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Concept Paper

Moving Towards Sustainable and Resilient Smart Water Grids

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Abstract: Urban water systems face sustainability and resiliency challenges including water leaks, over-use, quality issues, and response to drought and natural disasters. Information and communications technology (ICT) could help address these challenges through the development of smart water grids that network and automate monitoring and control devices. While progress is being made on technology elements, as a system, the smart water grid has received scant attention. This article aims to raise awareness of the systems-level idea of smart water grids by reviewing the technology elements and their integration into smart water systems, discussing potential sustainability and resiliency benefits, and challenges relating to the adoption of smart water grids. Water losses and inefficient use stand out as promising areas for applications of smart water grids. Potential barriers to the adoption of smart water grids include lack of funding for research and development, economic disincentives as well as institutional and political structures that favor the current system. It is our hope that future work can clarify the benefits of smart water grids and address challenges to their further development.

Keywords: water management; smart technology; ICTs; water efficiency; sustainability; resiliency; energy-water nexus

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1. Introduction

Modern infrastructures—including urban water grids—face sustainability and resiliency challenges. Changes in climate and population are making water supplies scarcer in some areas [1–3]. Water systems often waste substantial quantities of treated water in both the distribution system and at the end-use location, mainly through leaks [4,5]. In many places, such as the Southwest U.S., water must be conveyed over long distances to water treatment plants, resulting in the use of significant amounts of energy for pumping [6]. Maintaining water quality also remains a challenge in the distribution system, where contaminant intrusion and biofilms reduce water quality [7,8]. Problems with end-user plumbing can then further decrease water quality. The water distribution system is also vulnerable to targeted attacks through water poisoning, as well as catastrophic water main breaks due to undetected pipe deterioration [3,9].

Technological revolutions such as electricity and the combustion engine transform economies and societies, including supporting infrastructures supplying water, energy, and mobility. Information and communications technology (ICT) has been the dominant technological revolution for several decades. In addition to economic and social effects, ICT also drives changes in environmental issues and add to the portfolio of potential solutions [10]. The benefits of ICTs can presumably be enhanced through intentional adoption for sustainability and resiliency.

Compared to manufacturing and service sectors, adoption of ICT in infrastructure is relatively slow. One factor is presumably longer replacement time scales. The last decade has seen progress in the development of the smart electrical grid [11]. Smart electric meters and other two-way communication devices have been installed in homes and businesses to allow electric utilities to track electrical usage in real-time. This allows utilities to make continual adjustments to the system. Whether responding to a power transformer failure or trying to help shift electrical usage to off-peak time, the hope is that smart electrical grid will make power generation and delivery more efficient and resilient and less costly, while reducing total energy use [12].

Using ICTs in water systems could lead to smart water grids that are analogous to smart electrical grids. A smart water grid would integrate sensors, controls, and analytical components to ensure that water is efficiently delivered only when and where it is needed and help to ensure the quality of that water. Considering smart water grids as integrated systems is just beginning to be considered by researchers and utilities. In the literature, there are efforts to develop and analyze the components of smart water grids. Some of the literature focuses on the benefits of specific technologies such as smart pumps [13]. Other research takes a step further and analyzes the implementation of specific smart technology systems, such as automated meter reading (AMR) and advanced metering infrastructure (AMI) for water infrastructure, which are two different systems for using smart water meters for residential and commercial water consumption billing [14,15]. However, integrative, strategic, and macro-level discussions of smart water grids are lacking in academic and other literatures.

This paper begins to fill this gap by presenting a vision of how smart technologies could be implemented at several scales and combined to contribute to more sustainable and resilient water systems. Additionally, this paper seeks to outline the challenges to the realization of smart water grids. It is interesting to note that the smart phone is a marvel of modern information technology that is owned by hundreds of millions of consumers around the world. In contrast, much of the technology for water distribution and use is similar to that of fifty, or even a hundred years ago. Outside of the water treatment plant, there is little use of information technology in water systems. Clearly, there are structural differences in markets for personal information products *versus* water infrastructure underlying this dramatic gap in adoption. It is important to understand the barriers to the adoption of smart water grids and in the following sections, some issues are proposed.

For this initial work, the focus is on drinking water distribution in an urban environment. Future work beyond the current scope would include more environments and other parts of the water cycle. For example, agriculture is an important part of a complete vision for the smart water grid given its high share of water use.

In Section 2, we present an overview of the technological elements of the smart water grid in a systems context. Section 3 is a summary of sustainability and resiliency challenges for urban water systems and how smart water technologies could contribute to addressing these issues. In Section 4, example communities beginning to implement smart water grids are described. Finally, in Section 5, funding and economic issues we view are important challenges are summarized.

2. Overview of Smart Water Grid Technologies and Systems

2.1. General Overview

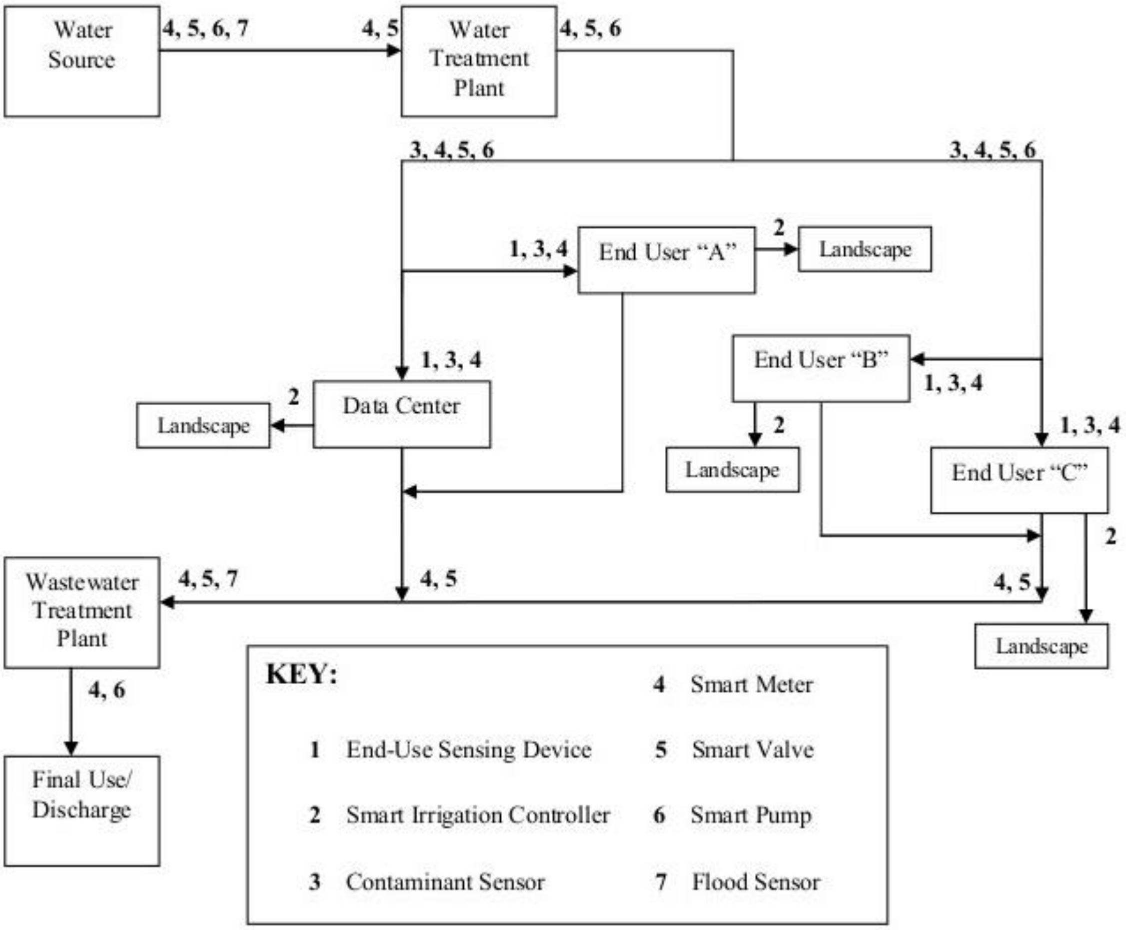
A theoretical smart water grid begins at the water source, where smart meters, smart valves, smart pumps, and flood sensors are installed. Water continues on through water treatment with more smart meters, valves, and pumps. Within the city water distribution system, there is the addition of water contaminant sensors. At the end-use locations (homes and businesses), end-use sensing devices, smart irrigation controllers, contaminant sensors, and smart meters may be used. Finally, water moves through the sewage system to wastewater treatment and final use or discharge, where the same technologies used at the beginning of the system are used here too. Figure 1 presents a visual depiction of a smart water grid.

2.2. Technological Description

2.2.1. Sensing Devices

Sensing devices that collect and transmit data about the water system on a real-time basis is the foundation of any smart water grid. At the municipal level, the most common way to monitor the water delivery system has been to manually read flow and pressure meters, while water contamination is commonly monitored by collecting water samples that are analyzed in a laboratory environment. In a smart water grid system, these parameters would be collected, stored, and transmitted to a computer by the meter itself, or from a sensor to detect contamination. This increases the amount and frequency of information about the system and decreases the need for field work. Smart sensors for municipalities include smart water meters for flow, smart water meters for pressure, and contaminant sensors and biosensors for contamination detection [16,17].

Figure 1. A simplified diagram of an example urban smart water grid.



Smart water meters have additional advantages over manual meters. One of these advantages is increased sensitivity to low water flows, which increases data collection accuracy. Other advantages of these more sensitive meters include the ability to measure backflow, which can indicate a problem in the system. They are also less susceptible to corrosion from particles in the system [18].

Whether in a residential, commercial or industrial setting, the typical situation for water use detection is a single flow meter measuring total water consumption of a facility. How total water consumption breaks down for different uses is generally not measured. Only measuring total flow has two disadvantages: leaks are difficult to detect by metering and users lack information on potential inefficiencies in the system. One option is to install additional meters within a facility. With current technology, installing meters for every fixture would be prohibitively expensive for most end-users.

An alternative to installing additional flow meters is to use a device that measure pressure waves. Each fixture has a pressure "signature" that propagates through the piping system, and a sensitive pressure-gauge can distinguish between these signatures. The HydroSense technology developed by Jon Froehlich and others needs only one sensor to determine the disaggregated use of all fixtures (e.g., faucets, toilets, and dishwashers) in a single family home [19]. If a fixture starts to leak, the end-use sensing device will pick up this flow as "noise" in the system. For larger end-users, multiple smart meters and end-use sensing devices would be more appropriate. The key point is that a combined flow meter and pressure sensor system requires fewer devices, substantially reducing costs.

A technological addition to the water system that is useful for water storage is the flood sensor. Flood sensors detect strain on water infrastructure, such as dams, and detect early flooding over flood embankments [20].

2.2.2. System Controls—Smart Pumps and Valves

Smart valves and pumps adjust their operations based on environmental conditions or signals from sensors. These adjustments can happen automatically or remotely by a human controller. The main benefit of smart controllers is increased efficiency. For example, variable speed pumps sense water conditions and will ramp up or down depending on those conditions. These pumps can also be equipped to sense clogs in the system and respond by breaking up clogs and/or reversing the flow. This is especially useful for wastewater and raw water conveyance. One manufacturer of a smart pump estimates up to 70% cost savings over the life cycle of the pump [13]. Smart valves adjust or block the flow of water in pipes based on environmental conditions. They can be used as part of pressure management strategies, as a part of leak detection activities, or to prevent environmental contamination due to combined sewer overflows [21,22].

At the end-use level, smart irrigation controllers show promise in helping to save water that is wasted on landscape irrigation. Smart irrigation controllers can receive and/or collect weather data or sense soil moisture levels, as well as other parameters, which helps determine proper water scheduling. Using this information, the watering schedule can be updated automatically on a daily basis. The valves and pumps that implement the actual watering of the landscape will then turn on and off at best times possible [23].

2.2.3. Data Transmission and Power

Once data is collected and stored temporarily in a data logger connected to a sensing/control device, it needs to be transmitted to a centralized location. Direct line transmission via cable is ideal in principle, because there would be no practical limits on bandwidth. While direct connection is an attractive option within an end-user facility, it may not be practical to hardwire the water delivery system. Another possibility is to bridge the smart meter from the broadband systems of water customers to the utility, but this is organizationally infeasible as the utility cannot be dependent on the end-user.

These jurisdictional and technical issues make wireless data transmission an attractive approach. Because the smart water grid is comprised of various technologies with different data transmission goals, a variety of wireless technologies and protocols are potentially useful. This includes mobile broadband (cellular towers), wireless broadband (Wi-Fi), personal area networks (device-to-device transmission), and satellite communication. For example, AMR, which is a drive-by meter reading system via personal area networks, is already becoming a common alternative to manual meter reading for water utilities for their water billing programs. In addition, satellite communication is a common technology used by smart irrigation controllers companies to update landscape water scheduling on a daily basis. The regularity in spacing of smart water meters suggest that a mesh network design, in which each device is a communication hub for neighboring devices, is a promising approach for the smart water grid [24]. Another promising technology for smart water grids is a wireless protocol able to broadcast a signal up to 45 miles that is designed specifically for smart meter communication [25].

Another issue that comes up with wired or wireless communication is the powering of devices. Direct connection to the power grid is feasible within a facility, but for devices on the water distribution system, off-grid power may be needed. This means that the power needed by the device to use a particular wireless technology/protocol will be an issue, along with the frequency of data collection and transmission by the device. Current off-grid power solutions include solar panels, water turbines, and long-life batteries [18,26–28]. The wireless communication protocol developed just for smart grids has the advantage of low-power usage [25].

3. Urban Water System Issues and Potential Smart Solutions

The section provides an overview of sustainability and resiliency issues for urban water systems: Losses, waste/overuse, quality, energy consumption, disasters and drought. The potential of the smart water grid to address each issue is reviewed, focusing not only on individual technological solutions, but also the combination of technologies to create a problem-solving system.

3.1. Water Losses

Water losses occur from leaks, unmetered consumption (legal or illegal), and meter inaccuracies [15]. A multi-city study done by Mayer and DeOreo found that 13.7% of indoor residential water use is due to leaking water fixtures in the U.S. [4]. At the level of the municipality and distribution system, the percent of water lost varies by location, from 3 to 8 percent in newer cities and 25 to 30 percent in older cities [5].

Smart meters and end-use sensing devices can help with leak detection. For example, continuous data from a residential smart meter could reveal a leak by showing a positive water flow when all fixtures are off. Finding leaks in municipal water supply could also be accomplished through smart step testing. Traditional step testing involves manually monitoring the flow rate on a section of pipe, while manually turning off valves in order to pinpoint the section of pipe a leak is located in—a water flow in an isolated pipe means there is a leak. With a smart step testing system, smart valves and smart meters can replace workers out in the field and would require only one person at a computer terminal. The process could even be automated, only requiring human attention if something goes wrong.

3.2. Water Waste/Over-Use

Water waste/over-use can be defined as consuming more water than is needed to achieve the desired function, e.g., maintaining landscape, flushing toilets, and cleaning dishes. Water conservation has seen improvement in recent decades through low-flow fixtures and educational campaigns [29]. An area where water over-use has yet to be addressed is watering of urban landscapes in water scarce regions. Landscape watering is significant in these locations, where more than 50% of the total household water used goes to landscaping, especially in the summer months. Comparing three U.S. cities, a residential home in Las Vegas may use 100 gallons per day of water for outdoor uses, while Atlanta homes may use 21 gallons and in Seattle, 9 gallons [30].

In arid regions, irrigation controllers are often used to apply water to landscapes. It is challenging to use traditional irrigation controllers to both save water and keep plants healthy. Smart irrigation controllers have the potential to manage this for the homeowner. In studies of smart irrigation controllers in the Western U.S., on average homeowners save water, though there are cases where water use increases when the end-user was actually under-watering their landscape before installing the smart irrigation controller [31,32]. Currently, smart irrigation controllers are not economically profitable for most homeowners, even in the arid West. There are, however, many areas in the U.S. where the investment in a smart irrigation controller would be profitable given modest improvements in design and reduction in prices [23].

3.3. Water Quality

Water quality monitoring in the water distribution system and end-use pipe system is usually very limited. At the same time, 30 to 60 percent of contamination events occur in the water distribution system. These events are often detected by consumers who have already been exposed. Once the existence of a problem is discovered, it may take days to identify the source of the event in order to fix it [33].

The water quality in the drinking water distribution system can be affected by several factors including disinfectant depletion (water age), contaminant intrusion from pressure differentials and pipe work (*i.e.*, installation, repair, and replacement), biofilms, pipe corrosion, accidents, and terrorism [7,8,34–36]. In a smart water grid, biosensors and multi-contaminant sensors could alert authorities to potential problems and their location immediately, while smart meters could detect leaks and pressure differentials that cause contaminant intrusion. Smart meters could also help in the monitoring of water age. Lastly, smart valves can isolate contaminated water to prevent its spread through the distribution system.

3.4. Energy Consumption

The most energy intensive portions of water delivery are usually source pumping and wastewater treatment [6,37]. The U.S. Environmental Protection Agency (EPA) estimates that it takes an average of 1.5 kilowatt-hours of energy to convey, treat, and distribute one thousand gallons of drinking water in the U.S. [38]. In the southern Los Angeles basin the estimate is 9.9 kilowatt-hours per thousand gallons [6]. This larger energy consumption is mainly due to the long distances and altitude changes for conveying water from source to drinking water treatment plant.

Undetected leaks and biofilms can also increase energy consumption. Leaks in the distribution system result in a loss of water pressure. Energy is required to rebalance this pressure loss. In turn, increasing the pressure actually increases the severity of the leaks, which means more water and energy lost [39]. Biofilms increase the frictional resistance in pipes, slowing the water down, resulting in increased pumping to compensate [40].

If pumping distances in the Southwest U.S. cannot be reduced, the use of smart pumps has the potential to at least reduce the energy consumption of pumping water, because they adjust their power levels based on environmental conditions—ramping up when water is flowing slowly and ramping down when water is flowing quickly [13]. Smart pumps can also be used in the distribution system as part of a smart pressure management program. Used in the same way as smart step testing described previously, smart pressure management with smart pressure meters, smart valves, and smart pumps can reduce pipe deterioration. This saves energy in the long-run, because leaky pipes lose pressure and require more energy to balance. Lastly, biosensors can locate problematic biofilms that slow the water flow.

3.5. Disasters

Disasters that affect urban water systems include water main breaks, weather and geologic events, terrorism, and accidents. Pipes normally break down as they age. Their breakdown can be accelerated, however, due to corrosive elements in the water or surrounding the pipe, high water pressure, pressure transients, vibrations, and traffic loads [3]. Eventually, the stress in the pipes may reach a point that causes a water main break.

Weather events, geologic events, terrorism, and accidents can directly cause damage to water infrastructure or damage water infrastructure through a domino effect [41,42]. For example, the terrorist attack on the World Trade Center caused significant damage to water mains and caused flooding that damaged communication infrastructure [42]. Disasters can also shut down water treatment facilities and prevent the distribution of drinking water to taps. Flooding events can also overwhelm sewer systems and prevent the proper disposal of wastes.

Smart pressure management could manage and prevent premature pipe deterioration that leads to water main breaks. Flood sensors could also detect a pipe that is about to break and alert authorities. Smart flood management could detect flooding and respond to reduce the amount of damaged caused using flood sensors, smart valves, and smart pumps. Flood sensors could detect a pipe break, which would trigger a smart valve to shut off the water supply. Then, a smart pump could pump water away from the immediate area.

3.6. Drought

Drought is currently a resiliency challenge in many areas and climate change may increase the magnitude, frequency, and locations of impact [2,43]. A typical strategy that municipalities employ to deal with short-term drought is to impose blanket, outdoor watering restrictions on residential customers [43]. There are several downsides to this strategy. First, it requires the type of enforcement that involves patrolling streets to look at people's lawns, which is resource intensive, and neighbors reporting each other, which is socially negative. Second, it may result in a loss of a household's landscaping. This type of loss would affect residents unequally, putting a heavier financial burden on lower income people. Lastly, it may not be an adequate strategy in times of extreme or long-term drought.

Long-term drought planning is a complex and is data and modeling intensive. The drought plan for the State of Arizona cites a lack of sufficient data and instruments to predict drought and mitigate its impacts. Two of the mitigation strategies that Arizona has chosen include increasing water storage and conservation [44].

The smart water grid enables more creative solutions for dealing with drought. For example, water restrictions could be managed better with a smart water grid system. Rather than using a simple lawn watering restriction that requires field enforcement and the potential loss of landscapes, a more flexible approach can be taken. If users are able to monitor their own water use on a disaggregated and real-time basis through the use of smart meters and end-use sensing devices, they can make decisions about how to save water during a drought. At the same time, utilities will be able to monitor on a real-time basis and from a remote location, what end-users are saving water during drought and what end-users are not.

Alternatively, smart water grids could support temporary drought pricing of water. In the same way that conservation-promoting tiered pricing and smart water meters can help people save money and conserve water on a daily basis through online tools and real-time data, drought pricing can also be supported by smart water grids. Consumers will be able to track their water rates and consumption more easily when drought prices and in use. If water utilities want to change the drought pricing in the middle of a billing period, consumers will easily be able to see this when using their online tools and can adjust their use patterns accordingly.

On the broader level of long-term drought and regional water planning, water saved from the reduction of water losses could be banked through water storage projects, creating more water availability during times of drought. Additionally, real-time data from smart water grids can feed into water resource planning and modeling, making drought and long-term water planning a more accurate and dynamic process.

3.7. Summary of Problems Potentially Addressed by Smart Water Grids

Table 1 summarizes the connections between smart technology and problems address. Components such as smart valves have the potential to address multiple issues, especially as part of a smart system such as smart step testing. Other components, such as flood sensor, are more limited in their contribution to a smart water grid.

Table 1. Components of the smart water grid, problems each component can address, and the smart systems that components are part of.

Component	**Problem(s) Directly Addressed**	**Problem(s) Indirectly Addressed**	**Embedding System for Component**
Smart Meters	Water losses, water quality, disasters, and drought	Energy consumption	Smart step testing and smart pressure management
Contaminant Sensors	Water quality	Energy consumption	Contaminant isolation
End-Use Sensing Devices	Water losses and drought	Energy consumption	N/A
Flood Sensor	Disasters	N/A	Smart flood management
Smart Valves	Water losses, water quality, and disasters	Energy consumption	Smart step testing, contaminant isolation, smart pressure management, and smart flood management
Smart Pumps	Energy consumption and Disasters	N/A	Smart pressure management and smart flood management
Smart Irrigation Controllers	Water waste/overuse	Energy consumption	N/A

4. Example Communities that are Developing Smart Water Grids

A number of communities have begun to install smart water technologies—AMI and AMR are probably the most popular components of the smart water grid that are implemented—but not many have begun to plan and implement a comprehensive smart water grid. Two communities that are partially on the way to implementing smart water grids are Singapore and part of the San Francisco Bay Area.

In Singapore, large scale research and development funding has led to a number of smart water grid projects, including the development of a laser-based contaminant sensor and a smart water grid in the Singapore business district. The smart water grid in the business district tracks pressure, flow, and disinfectant levels in the distribution system. This data is transmitted via Singapore's cell network to a computer center. At the computer center, modeling software is used on the data to locate problems in the water distribution system. Problems can be pinpointed to within 40 meters and when problems are found, an alarm is sent out to the utility [33,45,46]. Singapore has a multistage plan for implementing smart water grids in its city [47].

The East Bay Municipal Utility District (EBMUD) is the drinking water and wastewater utility for the eastern part of the San Francisco Bay Area. The EBMUD has several progressive programs including advanced leak detection device testing and deployment, smart irrigation controller rebates for consumers, and smart metering in conjunction with web-based tools for users. The web-based tools help consumers detect leaks on their property [48–50]. Data from the EBMUD's pilot AMR/AMI program helped the utility discover problems on the consumer end of the water system. When these problems were fixed, there was an average water use reduction of 20% [48].

In Singapore, one of the reasons for the aggressive pursuit of the smart water grid is due to insecure water resources. Singapore relies heavily on rainfall to meet its water needs and does not have enough land for water storage. Whatever reason these communities have for being early adopters of smart water grids, however, they are in the unique position to spread the word about the smart water grid by sharing their research and lessons learned with other communities.

5. Implementation Challenges for the Smart Water Grid

Assuming that the smart water grid is desirable, in this section we discuss challenges to its development and adoption in a U.S. context. One challenge is obtaining the funding to implement changes, which includes the lack of a federal agency that focuses on water or the smart water grid and political and institutional barriers to funding and investment. Other challenges involve economic disincentives, such as the lack of new water markets, burdens on smaller utilities, and the cost of actually fixing problems found by a smart water grid.

5.1. Funding and Investment

The current U.S. water system has much deteriorating infrastructure due for replacement. It is estimated that it will take 325 billion dollars over the next 20 years to install needed replacements in the U.S. system, including new pipes and meters. One side effect of deteriorating infrastructure is water leaks. It is estimated that municipalities lose 3.4 billion dollars each year to water loses, which are mainly leaks [15]. Presumably, some infrastructure replacements will include upgrades with smart technology, particularly smart water meters. However, many of the benefits of a networked system, like a comprehensive smart water grid, requires scale to be realized—scale that requires an investment that is difficult in the capital constrained environment of most U.S. water utilities.

One reason for the lack of investment in smart water grids is a lack of a federal agency's mission to support its research and development. The electricity sector is supported by the U.S. Department of Energy and the U.S. Department of Defense. The societal benefits of smart water grids span environmental, energy and security issues, but smart water grids have yet to be recognized as important enough to merit significant federal attention.

Another reason for the lack of investment and funding in smart water grids is due to institutional and political legacies in the water sector. First, U.S. water utilities were founded on principles of delivering an invisible service at the lowest cost possible [51]. Smart technology can have large upfront costs that many water utilities would be reluctant to pay. Second, water prices are often determined by boards whose membership is determined by popular election. Increasing water prices, even for sensible infrastructure maintenance, is often viewed negatively by voters. The general public tends to take supply of clean and inexpensive water as given. These factors constrain availability of capital.

5.2. Economic Disincentives

Water is a monopoly. While smart electrical grid holds promise to create new power markets, this is unlikely to happen for the smart water grid. Water resources are unlike smart electrical grids—the application of smart technology to create producer markets does not work for water, because water is a resource to be distributed (excepting desalinization) rather than something to be made (*i.e.*, electricity) The general lack of incentives to innovate in utilities affects adoption of smart water grid technologies.

For any investment in new technology, the benefits should outweigh the costs for those paying. With technology that increases resource efficiency, there is typically a threshold payback period or return on investment. Smaller utilities typically have less capital to invest and water utilities tend to be smaller scale than electricity utilities. For end-use, property renters that pay their own utility bills may have leases that are shorter than the payback period for investments. In cases where property owners' pay utility bills, property owners may make efficiency upgrades to decrease their utility bill or property owners may just pass on increased daily costs of inefficiency to renters in their monthly rent.

An economic issue for both utilities and consumers is the cost and other negative effects of fixing leaks once they are found by a smart water grid. Distribution pipes are often underneath other infrastructure, so accessing leaks to repair involves removing and repairing this other infrastructure. Repair restricts use of those infrastructures, including roads, causing inconvenience to residents. At the home level, some leaks such as faucet leaks or toilet flapper leaks are easy to repair, but some are not. Leaks that occur underground or behind walls may require professional repair, which can be expensive and take many years to pay back to the consumer through lower water bills [26].

Additionally, although the utility is most often responsible for paying for a smart water grid, many of the economic, sustainability, and resiliency benefits of a smart water grid are divided among actors beyond the utility. For example, an end-use smart meter helps the utility via automated meter reading and improved flow data, but also provides value to the end-user by informing efficiency actions. Another example is that a more secure water system benefits society as a whole, but from the perspective of the water utility, it is simply an additional cost.

Water infrastructure changes slowly. Many system elements such as pipes, valves and meters last for decades. Barring changes in water regulations, keeping the existing system going can make sense when its components are expensive and long-lived. A smart water grid system needs to achieve a certain size scale to realize many of its benefits, *i.e.*, the utility of a network increases with the number of nodes in the network. Incremental replacement of failed system elements with smart technology will not realize these size scale benefits. This scale issue is qualitatively different for newly developing areas installing water infrastructure for the first time. Newly developing communities and countries have opportunities that established ones do not.

6. Conclusions

Potential benefits of smart water grids include improved leak management, water quality monitoring, intelligent drought management, and energy savings. It is not yet well understood how different implementations of smart water grids yield what benefits and costs. We argue that integrative analysis of multiple benefits for larger-scale smart water grid systems could help pave the way for the future. For example, while viewing the smart water grid purely as a way to reduce water losses might not justify the investment, considering water losses *and* drought management might tip the balance. In addition, as the benefits can accrue to a number of different actors, e.g., utilities, homeowners, and society as a whole, there are important questions as how to distribute costs among beneficiaries. Support for research and development is needed to enable such work, coupled with cooperation with municipal water utilities.

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Author Contributions

Both authors contributed extensively to this work in all aspects. Eric William’s major contribution was leading the direction of the research, while Michele Mutchek’s major contribution was executing the research and writing of the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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