THEME : SMART WATER MANAGEMENT

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SMART WATER MANAGEMENT

1 | INTRODUCTION

"Smart water" or "digital water" emerged a decade ago as "something of a catch-all expression" for the collection, transmission, analysis, and presentation of data across the water cycle, "an enabler of innovation, as much as being an innovation itself" (OECD, 2012). In effect, this is the convergence of information technology, mobile and digital communication, and the Internet. The expression "smart" is an acronym; for "Self-Monitoring, Analysis and Reporting Technology." Smart water systems can be divided into five layers of information handling: (1) monitoring and data collection; (2) data transmission and recovery; (3) data interpretation; (4) data manipulation and; (5) data presentation. The monitoring and transmission devices are not "smart" per-se, they provide the data for layers (3, 4) and (5), which form the smart system.

Using the current definitions of smart water, its emergence goes back further than is currently appreciated. The first paper in the literature referring to smart stormwater was in 1984. Progress was gradual, with ten papers in all noted by 2003, followed by a dramatic rise from 2015. From the academic literature, it is evident that research is both disconnected and diverse, with the integration of approaches still some way away. Likewise, proof of concept modeling studies tends to predominate. In real-world applications, most work remains limited in scale (Webber et al., 2022).

Disruptive technologies change the nature of their intended market, such as anaerobic digestion in sewage treatment and the membrane bioreactor for water and wastewater treatment. In contrast, smart water developments tend to offer incremental improvements in efficiency and cost-effectiveness. It is the potential to integrate and redouble these incremental benefits into a smart water system that may become disruptive.

This paper provides an overview of how smart water approaches systems are starting to have an impact on municipal water and sewerage systems, domestic customers and the environmental impact of water utilities.

2 | DEMAND MANAGEMENT

Water shortages (low per capita availability, Kummu et al., 2010) and stress (high extraction of renewable resources, Kummu et al., 2016) are a rising concern in many areas and demand management measures are needed so at to secure future supplies. Demand management concerns how much water is needed, rather than wanted. For utilities, this concerns minimizing the amount of water that is put into the supply network to provide the service desired. Consumers are encouraged to minimize their consumption, including labeling schemes for buying water-efficient domestic goods and water metering. Metering drives demand management by generating data. The more frequent the readings, the more information each meter generates, and the greater the potential to influence consumer behavior and to manage the water network in real-time. Commercial and industrial customers can be encouraged to internalize their water use (net zero) and discharge (zero liquid discharge).

An efficient water system needs operating data across the network in real-time to diagnose supply or network failures such as bursts and to provide integrated control to mitigate their impact as soon as possible. The utility becomes proactive, preventing any actual impact occurring by predicting leaks or breakdowns, or minimizing and mitigating any impact if it does occur. This requires effective communications, data processing and data capture.

At the network level, examples in Australia (Beal & Flynn, 2014) include reducing monthly peak demand by 10% and deferring A$100 million in new infrastructure for 4 years, saving the utility A$20 million in finance costs. Deferring a A $20 million water treatment works upgrade by 7 years after reducing demand growth saw capital spending savings of A $7.9 million, while deferring a A$5 million pipeline upgrade for 5 years realized a saving of A$1.6 million.

3 | OPERATING EFFICIENCY

If assets and their monitoring are poorly integrated, utilities will operate at below efficiency. This is a particular challenge when smart systems are developed, because of a lack of common communications protocols. Shortfalls include more assets being deployed than are, in fact, necessary, with higher operations and maintenance costs as consequence. Efficiency also falls as assets age and require refurbishment or rehabilitation.

Pumps are a particular concern here. They account for 10% of global energy consumption (Riis, 2015) and 90% of pumps have not been optimized, and energy accounts for 20%–25% (Carvalho, 2015; Fargas-Marques, 2015) of water utility operating spending. Linking pumps with active water network pressure management lowers energy needs by 20% as well as reducing network distribution losses by 20%, and smart-enabled deployment of pumps and optimizing their usage levels can result in 11.5% improvements in energy efficiency (Bunn, 2015). Network pressure can be optimized by using an algorithm to identify the optimal placement of pressure-regulating valves within a network, reducing overall pressure by 15% and enhancing the operating life of the distribution network (Price et al., 2022).

4 | CAPITAL EFFICIENCY

Smart approaches are driving improvements in capital efficiency (Kingdom et al., 2018). By retaining septic tanks when developing a sewerage network, their storage capacity improves the network's efficiency. South East Water (Australia) considered developing a sewerage system costing A$507 million (A$20,280 per property). A network was developed for 51% of this cost by using a smart sewerage management system, whereby the septic tanks were deployed to smooth slows into the sewerage system. In particular, when rain is anticipated, sewage can be held back until flows through the stormwater network have eased (GWI, 2016).

Flood events are becoming more frequent and intense in many areas due to climate change. Yarra Valley Water (Melbourne, Australia) used the InfoWorks CS for future sewerage population needs in a suburb, and by optimizing the extant sewerage system for A$1 million, a A$10 million sewer project was avoided (Innovyze, 2009). It has also been used for real-time control systems in Bordeaux, France and Ottawa, Canada, with savings of 67% in Ottawa (C$65 million) by avoiding a new sewer tunnel while improving rain-generated wastewater capture from 74% to 91%. Savings of 63% in Bordeaux (€62 million) was achieved by improving the network's ability to store wastewater (Innovyze, 2008). The cost of making a property safe from sewer flooding in the UK ranges from £15,000 to £58,000 (Keeting et al., 2015). The sewerage and flood risk assessment model developed by Innovyze was combined with 16 flow monitors at 916 properties in a part of Blackburn, UK, considered vulnerable to sewer flooding resulting in the "At Risk" register being reduced to 118, along with improved flood risk prediction and lower insurance costs (Innovyze, 2010).

5 | NET ZERO AND RESOURCE RECOVERY

Wastewater should be regarded as a resource, creating value through water, nutrient and energy recovery. Water can be returned to the domestic network directly (direct potable) or indirectly (indirect potable), with a direct non-potable sale to industrial customers. Nutrient recovery is being driven by limited fertilizer stocks, and energy recovery is playing an increasingly important role in reducing utility energy costs and lowering their carbon footprints. Nutrient and energy recovery depend on controlling the waste treatment process to optimize yields.

Sludge to energy has the potential to significantly reduce a utility's carbon footprint as well as lower its operating costs. Wastewater contains at least seven times the energy needed to treat it. The Egå Renseanlæg wastewater treatment plant in Aarhus, Denmark, generates 150% of its energy (Freyberg, 2016). Further gains are being realized. An expansion and upgrading of a WWTW in Montpellier (France) from 2022 to 2031 from 470,000 to 695,000 PE is being driven by developing real-time process control and effective water, heat and energy reuse. This will see the facility generate 205% of the energy it consumes while reducing net CO_2 emissions by over 50% (Smart Water, 2022).

6 | LEAKAGE MANAGEMENT

Remote leakage detection enables leaks to be identified, minimizing the amount of digging and disruption needed, or avoided through trenchless techniques. Leakage monitoring and management are carried out within a district management area (DMA) or by acoustic leak detection. DMA is mainly seen in Europe, especially in France, England & Wales and Portugal, along with Israel, Singapore, Australia, Chile and Brazil and more recently, India, China and the Philippines, while countries where acoustic detection predominates include the USA and Germany. Hybrid approaches are also emerging where virtual DMAs (VDMAs) are developed through sensors, meter data analysis and dedicated software systems (Hays, 2017).

The DMA approach divides the distribution system into a number of separate sections. All the water flowing into, through and out of each DMA is measured using pipe and customer meters. This generated accurate data about water losses and allows the rapid detection of new leaks or deteriorating pipe performance. Smart metering generates this data in real-time.

Remote acoustic sensing allows the utility to monitor potential leakage in near-real time.

This involved a series of nodes which send data to a server via local mobile communications networks, with noise loggers placed along the network and acoustic signals correlated between the adjacent loggers. SYABAS serves 7.5 million people in Selangor, Malaysia. During a 190-day trial with SYBAS, 1461 km of mains pipeline were inspected, detecting 154 leaks that were losing 19,250 M^3 of water each day (Bracken & Benner, 2016).

Water pressure management has an important role to play in leakage reduction. Pressure management reduces network leakage by keeping water pressure within a distribution system to a practical minimum. Excess pressure within the network forces water out of the pipes through underlying leaks in the system and shortens pipe life due to the stress induced upon them (Dunning, 2015). Trials with i2O's oNet with Severn Trent, Portsmouth Water and United Utilities between 2008 and 2010 resulted in leakage reductions of 26%, 29%, and 36%, respectively. A contract with Anglian Water from 2014 to 2016, has resulted in 40% fewer burst mains and a 35% reduction in leakage.

Faster testing allows managers to predict rather than respond. The greater the lag between an incident occurring and its being addressed, the more damage can be done. A water leak can damage roads and pavements above it by leaching away the soil lying beneath the hard surface. Sewer leaks can also contaminate water supplies through egress into groundwater and poorly maintained water pipes.

7 | DOMESTIC DEMAND MANAGEMENT

The more advanced a water meter, the more scope exists for customers to modify their water consumption. With advanced metering infrastructure (AMI) or fully smart metering, customers get information detailed enough to allow them to see the impact of each individual intervention. A survey of 12 major meter trials between 1988 and 2015 (Lloyd Owen, 2018) without prior metering found a 10%–16% reduction in consumption when traditional meters are installed and a further 7%–15% reduction when these are replaced by AMI systems. Where AMI is used in hitherto unmetered households, 16%–17% reductions were noted. In Chennai, India, a trial found that smart water meters reduced overall consumption by 15%. It may become an enabling tool for affordability, as water use fell by 21% in low-income households, against 9% for high-income households (Ram & Begum Irfan, 2022).

25%–30% of water distribution losses occur within household boundaries rather than the network. Without real-time metering, this goes undetected, while metering identifies anomalous water consumption. Addressing this can lower overall domestic consumption by 5%–11% (Godley et al., 2008; Lloyd Owen, 2018). When Thames Water rolled out its smart meter program, they found that while the average per capita water consumption was 147 L per day, the mode was 100–105 (Tucker, 2021). The difference was accounted for by heavy users and internal leakage. The utility is now focussing on these areas.

Even amongst the leading users of smart water metering, wide-scale adoption started comparatively recently. Rollouts started in Israel in 2000, followed by the USA in 2004, Australia in 2010, Korea in 2010 and in England and Wales in 2014. While the scale and timing of deployments may differ across these countries, the growth trajectories after 2015 are similar. The time gap between adoption is material, as earlier adopters will be biased toward AMI (basic) metering compared with the full-blown AMR deployments seen in for example, at Southern and Thames Water in England (Msamadya et al., 2022).

8 | SEWER AND SEWERAGE MONITORING

For utilities, metering household sewerage enables them to generate a real-time understanding of the flow of water from a property and the relationship between foul water and other waters that enters the sewerage water network. For customers, it could become an incentive to reuse rainwater or gray water or for their gardens, reducing the loading into the storm sewerage network and levelling out rainwater flows through the catchment area. The meter would also enable utilities to compare the daily volume of water supply, wastewater discharge and rainfall at the household level and internal leaks. Network flow monitoring also shows where rain and foul connections are interconnected.

Sewer blockages occur due to wet wipes, sanitary pads and the such-like being flushed into the sewerage network, and "fatbergs" are allowed to form. Severn Trent noted one sewer blockage for every 130 people in one hotspot during 2019. These are typically only noted when sewer flooding starts. To combat this, the utility is installing 40,000 real-time mains sewer effluent level monitors by 2026. These monitors have no moving parts and are remotely enabled. They will record when levels are rising within a sewer (the usable area of the pipe is diminishing) and when a blockage is imminent, allowing preventative responses (Williams, 2021).

9 | INLAND WATER MONITORING

The more inland water quality indicators deployed, the greater the scope for assessing changes in water quality, allowing managers to anticipate pollution incidents rather than responding when their impact has already caused appreciable harm. A broad range of indicators are now available which allow for remotely enabled and managed data collection and transmission from water bodies in real or near real-time. Water contamination can be measured via parameters such as conductivity, pH, BOD and the presence of specific compounds. Indirect data can be obtained through changes in color and turbidity, along with dissolved oxygen. Water flow data (volume and height) is an integral component of flood risk monitoring and drought awareness. Such data also enables regulators to break down the source of contamination (sewage, agricultural effluent, industrial effluent and mining run-off), especially when wastewater treatment and combined sewer outfalls are effectively monitored.

10 | MANAGEMENT IN REAL-TIME

Real-time access to a broad range of data inputs enables a utility in the fastest and most efficient manner. This helps to minimize both service disruptions and potential damage to infrastructure, with this information being fed back into data loops which enhance their ability to predict and respond to similar events in the future.

Northumbrian Water adopted an integrated catchment level control system using periodic data collection for the entire utility in 2010. Poor quality data meant little was gained. In 2015, the Aquadapt system was adopted, generating updates for all operating assets every 30 min, including, for example, identifying the cheapest water and energy resources to use. This near real-time data provision has seen a 6% reduction in the water needed, energy efficiency rising by 14% and 20% less energy consumption, saving £1.7 million pa (Austin & Baker, 2014; and Baker, 2015).

Effective water network flow monitoring ranges from where it is introduced into the distribution network to the customer's meter. Flow anomalies and water losses will highlight deteriorations in the network's asset condition. For sewerage, this assists the utility in appreciating where rainwater and foul (waste) water actually flow through the storm and foul sewers and how combined sewers are, in fact, performing at the network level. None of this is possible without real-time monitoring.

Flood management has traditionally relied on 'hard' defences, rather than flood avoidance and amelioration. Smart flood management uses a five-stage approach: (1) Mapping and assessing each area's flooding vulnerability; (2) Deploying responses including flood prevention (increasing the natural or engineered absorptive capacity within or before a flood zone) and developing defences at property and area levels; (3) Monitor upstream water flows, soil saturation and the weather in real-time, feeding the data back to improve their predictive ability; (4) Maps continually updated to improve their accuracy and to highlight current or emerging vulnerabilities, and; (5) Forecast potential flooding events to maximize warning times. In urban areas, people can also be warned to postpone water-intensive applications such as baths and washing machines during critical periods to minimize the potential for storm sewer flooding.

Underground assets tend to be poorly appreciated. They can be allowed to deteriorate to the point where repair or rehabilitation is no longer feasible or replaced when in fact, they may still enjoy years or decades of useful life. More accurate appreciations have many benefits. For example, water pipe cleaning is an expensive process, only justified when there is no prospect of significant biofilm regrowth for at least a year. Pipe conditioning is a lower-cost alternative. To see where this applies, software such as PODDS (Prediction of Discolouration in Distribution Systems) predictive modeling can be used (Boxall, 2016). Here, water flow and turbidity are analyzed in real-time, blended with long-term time series data, to simulate the accumulation of materials onto a pipe surface, with the regeneration rate being a function of water quality. Jetting or conditioning was used, rather than swabbing, flushing or replacement, reducing a forecast cost of £75,000–333,000/Km down to £1,000%–57,000/Km.

11 | MONITORING COMBINED SEWER OVERFLOWS

The limitations of traditional monitoring approaches are highlighted by inland and bathing waters in England. While 71% of beaches tested were rated as "excellent" under the EU's Bathing Waters directive (DoE, 2022), 29% passed the EU's Water Framework Directive as being of "good ecological quality" (DEFRA, 2021). River water quality is declining, with 16% of inland waters passing the Water Framework Directive (JNCC, 2021). These inland waters are lightly monitored by the Environment Agency, with event duration monitors (EDM) at 12,393 of the 14,470 combined sewer overflows (CSOs, Environment Agency, 2022). This is "dumb" monitoring in the sense that it provides little data of practical value. Lots of clean rainwater over a long period of time has a greater EDM impact than a large discharge of concentrated effluent. The shortfalls in deploying non-smart technology have also been highlighted by the number of monitors found to be inoperable. Meanwhile, applying machine learning to sewage treatment works discharge data has identified a significant underreporting of actual spill events against those disclosed by the water utilities (Hammond et al., 2021).

The EU's revised Urban Wastewater Treatment Directive (EC, 2022) is designed to reflect a deepening alignment between various branches of EU environmental policy. In this case, to help utilities to become carbon neutral and to drive forward compliance with the Water Framework Directive. The EU estimates that 18% of pollutants entering their inland waterways are estimated to derive from storm sewers and urban runoff. The EU aims to see all combined sewer overflows (CSOs) fitted with smart monitors that will log the BOD loading from every overflow. This will allow for the effective identification of those CSOs where remedial action (sewage trapping and treatment) is needed and to what extent.

Compliance can pay when fines matter. Detectronic's ultrasonic flow sewer meter system integrates rainfall and sewer level data, blending this with external weather, sewer asset and historic data, including legacy data from other monitors to provide historic benchmarking. Trials ensured 160 pollution or flood-preventing interventions were carried out, saving clients £5 million in potential fines, along with additional reputational damage and post-event remedial works, against a £225,000 investment (Woods, 2015).

11.1 | Policy drivers

The explicit encouragement of smart water systems has been seen in a growing number of countries. In Jersey and Malta, this has seen the rollout of universal smart water metering programs to respond to water shortages. Korea and Singapore are developing comprehensive smart water grids. Smart approaches can also result from general measures designed to encourage efficiency. In Denmark, a tax of €1 per m^3 for any utility losses above a leakage threshold (Fisher, 2016) saw a smart leakage detection system rolled out in Copenhagen. In Australia, an annual irrigation allowance in Canberra for parkland, sports grounds, and residential gardens of 0.5 Ml per $1000\,m^2$ of total surface area per annum or $5000\,m^3$ per hectare per annum (ACT, 2007) has been driving both the adoption of smart metering and smart irrigation.

Policy in the USA is primarily driven at the state level. States facing water deficits have been proactive in policy development and implementation. In Texas, HB 2299, regarding garden irrigation systems, came into effect in 2008. This requires garden systems to be fitted with smart controllers and was modified to include automatic shut-off systems for rain and frost in 2011. In 2007, five types of smart controllers were being sold in the state, which rose to 11 by 2011 (Lee, 2011). California's Updated Model Water Efficient Landscape Ordinance AB1881 states that from 2012, all new irrigation devices in the state must have smart controllers. Arizona's Department of Water Resources implemented its Modified Non-per-Capita Conservation Program in 2010, requiring water providers to adopt the best management for water conservation. It includes a framework for future smart water implementation. A survey of water conservation measures in 2010 found that 5 of 15 communities examined offered rebates relating to smart irrigation: $22–100 for irrigation audits, $30–250 for domestic lawn smart irrigation systems, and one-third of the total cost for commercial smart irrigation upgrades (Western Resources Advocates, 2010).

Korea had sought world leadership in smart water grids by 2020 by linking all aspects of municipal, industrial, and irrigation water treatment and management with data flow that mimics the water cycle, via a centralized control facility. This stems from a central plan to sustain economic development through international leadership in selected information technology-related themes (G. W. Choi et al., 2016). Deployment and integration have been slower than anticipated. A living lab serving 8,000 people on Yeongjong Island has been in development since 2017 (Koo et al., 2021).

11.2 | New directions

While the development of smart approaches such as metering and monitoring is starting to be adopted, their integration into real-time networks and the application of hydraulic models (Kaye, 2015) to manage the impact of current and predicted weather conditions and other events is the next step. This, in turn, is driving the development of faster, more sensitive monitoring systems. At present, sewerage monitoring is at a comparatively early stage, especially for household sewers and combined storm overflows. As sewerage systems and treatment works are monitored at the plant and utility level, this will, in turn, offer the potential for integrating water and sewer systems management and monitoring.

Sampling sewage for the presence of COVID-19 in the community since 2020 has demonstrated the value of wastewater-based epidemiology (WBE) as a public health tool. WBE allows healthcare professionals to identify the presence of a disease before it is seen in the community. It also provides insights into drug use and abuse and the emergence of antimicrobial resistance. There is considerable potential for the smart integration of these disparate data threads into sewerage monitoring, especially as testing becomes more automated and rapid (P. M. Choi et al., 2018, 2020; Nature Microbiology, 2022).

Autonomous smart systems are also being developed. Pipebots are miniature robots (2.5–50 cm across) capable of operating within pipe networks and carrying out monitoring and maintenance work. They are currently at a conceptual stage, with various models being trialed (Zaidi, et al., 2022).

One of the challenges they face is developing suitable communication protocols for controlling the units and retrieving data from them (Nguyen et al., 2022).

The Internet of Things (IoT) offers the potential for the interconnection of monitoring systems into an all-encompassing whole, offering a world limitlessly and universally interconnected via the Internet. It draws on the analytical power of information increases as more data from more sources is integrated via device-to-device communications within a network. For water, this could be an extension of smart water with other utilities and water-consuming devices. Incorporating a network of IoT sensors into a centralized control system helped managers to appreciate and respond to emerging risks. These systems, in turn, appear to be capable of integrating learned experiences into their models, which in turn assist operators when analyzing IoT data. This approach can only go so far, as local contextual information is needed to allow an effective balance between managers and their operating systems for the most effective anticipation of risks and how they should be responded to (Horita et al., 2020).

11.3 | Digital twins and virtual reality

Virtual (VR) and augmented reality (AR) visualization allows extant or new assets to be examined by immersing users and developers within an effective simulation. This is evolving into what has been called the meta-verse. For example, a planned expansion of water treatment works can be virtually operated to ensure that assets are deployed in the most effective manner. Another approach is in underground assets to provide a detailed picture of the distribution of water mains and sewers in relation to other underground assets, thereby minimizing the potential for disruption and damage when these need to be inspected, maintained, or replaced.

Digital twins first emerged in the oil sector as a tool for managing oil rigs, they are virtual copies of an asset that is used to enhance the development and operation of the actual one. While it is a subject of growing interest in the water sector, it is an emerging approach, where the chief challenge is merging smart water's focus on data with the process engineering needs for water and wastewater treatment. The first water treatment digital twin, for the removal of trace contaminants, is anticipated to go online in the Netherlands in 2023 (Audenaert, 2022). Digital twins offer a number of potential advances, including improving plant management training, a better balance between cost and performance and carbon footprints, preparing to adapt to climate change, improved decision-making, and optimizing documentation and communications.

11.4 | Deep learning

An emerging aspect of smart water is the application of deep learning. It is currently being developed for demand forecasting, improving leakage detection and location, detecting abnormal water quality, identifying sewer defects and blockages, predicting system states such as combined sewer overflow water levels, urban flood modeling, forecasting, identifying cyber-security vulnerabilities, and optimizing wastewater treatment plants. It remains at an early stage, with sewer defect detection and leakage monitoring starting to move toward a commercial scale (Fu et al., 2022).

Deep learning is also improving monitoring where current systems are providing an incomplete picture. In 2018, 395 of the 1575 wastewater treatment works (WWTW) spills recorded by the Environment Agency in England were noted by the public rather than the sewage operators. Using machine learning, event duration monitoring data (when untreated wastewater starts and stops being discharged from a WWTW), and daily treated effluent flow pattern data, performance data was analyzed at two WWTWs. Data for the former was available from 2018 and the latter from 2009. Of 7,160 days without operator-reported spills, 926 were found, in fact, to have a real or putative spill of at least 3 h, of which 360 were spills lasting for more than 1 day. The model was found to be 96% accurate (Hammond, et al., 2021).

The Government Transparency Institute and the Water Integrity Network have developed a Water Integrity Risk Index (WIRI). This identifies potentially anomalous data from all forms of procurement (equipment, services, and consulting) through the systemic evaluation of any information that is available in the public domain and draws this together through big data. 98,000 water and sanitation tender contracts were examined in 12 cities across seven less-developed countries (Fazekas, et al., 2020). Corruption can be signposted through tender periods (shorter periods suggest less competition), how the bidding procedure is publicized, their use of official publication, and how long contract advertising lasted. They also matched announced investments in new mains pipes to the actual laying of pipes each year. Data going back to 2005 was examined, more systematically since 2012. There has been some improvement in city WIRI scores. The fact that this is being done at all may be altering behaviors.

11.5 | Current and emerging challenges

One constraint in developing economies is that the utility of smart metering deteriorates with intermittent water supplies, as air flows faster than water within the systems, artificially boosting measured water consumption. This is, in turn, an incentive to move toward continual supplies (Ferrante et al., 2022).

Big data needs systems capable of dealing with the data generated. Basic remotely read water meters typically generate two data reads per month, compared with AMI meters sending 720 (once every hour) to 2880 (once every 15 min) customer reads each month (Symmonds, 2015). The volume of data needs to be appreciated. Brazil's

Cachoeiro de Itapemerim has 55,309 metered connections, along with 1956 data points in 20 DMAs. Each data point generates 5.18 million units of data a day, 10.1 billion units across the utility, or 3.7×10^{12} data units annually (Sodeck, 2016). This all needs to be cleaned, to remove gaps, zeros, peaks, and constant values through the effective use of previously collected data. In this case, deviations from expected performance over the previous 30 days are reported every 30 min and presented in graphics, along with other data such as pressure, reservoir levels, and minimum night flows.

Inconsistent policy can also inhibit innovation. Until 2010, Ofwat rejected smart water meters in England and Wales, regarding them as too strongly linked with water scarcity, and only allowed intensified manual meter roll-outs in the southeast of England. By 2010, Ofwat appreciated (Ofwat, 2010) that smart meters have a role in leakage detection as an integrated element of supply-demand balance rather than a regulatory target (Worsfold, 2012). However, Defra still considered the financial case for smart water metering to be premature (MacDonald, 2010). Ofwat's vie eventually prevailed (Ofwat, 2017). Policy incoherence was exacerbated by a lack of incentives for innovation, as 5-year spending cycles are seen as poorly suited for longer-term projects. Smart metering was belatedly rolled out in 2015, focussing on the Thames valley and South East England.

International cooperation for hardware and software interoperability is needed to encourage the international deployment of smart water technologies. This will become a growing concern as various smart water applications start to be integrated (ITU, 2010). To date, the initiative for smart water standards at the national level to be seen is the Open IoT Standards set of guidelines developed by the Government of Singapore (Freedman & Dietz, 2017). International standards are being developed by the ISO (ISO 22158 for water meter electronic interfaces, ISO 24591-1 for smart water management, ISO 27000 series for data security, ISO 37120 for smart cities, and the ISO 55000 series for asset management) along with the ISO 19100 series for geographical information systems.

Cybercrime against water utilities is instigated by disgruntled former employees and increasingly organized crime and state-sponsored terror groups (Hassanzadeh et al., 2020). Typically, spear-phishing is used, whereby an unsuspecting person working within the utility's network inadvertently opens a corrupt link or file. The cost of replacing infected computers and software usually far outweighs the random demanded (Germano, 2019). Without suitable staff training and systems management, smart water potentially makes a utility more vulnerable to cybercrime due to the greater number of linkages between the utility's operations and its external monitoring systems. A concern with the Internet of Things approach is that a large number of cheap devices with poor password protection may provide new opportunities for cybercrime.

12 | DISCUSSION AND CONCLUSIONS

Population growth, urbanization, and the need to meet the United Nations' Sustainable Development Goal 6 (universal access to safe water, and broad access to safe sanitation by 2030) before 2050 are placing serious demands on water services in terms of water availability of funding needs. Smart water is a powerful tool in demand management at both the utility and household levels through appreciating the linkages between customers, utilities, and the water cycle. Demand management is a central element in easing water use and optimizing the effective deployment of funds.

By comprehensively monitoring and managing water at the river basin level in real-time, resource pollution can be lowered along with an improved awareness of current and potential flood and drought threats. The effective integration of various smart systems across the water cycle is the chief challenge. It offers the potential to optimize the incremental advantages every single approach offers into a more coherent overall approach. The greater complexity and the data generated by such an integrated approach will bring their own challenges, especially in terms of security and managing the data to best reflect actual needs rather than delivering externally assumed information outcomes.

Smart water remains an emergent approach. The pace of deployment of new approaches has, at most, slightly eased over the past 5 years, with the emphasis now on their deployment and integration. There is also a shift in innovation from water distribution towards wastewater and sewerage. Smart meters and systems are being adopted one utility at a time, with national or even regional policy frameworks very much remaining the exception. As a result, one of the chief obstacles to smart water adoption is the willingness of utilities to consider them and the willingness of their staff to operate them (Oberascher et al., 2022).

Water metering remains the public face of smart water. It has performed better than expected in terms of informing utilities about customer behavior and household leakage. Thin turn has helped utilities get a better idea about what their customers actually want and how their behavior can be beneficially modified.

Given the benefits offered by various smart water systems, a broad demand for its rapid adoption would be expected. The author estimates global capital spending on municipal water and wastewater was $610 billion in 2021. Global spending on smart water systems was estimated to be $14 billion in 2021 (Marketsandmarkets, 2021), or 2% of that total. While it is a growing market—the same firm estimated its market size to be $7 billion in 2015 (Marketsandmarkets, 2016)—its adoption still remains the exception amongst most utilities.

Why is this so? The Gartner Hype Cycle (Gartner, 2018) is a useful way to consider the recent development and deployment of smart water. When a new technology is announced, this creates an "innovation trigger" as initial interest is generated, leading to a "peak of inflated