Chapter 5
Water Losses

Water loss is defined as the difference between water pumped into the system and billed water (AIIB 2020; ADB 2010). The volume of water lost depends largely on the quality, maintenance, and approach to active leakage control of the water distribution network (EU ERDF n.d.). The volume of water lost before reaching water users is referred to as non-revenue water (NRW).

High NRW rates result from the loss of large quantities of water through leakages in water distribution networks. The losses comprise real losses (actual water losses in water distribution network) and commercial or apparent losses[1] (water consumption that is not billed to end-users) (Alegre et al. 2016; EU ERDF n.d.). NRW may result from poor management, lack of support from water service providers, untimely replacement of devices, inappropriate selection of pipes, or water theft. Physical factors, such as the distribution network or density of piped connections, and environmental factors, such as soil conditions, also elevate NRW rates (Jones et al. 2021; Lambert et al. 2014; Tabesh et al. 2018).

NRW management can reap several benefits for water service providers, such as greater reliability of supply, lower operational and maintenance costs, and preventing revenue loss (Al-Washali et al. 2019). In some cases, strong NRW management can also delay the development of new water distribution networks, due to the improved productivity of existing infrastructures (Liemberger and Wyatt 2019). As such, studies indicate that reducing global NRW rates by one-third can amount to savings that equate to serving 800 million people[2] and an annual global financial saving of USD 13 billion (Liemberger and Wyatt 2019).

In 2019, it was estimated that the global annual volume of NRW was 126 billion m^3, at the cost of USD 39 billion per year (Liemberger and Wyatt 2019). Although the global average NRW rate is 35%, this water loss can represent up to 60% of

[1] Refer to Sects. 5.7, 5.8, 5.9, and 5.10 of this guidebook for additional information on apparent losses.

[2] Assuming a consumption of 150 L/capita/day (Liemberger and Wyatt 2019).

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the water supplied in various low-income nations (Nasara et al. 2021). These hefty numbers underline the importance of effective NRW management.

NRW management for reducing water losses may be achieved in multiple ways, namely

1. Leak detection and pipe replacement: It can be achieved through a combination of active leakage monitoring, control and speedy repairs, targeted pipe replacements, and pipeline rehabilitation measures (Water Services Association 2019; Li et al. 2016). Appropriate leakage management can help recover revenue from water losses and, in some cases, mitigate the need for water source expansion (Bello-Dambatta et al. 2013; EPA 2016).
2. Technology usage for leak detection and repairs: Modern leak detection technologies include both hardware and software-based tools (Li et al. 2015). Such devices can quickly identify problem areas and leakages in the distribution network, better evaluate their impacts on water loss volumes, and improve the ability of service providers to respond rapidly and repair leaks (Elliott and Bartram 2011; Cassidy et al. 2021).
3. District Metered Areas (DMAs): A division of the water distribution network into smaller sections or zones with defined boundaries. It is a systematic approach to operational management that allows water service providers to analyse water-flow[3] profiles, identify potential problem areas with greater ease, and, thus, reduce leakage detection time (Al-Washalli et al. 2019; ADB 2010; Eliades and Polycarpou 2012).
4. Pressure management: Monitoring, regulating, and maintaining adequate pressure in water distribution systems. It contributes to leakage reductions, decreased new burst frequencies, and reduced water use (Vicente et al. 2016).

5.1 Leak Detection and Pipe Replacement

Leakages may be classified as 'background' leaks (small undetected flows), 'unreported' leaks (moderate-flow rates which gradually accumulate), and 'reported' leaks (heavy detectable leaks that require immediate repair) (Eliades and Polycarpou 2012). Common causes of leakages include ageing pipelines, poor condition of distribution network, and damage to exposed/improperly sealed pipelines (Elliott and Bartram 2011). Estimates suggest that leaks and physical pipe breakages lead to the loss of over 32 billion m^3 of treated water every year globally (Jones et al. 2021). Thus, as a large percentage of water supply is lost when distributed, reducing leakages at this stage is essential (EPA 2016). Appropriate leakage management can help recover revenue from water losses and in some cases mitigate the need for water source expansion (Bello-Dambatta et al. 2013; EPA 2016).

Leakage detection and pipe replacement can be achieved through a combination of active leakage monitoring, control and speedy repairs, targeted pipe replacements,

[3] Data of water entering and exiting the DMA.

and pipeline rehabilitations (Water Services Association 2019; Li et al. 2016). Active leakage detection involves identifying existing leakages on a regular basis through both acoustic[4] and non-acoustic[5] leakage tools (Charalambous et al. 2014). Following leakage identification, decisions about repair, replacement, or rehabilitation of the pipeline can be undertaken. These decisions may be influenced by factors such as pipeline conditions, performance, and deterioration rates (Charalambous et al. 2014). Once the target level of leakage has been achieved, regular checks on leakage control can help ensure that leakage levels do not increase over time (Wu and Liu 2017). When network leakages have been identified and repaired, service providers can also better gauge the extent of illegal connections and other forms of water thefts (ADB 2010).

Leak detection and pipe replacement programmes are in wide use across the ASEAN region. For instance, in Thailand, the Metropolitan Waterworks Authority (MWA)[6] has focused on repairs and improvements to the security of its waterworks systems (MWA 2020). It has reduced water losses by replacing damaged pipes and installing new pipes where required, which has resulted in a water loss reduction of 1.92% (between 2017 and 2018), with a water loss rate of 29.83% in 2018 (MWA 2018).

On identifying potential leakages, targeted pipe replacement programmes may be a more cost-effective solution than the extensive large-scale replacement of pipes. However, large-scale replacements can be adopted if piped networks are in poor operational conditions, or if leak repair and targeted pipe replacements do not reduce leakages (Charalambous et al. 2014; Wu and Liu 2017).

In Phnom Penh, Cambodia, Phnom Penh Water Supply Authority (PPWSA)[7] has actively implemented and maintained a large-scale pipe replacement programme since 1993. By 1999, a majority of the older 288 km pipeline network had been replaced. The entire rehabilitation process was completed by 2002 with all of the replacement work performed by the PPWSA staff (PPWSA n.d.-a). Further, a leak repair team was on standby on a 24/7 basis to repair any leakage in the water distribution network. This ensured that repair work could begin within an hour of receiving information about the leak (PPWSA n.d.-c). Such measures[8] helped reduce water leakages and NRW rates, from 72% in 1993 to only 9.78% in 2020. Despite an expansion of the pipeline distribution network from 2009 to 2011, NRW rates were maintained below 6% at all times (Biswas et al. 2021). Estimates suggest that the steep decline in NRW rates between 1993 and 2013 amounted to savings of USD

[4] E.g. mechanical listening sticks and ground microphones (ADB 2010).

[5] E.g. ground-penetrating radar technology, infrared photography, and gas injections.

[6] Agency responsible for the production, transmission, and distribution of water in Bangkok, Samut Prakan, and Nonthaburi.

[7] PPWSA is a state-owned utility, operating under commercial law, and is responsible for supplying drinking water to Phnom Penh.

[8] In combination with other WDM measures such as metering, programmes to identify illegal connections and suspension of supply for non-payment (Biswas et al. 2021).

150 million, due in part to the deferral of investments for water supply expansion (Water Global Practice n.d.).

5.2 Technology Usage for Leak Detection and Repairs

Leak detection and associated monitoring technologies have become increasingly sophisticated over time. Real-time monitoring[9] tools can identify potential problem areas and leakages in the distribution network, better evaluate their impact on water loss volumes, and improve the ability of service providers to respond rapidly and repair leaks (Elliott and Bartram 2011; Cassidy et al. 2021). Such technology can also imbue greater efficiency in ongoing leak detection operations (Al-Washalli et al. 2019) and help provide an estimate of the gradual accumulation of 'background' leaks not visible on the surface, comprising 90% of water lost through leakages (ADB 2010). Such background leaks can remain unidentified for months or years. For example, a minor leak of 4 L/min can result in the water loss of over 2 million litres/year (Elliott and Bartram 2011).

Modern leak detection technologies include both hardware- and software-based tools (Li et al. 2015). Hardware tools include acoustic detection devices (e.g. mechanical listening sticks, ground microphones, and leak noise correlators[10]) (ADB 2010; Elliott and Bartram 2011) and non-acoustic devices (e.g. ground-penetrating radar technology, infrared photography, and gas injections). Given the expensive nature of the equipment and the number of people needed to operate the tools, these methods are often costly. On the other hand, software-based tools such as water monitoring applications through sensors and smart meters[11] are more economical to implement. Such devices offer real-time monitoring and statistical analysis of water flows (on an hourly or daily basis) and thus estimate the volume of real water loss (Li et al. 2015; Loureiro et al. 2016; Wu and Liu 2017). The data derived from these processes can also help assess pipeline conditions to better plan and schedule pipe replacements and rehabilitation programmes (PUB 2020).

Modern technology usage for leak detection and repair has been widely adopted across ASEAN cities, such as in Singapore, Jakarta (Indonesia), Phnom Penh (Cambodia), Metro Manila (the Philippines), Johor (Malaysia), Bangkok, Samut Prakan, and Nonthaburi (Thailand), Vientiane (Laos), and Ho Chi Minh City (Vietnam). In Singapore, PUB, National Water Agency of Singapore, conducts regular inspections and leak detection surveys using advanced software-based technologies to reduce the leakages (CLC 2012). It utilises an Intelligent Water Management System (IWMS) for real-time monitoring of water assets across the network,

[9] Delivery of continuously updated information.

[10] Computerised equipment used to identify the exact leakage points in the distribution network (ADB 2010).

[11] Refer to Sect. 5.7 of this guidebook for further information on water meters (traditional and smart water meters).

thus providing a comprehensive overview of operations for timely action (PUB 2014). As of 2020, PUB has installed 346 water sensor stations across the city-state to monitor and track the water pressure of the distribution network. This has eliminated the need for installing temporary pressure loggers and pre-empted issues such as potential pipe bursts and leakages that influence pressure volatility (PUB 2020).

Similarly, in Jakarta, Indonesia's capital city, water service providers PALYJA and Aetra have installed both hardware and software-based leakage detection systems to provide early-warning alerts for leakages. For instance, AQUADVANCED—a sensory technology—has been used by PALYJA, and the leak noise correlator (underground pipe leakage detector), by Aetra. The AQUADVANCED technology also includes a 'live' hydraulic model of PALYJA's water distribution network to compare the modelled and actual conditions, thus improving water-flow monitoring and supporting decision-making (PALYJA 2016). Since its implementation in 2016, the 450 sensors using AQUADVANCED technology have detected 10–20 anomalies in the water distribution system daily (PALYJA 2016).

5.3 Leakage Detection—District Metered Areas (DMAs)

District Metered Areas (DMAs) are recognised as one of the most cost-effective methods to overcome water losses (Hou 2018; Bui et al. 2020). This involves a division of the water distribution network into smaller sections or zones with defined boundaries. Doing so allows the water service provider to analyse water-flow[12] profiles, identify potential problem areas with greater ease, and, thus, reduce leakage detection time (Al-Washalli et al. 2019; ADB 2010; Eliades and Polycarpou 2012).

Effective analysis of DMA water-flow data can reduce the duration of water loss significantly as zoning[13] contributes to a systematic approach to operational management (Bui et al. 2020; Kayaga and Smout 2011). Studies demonstrate that the introduction of DMAs can contribute to a leakage reduction benefit range of 26.6% to 59.7% on average, where leakage reduction improves with an increase in the number of DMAs (Ferrari and Savic 2015). The smaller the zonal distribution, the greater the availability of information and efficiency of leak detection. The division of the water distribution network into smaller sections can also protect the rest of the network from potential contamination events (accidental or malicious) (Bui et al. 2020). Moreover, as a by-product, DMA creation entails easier identification of illegal connections when leakages are repaired[14] (ADB 2010).

Although developed and developing countries alike have adopted DMA creation as a best practice for leakage monitoring, there is no universally acknowledged

[12] Data of water entering and exiting the DMA.

[13] Division of the water distribution network into smaller sections.

[14] If water-flow data indicates significant water loss (and unaccounted water) after leakage repair, it can indicate the presence of illegal connections (ADB 2010).

prototype for optimal zoning. Rather, countries often rely on their own local expertise and context (e.g. hydraulic, economic, topographic, and other practical factors) (ADB 2010; Di Nardo et al. 2013; Kayaga and Smout 2011). The water distribution network size has a bearing on the number of DMAs established, with one DMA for every 1000–5000 connections (World Bank 2016). However, where water networks are older, DMAs of approximately 500 service connections have been found to be reasonable (ADB 2010).

Due to its essential role in NRW management, DMA creation has been widely adopted in many ASEAN cities, for instance, in Jakarta and Bogor municipality (Indonesia), Metro Manila (the Philippines), Johor (Malaysia), Vientiane (Laos PDR), Ho Chi Minh City (Vietnam), and Singapore.

Although DMA creation is under the purview of water service providers in ASEAN, in Indonesia, BPPSPAM[15] (PUPR Ministry's Water Service System Improvement Body) has developed a guidebook for DMA creation, which applies to areas with high water loss comprising 500–3000 water connections (BTAMS I n.d.). In Jakarta, the water service providers PALYJA and Aetra have introduced DMAs to improve leakage detection (Aetra 2018; PALYJA 2016). As of 2014, PALYJA had established 95 DMAs and aims to build 52 more DMAs (PALYJA 2015). Similarly, Aetra established 174 DMAs by 2013 (Aetra 2018). As a result of DMA creation and leakage detection systems, 35,916 leakages were detected by PALYJA in 2016. This represented a 28% increase in leakage detection from 2015 (28,067 leakages) (PALYJA 2015, 2016). Meanwhile, Aetra increased leakage detection from 22,932 leaks in 2015 to 25,587 in 2016 (Aetra 2016).

In Johor, Malaysia Ranhill adopted a technology-driven approach and created SMART DMAs with semipermanent noise loggers (Ranhill Holdings 2019a). The implementation of SMART DMAs involved remote correlating noise loggers to detect leakages using GPRS transmission data on net night flow (NNF). The results from the initial installation (SMART DMA trial) of 295 noise loggers in Bandar Putra indicated a 35% reduction in NNF from 30.99 to 20.08 L/s after three months. This contributed to savings amounting to USD 4,000 per month for Ranhill SAJ (Primayer n.d.). By 2019, as many as 1128 DMAs had been created in Johor, with 43 DMAs created in 2019 alone, accounting for 95% of Ranhill's total connections (Ranhill Holdings 2019a).

5.4 Pressure Management

Pressure management is a key element of WDM that seeks to control and manage leakages by monitoring, regulating, and maintaining adequate pressure in water distribution systems. Pressure management can contribute to leakage reductions, decreased new burst frequencies, and reduced water use (Vicente et al. 2016). A reduced leakage rate can help further extend infrastructure life span and obviate

[15] Appointed to develop and implement national water service policies and strategies.

investment in new developments (Wu et al. 2011; Lambert et al. 2014). The volume of leakage has a linear relationship with the pressure system, such that decreasing pressure can reduce leakage (Bui et al. 2020). Estimates indicate that an average pressure reduction of 37% can reduce new pipe breakages by 53% on average (Thornton and Lambert n.d.).

In practice, pressure is regulated through measures of tank regulation, pump control, and pressure-reducing valve (PRV) installed in the water distribution network (Vicente et al. 2016). For greater pressure control over a smaller area, the PRVs are commonly installed at the DMA inlets[16] (Fontana et al. 2018). In addition to water demand, the pressure set by the PRV can depend on factors such as pipe elevation, topology, and building height (Fontana et al. 2018).

As a first step towards leakage management, it is recommended that pressures of the water distribution network be monitored and optimised to remove any excess pressure in the system (Charalambous et al. 2014). Pressure control is effective in preventing leaks by minimising pressure fluctuations and regulating pressures based on demand (Fontana et al. 2018). In particular, pressure monitoring is beneficial in situations of varying demand by providing high pressure during peak-demand periods and reduced pressure during low-demand periods. This contributes to constant and reliable water service to consumers and a reduction in leakage rates and pipe breaks (Elliott and Bartram 2011; Vicente et al. 2016).

As pressure management is commonly achieved through DMAs,[17] most ASEAN cities that have created DMAs also practise pressure management such as in Jakarta and Bogor municipality (Indonesia), Metro Manila (the Philippines), Johor (Malaysia), Vientiane (Laos PDR), Ho Chi Minh City (Vietnam), and Singapore.

5.5 Case Snippet (NRW Reduction): Metro Manila-Maynilad and Manila Water

Metro Manila has introduced and implemented effective WDM measures to reduce and prevent water losses since 2008 (Dimaano 2015). The responsibility for water and wastewater services within Metropolitan Manila lies with the Metropolitan Waterworks and Sewerage System (MWSS), which outsourced its management to two private concessionaires in 1997. Manila Water Company Inc. was awarded the concession for the east zone and Maynilad Water Services Inc. for the west zone. Maynilad Water Services is the Philippines' largest private water concessionaire by customer base and manages the water supply for the west zone, comprising 17 cities of the Metropolitan Manila area. Manila

[16] Entry points.

[17] Typically, pressure-reducing valves (PRVs) are installed on DMA entry points to regulate pressure.

Water is the exclusive water provider for the east zone of Metro Manila and the Rizal Province, consisting of 23 cities and municipalities.

Both concessionaires have reported progress in meeting NRW performance indicators, while expanding distribution lines and increasing the water connections (Abansi et al. 2018). The NRW reduction programme at Manila Water focuses on efforts such as leak detection, pipe replacement, and effective customer service complaint management. This programme has reportedly recovered nearly 750 million/litre/day (MLD). In 2019, the average NRW remained stable at a rate of 10.4%, indicating an improvement of 1% from 11.4% in 2018 (Manila Water 2020)

On the other hand, Maynilad has actively adopted several WDM strategies, including the NRW reduction programme. After privatisation in 2007, it established its non-revenue water reduction programme using a C + 3I strategy, e.g. 'Centralise', 'Isolate', 'Investigate', and 'Innovate'. The programme's key initiatives included the establishment of hydraulic systems and DMAs, leak repairs, selective pipe replacements, pressure management, hydraulic modelling and calibration, and DMA automation. The company assigned a central NRW team to spearhead the programme and partnered with Miya[18] to provide technical advice, training, and assistance

Within the first four years of initiation, approximately 472 MLD volume of water loss was recovered, and a total of 113 hydraulic zones,[19] 798 District Metered Areas, and 247 Pressure Management Areas (PMAs)[20] were established. The number of leak repairs leapt from 18,000 in 2009 to 40,000 in 2010 (Dimaano 2015)

In 2010, Maynilad also acquired the *Sahara*[21] leak detection equipment to detect and isolate leaks below ground level, which helped resolve 1000 leak incidents in an 830-km-long primary pipeline. In 2019, the company acquired a second set of leak detection equipment with an acoustic sensor inserted into a pipe, tethered to a monitoring system on the surface. This allowed the service provider's engineers to conduct audio and visual inspections inside pipes without interrupting water supply to customers (Maynilad 2020; The Manila Times 2021). The system also accurately detected structural defects and pockets of trapped gas within pipelines (Manila Standard 2021)

Since 2007, Maynilad has replaced approximately 2700 km of ageing, leaky pipe infrastructure that accounts for two-thirds of the water distribution network they manage (Maynilad 2020; The Manila Times 2021). Additionally, the utility managed to sustain its leak repair activities despite the enhanced community quarantine period due to COVID-19, repairing over 244 old and leaky pipes (Manila Standard 2021). As of April 2020, Maynilad has fixed 370,000 leaks since the launch of the NRW reduction programme (Maynilad 2020; The Manila Times 2021). These efforts have enabled the company to recover 979 MLD of water since 2008 (Maynilad 2020) and reduce its NRW rate from 67% in 2007 to 25% in 2019 (Fig. 5.1).

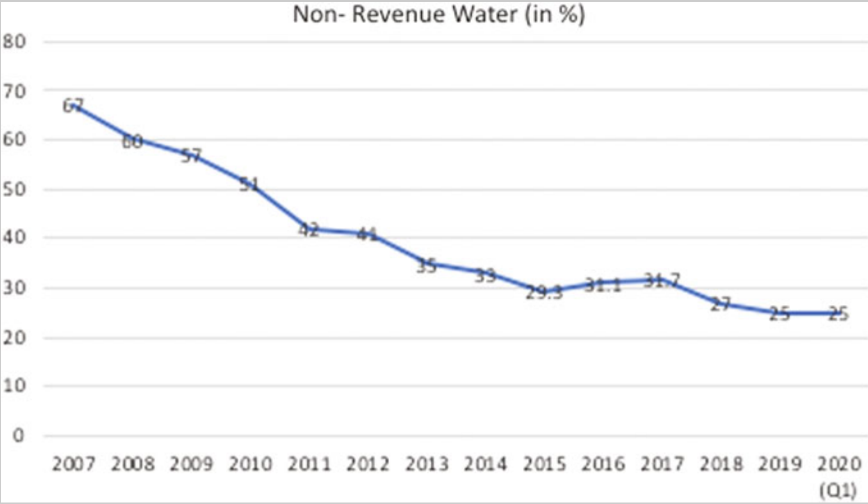

Fig. 5.1 Maynilad's NRW (2007–2020). *Source* Maynilad (2020)

5.6 Key Takeaways

1. The volume of water lost before reaching users is referred to as non-revenue water (NRW). Reducing global NRW rates by one-third can amount to savings which equate to serving 800 million people and annual global financial savings of USD 13 billion.
2. NRW management may be achieved through monitoring and accounting for water flow through leakage detection, pipe replacement, DMA creation, and pressure management.
3. Leakage detection can improve the condition of the distribution network by reducing the flow and frequency of additional leaks.
4. Modern leak detection technologies include hardware tools such as mechanical listening sticks, ground microphones, and leak noise correlators. They also include software-based tools such as ground-penetrating radar technology,

[18] A water operator that provides services to water utilities in commercial management, water treatment, and water efficiency schemes.

[19] Dedicated areas of water distribution network.

[20] DMAs with controlled pressure.

[21] Acoustic sensor inserted into pipe for monitoring (of Sahara brand name).

infrared photography, and gas injections. On average, a pressure reduction of 37% can more than halve the incidences of pipe breakages.
5. DMAs are integral to a systematic approach to operational management for water losses and reduce leakage by 26.6%–59.7% on average.
6. All ASEAN countries implement NRW management through a combination of measures (leak detection, pipe replacement, DMA creation, and pressure management). Several ASEAN countries have also adopted modern leak repair and detection technology, such as Singapore, Indonesia, Cambodia, the Philippines, Malaysia, Thailand, Laos, and Vietnam.

Commercial Losses

Commercial losses, also known as 'apparent losses' (Bao et al. 2013) or 'administration losses', are water losses that occur in the distribution system and which are not paid for by the water consumer (Jones et al. 2021; The World Bank 2016). Commercial losses are the result of customer meter under-registration, data handling and billing errors, unbilled authorised consumption[22] (Jones et al. 2021), and unauthorised use[23] (Al-Washali et al. 2020; AIIB 2020; Marsano and Jannah 2021). However, several different approaches can be taken to reduce commercial losses, including technical measures (e.g. water meter technologies) and non-technical measures (e.g. customer reporting and monetary instruments).

NRW management for reducing commercial losses may be achieved in two ways, namely

1. Water meters: Mechanical and/or smart water meters which monitor customer consumption patterns and reduce unmetered consumption (AWWA n.d.; Koech et al. 2018). Water meters can help reduce commercial losses by tracking the volume of water distributed from the storage locations to the distributor mains and supply service lines (EPA 2016; The World Bank 2016).
2. Customer reporting and monetary instruments: Commercial losses from water theft (e.g. illegal connections and meter tampering) can be reduced through a combination of customer reporting and monetary instruments (e.g. fines) (Jones et al. 2021; Marsano and Jannah 2021). Implementing a customer reporting programme encourages water users to have a greater awareness of their consumption and report illegal connections (ADB 2010).

[22] This refers to the legitimate consumption of water, which is neither unbilled nor metered. Legitimate consumption includes water usage for street cleaning, fire services, and the flushing of mains and sewers (Jones et al. 2021).

[23] Such as corruption or theft (ADB 2010; Jang 2018; Jang and Choi 2017; Nasara et al. 2021, Water Services Association 2019; Water Services Association 2019).

5.7 Water Meters

Water metering is deployed in many urban areas to address commercial losses and other systemic operational inefficiencies by managing water use and allocation more effectively (Tantoh 2021). Water meters can reduce commercial losses by measuring the amount of water that flows through pipes from the withdrawal area to the distribution and delivery points (ADB 2010; EPA 2016; The World Bank 2016).

The effectiveness of water meters in reducing commercial losses and water demand is recognised worldwide. Research suggests that water service providers can lower unmetered water consumption by between 15 and 30% if smart meters are installed in households, enabling water service providers to accurately bill customers for their water usage (AWE n.d.; Ornaghi and Tonin 2021).

The metering of water consumption may influence consumers' water demand and water-saving habits, with customers gaining a greater awareness of and a significant reduction in water usage (Reynaud et al. 2018; Tanverakul and Lee 2015). For instance, water savings from metering are estimated to be up to 25% of per capita consumption (Abu-Bakar et al. 2021). The reduction in water consumption can also lead to savings in customers' water bills (Harutyunyan 2015).

In general, water service providers charge their customers for water on a per-unit basis, with the price reflecting the quantity of water used. Water service providers should accurately meter all water in their systems and also all water distributed from their systems at the customer's point of service. The meters should be read frequently to support the water service provider's understanding of production quantity, rate structures, and provide data and accurate bills to customers (AWWA n.d.; China Water 2010).

Meters provide accurate data, necessary for customer billing, system performance studies, planning purposes, water system management, and the assessment of water conservation measures. An effective metering programme relies upon choosing and managing metering technology and collecting data that track customer consumption patterns. This includes determining the correct size and type of meter, the installation of meters and regularly evaluating their accuracy, as well as the repair and eventual replacement of all meters. These practices ensure optimum accuracy at a reasonable cost for both the water service provider and the customer (AWWA n.d.; Bello-Dambatta et al. 2013; Koech et al. 2018).

Many cities in ASEAN have installed water meters to reduce commercial losses and monitor water consumption. Water meters are used in Singapore, Jakarta (Indonesia), Zamboanga City Water District (the Philippines), Rayong, Chonburi, and Chachoengsao (Thailand), Vientiane (Laos), Yangon (Myanmar), and Brunei Darussalam. Water meters can also be found in Malaysia, Vietnam, and Cambodia.

For example, in Batam Municipality, Indonesia, water services are currently delivered by PT Adhya Tirta Batam (ATB), a private concessionaire.[24] ATB replaces

[24] As in Jakarta, ATB signed a 25-year concession with Batam Free Trade and Free Port Zone Management Body (BP Batam) through the Build, Operate, and Transfer (BOT) scheme. After

water meters every five years[25] with particular attention paid to meters that have already reached 1500–2000 m^3 of use (ATB 2017b). Replacing old meters ensures the continuity of accurate meter readings while also reducing the risk of commercial losses. Meters that were replaced yet found to be still in good condition were recalibrated, while defective meters were scrapped (ATB 2017b). Since 2009, ATB has established its own ISO/IEC 17025-certified laboratories to ensure the accuracy of its meters (ATB 2017c). ATB has improved efficiency within its operations due to this technology, with fewer staff needed to take manual water meter readings: the staff-to-customer ratio decreased from 7.47 in 1996 to 1.98 in 2019 (ATB 2017a).

Smart Meters

Smart water meters can also be installed to improve urban water demand management and planning and mitigate the limitations of traditional water meters. Smart water meters are devices that digitally measure water consumption and record information related to all aspects of the water cycle in real time. They also monitor when and how the water is used, sending that information to the water service provider. As the smart meters constantly generate and transmit data through solutions provided by Information and Communication Technologies (ICTs) such as wireless sensors, the meters do not need to be manually read by a human meter reader. Accordingly, smart meters engender greater efficiency in water management and facilitate better-informed decisions by providing real-time solutions to challenges faced by water service providers and consumers alike (Greater Western Water n.d.; Koop et al. 2021; Smart Nation n.d.).

Research shows that smart water meters can reduce the incidence of water leakage by 50% through monitoring, resulting in improved operational efficiency and a reduction in economic losses for the water service provider (Fetterman et al. 2020; Li et al. 2020; Marais et al. 2016; Pimenta and Chaves 2021).

Traditional or conventional water meters measure water flow and monitor water consumption to increase billing accuracy. They tend to be low cost and reliable and require little maintenance.[26] However, weather conditions and the age of the water network could affect the longevity of these meters (Fontanazza et al. 2012). Additional costs are incurred when installing and replacing old water meters with new water meters (Bello-Dambatta et al. 2013; Couvelis and van Zyl 2015). Furthermore, as traditional mechanical water meters offer neither real-time data nor automatic water consumption monitoring, water service providers may also employ staff to make periodic visits to water meter installation sites. Staff would be required to manually read the meters at a set time interval; water users are then billed based

completing the concession in November 2020, ATB transferred its water assets, operations, and maintenance services to BP Batam, which provides Batam's water supply.

[25] This practice is in accordance with Law Number 2 of 1981 concerning Legal Metrology and Government Regulation Number 2 of 1985. This concerns the obligation and exemption to be calibrated and/or recalibrated as well as the requirements for measuring and weighing instruments and their equipment (ATB 2017b).

[26] Although there is no agreed time limit to replace mechanical water meters, they tend to have a life of up to 17 years.

on their past consumption levels. While this process may be adequate for the water service provider's billing purposes, it provides limited data on seasonal patterns, leakages, and actual water consumption levels (Koech et al. 2018). In addition, this process may be expensive for water service providers, is labour intensive, is potentially time consuming, and can result in inaccurate water meter readings and bills (Marais et al. 2016; Mudumbe and Abu-Mahfouz 2015; Pimenta and Chaves 2021).

By contrast, the advantages of smart water metering are significant. Smart meters can

1. Increase consumer awareness: Smart water meters can increase consumer awareness of water consumption through near real-time consumption feedback and, thus, lead to a reduction in water consumption (Fetterman et al. 2020; Koech et al. 2018; Liu et al. 2017; Marais et al. 2016; Monks et al. 2019; Pimenta and Chaves 2021). Research suggests that smart meters can reduce water consumption by an average of 12.15% due to near real-time consumption feedback to the consumer (Sønderlund et al. 2016). For instance, a five-year study in Sydney that examined the use of smart water meters in households found that those with in-home display smart meters consumed, on average, 6.4% less water than those without (Davies et al. 2014).
2. Collect and transmit data in real time: As smart water meters show real-time data on water timing and usage patterns, this facilitates water service providers' efforts to accurately detect leaks (Bello-Dambatta et al. 2013; EPA 2016; Kayaga and Smout 2011). The collection of real-time data can better support water conservation policies by forecasting consumption based on the data, which can also help both water service providers and users save water (Beal and Flynn 2014, 2015; Morote and Hernández-Hernández 2018).

   In addition, the wireless sensor network and real-time data also enable water service providers to alert customers to leak more quickly, rather than relying on manual readings of customers' water meters. Water service providers can also use this data to provide customers with more timely information about their water consumption through various mediums which are low in cost (or free) for the water service provider and suit the customer on the go (e.g. text alerts, emails, websites, and mobile phone applications) (Geetha and Gouthami 2016; Liu et al. 2015; Perera et al. 2015). Studies suggest that smart meters and the use of an online portal (for customers to check water consumption) can reduce the duration of leaks, from an average of 29 days to 19 days, equating to a 34% reduction. They may also reduce the probability of recurrence of leaks by 50% (Fuentes and Mauricio 2020; Schultz et al. 2018).
3. Enable water service providers to monitor water flow and consumption: Smart water meters can form part of a bigger wireless sensor network which may have a central hub. A central hub allows water service providers to accurately monitor the flow of water and bill water users based on real data, rather than rely on estimates of water consumption (Beal and Flynn 2014, 2015; Fuentes and Mauricio 2020). Research shows that regularly updated information on the water consumption of users enables water service providers to identify system losses and pinpoint

pipe leaks more quickly and accurately than traditional meters (Joo et al. 2015; Li et al. 2020).

4. Identify meter tampering and water theft: Smart water meters with real-time data and automated technologies that use algorithms can rapidly detect meter tampering and water theft. These smart meters can identify where and when there is a sudden shift in usage (Monks et al. 2019). Research shows that smart meters can significantly increase the detection of water thievery (Monks et al. 2019; Morote and Hernández-Hernández 2018).
5. Reduce staff and labour costs of water service providers: Smart water meters can reduce the number of staff required to perform manual meter readings, thus lowering operational costs. Smart meters can also reduce the amount of estimated readings in those instances where access to the meter is not possible (March et al. 2017). Research suggests that smart meters can produce significant savings and reduce operational costs for water service providers (Monks et al. 2019).
6. Improve cash flow: Smart meters can augment revenue collection via monthly billing of customers, using the automated reading taken at a nominated day and time. As manual meters may be under-read by the water service provider staff (by accident or on purpose), the greater meter reading accuracy that real-time data affords may result in additional revenue for the water service provider. The water service provider may further improve its cash flow by reducing billing and collection costs when monthly billing is coupled with electronic billing and collection. Using an electronic billing system could reduce postal charges and extra mailing costs, such as reminders for payments. Research shows smart water meters coupled with monthly e-billing, and an online payment system can result in improved cash flow and more efficient billing operations (Beal and Flynn 2014, 2015; Monks et al. 2019; WSAA 2019).

Smart Meters in ASEAN

There is growing interest in smart meters in the ASEAN due to their efficiency in reducing commercial losses and improving urban water demand management (Rahim et al. 2020). Several cities across the region have installed, or are in the process of installing, smart meters, to reduce commercial losses. Brunei Darussalam, Singapore, and Kuala Lumpur (Malaysia) have all installed smart meters. In Brunei Darussalam, for instance, the Datastream Digital Network[27] launched the ‘Unified Smart Metering System’ (USMS), which features meter data management and measurement, and a unified electricity and water billing customer service portal system. This system allows households to monitor their water usage levels, thereby enabling them to better manage their consumption and finances. Starting from March 2020, the new smart prepaid water meters were set to be rolled out to 2000 households in the first phase of testing. Over the next five years, it is intended that this is expanded to over

[27] DST is a telecommunications company in Brunei Darussalam which provides mobile services, broadband, broadcasting, and content.

200,000 homes and commercial buildings, with the aim of replacing existing utility meters used nationwide (The Bruneian 2020).[28]

Smart Meters Outside of ASEAN

Beyond ASEAN, in Loudoun County, Virginia, USA, the local water utility, Loudoun Water,[29] installed Advanced Metering Infrastructure (AMI) in 2017 to monitor water consumption in real time and to also promptly identify leaks in the water distribution network. The AMI solution comprised Sensus iPERL residential and OMNI smart water meters (Water Technology 2018). The installation of the smart meters[30] was a response to the utility's 78,000 customers who complained that it was difficult to read their meters manually. Leaks in the water distribution network also went frequently undetected.

The smart meter solution enabled Loudoun Water to view all of its customers' water consumption levels online and also provided it with data for the proactive repair of leaks through the smart meter's FlexNet Communication Network and alert system.[31] Loudoun implemented a four-step procedure to alert customers to leaks: (1) an automated call or a letter providing initial information of sustained, increased consumption was generated after the first alert by the system within 72–95 h; (2) a follow-up letter to customers indicating that the leak remained unrepaired. After 10–11 days of the first leak alert sent to consumers, Loudoun provided suggestions for leak repairs to the consumer; (3) a visit to the property was made to identify the physical location of the leak within 21 days of the first notification of a leak; and (4) a personal telephone call before the commencement of the next billing cycle. In total, 13,000 telephone calls were made to customers in 2017, 2600 letters were issued to the customers, and 1500 property visits were made to the customer's premises later. Approximately, 80% of the leaks were corrected based on Loudoun Water's first notification outreach to customers. Loudoun's action plan enabled customers to lower both their water usage levels and their water bills (Sensus-3 n.d.).

Another example is the municipality of Terre di Pedemonte, Switzerland. Società Elettrica Sopracenerina (SES), the local water service provider, installed smart meters in May 2015 as part of a pilot programme. The Switzerland pilot-SmartH20 project[32]

[28] Due to COVID-19, the roll-out of the smart meters has been delayed. As such, 5000 units of DN15 meters and 200 units of DN25 were expected to arrive between April and June 2021. The replacement work of conventional meters with smart meters will be implemented once they are available. As of December 2020, the installation works have not started yet. The meter replacement is to be carried out in stages over five years (Brunei Darussalam representative in AWGWRM. Email interview, 22 December 2020).

[29] Loudoun Water provides waste and wastewater services to over 800,000 households and businesses in Loudoun County. Loudoun Water is a political subdivision of the State of Virginia and is not a department of Loudoun County (Loudoun n.d.).

[30] Sensus iPERL residential and OMNI water meters, all connected by the FlexNet Communication Network.

[31] The smart meter alarm system detects issues such as leaks, reverse flow, empty pipes, and meter tampering (Water Technology 2018).

[32] The SmartH20 is an Information and Communication Technology (ICT) platform for efficient management of water consumption. The EU-funded SmartH20 project is aimed at aiding water

(ETH 2015; Rizzoli et al. 2018) involved the implementation of a gamified portal, where a gamified application was connected to a user's smart meter, serving as a rewards-based marketplace, where target achievement-based collectables like points, badges, and rewards were awarded to users. As part of the project, consumers could set weekly or monthly water-saving targets (5%, 10%, or 15% reduction) and were awarded 'points' based on their target achievements (Novak et al. 2016).

As part of the SmartH20 project campaign, a questionnaire was sent to 70,000 of the canton's 158,647 total households. A total of 462 households responded to the questionnaire, with data extracted from this exercise being used to determine the general profile of users interested in water awareness and efficiency. Some examples of data (per household) extracted include number of bathrooms per home; number of showers per week; number of taps; and duration of showers (Bertocchi et al. 2016).

This pilot project demonstrated the efficiency and accuracy of smart meters, with a 33.4% reduction in water usage with respect to a historical baseline. However, after adjusting for seasonal factors, a water consumption reduction of 3.4%–8.4% was attributed to the use of the portal. The main objective of the pilot was to familiarise the core user group with the ICT-based portal. Based on the experience of the core user group, a larger active user group could be built. The core group consisted of 27 basic and 16 gamified portal users. It was observed that the user activity in the gamified portal version was higher to the user activity in the basic portal, suggesting that the gamified portal prompted more interest among users (Rizzoli et al. 2018).

The water consumption reduction results (based on consumption class) solely attributed to the use of the portal and savings tips (without gamification) are given in Table 5.1. The average reduction is calculated over three months (1 November 2015–6 February 2016) relative to the baseline reading (on 31 October 2015) (Micheel et al. 2015).

Table 5.1 Average reduction in consumption (seasonally non-adjusted) from 1 November 2015 to 6 February 2016, Locarno, Switzerland

Consumption class	Number of users	Average reduction (%)
Low	10	41.2
Medium–Low	22	26.9
Medium–High	10	41.2
High	01	21.2
Overall	43	33.8

Source Micheel et al. (2015)

service providers, municipalities, and citizens with the development of an ICT-based platform to design, develop, and implement better water management practices and policies (EU n.d.). SmartH20 uses the multi-stage behaviour model to influence water consumption demand, and its mechanisms include interactive water consumption visualisations, water-saving tips, water-saving goals, various types of gamified incentives (personal, social, virtual, and physical), and a hybrid physical-virtual card game (Novak et al. 2016; Rizzoli et al. 2018).

5.8 Programmes to Identify, Remove, and Replace Illegal Connections

Commercial losses from water theft are a key concern for water service providers due to the loss of revenue for water service providers. Water theft can take the form of illegal connections,[33] illegal reconnections,[34] meter tampering,[35] and meter reader corruption[36] (ADB 2010; Jones et al. 2021; Marsano and Jannah 2021; Sekyere et al. 2020).

To reduce commercial losses, water service providers can implement programmes to identify, remove, and replace illegal connections. These programmes include imposing fines on customers for excessive water consumption, suspending the accounts of non-paying customers, and implementing verification programmes to monitor inactive accounts (ADB 2010).

Many cities across ASEAN have implemented such programmes to identify, remove, and replace illegal connections to reduce commercial losses. These include the imposition of fines and the suspension of accounts of non-paying customers, for instance, in Brunei Darussalam, Singapore, Phnom Penh (Cambodia), Jakarta and Bogor Municipality (Indonesia), Carmona District (the Philippines), Bangkok (Thailand), Johor (Malaysia), Vientiane (Laos), Yangon (Myanmar), and Ho Chi Minh City (Vietnam).

In Jakarta, Indonesia, both water concessionaires, Aetra and PALYJA, have implemented measures to reduce water theft via illegal connections. In 2018, Aetra introduced a 'master meter programme' to prevent water theft, which involves the installation of a temporary meter to ensure that public water services are delivered to underprivileged areas to deter residents from illegally connecting to Aetra's pipe network. As a result of this programme, Aetra detected 732 illegal connections (Aetra 2018), reducing the number of illegal connections by nearly 50% when compared to 2016 (Aetra 2016). PALYJA has also detected cases of water theft. In 2016, the incidences of water theft that it detected included 2,704 illegal connections and 2,147 illegal uses. Some of the incidents concerning illegal connections were considered criminal offences, warranting police investigations (PALYJA 2014, 2016).

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[33] This is when a consumer is not a customer of the water supply system but has connected himself/herself to the network (Ramos et al. 2020; Water Integrity Network 2015b).

[34] This occurs when a customer reconnects himself/herself to the water distribution network after having been disconnected from the network due to non-payment (Water Integrity Network 2015b).

[35] Meter tampering is 'fraudulent manipulation' where customers falsify their true water consumption readings. It is a concern for water services providers because it represents a loss of income (Monedero et al. 2015; Morote and Hernández-Hernández 2018).

[36] This includes, for example, customers colluding with their water service provider's meter (human) readers to falsify the water meter readings, thus lowering their water bill (Water Integrity Network 2015a).

5.9 Case Snippet (Commercial Losses): Johor and Ranhill SAJ

Johor, Malaysia, has put effective WDM measures in place to reduce and prevent commercial losses. Ranhill SAJ is the sole water operator in the southern Malaysian state (Ching 2017). It is a subsidiary of Ranhill Utilities Berhad, which operates integrated water supply with three core activities: water treatment, water distribution, and billing and collection (Ranhill SAJ n.d.). As noted below, the water utility pays particular attention to upgrading meters and preventing non-payments and meter tampering to avoid commercial losses in Johor.

Although the 25% NRW target set in the Eleventh Malaysia Plan[37] still applies to Johor, SPAN[38] has set itself an ambitious seven-year plan and key performance indicators (KPIs) for Ranhill SAJ,[39] to address commercial losses (Malay Mail 2019). The programme's aim is to achieve a reduction of NRW from 24.12%, to 5% (Global Water Security 2019), and a commercial loss of 1% (Ranhill Holdings 2019a) by 2025 in Johor (The Star Malaysia 2018)

Ranhill SAJ has, in addition, implemented various WDM measures to reduce commercial losses through water theft prevention, non-payment compliance enforcement, and meter replacement programmes. The water theft prevention measures involved appointing 38 additional staff for the newly established Enforcement and Preventive Section within its Customer Service Department. This initiative has resulted in the detection of 9620 cases, of which 9569 have been solved (Ranhill Holdings 2019a). Ranhill SAJ has also imposed a total of RM910,000[40] worth of water loss charges on the offenders and collected RM795,000 thus far (Ranhill Holdings 2019a)

Ranhill SAJ has put in place sanction mechanisms to reduce commercial losses. The water utility will suspend a customer's water connection if their water bill remains unpaid after the timeframe (i.e. 30 days after issuing the water bill). The water utility will also charge the customers their ongoing water bills and additional reconnection fees

Ranhill SAJ also undertakes water meter replacement and upgrading programmes in Johor—schemes that have resulted in positive outcomes. As of 2017, estimates suggest that 92.1% of meters in Johor (i.e. 1.05 million customers) had been in use for less than seven years, a proportion that tops Malaysia's national average of 82.3%. Ranhill SAJ replaces old and poorly functioning water meters with more durable electromagnetic meters (EFM) or R800 metrology mechanical meters. In addition, Ranhill SAJ has set aside an investment of RM 2.04 billion for the period of 2018–2022 to carry out upgrades to infrastructure, including the replacement of old water meters (The Star Malaysia 2020). As of December 2019, R800 metrology mechanical meters had replaced 11,931 water meters in Johor, while EFM had replaced 109 m (Ranhill Holdings 2019a)

5.10 Key Takeaways

1. Commercial losses may result from water theft, incorrect water meter readings, and illegal connections. Technical measures (e.g. water meters) and non-technical measures (e.g. customer reporting) can reduce commercial losses and are usually undertaken by water service providers.
2. Water meters are particularly efficient in reducing commercial losses by measuring the amount of water that flows through pipes from the withdrawal area to the distribution and delivery points. Water metering is an accepted practice in WDM in developing countries to control water consumption based on pricing. By metering water, water service providers can reduce unmetered water consumption by up to 30%.
3. Smart water meters are particularly efficient in reducing commercial losses, by using real-time data and a sensor network, and by increasing consumer awareness of water consumption which reduced water loss by 12.15% on average.
4. The use of real-time data and a sensor network with smart meter technology can also reduce the probability of water leakage by 50% through monitoring; this significantly reduces water theft (up to 80% in some studies) and labour costs for the water service provider. The installation of smart meters can not only save water service providers time and money through accurate real-time data and monitoring but also help support better water conservation practices and improve urban water management planning.
5. All ASEAN countries have installed traditional water meters to reduce commercial losses. However, there is growing interest in smart water meters, due to the efficiency that they offer in terms of providing real-time data on water consumption. Some ASEAN countries, such as Brunei Darussalam, Singapore, and Malaysia, have already installed, or are in the process of installing, smart meters to reduce commercial losses further.
6. Many major cities across ASEAN have implemented programmes to identify, remove, and replace illegal connections to reduce commercial losses. These include the imposition of fines and the suspension of accounts of non-paying customers, for instance, Brunei Darussalam, Singapore, Phnom Penh (Cambodia), Jakarta and Bogor Municipality (Indonesia), Carmona District (the

[37] Malaysia’s five-year development plan 2016–2020.

[38] Suruhanjaya Perkhidmatan Air Negara.

[39] Water licensee.

[40] RM 1 = USD 0.24.

Philippines), Bangkok (Thailand), Johor (Malaysia), Vientiane (Laos), Yangon (Myanmar), and Ho Chi Minh City (Vietnam).

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