

Smart rainwater management systems powered by the internet of things: a UK case study

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ABSTRACT

Climate change is projected to significantly alter existing rainfall patterns. Traditional water and wastewater assets are unlikely to be able to respond to such events, particularly when factoring in increasing population growth. Novel source control and non-potable use strategies are required to limit the impacts of extreme events on water resources.

A novel, smart Rainwater Management System (RMS) was developed by Over the Air Analytics Ltd. building on research conducted at University of Exeter. The technology sees the commercial application of emerging Internet of Things (IoT) protocols and communication platforms to manage rainwater at source to mitigate flooding and provide alternative water resources in urban settings. With new technologies in data gathering, communications, power management, and associated software, IoT systems can enable real-time management of water sector assets. In addition, the reducing cost of such technologies is enabling their deployment in a widening set of technical niches. In this paper, results from a trial with the Future Cities Catapult (London) are presented including high resolution data acquisition and analysis of an innovative smart RMS. Over a 4-month trial period, at a residential property, the smart RMS successfully attenuated the rainfall from several storm events, whilst enabling rainwater reuse for non-potable applications (i.e. WC flushing). Despite some gaps in the data, due to power and connectivity disruptions, the system showed a high degree of reliability, with little downtime. The study concludes that the use of IoT in RMS shows potential to increase the flexibility and resilience of water and wastewater assets by adapting to the challenges of climate changes in an affordable, reliable and scalable system.

Keywords: Internet of Things, Smart rainwater harvesting, Smart rainwater management systems.

1 INTRODUCTION

Water management in the UK could see a wide range of “previously impossible”, innovative solutions enter the marketplace in the coming decade as environmental pressures, legislation and flexible Internet of Things (IoT) enabled devices are harnessed at a plot scale [1]. This paper seeks to; 1) briefly define key drivers and opportunities in this sphere and 2) interrogates data collected from a smart Rainwater Management System (RMS) installed in London.

Design guidance for UK drainage systems suggests climate change could see rainfall intensities increase by up to 40% over the 21st century [2]. This is expected to result in an increase in the frequency and severity of flooding and pollution from combined sewer discharges. 2007’s floods served as a reminder of economic losses associated with flooding with the Environment Agency reporting that two-thirds of the damage was caused by surface water flooding [3]. In terms of water availability, dramatically drier summers are predicted, [4], whilst the UK population is expected to increase by 20% in the next 20 years, [4], with greatest growth predicted in drier areas of the UK. Ofwat’s Water 2020 report encourages more efficient use of scarce resources and supports an increased focus on resilient services which are “able to anticipate...and recover from shocks now and in the future” [4]. Butler et al, [5], suggests adaptation and mitigation strategies have a role to play in increasing the resilience of our urban infrastructure to shocks such as drought and flooding. Novel source control strategies are needed as part of a toolkit of options to manage our water infrastructure systems over the 21st century.

Current solutions for managing water and stormwater resources usually involve centralised, hard infrastructure (which focus on either potable water OR stormwater management), i.e. increasing reservoir capacity and installing sustainable drainage systems (SuDS). These solutions can be costly (i.e. capital, operational and environmental costs) as they have a high land take and carbon footprint. The proven ability of rainwater harvesting (RWH) to reduce domestic and commercial properties’ potable water use has seen a growth of RWH in developed nations’ water infrastructure [6]. Supporting this, recent research has exemplified that, subject to appropriate design, the benefits of RWH can extend beyond the reduction in potable water use. RMS build on traditional RWH as they seek to achieve stormwater management as well as reducing potable water demands [7]. These configurations provide a dual-purpose solution: providing drought mitigation through increased water efficiency; whilst controlling stormwater discharges, to limit surface water flooding, combined sewer overflows and the economic, social and environmental impacts associated with intense rainfall events in urban areas. Policy documents firmly promote rainwater reuse as the preferred drainage method for new developments [8]. In addition, experts have called for increased monitoring and documentation of ‘practical evidence’ to improve the implementation, effectiveness and understanding of SuDS [9]. However, despite policy-level support for the inclusion of rainwater reuse as part of the SuDS design train, they represent a niche marketplace [10].

Typically, SuDS are implemented without monitoring systems, making it difficult to assess true system performance [9]. Historically the lack of data collection has been associated with the high cost of SCADA (Supervisory Control and Data Acquisition) systems. SCADA is a software package, based on a real-time database, interfaced to hardware via Programmable Logic Controllers (PLCs), or other commercial hardware modules [11]. At centralised assets this technology has been widely used to track and control asset performance for several decades. However, the need to (i) train end-users, (ii) access a network with sufficient capacity and security to safely store data, and (iii) foot the costs of implementation, are potential shortcomings to the system [12]. Smart, real-time control

systems for rainwater management have yet to be deployed throughout the water management infrastructure and consequently the application of IoT in the water sector represents a highly disruptive innovation. The market is nascent, but its potential is enormous. Accenture predict that IoT technology could increase GDP by £350 billion by 2030 [12]. Furthermore, Gartner predict there will 20.8 billion connected things by 2020, a conservative estimate based on 30% annual growth [1]. The development of digitally connected IoT technology poses an opportunity for big data to be included in the future design and operation of RMS [13]. Building on the need for RMS to; 1) provide demonstrable water savings; 2) achieve stormwater control criteria and; 3) for IoT to be integrated and demonstrated as a viable low-cost alternative to SCADA, a pilot installation of a smart RMS was completed in conjunction with the Future Cities Catapult.

2 INVESTIGATING SYSTEM PERFORMANCE

2.1 Pilot design and set-up

OTA Analytics installed a household-scale RMS, in Clapham (London) in February 2017, in conjunction with the Future Cities Catapult. The RMS was designed such that the homeowner could flush their WC with rainwater from an 800 L above ground tank. The system included a mains top-up, filling the tank when below a set level of 100 cm (i.e. equivalent to 490 L in the tank) (Figure 1). At the request of the homeowner, the top up was installed to ensure approximately 400 litres of mains water was stored above the pump inlet at all times. The installation included a pressure activated submersible pump which was directly connected to the downstairs WC. The control system was programmed to enable access to a range of rainwater reuse philosophies e.g. daily automatic irrigation; automatic stormwater release prior to storms; or maximising rainwater storage for summer months. The system was configured to enable the users to maximise rainwater reuse in the summer, whilst reducing to a lower storage level during winter months.

Data collection and RTC were achieved through installation of OTA’s active control hardware and a communications module. The project initially planned to access the LoRaWAN network associated with the Digital Catapult’s “Things Connected” team. However, challenges (associated with the basement location of the system) prevented connectivity via this communication platform. Therefore, a WiFi/3G platform was installed to enable connectivity. The site was monitored and controlled via OTA’s cloud-based SYMiotIC dashboard for 117 days.

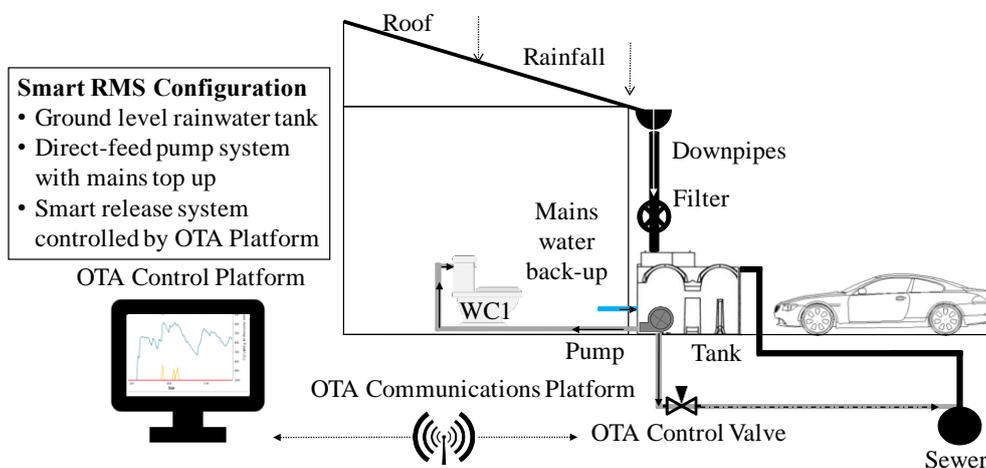


Figure 1 Diagram of pilot design and set-up

2.2 Application and need for RTC in RMS

Unlike traditional offline data logging technologies (which are limited in terms of the frequency of data collection), the SYMBiotIC platform was configured to capture and interrogate data at 1 minute time intervals. The platform was launched, building on intellectual property derived from the University of Exeter’s Centre for Water Systems, and on a five-year collaboration with one of the UK’s leading water company’s innovation department. The SYMBiotIC platform enables real-time monitoring and control of RMS and is built to offer five key modules:

- **Acquire:** The system can capture and store large volumes of data at the edge. When the system is linked to the cloud server, the edge hardware encrypts and uploads data in real-time, at up to 1 minute intervals.
- **Assimilate:** The platform cleans incoming data using proprietary algorithms to display data in bespoke outputs (tables / charts etc) on a customer dashboard.
- **Interpret:** Data is visualised and shared with key stakeholders in real-time via the dashboard or notification, via email, of events (e.g. alarms).
- **Analysis:** Bespoke analyses can be set-up to automate reporting against customer KPIs.
- **Act:** The SYMBiotIC decision support engine can be configured to act on behalf of a customer to achieve a customer objective, e.g. drain RMS tanks prior to a storm.

3 DATA ACQUISITION AND RELIABILITY

Data was collected at one minute intervals for 117 days between 18th February and 14th June 2017 (Figure 2). After two weeks’ operation of the pilot system, there was an eight-day gap in data collection (Figure 2). After this, the system operated for >3 months with seven consequent gaps in the data, each of which lasted between 1-14 hours. This is equivalent of 105.5 days of data collection at 1 minute intervals, where the system acquired more than 150,000 data points. The depth of data acquired may increase demand profiling intelligence, and further analytical processes can be executed to meet user needs associated with this opportunity.

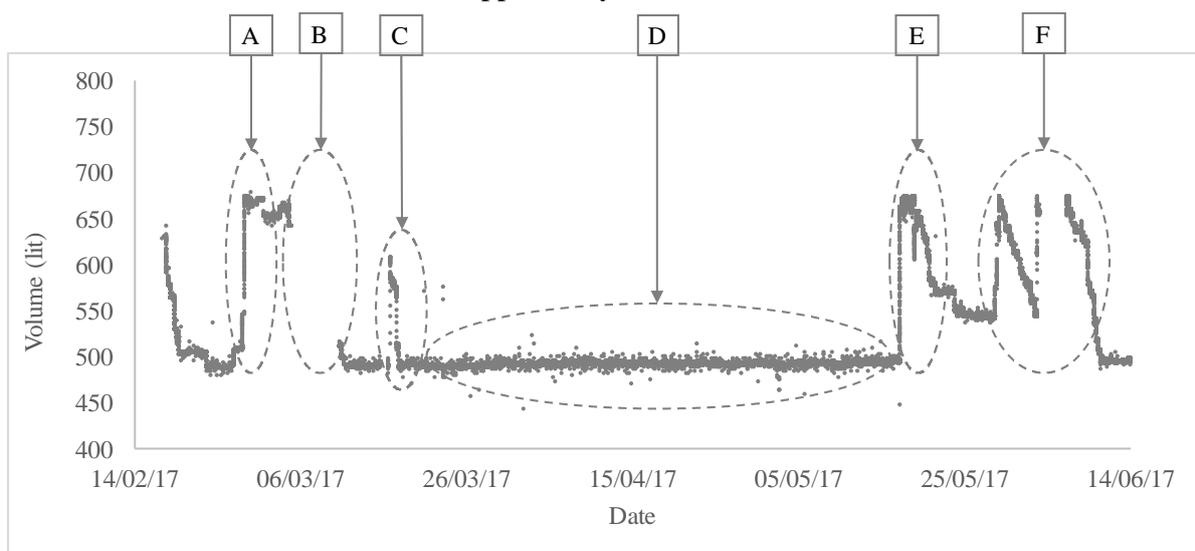


Figure 2 Water level in RMS over 117-day operational period, showing A) storm capture, B) data gap C) smaller storm capture and non-potable water use, D) average tank level with mains top-up operations during dry period, E) storm capture and non-potable water use and F) storm captures

3.1 System reliability

In this pilot, Data were collected for >90% of the operational period, and the system's hardware downtime accounted for only 3% of the total period. For a system designed solely as a 'monitoring' tool, relatively short gaps might not pose a high failure risk. In such cases, various mathematical and data analysis methods can be used to address the data gap issue. Where systems are designed for RTC system downtime can result in significant potential risks. Therefore, measures should be undertaken to ensure maximum uptime of the system components. This is particularly true for communication methods.

There are two main system components that might result in system downtime and/or a gap in the data (i.e. when system is operational but data is not recorded): a power cut and/or internet downtime (for WiFi-enabled systems). Likelihood and frequency of power cuts varies across electricity distribution companies. Typically, in the UK, there are between 40 to 80 customer interruptions per 100 customers per year, resulting in 40 to 80 customer minutes lost per year [14]. Internet downtime impacts most UK firms (internet users), with estimated failure accounting for 43 hours of downtime per user, annually [15]. A US study estimated downtime of 87 hours per annum, for companies targeting uptime of 99% and downtime of 8.76 hours for those targeting uptime of 99.9% [16].

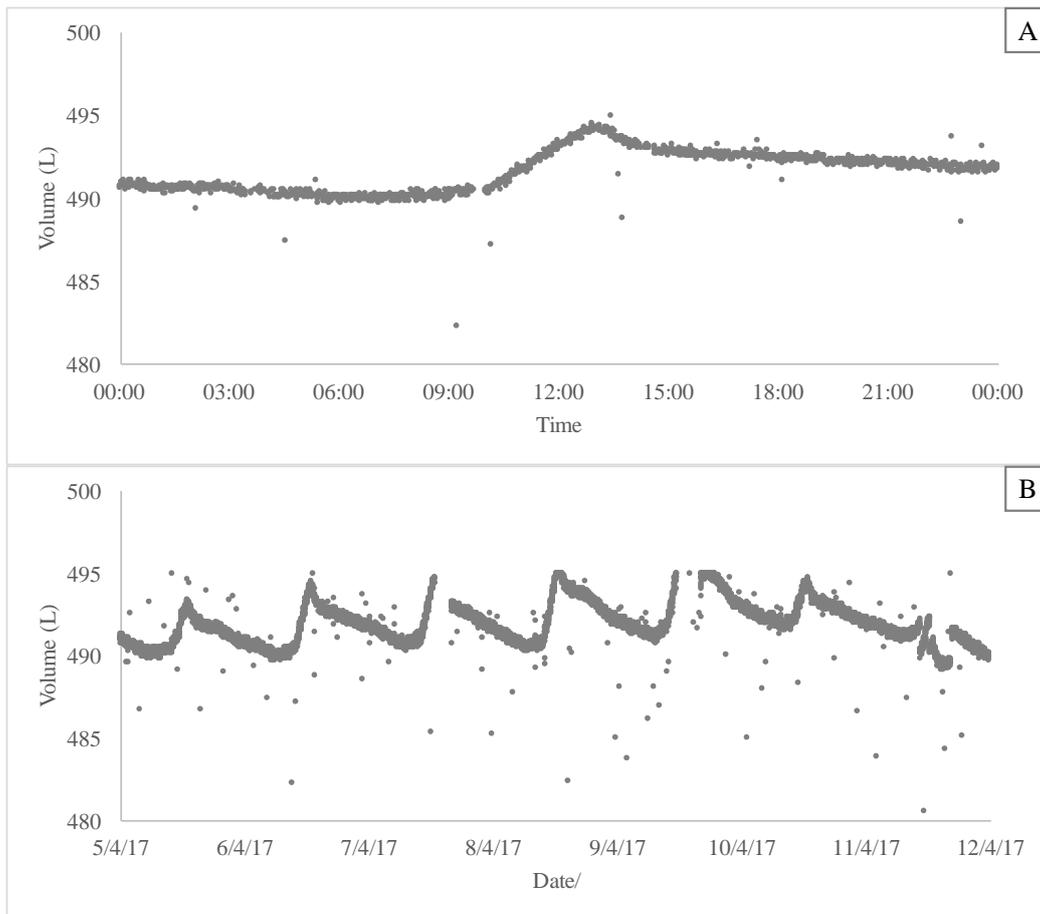
A conservative estimate of combined power and internet downtime (88.2 hours) was determined to estimate likelihood of missing a notification during winter months. There is a higher probability of a storm during winter, and adverse weather is more likely to cause disruptions to infrastructure and increase the risk of downtime. If an assumption is made that all downtime (88.2 hours) occurs in winter, there is a 4% probability of missing a 1-year return storm event due to downtime (based on a 90-day winter period, or 2160 hours). For a system with target uptime of 99.9%, the probability is below 0.5%. This is a 'worst-case scenario', with low risk of all downtime occurring during 3 months of the year.

3.2 Data adequacy for demand profiling

During the operational period, a total of 24,189 L of water was discharge from the tank (Figure 3). System data suggests that 12,549 L may have been released through control valves, and 11,639 L may have been used for non-potable use. If each of the two residents in the household had an average consumption of 150 L water/ day (in line with the UK per capita average [17]), the data implies that rainwater reuse for non-potable use may have accounted for up to 37% of their demand.

During the pilot (105.5 days of available data), two residents would be expected to use between 3,545 and 7,976 L of water to flush their WC, assuming each resident flushed the WC 4.5-6 times/ day [17] using 4-6 L of water/ flush [18]. This is below the estimate calculated from tank levels (11,639 L), which may be due to the gaps in the data, inaccuracies in flush volume, or "non-average" flushing patterns by the participants.

A water meter was considered in the design and installed in the system to measure the water use from the tank. Data from this meter is not presented here (to calculate water demand), as there was no agreement in place to access the metered data before the end of the pilot study. However, if accessible, this data could verify the systems' estimates on the volumes used for non-potable use and released through control valves.



*Figure 3 Non-potable water use, based on RMS tank volume over
A) 24 hours (6th April 2017) and B) 7 days in April 2017*

4 STORMWATER MAANGEMENT

Stormwater capture was observed on six occasions (Figure 2A, C, E, F). This value was calculated from the number of times the tank level exceeded the mains top-up level of 100 cm (equivalent to 490 L of water in the tank). During each storm capture event, the RMS's tank volume increased, over several hours. Meanwhile some rainwater was used for WC flushing while the excess water was released in a controlled manner (e.g. Figure 4). During the operational period, the total increase in water volume in the tank was 24,055 L (from mains top-up and rain capture). Data from on-site water meters have not been included in this analysis, but will be accessed later to validate the data inferred from the OTA control system.

The OTA system is designed to maintain the tank level and automatically operate the release valves prior to a storm, based on the individual system design. However, a manual system over-rule might be required, in order to operate the system. In order to test these, OTA carried out preliminary tests on the operation of the RMS valve, during which they intentionally, manually released rainwater from the tank, on three separate occasions. Following this, automated valve operations were implemented using OTA's control algorithm. This automation triggered the release of controlled flows from the rainwater tank on seven occasions, through the opening of the control valve to release excess water. In total, these tests led to the release of 836 L of water.

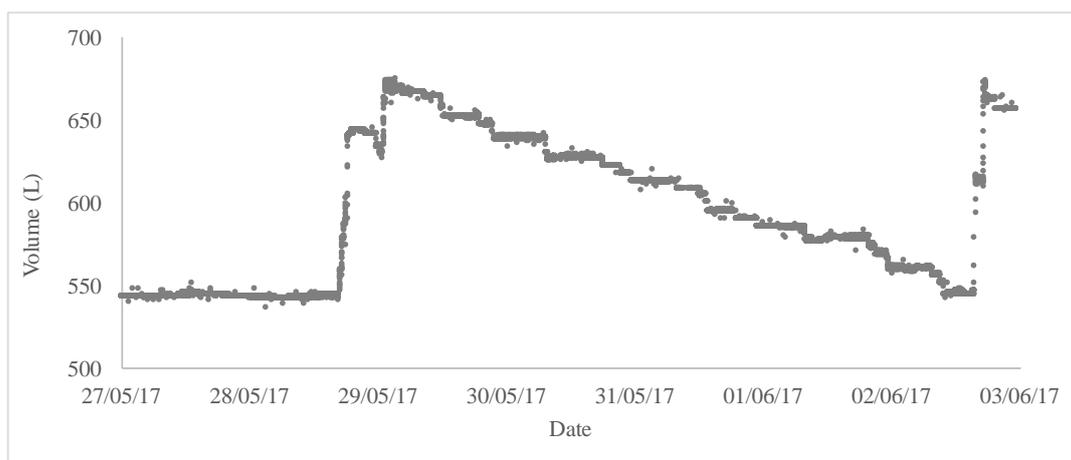


Figure 4 A storm capture event depicted by associated rise and fall in tank volume

Towards the end of the trial, there were several storm events in quick succession (Figure 2F). To capture and store the rainfall from three storms in a fortnight, the tank level was actively managed to ensure it emptied, through controlled release or non-potable use, prior to the next storm event.

5 CONCLUSIONS AND FUTURE WORKS

The work presented in this paper demonstrates the high resolution of data that can be acquired from a smart RMS. By substantially increasing the data collection frequency, the system demonstrated an ability to capture micro component data such as toilet flush events. This increased resolution improves the ability to accurately profile water demand, although cost-effectiveness of such high-resolution data might vary depending on a projects' goals. We have demonstrated that, over a period of four months, our systems continuously monitored non-potable water use, attenuated stormwater and released it in a controlled manner from the RMS with a high degree of reliability and little downtime. Downtime and data gaps need to be managed, potentially through pooling intelligence across a group of smart installations. Such groups of installations could form a network, in which there is a failsafe or fall-back option for RTC if one system in the network enters a period of downtime. This would help to achieve a more robust level of service, reducing the possibility of missing an event notification, such as a rainfall or storm event which would otherwise have been captured or managed. Validation from local water meters, could be used to further support the data collected by the system on non-potable water use. The use of IoT in this RMS provides an affordable, reliable and scalable system for the decentralised management of water resources, providing resilience and flexibility in the face of a changing climate.

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