through multiple channels

Sustainability and Circular Economy:

- Water Reuse for Urban Uses: Water recycling to guarantee hydric sustainability and improve the urban environment for a better quality of life. Automated remote control for irrigation optimization and water quality control.

- Enernova: Remote real time analysis of energy consumption recorded by power meters to optimize energetic efficiency
- PALACE: Multi-model software for water demand prediction, based on a hybrid (time series + external factors) approach

Smart Asset Management:

- Universal AMR System (>40.000 active meters in 2013; to be fully operative in 2015): Remote Meter Reading solving the problems associated to manual Reading, providing added information and services to the consumers
- Metresa-Metrawa: Decision Support System for optimal network renewal, able to prioritize asset replacement/rehabilitation and deliver the best technical solutions
- Idrolewell: comprehensive water well monitoring system, able to perform a complete, real time, continuous diagnosis of the groundwater catchment and pumps.
- Smart infrastructures for flood and waste water discharge prevention, such as the automated stormwater retention tank "Eng. Jose Manuel Obrero" (60.000 m3) or the Floodable Park "La Marjal"
- Ice Pigging: Water supply network cleaning by soft ice injection. This innovative technology greatly improves cleansing efficiency while reducing water use to the minimum

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VALUABLE LESSONS FROM A LARGE URBAN UTILITY'S MOVE TOWARDS A SMART WATER SYSTEM

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Keywords: Smart Water System; Real-Time Decision Support; Distribution System Modeling; TEVA-SPOT

ABSTRACT

Over the last decade, our industry has seen a rapid growth and advancement in technologies that together have the capacity to transform the way we view our water systems and ability to improve them. These advancements have taken the form of remote monitoring devices, real-time communication, big-data management tools, real-time data analytics and modeling software, and automated controls.

Some United States utilities are embracing these advancements to build smarter water systems driven by a variety of issues, which can range from supply deficiencies and increasing energy costs, to water security, improved process control and tightening water quality regulations. However, the move to actually implement these smart water initiatives commonly requires a combination of support by multiple stakeholders, sufficient funding, and a strong business case to justify the capital and operational investments in light of other high-priority projects that address more acute and immediate needs.

Through funding and support from the US Environmental Protection Agency (EPA) Water Security Initiative (WSI), a group of large US utilities were selected as part of a pilot program dedicated to the evaluation and implementation of smart water technologies. For these utilities, the WSI led to the development of a comprehensive surveillance and monitoring system to provide real-time detection of a potential contaminant threat. Among the key components evaluated through the WSI were water quality monitoring, distribution system monitoring and modeling, enhanced security monitoring, consumer complaint surveillance, public health surveillance, and information technology systems integration.

This paper will discuss some of these components and their capacity to support and/or streamline decision-making. Of particular focus will be the evaluation and use of advanced distribution system modeling applications including TEVA-SPOT for locating optimal water quality sensor locations. Critical to the project were the lessons learned related to integration of multiple data systems, cost-benefit trade-off for advanced solutions, sustainability of solutions for future change management, and technical staffing requirements – all of which are important aspects to consider when evaluating any potential smart water system.

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A STUDY ON THE DEVELOPMENT OF A SIMULATOR FOR EFFICIENT WATER INFORMATION DISTRIBUTION IN SMART WATER GRID ENVIRONMENT

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Keywords: Smart Water Grid; Water Information; ICT; Simulator; Web-GIS.

ABSTRACT

Nowadays, more efficient distribution of water information has been required for more strategic response against water shortage due to the global climate changes, minimizing duplicated supply of the information, and implementing integrated ICT based water management. This study mainly focuses on the development of a simulator to supply water related information to the various users covering policy makers of water resources and drinking-water producers such as central and municipal government officials with government-affiliated employees, and individual water users. The water related information includes diverse level of information produced from several research teams participated in the government sponsored smart water grid research project.

As a first step to develop the simulator, the user's requirement analysis will be made. This includes in-depth discussion and questionnaire to reflect users' diverse requirement and to get a grasp of major information with higher priority. Along with the requirement analysis, the state-of-the-art will be made to see the major trends of technical perspectives common types of water information. Also, for more efficient information gathering and utilization, the data collection unit will be divided into four different grid scales--mega, macro, meso, and micro. The mega and macro grid represents the information at national level and major watershed level, which are approximately 21 large scale watersheds in South Korea, respectively. The meso and micro grids represents municipal level of information and individual industrial complex or collective residential units such as apartments, respectively.

For much easier information supply to the unspecified enormous users, the simulator will be developed in a web-GIS based environment. Thereby this can utilize numerous advantages of web based development through the adoption of relevant international standards for web programming. Also, the simulator has major functions of information searching related to integrated water management, water facilities, watershed status, real time water monitoring, emergency management, map representation, etc. The major components of the simulator are integrated DB, GIS DB, linkage module of DB connection, visual representation module, GIS module, and information analysis module. The major types of the information provided from the simulator will be the usage and distribution of water resources required by central government such as supply and demand, water quality, regional water uses, water consumption, optimal distribution scenarios; quantity and quality information required by municipal government such as real time water quality monitoring including DO, PH, temperature, TOC, chloride, water shortage, water leakage, etc.

The simulator will be expected to dedicate for effective water information supply in simple, easier and visual form to the public thereby sharing the needs of efforts to save water and prevent the damages from the natural disaster as the preparation of the global climate changes. Furthermore, the water information provided from the simulator can support to activate the growth potential of domestic water market, which eventually leads to expand to oversea countries.

BRINGING THE SMART WATER GRID TOGETHER WITH LOCATION

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Keywords: Smart Water Grid; Geographic Information Systems; Web GIS; Arcgis.

ABSTRACT

Water scarcity, aging infrastructure, water quality, and the impact of energy consumption to operate water systems pose significant challenges to effective and efficient use and delivery of water. It is generally accepted by scientists, technologists, and policy makers that an innovative approach to addressing these challenges is a smart grid for water infrastructure. A smart water grid consists of an integrated system of advanced metering infrastructure, sensors monitoring hydraulic and quality characteristics, advanced modeling, Geographic Information Systems (GIS), and other technologies all supporting real-time information related to the status and performance of the system. In a perfect world these systems would be fully automated and process controlled, similar to a smart grid for electric. However, water systems are different from electric systems in that the cost to fully integrate the physical system in an automated process control environment is relatively more expensive for a water system (e.g., equipping and operating large valves with automated devices compared to electrical switches), especially considering total utility net revenues. Moreover, sensors are not fault proof and system appurtenances do not always operate as planned. Because of these limitations, human interaction with water systems is required and crucial.

The single common factor to all these systems, including the human component, is location. Every sensor, meter, valve, and pipe is physically located somewhere in space and is connected to other system components. The location of people who operate and maintain the system is also important. Without location how do operators and crews know what is going on in the system, where to go, and what to do? Due to this common integrating factor, GIS becomes one of the most critical IT systems in support of the operations and management of the smart water grid.

While it is generally not feasible to fully integrate a water system in a process control type of environment, a modern GIS can integrate these systems through their commonality; the location on a map. Through an integrated GIS, the location of issues can be easily and quickly identified and communicated to the system operators, dispatchers can effectively find a route the closest first responders, networks can be traced to identify which valves to operate or which customers are affected, field crews and operators can view critical data from multiple systems within a single interface, and officials can clearly and effectively inform the public with real-time interactive maps.

This paper describes how the Esri's ArcGIS Platform can facilitate the operation and management of the smart water grid through commercial off the shelf (COTS) GIS software easily deployed in a modern IT environment. This platform consists of:

EFFECTIVE CHANNEL ALLOCATION AND SCHEDULING SCHEME FOR AMI SYSTEM

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Keywords: ICT; Automatic Meter Reading; Advanced Metering Infrastructure; Smart Water Grid

ABSTRACT

This paper is about channel allocation and scheduling scheme to construct wireless Advanced Metering Infrastructure(AMI) network for effective smart water grid. Recently, high-efficient, next-generation infrastructure system using information communication technology is increasingly required to overcome limitation of water resource management, and Smart Water Grid is being developed to resolve imbalance by effectively allocating, managing and carrying water resources. From this perspective, the Automatic Meter Reading(AMR) system is a technology automatically reading real-time meter and conveniently searching, printing out, and managing meter detecting data at a control office or where a specific reading meter system is installed, without meter men's visit to households in a remote place to read utility meter of every kind used by consumers such as apartment houses, mixed-use buildings, villas, detached houses. The AMR technology is classified into wired method and wireless method depending on communication systems composed. Typically, a wired method of the technology is using telephony network and power line network, whereas a wireless method of the technology is composing low power wireless reading meter network and gathering reading meter data and sending them to remote sites by using CDMA network or wireless LAN. Characteristics of utility serve a major factor to determine a wired/wireless communication method.

As electricity, power line communication network is effective to use as power network is already constructed and no additional cost occurs to use. However, utility such as water or gas supply composes wireless communication systems due to difficulty in electricity supply, and recently wireless AMR technology applied to various utilities is widely distributed due to rapid development in wireless technology and decreased price in wireless communication devices. Apart from this meter reading service, wireless AMR service evolves itself into Advanced Metering Infrastructure(AMI) which can offer a wide array of interactive services such as services for the elderly living alone and notification of electricity use according to utility characteristics[6]. As such, for wireless AMR, non-licensed ISM band of 424MHz and 2.4GHz bands is used in South Korea as it can be used free of charge. Currently, as wireless AMR network is composed by using communication channel to the frequency bands specified above to compose low power wireless metering reading network in wireless methods, reliability on wireless communication is lowered as chances of collision between data is higher as the number of consumer is higher. To reduce chances of collision between data, a prerequisite is to limit consumer expandability as the number of consumer node is limited, and a change of metering value cannot be collected between fixed metering periods in schedule-based one way wireless AMR systems. This makes it difficult to expand as various services. Therefore, the article aims to enhance efficiency of management through physical, logical consumer channel clustering and reliability on metering reading data, and achieve expandability of wireless metering reading network through channel use that can be

identified between proximate clusters, by suggesting channel set-up based on multichannel cluster mixed with network channel and group channel to resolve the problems stated above and implement various services. Further, the article aims to reduce installment time and maintenance repair cost through hierarchical network structure composed with four differentiated devices in wireless AMR systems, and suggest wireless AMR network based on multichannel cluster substantializing various services by supporting various operation modes through quick error recovery and back up functions.

Acknowledgments

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SECURITY CHALLENGES AND DIRECTION FOR DEVELOPING SMART WATER METERS

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Keywords: Smart water meter; Advanced Metering Infrastructure; Water Meter; Customer Domain; Security

ABSTRACT

The Advanced Metering Infrastructure (AMI) is one of the integral components of the smart water grid where water consumption data is collected, stored, and transferred to the utility Meter Data Management System (MDMS). The organizations which are directly involved in promoting and developing the Smart Water Grid have tried to figure out the operating scenarios in the overall domain from the smart meters up to MDMS, and logical/physical components that should be expected to exist to perform those operations in the full extent. However, how such domain will take shape is still up in the air and requires some time until the actual implementation are in full swing.

One of the daunting tasks in realizing the services in this domain is the security issue. While the utility operation system, which is intrinsically the SCADA system, can be almost completely isolated from the outside world from the communication point, the customer domain such as AMI will lie in the open domain. Water metering devices are located in an open network domain as the network equipments in the current Internet. Any cyber attack that is excruciating service providers and consumers of the current Internet could take a toll on the services in the Smart Water Grid at the same level.

In order to analyze the security threats in the customer domain, we need to understand the information flow between smart water devices in the customer domain and MDMS in the utility operation domain. Based on the characteristics of devices that consist of the customer domain and the information flows to provide the smart services, we classify the types of the possible security attacks which exploit the vulnerability of devices and information flow related to the operations between them.

In this paper, we address two issues. First, in order to understand cyber security threats and define security requirements we explain the logical model of the AMI, and then based on the logical model we analyze the information flows to provide the smart services in this domain. Second, we address the implementation issue of the smart water meter. We propose possible approaches for developing the smart water meter in which the security functions should be integrated into metering and communication functions in the same box in economic and efficient ways.

Appendix B

Additional Information

Radiation Protection Dosimetry (2012), Vol. 151, No. 1, pp. 17–29
Advance Access publication 10 January 2012
doi:10.1093/rpd/ncr468

RADIOFREQUENCY FIELDS ASSOCIATED WITH THE ITRON SMART METER

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This study examined radiofrequency (RF) emissions from smart electric power meters deployed in two service territories in California for the purpose of evaluating potential human exposure. These meters included transmitters operating in a local area mesh network (RF LAN, ∼250 mW); a cell relay, which uses a wireless wide area network (WWAN, ∼1 W); and a transmitter serving a home area network (HAN, ∼70 mW). In all instances, RF fields were found to comply by a wide margin with the RF exposure limits established by the US Federal Communications Commission. The study included specialised measurement techniques and reported the spatial distribution of the fields near the meters and their duty cycles (typically <1 %) whose value is crucial to assessing time-averaged exposure levels. This study is the first to characterise smart meters as deployed. However, the results are restricted to a single manufacturer's emitters.

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INTRODUCTION

Advanced metering infrastructure (AMI) refers in general to two-way communicating systems that monitor, collect and transmit data on the transport and consumption of electricity along its full supply chain ending at the residential or business consumer. At a residence, a smart meter is the key component of this infrastructure, replacing the electro-mechanical meters that were read manually, while adding a range of sophisticated functions designed to improve efficiency and reliability and to provide pricing options for end users to economise on their electricity consumption(1). Most of the smart meters being installed today use radiofrequency (RF) wireless communications to transmit data. With the prevalence of smart meter technology expanding rapidly and with >10 million units deployed in California alone, it becomes a priority to develop valid information to inform the public on the levels of exposure to RF electromagnetic fields likely to result from this technology. This paper characterises the RF fields emitted by smart meters manufactured by Itron that have been installed across the service territories of Southern California Edison (SCE) and San Diego Gas and Electric (SDG&E).

Within these territories each residence with a smart meter belongs to a 'mesh network' consisting of roughly between 500 and 750 residences through which data are transmitted wirelessly to a single residence designated as a 'collection' point whose smart meter wirelessly relays the network's data to a central regional repository for storage and analysis. The smart meter of each residence within a mesh network, with the exception of the residence that serves as the collection point, contains two transmitters, each with its own antenna. These are referred to as 'endpoint' smart meters. One transmitter, operating in the Federal Communication Commission's (FCC) license-free band of 902–928 MHz in a spread spectrum frequency-hopping mode, interconnects the residences through a local area network commonly referred to as an RF LAN. The second transmitter operates in the FCC's license-free band of 2.4–2.5 GHz interacting with devices and equipment within a residence to constitute a home area network (HAN). The HAN serves to control the times when particular electrical appliances and equipment operate, thereby taking advantage of time-of-day electricity pricing. The smart meter in the residence that serves as a mesh network's collection point is equipped with a third transmitter and antenna, the 'cell relay', which operates within a cellular-like communication band (typically, ∼850 or ∼1900 MHz) over a high-speed wireless wide area network (WWAN). Figure 1 illustrates the various components of a mesh network as described.

Between four and six times per day, for periods on the order of milliseconds, the smart meters transmit data on energy consumption. In addition, they may act as repeaters for other smart meters within the mesh network that encounter difficulty in directly communicating with their designated cell relay meter. Network overhead functions, such as brief emissions of beacon signals throughout the day, also

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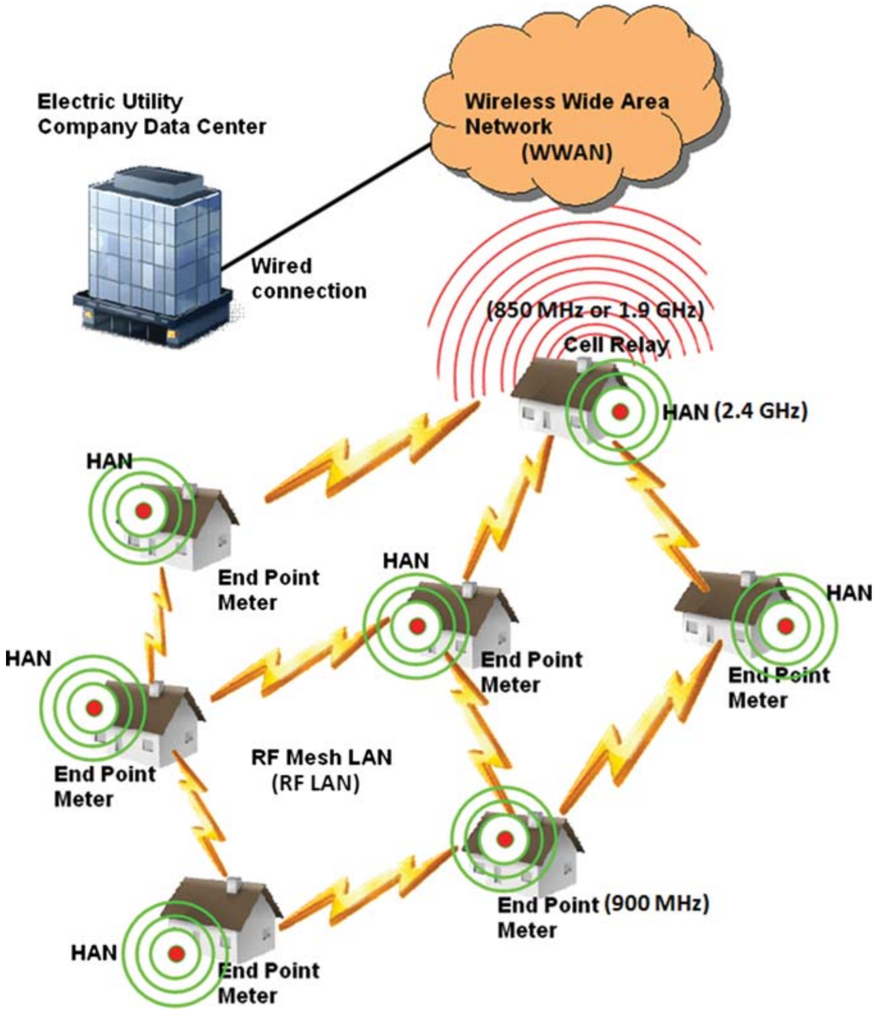

Figure 1. Components of a wireless mesh network.

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result in RF emissions from the smart meter. The smart meters, thus, operate with a low duty cycle, meaning the total fraction of the day (or any chosen unit of time) a given smart meter is actually transmitting. Given the smart meters' intermittent operation, brief duration of any active transmission (approximately in milliseconds) and frequency hopping, a characterisation of RF emissions with a large sample of smart meters could be a daunting challenge at residential locations. This problem was surmounted with the cooperation of the manufacturer who provided facilities and smart meters programmed to transmit continuously. This paper reports the evaluation of Itron, Inc.'s model CL200, an endpoint smart meter and C2SORD, a cell relay meter (that provides WWAN capability), in terms of antenna power, the magnitude and spatial pattern of their RF emissions and the range of duty cycles that characterise their operation. Throughout this paper, the terms 'smart meter' and 'meter' are synonymous unless otherwise specified.

METHODS

Antenna emission patterns

To assess emission patterns, measurements were conducted in the Itron facility anechoic chamber (4.9 W×7.6 L×3.7 H meters) for both endpoint (RF LAN) and cell relay (WWAN) meters. Pattern data were obtained in 15° increments in all possible directions using a dual-axis rotating system. Associated

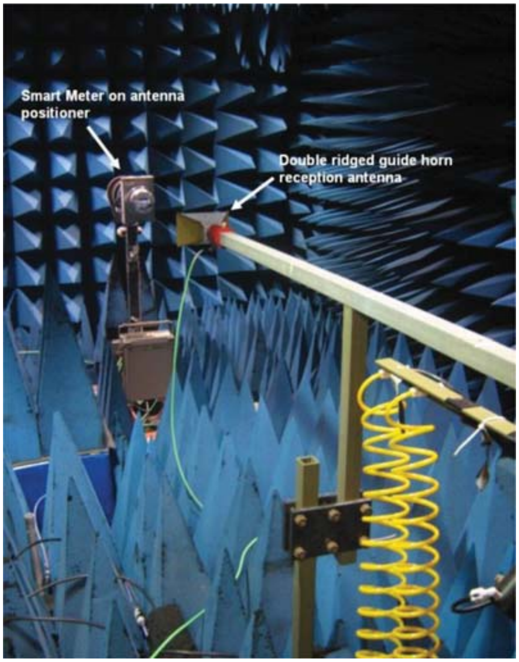

Figure 2. Interior of anechoic chamber showing reception horn antenna with smart meter on antenna positioner in background. During pattern measurements, the spectrum analyser shown below the smart meter is removed.

instrumentation included a spectrum analyser (Agilent model E4405B) as the detector connected to a sense antenna (ETS model 3115 double-ridge guide horn) inside the anechoic chamber with instrumentation interfaced with a systems controller (Sunol Sciences model SC104V). Data acquisition and analysis software provided for analysis and graphic display of measured antenna patterns (MI-Technologies model MI-3000 workstation). Figure 2 shows the interior of the anechoic chamber with the reception horn antenna used to receive the signal emitted by the smart meter installed on the dual-axis rotator system.

Vertical profile of fields

RF exposure limits, such as those issued by the FCC, ICNIRP and IEEE are specified in terms of both time averaging and spatial averaging over the dimensions of the body(2–5). The FCC recommends that an average of the RF field power density be measured along a vertical line representing the axis of the body. To assess the antennas' fields against these spatial criteria, the smart meter was positioned on a nonconductive table at a height of ~0.9 m (3 ft.), and the Narda Model SRM-3006 was used to record RF fields as its probe was moved slowly from the concrete floor to a height of 1.83 m (6 ft.).

THEORETICAL ESTIMATION OF FIELD CHARACTERISTICS

Reflections

By way of background, the FCC provides guidance for calculating RF emissions that includes conservative assumptions concerning ground reflections (Equation (A1))(2). In practice, the application of a ground reflection factor to estimate exposure levels becomes less relevant at locations that are very close to the smart meter for two reasons. First, at such distances, the RF field striking a reflective ground will be small, because the emissions in the elevation plane propagating downward are generally of reduced magnitudes relative to the peak emission. Secondly, within a few feet of the smart meter, the propagation pathlength of the reflected field is usually substantially greater than the path of the incident field, and thus significantly attenuated according to the inverse square distance of its pathlength. Thus, in very close proximity to a meter, where the intensity of the incident field is greatest, Γ (the reflection coefficient) may be set to unity, when compared with the factor of 2.56 recommended by the FCC, with little loss of accuracy(2). As distance from the smart meter increases, the body becomes more uniformly illuminated by the diverging beam of the incident field. Ground reflected fields then have a greater potential of enhancing the radiated field due to in-phase superposition. However, at these greater distances, the magnitude of the incident-plus-reflected field becomes extremely small in comparison with the field present in close proximity to the meter. To assess the potential effect of reflection on the total field emitted by a smart meter, a method-of-moments technique was used to compute incident and reflected RF fields produced by a horizontally oriented 915 MHz half-wave dipole antenna as functions of distance from the antenna and height above-ground incorporating realistic parameters of ground conductivity and dielectric constant (σ=0.005 S m^{-1}; ε_r=13).

Total field versus distance

Equation (A1) was used to compute power density as a function of distance for an endpoint meter under a set of highly conservative conditions:

- RF LAN and HAN transmitters are both operating at their respective 99th percentile power levels [26.0 dBm (398 mW) and 20.6 dBm (115 mW)]
- both transmitters are operating at their 99.9th percentile duty cycle [The duty cycle of the

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HAN transmitter was assumed to be the same as the RF LAN transmitter] (see below for a further analysis of duty cycle)

- the composite RF field includes ground reflection enhancements at all distances based on the calculated enhancement factor at 3.05 m (10 ft.) from a smart meter,
- the maximum RF field from both transmitters are coincident at the exact same point in space
- spatial averaging is not applied, with the beam's maximum level assumed to apply at all heights above ground (i.e. across a body's full dimension).

METER FARM MEASUREMENTS

Itron's facility includes a 'smart meter farm' that is used to evaluate the performance of their meters operating in mesh networks. The facility includes ~7000 meters located across 20 acres. For the most part, the farm's smart meters are organised into groups of 10 mounted on wooden racks with steel posts (Figure 3). The meters are arranged on racks that are 1.22 m (48 in.) wide in two rows of 5 meters each, one above the other. The meters are mounted so that there is a 40.6 cm (16 in.) vertical spacing of the two rows of meters, centre to centre, and the bottom row of meters is nominally 1.22 m (4.0 ft.) above the ground. In the area in which measurements were performed, the meter racks were 4.88 m (16 ft.) apart, side to side, with the rows of racks 6.25 m (20.5 ft.) apart. Measurements were performed on both individual smart meters and groups of 10 meters comprising a rack using a Narda model B8742D broadband probe, a Narda model 8715 meters and a Narda spectrum analyser model SRM-3006.

A total of 10 smart meters were inserted, one at a time, into the upper centre meter socket in the rack for individual measurements of fields using the broadband field probe. To facilitate measurements, the meters had been programmed to operate continuously on one of the three specific frequencies within their respective bands, a low frequency (902 MHz), a middle band frequency (915 MHz) and a high frequency (928 MHz). Broadband probe readings were adjusted with the manufacturer's correction factor (CF) (a factor, CF, that corrects for probe response at specific frequencies) applicable at 915 MHz (CF=0.67) (the HAN radios were not active). Note that measurements with an isotropic probe directly at the meter's surface must be made with care due to the potential for erroneous readings. Nonetheless, because others may inappropriately apply such probes in this fashion, it was deemed relevant to examine the response exhibited when the probe contacted the smart meter cover.

Figure 3. The broadband field probe with an attached cardboard spacer near a rack of 10 smart meters.

Next, the Narda model SRM-3006 measured the 902–928-MHz spectrum as a function of distance from the front of the centre of a rack of 10 endpoint meters operating continuously with the RF LAN antenna programmed to the frequencies discussed above; the HAN transmitter was off.

OPERATIONAL DUTY CYCLE OF METER TRANSMITTERS

In terms of compliance with RF exposure standards and guidelines, it is more appropriate to assess time-averaged exposure. As indicated in the Introduction section, the collection of sufficient data to characterise the actual meter operation with on-site residential measurements would be unrealistically time consuming and laborious.

Instead, the utility company data management system offers an alternative source of data with which to bracket realistic values of meter duty cycles over a very large sample size.

SCE collected information on the number of data packets associated with either downlink or uplink communications from ~47 000 smart meters in a part of its service territory for 89 consecutive days from 30 July through 26 October 2010. Downlink activity relates to data being propagated away from a cell relay meter (to the RF LAN) while uplink activity is related to the transmission of data towards a cell relay meter (from the RF LAN). A presumption was made that both downlink and uplink traffic resulted in activity of the 900-MHz RF LAN transmitters in the meters. Using a conservative estimate for the maximum packet duration provided by Itron of 150 bytes for endpoint meters, with 8 bits per byte, and a data transmission rate for the 900 MHz RF LAN radio of 19.2 kbps (kilobits per second), the amount of transmitter activity was estimated for each of the meters on a daily basis.

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Similar efforts to characterise duty cycles were made by SDG&E, with support from Itron. In the SDG&E study, 6865 endpoint and cell relay meters were monitored over an observation period of 1 d ending 2 December 2010. The data were acquired for meters distributed across 10 cells of ∼600 smart meters per cell. In this study, while substantially smaller in size than the SCE study, a more accurate and direct assessment of the transmitter activity was made by interrogating the actual number of bytes of data transmitted. This approach does not rely on any assumption of the data packet size as in the SCE data and, hence, minimises uncertainty in the assessment of duty cycles.

RESULTS

Basic description of meters

The RF LAN and HAN antennas are quarter-wave slots formed on the printed circuit cards of the meter and are contained within the envelope of the meter ranging from 2.1 to 2.5 cm from its front surface. The cell relay antenna is a dual-band (850/1900 MHz), flexible dipole affixed to the interior curved surface of the meter cover. While these antennas’ fields can approximate the pattern of a perfect dipole in free space, their proximity to other components within the smart meter tend to distort the emission patterns.

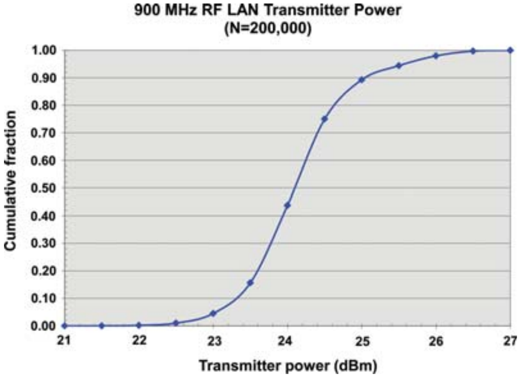

Figure 4. Cumulative fraction of the 900-MHz RF LAN transmitter output power versus transmitter power for a sample of 200 000 units. The median transmitter power is ∼24.1 dBm (257 mW).

Based on data archived by the manufacturer on 200 000 endpoint meter units, the modal (most likely) transmitter output powers were 24.5 dBm (282 mW) for the RF LAN (900 MHz) and 18.5 dBm (70.8 mW) for the HAN (2.4 GHz) transmitters; the median RF LAN power output was ∼24.1 dBm (257 mW). Based on an analysis of a subsample of 65 000 meters, the 0.5th and 99.5th percentile output powers were, respectively, 21.0 dBm (126 mW) and 26.0 dBm (398 mW) for the RF LAN and 16.0 dBm (39.8 mW) and 20.6 dBm (114.6 mW) for the HAN transmitters. The distribution of power levels for the RF LAN transmitter is shown in Figure 4. The distribution of HAN radio power levels is not shown. The cellular transceivers used in cell relay meters investigated operate with the maximum power levels shown in Table 1.

Antenna emission patterns

The measurements resulted in a three-dimensional representation of the patterns for each of the antennas in the smart meters. A total of six sets of patterns, which included both horizontal and vertical polarisation plots, were obtained for the 900-MHz RF LAN in (i) an endpoint meter, with examples of patterns shown in Figure 5 and in (ii) a cell relay meter; the 2.4 GHz HAN radio in (iii) an endpoint meter and in (iv) a cell relay meter; and the patterns of a cell relay meter (which provides the WWAN connection) using the dual-band antenna in (v) the GSM band (850 MHz) or (vi) the PCS band (1900 MHz).

Note that for any given *in situ* antenna, the maximum effective isotropic radiated power (EIRP; defined by FCC as ‘the product of the power supplied to the antenna and the antenna gain in a given direction relative to an isotropic antenna.’(2)) determined by the measurement system is the absolute greatest value of EIRP recorded at any elevation/azimuthal angle combination. The maximum EIRP in any direction can be determined by referencing the maximum

Table 1. Maximum transmitter powers employed by the Sierra Wireless cellular transceivers used in the Itron cell relay meters.

	GSM modem model (MC8790 FCC ID: N7NMC8790)	CDMA modem model (MC5725 FCC ID: N7N-MC5725)
Frequency band	Maximum power output (dBm) (mW)	
850 MHz	31.8 (1514)	25.13 (326)
1900 MHz	28.7 (741)	24.84 (305)

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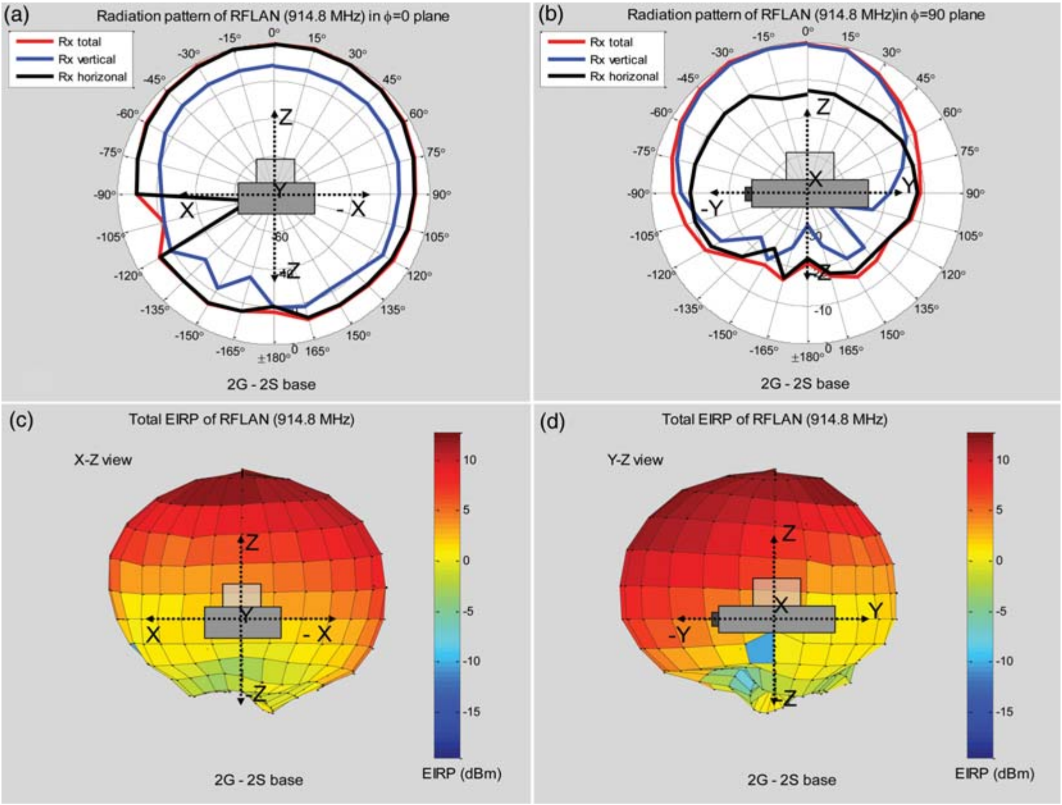

Figure 5. Illustrative patterns of the 900-MHz RF LAN transmitter in an endpoint smart meter; (**a**) azimuth plane relative field, (**b**) elevation plane relative field, (**c**) azimuth plane total EIRP and (**d**) elevation plane total EIRP.

Table 2. Summary of antenna pattern measurement data.

Meter	Antenna	Max test EIRP (dBm)	TX test power (dBm)	Gain (dBi)	Max TX power[a] (dBm)	Max EIRP[b] (dBm)
Endpoint	RF LAN, 914.8 MHz	12.8	9.9	2.9	24.0	26.9
Cell relay	RF LAN, 914.8 MHz	15.0	14.1	0.9	24.0	24.9
Endpoint	HAN, 2440 MHz	19.4	15.2	4.2	18.3	22.5
Cell relay	HAN, 2440 MHz	17.9	12.8	5.1	18.3	23.4
Cell relay	GSM, 836.6 MHz	24.9	23.1	1.8	31.8	33.6
Cell relay	GSM, 1880 MHz	23.9	22.3	1.6	28.7	30.3

[a] Nominal specified transmitter (TX) power.

[b] The maximum TX EIRP assumes the nominal specified transmitter power.

transmitter power that is delivered to the antenna. Table 2 summarises the EIRP with the transmitter operating at its maximum power expressed in dBm (i.e. referenced to 1 mW) derived for the six pattern conditions. As shown in the example illustrated in Figure 5c and d, the maximum EIRP may not be aligned normally to the face of the smart meter.

Vertical profile of RF fields

The vertical profile for the 900-MHz RF LAN is shown in Figure 6, and the results for this and the HAN antenna are shown in Table 3. If these values are generalised to all Itron meters of this model, then spatially averaged exposure near the smart

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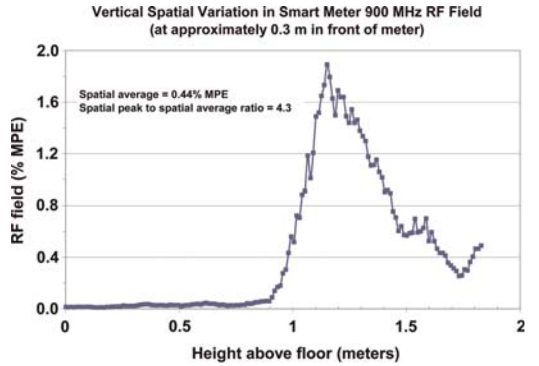

Figure 6. Vertical spatial profile of smart meter 900-MHz RF LAN field from 0 to 1.8 m (0 to 6 ft.) above the floor at a lateral distance of ~0.3 m (1 ft) in front of the smart meter.

Table 3. Spatial variability in measured RF fields in front of smart meter.

Frequency band	Measurement distance (m)	Spatial average (% of MPE)	Spatial peak to average ratio	Spatial average (% of peak)
900 MHz (LAN)	0.30	0.44	4.3	23.3
2.4 GHz (HAN)	0.15	0.24	5.6	17.8

meter would range from about one-fifth to one-fourth of the peak value in the main beam.

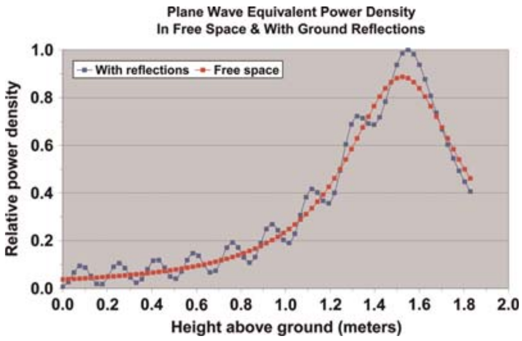

Figure 7. Relative calculated plane wave equivalent power density along a 0–1.8-m (6-ft.) vertical path, 0.3 m (1 ft.) adjacent to a 915-MHz half-wave dipole positioned at 1.5-m (5 ft.) above the ground. Power density values are compared with and without ground reflections.

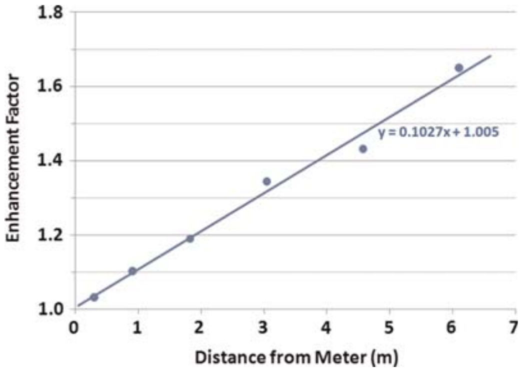

Figure 8. Ground reflection enhancement factor versus distance.

THEORETICAL ESTIMATION OF FIELD CHARACTERISTICS

Reflections

For a distance of 0.3 m (1 ft.) from the smart meter, a comparison of the power densities computed with and without the presence of reflections shows relatively modest deviations attributable to reflections for a vertical profile from the ground to a height of 1.83 m (6 ft.) (Figure 7). The power densities of the reflected and free space fields averaged over a 1.83 m height were calculated as a function of distance from the meter. The enhancement factors—representing the ratio of power density with reflections to power density without reflections—over distance were 1.03 at 0.3 m (1 ft.) from the meter to 1.65 at 6.1 m (20 ft.) (Figure 8). The latter enhancement factor for the ground conditions given remains noticeably less than the more conservative value of 2.56 commonly used (see Appendix) to represent a scenario for far-field whole-body exposure. These results represent overestimates of enhancement factors from operating smart meters, because the horizontal dipole used for this computational exercise radiates equally at all elevation angles, in contrast to the smart meters characterised empirically (Figure 5) for which the elevation plane patterns show reduced values for the fields directed at steep downward angles towards the ground. The data supporting this are shown in Table 4, listing field reductions in dB at the ground plane at elevation angles of −90°, which corresponds to the position at ground directly beneath the meter, and at −75° and −60°, which correspond to ground positions 0.41 m and 0.91 m away, respectively, for a meter more typically mounted 1.5 m above the ground. The reductions, referenced to the power density in the main beam at the same distances, are in the range of −3 to −10 dB (equivalent to reductions of 10 to 50 % of the power density in the main beam) with the lone exception associated with the 1880-MHz PCS transmitter in a cell

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Table 4. Approximate RF field reductions (dB) caused by smart meter elevation plane patterns in the 60° to 90° range below a horizontal to the meter.

Angle (°)	Field reduction (dB)					
	900 MHz RF LAN endpoint meter	900 MHz RF LAN cell relay meter	2.4 GHz HAN endpoint meter	2.4 GHz HAN cell relay	850 MHz cellular cell relay	1880 PCS cell relay
60	−8	−7	−3	−11	−7	0
75	−10	−8	−4	−8	−10	−4
90	−11	−8	−8	−8	−10	−7

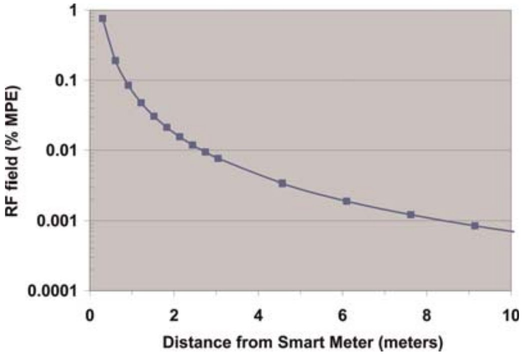

Figure 9. Calculated maximum RF fields near Itron endpoint smart meters based on 99th percentile transmitter power values, main beam exposure (point of maximum RF field), inclusion of the possibility of ground reflected fields and an assumed 99.9th percentile duty cycle.

relay meter at an angle of −60°. In addition to these considerations, and, as alluded to above, the fall-off of incident power density with distance overwhelms any corresponding increase in the reflection enhancement factor.

Total field versus distance

Under the calculation assumptions described in the Methods, and as shown in Figure 9, the time-averaged RF power density at 0.3 m (1 ft.) from an endpoint meter would be expected to not exceed 0.8 % of the FCC maximum permissible exposure (MPE)(2). The additional RF power density associated with the cell relay's time-averaged transmissions would not exceed ~1 % of the MPE (although transmitting at a greater input power than RF LAN, it is offset by the cell relay's lower 99.9th percentile duty cycle). Even at very close distances, such as 1 ft. directly in front of an end-point meter, with an unrealistic assumption that the transmitters operate at 100 % duty cycle (at which point the mesh network would not function) the resulting power density is less than the FCC MPE. For a more typical, realistic exposure distance of 3.05 m (10 ft.), the time-averaged RF power density is ~0.008 % of the MPE. Spatial averaging would bring these values down further to approximately one-fourth of the magnitudes shown.

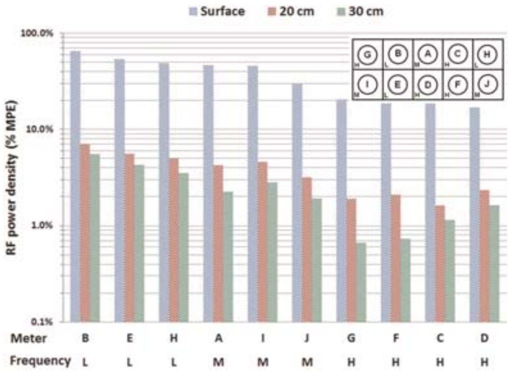

Figure 10. Corrected broadband probe RF field readings of the 900-MHz RF LAN transmitters from 10 smart meters at the surface and at 20 and 30 cm from the meter.

METER FARM MEASUREMENTS

With the results charted as a percentage of the FCC general public MPE, two issues are immediately apparent. First, the readings appear to be related to the channel to which the 900-MHz RF LAN transmitter was programmed, with the highest (lowest) reading associated with the lowest (highest) frequency (Figure 10). At 20 cm, the mean value of readings of the low-frequency (L) meters is 5.8 % of MPE while the mean value of the readings of the high-frequency (H) meters is 2.0 %, corresponding to a low-to-high-range difference of ~4.6 dB (factor of 2.9), i.e. a variation of ±2.3 dB relative to the middle frequency (note M in Figure 10 refers to mid-frequency). During normal operation in a residence, the frequency of the RF LAN transmitter is

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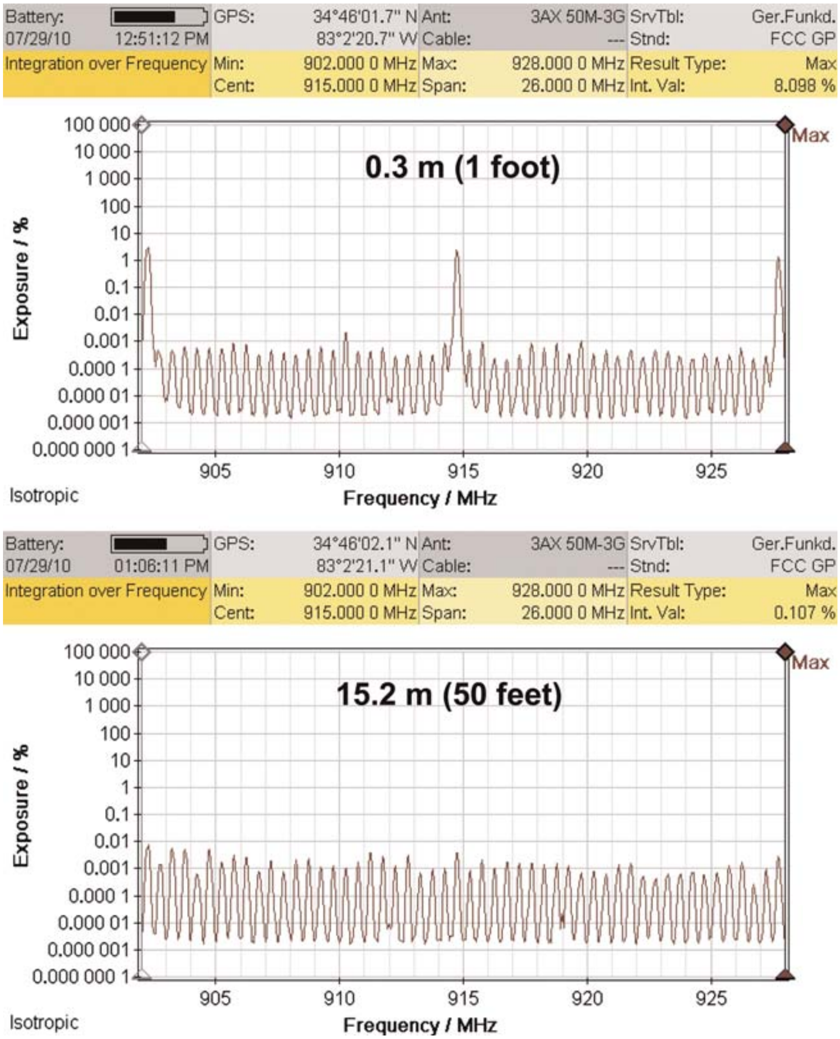

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Ant: 3AX 50M-3G
Cable: ---
SrvTbl: Ger.Funkd.
Stnd: FCC GP
Integration over Frequency
Min: 902.000 0 MHz
Cent: 915.000 0 MHz
Max: 928.000 0 MHz
Span: 26.000 0 MHz
Result Type: Max
Int. Val: 8.098 %

Battery: 07/29/10 01:06:11 PM
GPS: 34°46'02.1" N 83°2'21.1" W
Ant: 3AX 50M-3G
Cable: ---
SrvTbl: Ger.Funkd.
Stnd: FCC GP
Integration over Frequency
Min: 902.000 0 MHz
Cent: 915.000 0 MHz
Max: 928.000 0 MHz
Span: 26.000 0 MHz
Result Type: Max
Int. Val: 0.107 %

Figure 11. The 900-MHz band comprises the RF field from rack of 10 smart meters at 0.3 m (1 ft., top) and 15.2 m (50 ft., bottom).

hopping across the band, roughly in a random fashion.

Secondly, the readings at the meter surface are considerably greater than those at 20 cm, in most cases on the order of a 10-fold difference. This occurs because the probe's protective shell surface is placed in contact with the face of the smart meter, bringing the probe elements within the reactive near-field region of the source antenna. The 900-MHz RF LAN antenna is only ~2.1 cm behind the meter envelope face, comparable with ~0.06 wavelengths. Under these conditions, the probe may couple to the field source leading to erroneously high readings. Generally, proper practice dictates that field probes not be used in such close proximity to the source because of this very issue. IEEE Standard C95.3–2002 recommends a minimum measurement distance of 20 cm to minimise near-field coupling and field gradient effects when using common broadband field probes(6). Measurement data can also be distorted when using an isotropic probe to measure steep spatial gradients close to a radiating element of the smart meter. These gradients can lead to considerable variation in the field amplitude measured over the volume of space occupied by the probe elements. This is particularly the case for field probes comparable with the size of the source antenna when in the reactive near field. The elements inside the

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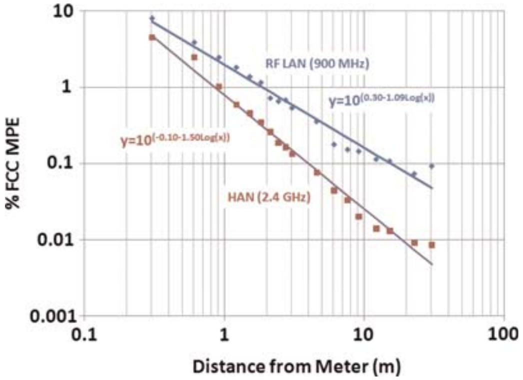

Figure 12. Emission levels from rack of 10 RF LAN- (end-point) and HAN antennas versus distance with best fit formulas. LAN meters rated nominally at 250 mW and HAN meters at nominally 70 mW.

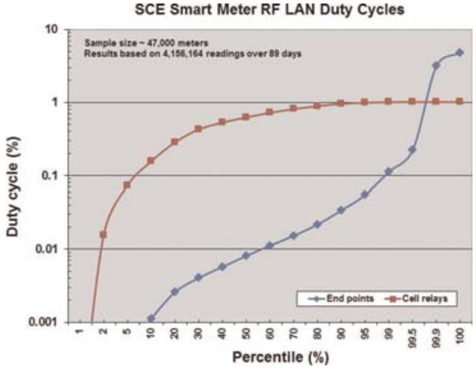

Figure 13. Analysis of SCE daily average RF LAN duty cycle distribution for different percentiles based on 4 156 164 readings of transmitter activity from an average of 46 696 Itron Smart Meters over a period of 89 consecutive days. Analysis based on estimated transmitter activity during a day (see text).

Narda B8742D probe are ~8 cm in length, approximately the same length as the slot antenna of the 900-MHz RF LAN antenna, which is ~6.3 cm in length. Based on the potential for significant probe coupling with the smart meter's internal transmitting antenna, the measured values reported for surface contact of the probe with the smart meter should be considered, in all likelihood, as substantial over estimates of the actual field. Measurements at 20 and 30 cm, however, are considered reliable, because they are substantial fractions of the 900-MHz wavelength (20 cm is equivalent to 0.6 wavelengths and 30 cm is equivalent to 0.9 wavelengths). With respect to HAN transmitters programmed to continuous low-, medium- and high-frequency transmission within the operational band (~2.4 GHz), a similar pattern was observed with the greatest fields associated with the lowest frequency of operation and the lowest RF fields generally associated with the highest frequency (data not shown).

The integrated value of the field measured with the Narda model SRM-3006 represents the aggregate RF field from all detectable meters at the measurement position. The Narda's display of data (Figure 11) for a distance of 0.305 m (1 ft.), expressed as per cent of the general public power density MPE on the vertical axis, clearly shows the peaks for each of the three programmed frequencies. The smaller peaks shown represent the RF fields associated with the thousands of other meters actively transmitting within the meter farm. When this spectrum was integrated, the aggregate RF power density for continuous transmission was slightly greater than 8 % of the FCC MPE (Figure 11, top; noted near the upper right corner of the spectrum display). As the measurement distance increased to ~15.2 m (50 ft.), the signals from the rack were indistinguishable from the ambient background RF environment (Figure 11, bottom). The signal level/distance profile for the RF LAN antenna is shown in Figure 12. The figure shows a similar profile for a rack of 10 m with only the HAN antenna active. The HAN amplitude is comparatively lower because of the HAN's smaller transmitting power compared with the RF LAN emitter and the greater FCC MPE for the 2.4-GHz band (1 mW cm^{-2} for the 2.4-GHz HAN emitter compared with ~0.6 mW cm^{-2} for the ~900-MHz LAN emitters, both values for the general public). At 0.2 m (~8 in.), the peak power density from the HAN emitter was 2.5 % of the FCC MPE. Between 2 and 3 m from the rack the combined peak contributions from the RF LAN and HAN fall to <1 % of the FCC's MPE for the general public.

A prominent feature of the rack's profile is that the power density does not fall off with the inverse square of the distance, a relationship represented in the formula that characterises a single source in free space (see Appendix). Two principal factors contribute: first, as the measurement distance becomes greater, the contribution of weaker, ambient RF fields from the other meters within the farm become a greater fraction of the total integrated value of the field; and second, as the overall fields become weaker at greater distances, the instrument noise floor becomes a more significant factor relative to the integrated ambient fields.

Additional measurements were conducted immediately behind the rack. The measurements indicated maximum power densities of <1 % of the FCC's general public MPE for the 900 MHz RF LAN radios. Behind the smart meters, the HAN emissions were not detectable with the broadband probe.

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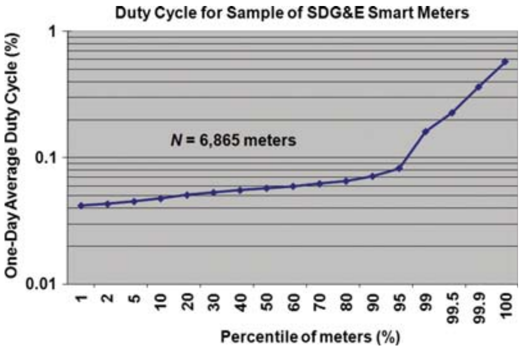

Figure 14. Duty cycles for a sample of 6865 Itron smart meters deployed by SDG&E based on transmit duration during a single day of observation.

OPERATIONAL DUTY CYCLE OF METER TRANSMITTERS

During the SCE data acquisition period, some meters were found to not respond for various reasons or their data were corrupted resulting in a total number of 46 698 meters from which valid data were obtained. The data collected over the 89-d period consisted of a total of 4 156 164 values, expressed in seconds per day, which were then converted to duty cycle.

The maximum duty cycle for the RF LAN transmitters was 4.74 %, which occurred in the highest 1/10th percentile of values, dropping to a 99th percentile duty cycle of only 0.11 % (Figure 13). From the 10th to 99th percentile, the duty cycles ranged from ∼0.001 to 0.1 %. The data presented in Figure 13 must be recognised as a likely conservative approach insofar as the total data packets (uplink and downlink) passing through an endpoint meter were tallied by the SCE data collection effort with the same assumed packet size assigned to each (i.e. 150 bytes).

Cell relay duty cycles, for data transmitted back to the utility over a WWAN, are dependent on the uplink bandwidth provided by the contract wireless carrier used by the electric utility. Using results from the SCE duty cycle study relative to uplink data for the cell relay meters, an estimate of the maximum cellular transmitter activity was made. In this analysis, the greatest uplink data passing through the cell relay was assumed to be transmitted to the WWAN by the cellular transceiver in the cell relay with a throughput of 1.536 Mbps (data rate for the CDMA EVDO Rev A cell relay modem ranges from 1536 to 3072 kbps.) with a one-third encoding overhead. Under this condition, the maximum duty cycle for the cellular transceiver in a cell relay was estimated to be ∼0.088 %. This very small value is due to the high data rate provided by the CDMA EVDO technology. Thus, while the cellular transmitter is rated at a power of nominally 1 watt, the effective duty cycle will have the effect of reducing time-averaged RF power density.

In the SDG&E sample, the smart meters with the highest activity had lower duty cycles than the SCE smart meters with the highest activity, but overall the duty cycles were in equivalent ranges (Figure 14). For instance, half of the SDG&E meters exhibited duty cycles of ∼0.06 % or more, compared with ∼0.01 %. The 50th percentile of duty cycles in the SCE data was ∼0.01 % for SCE; SDG&E's 95th percentile value was 0.08 % compared with SCE's 0.06 %. The differences in these two data sets are confounded by the fact that the data were collected in different ways, using different parameters for assessing transmitter activity, and represent substantially different sample sizes and sample collection periods. Nonetheless, because of uncertainties associated with data packet sizes in the downlink and uplink streams within the Itron mesh network, the SDG&E approach should yield more accurate values for smart meter duty cycles. Of further relevance, during this data collection period, a seasonal update was performed as well as a meter firmware download (which would require a large number of uplink transmissions to acknowledge such downloads). These factors would tend to drive the apparent duty cycle of meters upward when compared with other times of the year. Importantly, any differences between these preliminary studies of Itron smart meter duty cycles should not be viewed as differences in how the two utilities' networks are designed to operate but, rather, as the result of the differences in how data were collected.

DISCUSSION AND CONCLUSIONS

This study characterised RF emissions from the Itron model CL200 endpoint meter and model C2SORD cell relay meter. The results of this investigation indicate that, under virtually any realistic condition of deployment with the meters operating as designed, the RF power densities of their emissions will remain, in most cases, two orders of magnitude or more below FCC's MPE levels for the general public (0.6 mW cm^{-2} at 900 MHz) both in front of and behind the meters(2). This observation applies to cell relay meters as well as to endpoint meters, even when the latter are clustered together. In contrast to exposure assessments of smart meters, for devices that are intended to be placed immediately next to the body (within 20 cm), such as a cell phone, compliance is determined by the maximum specific absorption rate in 1 g of tissue. [The FCC uses 1 g of tissue for setting limits to local SAR although IEEE and the International Commission on

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Non-Ionising Radiation Protection (ICNIRP) use 10 g. IEEE states that the change 'is based on the biologically based rationale of ICNIRP[3] related to exposure of the eyes and extensive theoretical biophysical research quantifying RF energy penetration in biological tissue. The results of this research show that RF energy is incapable of causing significant local temperature increases in small tissue volumes within the body'[5].]

The study addressed several key aspects of the FCC's exposure limits. First, it reported that, power density averaged across the dimensions of a human body in close proximity (0.3 m) to an endpoint meter, as the FCC states whole-body exposure should be assessed, would be lower by roughly a factor of 4 than the maximum power density at that distance. Secondly, reflections under conservative assumptions are relatively minor compared with the incident field at a close range. While at greater distances the relative contribution of the reflected component increases, the fall-off of absolute total power density (incident plus reflected) dominates reflective enhancements. Thirdly, as the units are presently deployed, the duty cycles in the utilities' respective service territories for the Itron units were, with a few individual exceptions, no more than 1 %. The duty cycle is an important figure, as FCC exposure compliance is determined for a 'source-based' device like a smart meter (Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields (1997). Office of Engineering and Technology Bulletin 65, Edition 97-01, Federal Communications Commission, August, p. 76. See also: 47 CFR 2.1093 (d)(5)), as the power density averaged over a 30-min period for the general public (6 min for occupational populations). With the potential expanding functionality of smart meter technology in the coming years with potentially greater amounts of data that may be transmitted, duty cycles and thus average power density would correspondingly increase should the throughput rates now used remain unchanged; higher data throughput rates, however, could lower the average power density because of shorter transmission durations for given amounts of data.

A final issue concerns the extent to which a wall would attenuate the power density of a smart meter emission. A limited set of measurements were taken as part of this effort with a smart meter operating in either the 900 MHz or 2.4 GHz bands. In one case, the front of the meter faced several different sizes of wire mesh, and in a second, the unit was placed in the position of a meter mounted against a stucco wall (i.e. radiating away from the wall) of a composition typical of walls in the service territories in southern California. The 900-MHz emission was attenuated to a greater degree than the 2.4-GHz emission, with greater shielding effectiveness afforded by the finer mesh. Total attenuation for the meters facing a wire mesh varied from 4.1 to 19.1 dB (900 MHz) and 1.2 to 11.4 dB (2.4 GHz). For the stucco wall-mounted simulation, the power density was attenuated by 6.1 dB (900 MHz) and 2.5 dB (2.4 GHz).

To conclude, this study developed a general paradigm for assessing power density levels in proximity to smart meters that will be applicable to future assessments of emissions from the broad variety of wireless smart meters currently on the market.

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APPENDIX

The FCC recommends power density calculations that include ground reflections as follows:

$$S = \frac{P_t \times G_{\max} \times \delta \times \Gamma}{4\pi R^2} \tag{A1}$$

where S is plane-wave equivalent power density (W m^{-2}), P_t is maximum power (W), $G_{\max}$ is the maximum possible antenna power gain (a dimensionless factor). δ is the duty cycle of the transmitter (percentage of time that the transmitter actually transmits over time). More specifically, δ is the maximum duty cycle as found over any 30-min

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period. This is because the averaging time for the MPE in the FCC rules and the IEEE standard (C95.1-2005) for the general public and applicable to the frequencies used by the Itron smart meters is 30 min. In most cases, estimates of δ are based on understanding of the mesh network characteristics. In any event, δ is generally a very small value since the smart meters do not transmit most of the time. R is the radial distance between the transmitter and the point of interest (meters). Γ is a factor that accounts for possible in-phase ground reflections that could enhance the resultant power density. Under ideal reflective conditions, such as with a metallic ground plane, a field reflected from the ground could add constructively (in phase) with the field directly incident from the source to cause a maximum 2-fold increase of the field strength at the reception point. Were this to happen, the phenomenon could lead to an increase of $(2)^2$ or 4-fold in the power density since the electric field is proportional to the square of the field strength. In this case, the value of Γ in Equation (A1) would be 4. Under more realistic environmental conditions, where perfectly reflective surfaces are rare, an electric field strength enhancement of 60 % has been recommended by the FCC (FCC, 1997). This corresponds to an enhanced electric field strength of 1.6 times the field arriving from the source without reflection or a power density enhancement factor of $(1.6)^2$ or 2.56 for use in Equation (A1).

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