The evolution of urban water metering and conservation in Australia

Richard Koech¹, Yeboah Gyasi-Agyei² and Terry Randall³

¹School of Health, Medical and Applied Sciences, Central Queensland University Australia, Bundaberg Campus, University Drive, Bundaberg QLD 4670, Australia.

²School of Engineering and technology, Central Queensland University Australia, Bruce Highway, Rockhampton, QLD 4702, Australia.

³Port Macquarie-Hastings Council, Port Macquarie, NSW 2444, Australia.

Abstract

Water metering has traditionally been seen as a means of measuring the amount of water consumed primarily for billing purposes. However, with the recent entry into the market of smart water meters, metering is now increasingly considered as an integral aspect of integrated water management. The purpose of this paper was to undertake a review of urban water metering in Australia, and to understand the nexus between water metering and water conservation. The review has demonstrated that metering has contributed to water conservation. The use of smart meters, and their integration with other household appliances, is on the increase.

Keywords

measurement, water meter, policy, regulation, conservation

Introduction

With the increase of population in urban areas, the demand for water has followed forth. The changing lifestyles and eating habits has added into the increased demand for water, which has further been exacerbated by the adverse effects of climate change, and the need to allow more water for environmental purposes. In many cities, it is no longer feasible to rely on increasing the supply of water so as to meet the increasing demand. In order to address the challenges brought about by these changes, the water sector has undergone a number of policy and institutional reforms over the past decades. A brief history of the water institutional reforms in Australia from the pre-European settlement era (1788) to 2004 is described in McKay (2005).

The reforms mentioned above include those agreed upon by the Council of Australian Governments (COAG) in 1994, which aimed at achieving efficient use of water through strategies such as pricing for full cost recovery, delinking water access rights from land ownership, water trading and setting aside water for the environment (Neal, 1994). The water reforms that were initiated in 1995 following the 1994 COAG agreement appear to be the most notable based on their impacts (McKay 2005), and heralded the requirement for metering water consumption nationally. In particular, the reforms were intended to introduce universal measurement of water consumption, and hence, to ensure equity in water usage charges, and better demand management and leakage detection (National Measurement Institute [NMI], 2010). This approach is in tandem with the adage that goes: “You cannot manage what you cannot measure.”

Metering of water is not only crucial for equity purposes, but also has fairness and legal implications, as inaccurate metering may lead to some users being randomly advantaged or disadvantaged (Water Use Efficiency, 2009). A water meter that under-reads (or has a negative error), implies that cumulatively, it will record less volume of water than actually supplied, and hence a direct loss to the supplier. On the other hand, a water meter with a positive error means a financial loss to the client. As

will be discussed later in the paper, the water reforms put into place mechanisms to ensure that water meters in use for trading purposes have an acceptable range of accuracy.

Subsequent to these key reforms in the water industry, there have been a number of significant governance and regulatory changes effected relating to water metering in urban areas. Perhaps the most important change was the development of the *National Framework for Urban Water Metering* which provides guidelines for metering of water in urban areas (NMI, 2010). The framework was developed by the NMI in collaboration with the Australian urban water industry including the Water Services Association of Australia (WSAA). To operationalise the framework, the key documentations that have been developed include: Metering Codes of Practice which provide guidelines such as meter selection, installation and verification; Pattern Approval Standards, Australian Standards and Australian Technical Specifications which contain requirements such as pattern approval verification methods and customer complaints.

The purpose of this paper is to conduct a review of urban water metering, with the aim of highlighting the critical role of water meters in water conservation. This will be conducted by analysing the major developments in urban water metering in Australia in the last three decades, with an emphasis on changes in technologies, evolution of purpose of water metering, water conservation and governance, and regulatory issues related to water metering. The role played by water metering in other water management options such as water restrictions and bans practised in urban areas with severe water shortages is also discussed. To the best of our knowledge, no such review has been undertaken, and thus this review is expected to be useful to a broad range of audience including policy makers, water utilities, and researchers. It is anticipated that this review, although focussed on Australia, will provide some important lessons relevant to other countries in the region and beyond.

Overview of water meters

Water meters intended for metering of water in full-flowing conduits may be broadly categorised as mechanical, magnetic, and ultrasonic flow meters. Mechanical meters are widely used for metering cold water for domestic purposes in urban areas.

Water meters come in different types, sizes and brands, with either a mechanical or electronic metering system. While most residential properties in urban areas utilise 20 mm diameter (commonly expressed as DN20) water meters, for commercial properties the sizes may range from DN20 – 150 (Sydney Water, 2016). Typically, water meters have to be physically read by a meter reader at a set time interval, a process that is labour-intensive. For most domestic residences in Australia, meter reading is undertaken on a quarterly basis. While this may be adequate for billing purposes, it provides limited information on actual water use behaviour, leakage and seasonal variation (Aravinthan et al., 2012). The water meters described above are also referred to as conventional water meters because of their widespread use over a long period of time.

Effective management of water resources requires accurate, timely and reliable measurement and monitoring of water consumption practices (Willis et al., 2010). Hence, in more recent times, a developing technology known as Smart Water Metering (SWM) is now being used in many countries including Australia. A smart water meter is a standard or conventional water meter, and fundamentally performs the same function as the standard/conventional water meter. However, to make it ‘smart’, the meter is attached to a device that allows higher frequency meter reading, storage, display and transfer of water consumption data in near real time (Figure 1). In this paper, the combination of the standard water meter and the above device is referred to as ‘smart water metering (SWM) technology’.

Figure 1: Residential water meter fitted with a smart water meter radio transmitter in Port Macquarie (photo by Terry Randall).

SWM technology allows water authorities to gain water meter readings remotely and at a higher frequency, and in a format that can be utilised for various purposes including demand management, leakage detection, and water conservation (Pericili and Jenkins, 2015). In particular, the ability to collect, analyse and relay water use data to the water user almost in real-time has the potential to cause significant changes in water use behaviour patterns (Aravinthan et. al., 2012).

Water utilities thus can use the detailed smart water meter data to explore patterns in water use of different categories of customers (Laspidou et al., 2015), and be able to forecast consumption (Walker et al., 2015), which is very critical for planning purposes. The meter data can also be used for leakage detection, and thus facilitate quick action to avert significant water losses, and the associated environmental, health and sustainability issues. A major disadvantage of conventional water meters, which has been addressed by the smart water meters, is that meter reading occurs well after water usage, making it impossible to respond to situational events such as leakages.

The performance of a water meter, just like many other metrological instruments, degrades over time because of a variety of reasons, including mode of installation, water quality, flow rate, meter design, and weather. The effects of these problems on the water meter in most cases worsen with the age of the meter or volume of water passed through the meter. The useful life of the DN20 water meters commonly used for domestic purposes in Australia is about 15 years, or when the accumulated volume is about 3500 m³ (WSAA, 2012a), after which the accuracy of measurement generally declines.

Legal, institutional and regulatory issues in water metering

Measurement, especially for trade purposes, is a sensitive matter of national significance because of its likely ramifications when transgressions occur. Therefore, in many countries around the world, including Australia, the ultimate responsibility of this undertaking is vested upon the government of

the day. However, an effective measurement system requires collaborative efforts of key stakeholders, both at the national and international levels.

The key stakeholders involved in water metering in Australia and their interactions are shown in Figure 2. These stakeholders and their interrelationships have evolved over time, and their roles in water metering are discussed below.

Figure 2: Key organisations involved in water metering in Australia

National Measurement Institute (NMI)

The legal issues pertaining to utility meters used for trade (gas, electricity and water meters) are laid out in the National Measurement Act 1960, National Measurement regulations 1999 and National Trade Measurement Regulations 2009. The NMI, currently a division within the Australian Government's Department of Industry, Innovation and Science, is responsible for administering the Act and the Regulations. The NMI is, therefore, legally responsible for Australia's measurement system. There are also state laws applicable to water metering, for example the Water Management Act 2000 No 92 in the state of New South Wales.

In particular, the NMI is responsible for the verification and pattern approval of water meters, including the production of relevant documents and appointment of the testing laboratories to undertake the tasks, discussed further below. It also collaborates with national institutions such as WSAA, National Association of Testing Authorities, Australia (NATA) and Standards Australia in developing standards related to water meters. The NMI represents Australia in the International Organisation of Legal Metrology (OIML), an inter-governmental organisation formed to facilitate the standardisation of measurement in various jurisdictions so as to increase international trade.

Water utilities

In the metropolitan cities of Australia, water supply including metering is largely the responsibility of state-owned water corporations. On the other hand, this function is mainly undertaken by local councils in urban centres/towns within regional areas. Therefore, these corporations/councils are responsible for water meter installations, maintenance, compliance testing and reading for billing purposes (compliance testing of water meters will be discussed later in this paper). The majority of water meter testing is undertaken in independent testing laboratories accredited to NATA. The major water utilities in Australia are shown in Figure 3.

Figure 3: Water utilities in major cities in Australia

Most of the major urban water utilities are members of the WSAA, an industry organisation that represents over 70 public and private water agencies that provide water and sewerage services to over 20 million customers in Australia and New Zealand (WSAA, 2016). The contribution of the WSAA to the water industry and specifically water metering in urban areas include: development of codes of practice in collaboration with other organisations, and facilitation of research and sharing of information.

Testing laboratories

Water meter testing laboratories are independent entities and they play a pivotal role in ensuring the integrity of water measurement in urban areas. Their facilities offer a range of water metering services including calibration, in-service compliance testing, verification and pattern approval. The testing is

undertaken in accordance with NMI regulations and relevant national (mostly developed by Standards Australia) and international standards.

Calibration basically involves the comparison of a water meter performance against a reference or standard meter. In-service compliance testing is undertaken on utility meters to ensure their continued accuracy with time. This is particularly important because the accuracy of water meters in service may be affected by factors such as age, usage patterns and water quality (Arregui et al., 2005). In the case of mechanical meters commonly used for metering water in urban areas, the degradation in the performance is predominantly caused by wear and tear of the moving parts within the meter. Over time, water can pass through the meter without being recorded, causing the meter to under-read. Additionally, worn internal components can allow unmetered water flow at low velocities, thus impacting on the minimum flow measurement ability of the water meter.

Once the error of measurement of a meter has been determined in a testing laboratory through calibration, it may be possible to improve its accuracy through adjustment of its settings. On the other hand, meters that are found to have totally broken down would normally be removed from service by the water utilities.

National Association of Testing Authorities, Australia (NATA)

NATA is a non-profit organisation with broad membership that includes all the major industries, State and Federal government agencies, and professional bodies. NATA's main contribution to water metering is in the assessment and accreditation of laboratories that are involved in testing of water meters. It is a requirement that the testing laboratories appointed by NMI undertake pattern approval and verification of water meters to be accredited to NATA.

NATA accredits water meter testing laboratories as per the international standard ISO/IEC 17025 (ISO 2005), which gives an assurance that the laboratories meet the general requirements for testing and calibration. The laboratories use this standard as a guide to improve their overall management system with particular emphasis on quality, administrative and technical operations.

Among other requirements, facilities accredited to NATA are mandated to participate in inter-comparison exercises or proficiency testing in order to maintain their accreditation or when seeking to expand the scope of their accreditation. This basically involves the comparison of test results of the same water meter obtained from different testing facilities. This procedure enables testing facilities to benchmark their performance against their peers, verify their methods and testing procedures, and most importantly, identify opportunities for further improvement in their testing (Koech et al (2015a, b)).

Hence, the involvement of NATA in water meter testing helps to maintain independent quality assurance in the testing processes and, thus, provide a peace of mind to customers. With international accreditation through NATA, products including water meters tested locally at accredited facilities are easier to market internationally.

Standards Australia

Standards Australia is similar to NATA as it is also a non-government and non-profit organisation. The main purpose of Standards Australia is to facilitate any interested party in the development of both national and internationally-aligned standards used in all sectors of the economy including the sampling and testing of water meters. To discharge this mandate, Standards Australia collaborates with organisations such as NMI and independent testing laboratories. The Australian Standard [AS]

3565.4 (2007) used by the urban water utilities as a guide to in-service compliance testing is one example of such standards.

The use of these standards by water utilities and water meter testing facilities provides consistency in the processes used, and contributes to the improvement of the quality of service to consumers. This also helps the states and the Commonwealth Government in the development of laws and regulations at various levels.

Pattern approval, verification and compliance testing of water meters

In the recent years, a series of measures have been implemented in Australia to provide quality control on matters related to water meters used for billing purposes in urban areas in order to protect both consumers and water utilities. As per the national Measurement Act 1960 and the *National Framework for Urban Water Metering*, it is a legal requirement that water meters installed for trading purposes must be of an approved pattern and performance verified by an independent body. Water meters exempted from this rule, if any at any one time, are specified in the NMI website.

The pattern approval process does not seek to only ascertain the measurement accuracy of the water meter, but also their performance under a range of environmental and operating conditions as explained later. Testing must be undertaken for all new meters before use for utility purposes, whether manufactured locally or imported into Australia, in order to verify their performance. In addition, when a water meter has been repaired, it must be retested to verify that its performance is still within acceptable legal limits. State regulations also stipulate that in-service water meters be routinely tested to ensure their continued accuracy of measurement.

Water consumers may also, at any time, request the testing of their water meter if they have any concerns. The general process of a water meter from design to installation and use is summarised in Figure 4 and explained in more detail below.

Figure 4: Approval and performance management of utility water meters

Pattern approval

Pattern approval is defined by the NMI as “the process whereby an impartial body examines the patterns of an instrument (in this case a water meter) against a set of national or international specifications in order to determine whether the instrument is capable of retaining its calibration over a range of environmental and operation conditions.” The internationally recognised standard for pattern approval of water meters is OIML R 49 – 2 (2006), while the materials, construction, and other technical requirements are described in OIML R 49 – 1 (2006). These standards are developed by the International Organisation of Legal Metrology (OIML). In Australia, the modified versions of these standards are NMI R 49 – 2 (2009)/NMI M 10 - 2 (2011) and NMI R 49 -1 (2009)/NMI M 10 – 1 (2010) respectively.

Perhaps the most important test during pattern approval process is the intrinsic error of indication of the water meter, which is the deviation of the measurement indicated by the meter under test (EUT) from the actual reference value, and is commonly expressed as a percentage as:

$$\text{Error of indication (\%)} = \frac{V_i - V_a}{V_a} \times 100 \quad \dots \dots \dots \text{Eqn. 1}$$

where: V_i is the volume recorded by the EUT

V_a is the actual volume (as determined by a reference method)

As per the standard NMI M 10 – 1 (2010), water meters commonly used for metering water in urban areas shall not have errors exceeding $\pm 2.5\%$ between the minimum and maximum flow rate under rated operating conditions.

Verification

The performance of water meters of a pattern that has been approved for use as utility meters must be verified before use. This is undertaken by testing facilities appointed by NMI, while the recommended procedures are outlined by *National Instrument Test Procedures for Utility Meters* (NMI, 2013). The document, which was produced by NMI, also provides guidelines on the sampling methods used for the meters to be tested.

The water meter verification process involves testing to determine the error of indication, as described above in the case of pattern approval. The objective here is to ensure that, before the meter is released into the market for use, the associated measurement error is within the limits specified by NMI. The other fundamental objective of the verification process is to confirm that the meter is of a pattern approved by NMI to be used for trading purposes.

In-service compliance testing

Water consumers and water utilities alike have a vested interest in ensuring that their water meters are continuously measuring accurately over their service life, a process that is accomplished through the in-service compliance of water meters. The procedures used in the compliance testing of in-service water meters are detailed in a Code of Practice produced by WSAA (WSAA, 2012b) as well as the Australian standard AS 3565.4 (2007).

Basically, this exercise involves the determination of the error of measurement of a sample of water meters, similar to the pattern approval and verification processes described above. However, the flow rates used for testing are typical of what would be expected of the majority of consumers. For instance, in the case of DN20 water meters which are commonly used as utilities meters in urban areas, the test flow rates range from 300-2400 L/hr.

To illustrate the significance of in-service compliance water meter testing, typical results from previous work (Koech et al., 2015c) are shown in Figure 5. Two water meter models (A and B), each with a sample size of 30 meters, were tested. The results show clear deterioration in the performances of some meters, with one returning an error of indication of -100%, meaning it had stopped recording flow (Figure 5b). On the basis of this reading, the client would have been assumed (wrongly) not to

have consumed water, and hence a direct loss to the water utility. On average, Model A performed better than Model B.

Figure 5: Boxplot of error test results of two models of in-service water meters (adapted from: Koech et al., 2015c) [The bold horizontal line within the box represents the median (50th percentile); the bottom and top of the box are the lower (25% percentile) and upper (75% percentile) quartiles; the whiskers represent the maximum and minimum values, excluding outliers. The circles and stars represent the outliers and extreme outliers, respectively. The superscript/subscripts next to the circles/stars represent water meter numbers.]

The compliance testing is performed by laboratories accredited to NATA. As detailed in the reference documents cited above which contain the acceptance criteria, the results of the testing will determine whether the population of the water meters, from which the tested sample was taken from, will have their compliance extended or terminated.

Water utilities normally allow customers who have concerns about the accuracy of their water meters to request to have them tested. Normally, there is a charge attached to the service, however, when the meter is confirmed to be faulty, the customer is generally reimbursed.

Nexus between metering and water conservation

As a consequence of the 1994 COAG agreement, water metering was introduced nationally in 1995 to among other things align actual consumption with water charges and to contribute to water management efforts, for instance through leakage detection. Water metering is fundamental to both the supply and demand dimensions of water conservation, and it is thus envisioned that it would be important to water consumers and water utilities alike in their efforts to conserve water.

However, it is acknowledged that water meters are mere tools and cannot on their own conserve water. Therefore, it is ultimately up to the water utilities to analyse and use the information generated using water meters to enhance their water management strategies. On the other hand, the information may be used to bring about behavioural changes amongst consumers as to better manage water use at the household level. In severe circumstances, water restrictions, bans or quotas are effected. The nexus of water metering and water conservation is explained in more detail below.

Metering and leakage detection

Water loss due to leakage is a significant problem affecting water supply in urban areas, with some research in Australia showing that it accounts for up to 10% of water consumption (Britton et al. 2013). Loss of water due to leakage may occur along the water distribution lines, which are often buried underground, and also within the various facilities that consume water (e.g. residential homes and business facilities).

Leakage losses along water distribution lines, which range from small leaks to large water main breaks, may be caused by a variety of reasons including aging pipes (and fittings) and sudden increases in pressure. The difference between the water supplied and the water consumed, obtained using the water meter data, is a good indication of the amount of water lost due to leakage. There are also mathematical models and software that can be used for this purpose (e.g. Oren and Stroh, 2013; Buchberger and Nadimpalli, 2004).

Some studies have attempted to quantify the proportion of water lost due to leakage in urban areas in Australia. For instance, Doolan (2011), found that about 80% of properties in a Sydney suburb in Australia lost water through leakage at some point in time during an 18-month trial, which on average was responsible for about 3% of total water usage per customer.

Both conventional water meters and the smart water meters can be used to detect leakage losses. However, since data from conventional meters is typically obtained quarterly, they provide limited information on actual water use behaviour and seasonal variation (Aravinthan et al., 2012), and, hence, they are of little use in leakage detection. The SWM technology is thus very useful in leakage detection because of the high frequency data that can be obtained remotely.

Results from a case study conducted by Randall and Koech (2017) in the regional town of Port Macquarie located in the mid-north coast of New South Wales is used here to illustrate how smart water meters can be used for leakage detection to facilitate water conservation. The six months' study was undertaken within the central business district of Port Macquarie with 158 smart water meters installed in residential homes, business premises and public facilities. Hourly meter readings from all the 158 meters were obtained for the entire six-month study period.

For a typical water consumer under normal circumstances, it is generally expected that at some point within a 24-hour period the minimum flow rate recorded by the water meters would be zero, meaning no water flow through the meter (zero consumption). For a residential consumer, a zero-flow situation would be expected to occur when there is no person at home, people are asleep or when people/appliances are not using water. On the other hand, there are businesses which close at certain times and, hence, consumption would normally be expected to be zero. This normal water consumption is depicted in Figure 6, between 1/08/2015 and 1/10/2015.

Figure 6: Smart water meter consumption pattern consistent with leakage (Randall and Koech, 2017)

However, if there are leakage losses caused by leaking pipes, taps or appliances, the baseline (minimum) flow would never return to zero as shown in Figure 6 from date 1/10/2015 onwards. Actually, Figure 6 shows that the leakage progressively worsened during the study period. Exemptions where water consumption would not return to zero include commercial businesses that operate continuously (do not close), cooling towers for large air conditioning systems and a range of fixed flow appliances. In this case, the baseline flowrate will be elevated (non-zero), but uniform unlike the consumption pattern shown in Figure 6 between 1/11/2015 – 1/02/2016.

Out of the 158 meters in the Port Macquarie study, data from 21 of them revealed the presence of a leakage. The average hourly minimum flow rate (over a month) of each of the 21 meters was used to

determine the water loss. In total, the water loss due to leakage, and hence the potential water savings, was determined to be 1.56% of the total water consumption over the study period.

The discussion on water leakage so far has focused on how water metering can be used to identify water losses through leakages and, hence, determine the potential water savings, if remedial actions are taken (e.g. leakage repairs or replacement of old pipes). The following discussion goes beyond water leakage, and includes the use of water meter data to influence behavioural change among water consumers towards better water conservation practices.

Metering to influence consumer behaviour

There is an abundant evidence in the literature suggesting that when customers are provided with water consumption data (especially from smart water meters) and other forms of information and feedback, they are more likely to take steps that lead to water conservation (Table 1).

Table 1: Water meters and water conservation

Study description	Strategy	Water conservation benefit	Reference
A smart water meter study in two suburbs located in mid-coast of New South Wales	Provision of detailed and customised water-use information to household, made possible by use of SWM technology.	Changed consumer behaviours (e.g. shorter showers) leading to water savings of approximately 8%.	Liu et al. (2016)
Smart water meter studies undertaken in different locations by different researchers.	Providing consumption feedback to customers.	Reduction of water consumption between 3 and 53.4%, with an average of 19.6%.	Sonderlund et al. (2014)
Sydney Water's smart metering residential project	Use of digital in home display to provide customers with near real-time water consumption data.	Reduction in water consumption in households of between 7% and 10%.	Doolan (2011)
Smart water meter study in Hervey Bay, Queensland, to identify households with post-meter leakage.	Communications with the households, including fact sheets and details of potential losses.	Reduction in baseline flows of 89% .	Britton et al. (2013)
Mackay Regional Council and TasWater, Australia	Rapid leak detection and better customer engagement.	More than 10% reduction in residential water demand	Beal & Flynn (2014)

Matters dealing with influences of human behaviour towards conservation are complex, and a detailed discussion is beyond the scope of this paper. It suffices to say that behavioural changes amongst water users may be affected by personal factors such as education and views on environmental protection or

external factors such as economic considerations (Sauri, 2013). The key economic consideration here is the price attached to the water consumed, which is derived from water meter reading. There is a broad consensus that putting a price on water reduces demand, and hence, leads to water conservation (Worthington and Hoffman, 2008).

A household survey undertaken in ten Organisation for Economic Cooperation and Development (OECD) countries including Australia found that water pricing plays a key role in reducing water consumption, even though water expenditure account for approximately 1% of household income (Grafton et al., 2011). The survey also found that environmental concerns and use of water saving devices are important in enabling households to conserve water. The positive link between pro-environmental behaviour and water conservation was also confirmed by an Australia-wide study undertaken by Dolnicar et al. (2012).

Another Australia-wide survey on water conservation behaviours conducted by Dolnicar and Hurlimann (2010) found that Australians are generally willing to partake in water conservation efforts. However, the study concluded that barriers such as the perception of some measures being inconvenient and/or impractical, and the cost of purchasing water saving appliances, limit the adoption of concrete actions and behaviours to actualise water conservation.

In the studies cited above, water meters are at the centre of the water-saving strategies because of the crucial consumption information they provide. Hence, the majority of the literature reviewed for this paper demonstrated that there is a positive correlation between interventions reliant on water metering (e.g. provision of consumption feedback) and water conservation. However, other studies have found that the impact of some of these interventions may be short-lived, with consumers giving up on pursuing water conservation after some time. For instance, in a study conducted by Fielding et al. (2012) in South East Queensland, households that received interventions such as relevant information and customised feedback initially recorded water savings, but relapsed to the pre-intervention consumption level after about one year. This underscores the necessity, in certain circumstances, of non-monetary water regulations discussed below.

Water restrictions and bans

Barret (2004) opined that, to achieve water conservation in residential areas, water pricing should be combined with non-monetary water regulations such as water bans/restrictions and quotas. This is partly because, in Australian households the price of water is low relative to other basic requirements such as rent and food, and, hence, it would be imprudent to rely solely on it to achieve water conservation (Worthington and Hoffman, 2008).

Water restrictions and bans are prevalent in areas where, for a variety of reasons, it is difficult to increase water supply to meet the demand, often after exhausting the option of reducing the demand (by pricing water) to achieve water conservation. This may also happen during periods of extended drought, causing severe draw-down of water reservoirs. As an illustration, a typical example of a water restriction regime in a regional town in Australia is shown in Figure 7. In this example, the level of water restriction is dependent on the amount of water available in storage, and when the combined storage is less than 25%, emergency water restriction is declared which entails the banning of all external use of potable water (Port Macquarie-Hastings Council 2017).

Figure 7: Port Macquarie-Hastings Council water restrictions (Adapted from: Port Macquarie-Hastings Council 2017)

Irrigation activities within households is often the first to be targeted during water restriction regimes, as the practise contributes to more than half of all water consumed by households in most urban areas in Australia (Brennan et al. 2007).

Even in circumstances of water restrictions, bans or quotas, water metering has a role to play. For instance, water meter data can be used to monitor if consumers are adhering to the regulations.

Policy implications and the future of water metering

In the last three decades in Australia, the reforms that have occurred in the water sector at large, and urban water supply and metering in particular, have had many implications. There is an acknowledgment that water is a resource of national importance and transcends state boundaries (for example River Murray which is Australia's longest river). Therefore, the Commonwealth Government, the State and Territory governments, as well as the local councils work together to manage this important resource. The Commonwealth Government, through the NMI, is legally responsible for Australia's measurement system. The State and Territory governments have the bulk of legislative powers over water matters (McKay, 2005).

The reforms have also ensured that the government (Commonwealth, State/Territory, and local councils) collaborates with a wide range of stakeholders in the management of water resources and supply in urban areas. These stakeholders include non-profit and non-government organisations, private companies, professional organisations, and local communities. This cooperative governance system has been termed 'world-leading' by some experts (e.g. Carmody et al., 2017). The inclusion of other players is meant to guarantee that viewpoints from various sources are considered in decision making processes. Perhaps most importantly, urban water metering in Australia is now well regulated and standardised, which is beneficial to water consumers, water utilities and the environment.

The reforms have also created an enabling environment for research and development, and the adoption of new technology. For instance, a study commissioned by WSAA (Beal and Flynn, 2014) concluded that in Australia and New Zealand, the use of the SWM technology is expected to expand in the future. The key drivers of the technology were identified as customer-focussed benefits (e.g. feedback on consumption), better peak water demand management, and the reduction of manual reading, and, therefore, operating costs. Beal and Flynn (2015) estimated that at least 250,000 smart water meters had either been installed or planned for installation, while about two thirds of business surveyed reported projects underway or set to start within one year from the date of the survey.

Research into how to better harness the full potential provided by the SWM technology in urban water management is growing, and some of the proposals and trials, and their likely benefits or impacts are shown in Table 2.

Table 2: Proposals and trials to enhance the use of smart waters in water management

Proposal/trial	Benefits or impacts	Reference
Web-Based Knowledge Management System (WBKMS) to integrate smart metering, consumption data and communication networks.	To provide real-time and detailed water consumption data to the consumer and the water utility.	Stewart et al. (2010)
A trial using bottom-up end use levels of water demand to analyse water consumption disaggregated into specific uses (e.g. shower and dishwasher).	The approach can enhance infrastructure planning of urban water supply.	Gurung et al. (2014)
Water management system using an open-source application to create a robust and intelligent system.	The system will provide consumers with consumption data, alert them to abnormal usage and hence reduce waste.	Mudumbe and Abu-Mahfouz (2015)
Smart water grid with smart water meters installed at the source, water treatment facilities, distribution networks and in homes and businesses, and sewerage works. The system is also envisioned to have smart pumps, valves, irrigation controllers, sensors and other equipment.	The system is expected to reduce water losses and increase the efficiency of water use.	Mutcheck, M. And Williams, E. (2014).

The continuing development in information and communication technology (ICT) and the internet is, therefore, likely to expand the scope of the use of smart water meters in terms of the management of urban water resources. The integration of smart water meters with other appliances that are also 'smart' such as dishwashers could open new avenues for more water conservation.

Conclusions

Water metering is an integral aspect of integrated water management in urban areas. The purpose of this paper was to conduct a state-of-the-art review of water metering in Australia. In order to contextualise the present state of affairs of water metering, it was necessary to reflect upon the major

water reforms that were implemented in 1995 following the 1994 COAG agreement. Notable was the development of the *National Framework for Urban Water Metering* to guide water metering in urban areas in Australia.

As per the National Measurement Act 1960, the NMI is the legal custodian of all matters related to measurement on behalf of the Australian Government. In order to protect the integrity of measurement including using water meters, NMI works closely with non-government/non-profit organisations such as NATA and Standards Australia, industry organisations such WSAA, water utilities and independent meter testing facilities.

Overall, there has been an increase in the adoption of the SWM technology, and this trend is expected to continue into the future. The literature reviewed for this paper suggest that this technology has been used to achieve water conservation in urban areas mainly by detecting leakages and providing data and information to modify consumer behaviour. The future will likely see more integration of smart water meters with other household appliances such as dishwashers and washing machines. Water metering may still be useful in situations whereby water restrictions or bans have been implemented.

References

- Aravinthan, V., Ho, G., Gray, J., Butler, R., & Connell, D. (2012). *What are smart meters? [Fact sheet]*. Retrieved from: https://eprints.usq.edu.au/21068/1/Aravinthan_Ho_Gray_Butler_Connell_FactSheet_PV.pdf
- Arregui, F., Cabrera, E. J., Cobacho, R., & Garcia-Serra, J. (2005). *Key Factors Affecting Water Meter Accuracy*. IWA Specialised Conference “LEAKAGE 2005”. Halifax, Canada.
- AS 3565.4 (2007). *Meters for Cold and Heated Drinking Water Supplies, Part 4: In-Service Compliance Testing*. Standards Australia, Sydney.
- Barret, G. (2004). Water conservation: the role of price and regulation in residential water consumption. *Economic Papers*, 23 (3), 272-285.
- Beal, C. D., & Flynn, J. (2014). *Review of Smart Metering and Intelligent Water Networks in Australia and New Zealand*. Report prepared for WSAA by the Smart Water Research Centre, Griffith University, Brisbane, Australia.
- Brennan, D., Tapsuwan, S. & Ingram, G. (2007). The welfare costs of urban outdoor water restrictions. *The Australian Journal of Agricultural and Resource Economics*, 51, 243–261.
- Britton, T. C., Stewart, R. A., & O’Halloran, K. R. (2013). Smart metering: enabler for rapid and effective post meter leakage identification and water loss management. *Journal of Cleaner Production*, 54, 166-176.
- Buchberger, S. G., & Nadimpalli, G. (2004). Leak Estimation in Water Distribution Systems by Statistical Analysis of Flow Readings. *Journal of Water Resources Planning and Management*, 130 (4), 321-329.
- Carmody, E., Cosens, B., Gardner, L., Gray, J., Holley, C., Lindsay, B. et al. (2017). National Water Reform – Public Inquiry, Submission 6. Retrieved from: https://www.pc.gov.au/__data/assets/pdf_file/0006/216258/sub006-water-reform.pdf
- Dolnicar, S., & Hurlimann, A. (2010). Australians' Water Conservation Behaviours and Attitudes. *Australian Journal of Water Resources*, 14 (1), 43-53.
- Dolnicar, S., Hurlimann, A. & Grun, B. (2012). Water conservation behaviour in Australia. *Journal of Environmental Management*, 105, 44-52.

- Doolan, C. (2011). Sydney Water's Smart Metering Residential Project: An insight into the benefits, costs and challenges of smart metering. *Water*, 38, 77–80.
- Fielding, K., Spinks, A., Russel, S., Mcrea, R., Stewart, R., & Gardener, J. (2013). An experimental test of voluntary strategies to promote urban water demand management. *Journal of Environmental Management*, 114, 343-351.
- Grafton, R. Q., Ward, M. B., To, H. & Kompas, T. (2011). Determinants of residential water consumption: Evidence and analysis from a 10-country household survey. *Water Resources Research*, 47, W08537, 1-14. doi:10.1029/2010WR009685.
- Gurung, T. R., Stewart, R. A., Beal, C. D., & Sharma, A. K. (2014). Smart meter enabled water end-use demand data: platform for the enhanced infrastructure planning of contemporary urban water supply networks. *Journal of Cleaner Production*, 87, 642-654.
- ISO (2005). *General requirements for the competence of testing and calibration laboratories*. ISO/IEC 17025, Geneva.
- Koech, R. K. (2015c) Water Density and their effect on gravimetric water meter calibration and measurement uncertainties. *Flow Measurement and Instrumentation*, 45, 188-197.
- Koech, R.K, Camargo, A., Molle, B., Saretta, E., Frizzone, J., Benhu, G., & Pezzaniti, D. (2015a) Intercomparison dripper testing within the INITL. *Flow Measurement and Instrumentation*, 46, 1-11.
- Koech, R. K, Camargo, A., Molle, B., Saretta, E., Frizzone, J., Benhu, G. & Pezzaniti, D. (2015b) Intercomparison testing and evaluation of sprinklers within the INITL. *Journal of Irrigation and Drainage Engineering*, 142 (2), 04015048 - 1-8.
- Laspidou, C., Papageorgiou, E., Kokkinos, K., Sahu, S., Gupta, A., & Tassioulas, L. (2015). Exploring Patterns in Water Consumption by Clustering. *Procedia Engineering*, 119, 1439-1446.
- Liu, A., Giurco, D., Mukheibir, P. (2016). Urban water conservation through customised water and end-use information. *Journal of Cleaner Production*, 112, 3164-3175.
- McKay, J. M. (2005). Water Institutional Reforms in Australia. *Water Policy*, 7 (2), 35-52.
- Mudumbe, M. J. & Abu-Mahfouz, A. M. (2015, July). *Smart Water Meter System for User-Centric Consumption Measurement*. Paper presented at the 2015 IEEE 13th International Conference on Industrial Informatics (INDIN), Cambridge, UK.
- Mutcheck, M. & Williams, E. (2014). Moving Towards Sustainable and Resilient Smart Water Grids. *Challenges*, 5(1), 123-137.
- National Measurement Act 1960. Retrieved from:
<https://www.legislation.gov.au/Details/C2016C00085/Download>
- National Measurement Institute (2010). *National Framework for Urban Water Metering, Version 1.00, 27th May 2010*. Commonwealth of Australia, Sydney.
- National Measurement Regulations 1999. Retrieved from:
<https://www.legislation.gov.au/Details/F2015C00296/Download>
- National Trade Measurement Regulations 2009. Retrieved from:
<https://www.legislation.gov.au/Details/F2009L03479>
- Neal, E. (1994). *Report of the Working Group on Water Resource Policy to the Council of Australian Governments*. COAG Working Group on Water Resource Policy.

- NMI M 10 -1 (2010). *Meters Intended for the Metering of Water in Full Flowing Pipes. Part 1: Metrological and Technical Requirements*. National Measurement Institute [NMI], Commonwealth of Australia, Sydney.
- NMI M 10 -2 (2011). *Meters Intended for the Metering of Water in Full Flowing Pipes. Part 2: Test Methods*. National Measurement Institute, Commonwealth of Australia, Sydney.
- NMI (2013). *National Instrument Test Procedures for Utility Meters, NITP 14*. National Measurement Institute [NMI], Commonwealth of Australia, Sydney.
- NMI R 49 - 2 (2009). *Water Meters Intended for the Metering of Cold Potable Water and Hot Water Part 2: Test Methods*. National Measurement Institute, Commonwealth of Australia, Sydney.
- NMI R 49 -1 (2009). *Water Meters Intended for the Metering of Cold Potable Water and Hot Water. Part 2: Metrological and technical requirements*. National Measurement Institute [NMI], Commonwealth of Australia, Sydney.
- NMI R 49 -1 (2009). *Water Meters Intended for the Metering of Cold Potable Water and Hot Water Part 1: Metrological and Technical Requirements*. National Measurement Institute [NMI], Commonwealth of Australia, Sydney.
- NMI R 49-1 (2009). *Water Meters Intended for the Metering of Cold Potable Water and Hot Water. Part 2: Metrological and Technical Requirements*. National Measurement Institute [NMI], Commonwealth of Australia, Sydney.
- OIML R 49-1 (2006). *Water Meters Intended for the Metering of Cold Potable Water and Hot Water. Part 1: Metrological and Technical Requirements*. International Organisation of Legal Metrology (OIML), Paris.
- OIML R 49-2 (2006). *Water Meters Intended for the Metering of cold Potable Water and Hot Water. Part 2: Test Methods*. International Organisation of Legal Metrology (OIML), Paris.
- Oren, G., & Stroh, N. (2013). Mathematical Model for Detection of Leakage in Domestic Water Supply Systems by Reading Consumption from an Analogue Water Meter. *International Journal of Environmental Science and Development*, 4 (4), 386-389.
- Pericili, A. & Jenkins, J. (2015). *A Review of Current Knowledge: Smart meters and domestic water usage*. Foundation for Water Research, Marlow, Bucks SL7 1FD, U.K.
- Port Macquarie-Hastings Council (2017). *Water Supply Policy 2015, Amended 20 July 2016*. Retrieved from: <http://www.pmhc.nsw.gov.au/Services/Water/Water-restrictions-and-trigger-levels>
- Randall, T. and Koech, R. (2017). *Smart water metering technology for water conservation in urban areas*. Unpublished manuscript.
- Sauri, D. (2013). Water Conservation: Theory and Evidence in Urban Areas of the Developed World. *Annual Review of Environment and Resources*, 38, 227-248.
- Sonderlund, A. L., Smith, J. R., Hutton, C., & Kapelan, Z. (2014). Using Smart Meters for Household Water Consumption Feedback: Knowns and Unknowns. *Procedia Engineering*, 89, 990-997.
- Stewart, R. A, Willis, R., Giurco, D., Panuwatwanich, K. & Capati, G. (2010). Web-based knowledge management system: linking smart metering to the future of urban water planning. *Australian Planner*, 47, 2, 66-74.

- Sydney Water (2016). *Water meter installation guide*. Retrieved from: http://www.sydneywater.com.au/web/groups/publicwebcontent/documents/document/zgrf/mdq3/~edisp/dd_047502.pdf
- Walker, D., Creaco, E., Vamvakieridou-Lyroudia, L., Farmani, R., Kapelan, Z., & Savić, D. (2015). Forecasting Domestic Water Consumption from Smart Meter Readings Using Statistical Methods and Artificial Neural Networks. *Procedia Engineering*, 119, 1419-1428.
- Water Efficiency Division 2009. National Framework for Non-urban Water Metering: Final 686 Regulatory Impact Assessment. Australian Government, Department of Environment, Water, Heritage and the Arts, Canberra.
- Water Management Act 2000 No 92. Retrieved from: <http://www.legislation.nsw.gov.au/inforce/b686ac2a-0b9d-c94d-82a6-c2edfb2fafd9/2000-92.pdf>
- Willis, R., Stewart, R.A., Panuwatwanich, K., Jones, S., & Kyriakides, A. (2010). Alarming visual display monitors affecting shower end use water and energy conservation in Australian residential households. *Resources Conservation and Recycling*, 54, 1117–1127.
- Worthington, A. & Hoffman, M. (2008). An empirical survey of residential water demand modelling. *Journal of Economic Surveys*, 22 (5), 842-871.
- WSAA (2012a). *Meter Selection and Installation Code of Practice, WSA 12 -2012, First Edition, Version 1.1*. Water Services Association of Australia Limited, Sydney, Australia.
- WSAA (2012b). *Compliance testing of In-Service Water Meters Code of Practice, WSA 11-2012, First Edition, Version 1.1*. Water Services of Australia Limited, Sydney.
- WSAA (2016). *Annual report 2015-2016*. Retrieved from: https://www.wsaa.asn.au/sites/default/files/publication/download/WSAA_Annual%20Report%202015-2016_Final.pdf

Highlights

- Reforms instuted in Australia in the past three decades have improved water management in urban areas through metering.
- Water is a resource of naonal importance, and hence its management is a collaborave eort involving the government (Federal, State/territory, local), non-government/prot organisaons, private sector, professional organisaons and local communiies.
- The review undertaken has shown that the use of smart water meters is on the increase.
- The benet of water metering has evolved over me, and is now seen as a means of achieving water conservaon.