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Research Report

Managing Water Losses

in Urban Water Systems : An International Perspective

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About the Centre

The Centre for Water Technology and Policy at The University of Hong Kong is an inter-faculty collaborative unit between the Faculty of Engineering and Faculty of Social Sciences. Through inter-disciplinary research and analysis, the Water Centre generates professional insights on complex, multi-dimensional problems in the urban water sector. The strengths of engineering and social sciences disciplines are purposefully converged and fused, through innovative inter-disciplinary research design and analytical lens, to create unique diagnostic capabilities for us to deliver on those insights. The Water Centre was established in 2018 through a generous donation made jointly by Philomathia Foundation and WYNG Foundation.

Preface

Water loss refers to the problem of fully treated tap water that is lost from a city's water supply system, either through leakages or otherwise, and which never reaches the users. Water loss is an avoidable predicament, however. As evidenced by the experiences of a number of global cities, this plight could be fixed by an effectual application of a judicious mix of technologies and policies.

In Hong Kong, water loss is a sticky problem, persisting for years, in spite of vast investments of a plethora of measures to contain it. The proportion of unmetered water consumption, a proxy of water loss rate, has hovered between 30 percent to 35 percent in the past twenty years. This metric denotes the percentage of total treated water that has not reached any of the three million plus billing water meters in the city.

In this Research Report, we purposefully situate Hong Kong's water loss problem within a larger, yet confined, international, comparative context. This global perspective should provide a backdrop, as well as some rough benchmark, for us to appreciate the scope and severity of this issue in our city. We examine, through desk-top research, the question of how water losses have been managed by water supply agencies in six cities around the world. These cities were selected for the report because their combined lessons should offer us a glimpse into solutions that could inform our own approach to tackling this longstanding conundrum.

The consolidated findings gathered from these six urban water systems suggest that there are multiple ways to address a universal challenge successfully. While some cities have attributed their achievements to some forms of strategic integration and effectual implementation of conventional and new technologies, other cities have ascribed their favourable outcomes to governance and institutional reforms as the main driver for improvements in performance.

Contents

Acronyms and abbreviations

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
AWWA	American Water Works Association
BWC	Berlin Water Company
DMA	District Metering Area
DVGW	German Association of Gas and Water Experts
ELL	Economic Level of Leakage
EPA	Environmental Protection Agency (of the United States)
GIS	Geographic Information System
HRC	Halifax Regional Council
HRWC	Halifax Regional Water Commission
ICT	Information and Communications Technology
ILI	Infrastructure Leakage Index
IPART	Independent Pricing and Regulatory Tribunal
IRP	Integrated Resource Plan
IWA	International Water Association
JWWA	Japan Water Works Association
KPI	Key Performance Indicators
LIDAR	Light Detection and Ranging Technology
MHW	Ministry of Health and Welfare (of Japan)
MNF	Minimum Night Flow
NRW	Non-Revenue Water
NSE	Nova Scotia Environment
NSURB	Nova Scotia Utility and Review Board
NSW	New South Wales
PLC	Power Line Communication
PMS	Pressure Management Scheme
PRV	Pressure Reducing Valve
PWD	Philadelphia Water Department
RWR	Revenue Water Ratio
SCADA	Supervisory Control and Data Acquisition
SWA	Seoul Waterworks Authority
WRB	Water Revenue Bureau (of Philadelphia)
WSAA	Water Services Association of Australia
WSD	Water Supplies Department (of the HKSAR Government)

Glossary

Acoustic leak detection

Microphones or sensor technologies are used to locate leaks by characterizing sounds that are different from normal water flow in the water distribution system.

Advanced Metering Infrastructure system

Considered as an upgrade to the Automatic Meter Reading (AMR) system, the Advanced Metering Infrastructure (AMI) system integrates the water meter network, communication technologies and sensors for real-time data collection of water consumption and status data. Unlike the AMR system, the AMI system does not require utility personnel for data collection, as the data is automatically transmitted to the server.

Apparent water loss

Apparent water loss involves water usage that should be tariffed as a revenue-generating water. Yet, it appears as an apparent water loss due to theft, unauthorized consumption, and metering inaccuracies.

Asset management

Asset management is the practice of managing the entire lifecycle (creation, maintenance, renewal, expansion, full/partial decommissioning) of a water supply system. The goal is to meet the required level of service in the most cost-effective manner by creating, acquiring, maintaining, operating, rehabilitating and disposing of assets to provide for present and future water utilities opting for water loss reduction solutions.

Automatic Meter Reading system

A communication technology system that collects water consumption data, diagnostics and status data from water meters through communication networks such as broadband and 3G. This requires utility personnel to be in close proximity for data to be transferred to the device, and then into a database that is later sent to master stations or AMR servers.

Economic Level of Leakage

The optimum leakage level in economic terms that can minimize the total present value cost in leakage management.

Infrastructure Leakage Index

The ratio between actual real losses and estimated minimum real losses.

Leak/break response time

The time it takes for water utilities and executing agencies to respond to a leak or break in the water distribution system.

Master Metering

A master meter records water usage that passes through all the dwellings and units within an entire complex, such as a large housing estate or a commercial complex.

Minimum Night Flow

The measured water flow into a district metered area in the middle of the night where water demand is at its lowest. This is a common method used to evaluate water loss in a supply network.

Non-revenue water

Water produced by a city's waterworks but is "lost" from water pipeline networks before it could reach the customers. This loss can take on the form of real losses, such as water leaks, or apparent losses, through theft or metering inaccuracies.

Real losses

Real losses refer to actual physical water that leaks from the water supply system, through cracks or openings in pipes and transmission mains.

Supervisory Control and Data Acquisition system

A computer-based system architecture that makes use of data communications technology to gather, monitor and analyse real-time data. In terms of water management, the SCADA system is used for monitoring water supply distribution networks and asset management to quickly identify supply system issues and to facilitate optimal response time.

Water tariffs

The water price that is charged to consumers over certain time intervals according to meter readings.

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Chapter 1

INTRODUCTION

1. INTRODUCTION

Water loss is a public policy problem that has been afflicting Hong Kong for more than thirty years. According to a 2018 report issued by The Ombudsman on the maintenance and risk management of government water mains, the amount of freshwater lost in each year, if saved, could meet the demand of two million local residents.

From the government's perspective, Hong Kong's water rate loss is relatively high by international standards because the city is particularly susceptible to high water pressure in its water distribution system and is plagued by peculiar pipeline distribution issues. The main causes, claimed by officials, include the city's hilly terrain, high density, as well as vibrations and disturbances caused to underground water mains by busy traffic and frequent roadworks.

Recognized as a perennial problem and accorded top priority concern, the Water Supplies Department said that, since the early 1990s, they have been combating the water loss problem by implementing a host of water loss control measures directed at government mains[a]. These measures were informed by four globally mainstreamed methods, codified by the International Water Association. They are: (i) pressure management; (ii) active leakage detection and control; (iii) speed and quality of repairs; and (4) replacement and rehabilitation of aged water mains (Water Supplies Department, 2020).

The Water Supplies Department has asserted that the leakage rate of government mains has been lowered from about 25% in 2000 to around 14% in 2021. This metric, however, provides only a *partial* view of the city's overall water loss predicament. We need to use another measure to gauge the overall efficiency of the city's entire water supply distribution network.

In the case of Hong Kong, that alternative metric is the rate of unmetered freshwater consumption (UFC)—which is the ratio between the amount of unmetered freshwater and the total amount of freshwater produced by the city's waterworks. The UFC rate, expressed as a percentage, gives us the most accurate and comprehensive view of the city's water loss situation, for two reasons. First, the two key parameters used in the equation are metered measurements, not estimated values susceptible to wide margins of errors. Secondly, these two parameters cover both government mains and private mains, although they do not offer a breakdown between these two components.

[a] The city's water supply distribution network is comprised of two major components: government mains and private mains.

In the past twenty years, spanning from the early noughties to the early 2020s, the UFC rate in Hong Kong has hovered between 30% - 35%[b]. To fully tackle the city's *overall* water loss problem, policy interventions should focus on the reduction of this UFC rate, and not just the reduction of the water loss rate of government mains. As such, the government's recently proclaimed target to lower water leakage rate of government mains from 15% in 2019 to below 10% by 2030 would still fall short of the efforts needed to suppress the city's *overall* water loss rate. This target, limited to government mains, has left out a big chunk of the problem, which lies in the domain of leaky pipes buried in private premises.

For public policy analysis purposes, an international perspective on municipal management practices is always useful because it offers us a comparative view of the strengths and limitations of various approaches used to tackling such municipal management problems as water loss, which take on similar attributes in different parts of the world. Stylized successful experiences, known as international best practices, form the basis of policy learning, traversing jurisdictional boundaries and cultural divides.

In the spirit of stimulating and invigorating policy debates and policy learning in Hong Kong in regard to the field of water loss management, we have selected from around the world six cities that have made significant strides in suppressing the water loss rate in the past four decades. They are Berlin, Halifax, Sydney, Philadelphia, Seoul, Sydney and Tokyo.

We intend to achieve two purposes with this Research Report. First, we aim at informing non-specialists and the wider community on the intricacies of water loss management from an international, comparative angle, written in as much a plain language as possible. By raising the level of water literacy of the general public on this topic, the average person should feel comfortable, even confident, to engage in policy deliberations of this problematic in a meaningful manner.

Secondly, we aim at drawing up some key lessons from examining a cross-section of successful strategies in managing water loss in cities that carry social, economic and physical attributes that are similar to those of Hong Kong. As such, these lessons should be considered highly relevant to Hong Kong's plight, overriding the exceptionalism argument that the government has used to excuse itself for not being able to attain water loss reduction outcomes comparable to those already accomplished by a number of cities around the world.

[b] Calculations are based on data retrieved from the Annual Reports published by the Water Supplies Department.

To help provide an overall structure for the reader to appreciate the underlying inter-connectedness of a seemingly random choice of cities, we purposefully arrange the six cases in a particular order to accentuate several important thematic arguments that bind them together.

We first examine the water loss management experiences of the water agencies of Seoul and Berlin, to understand how they have skillfully applied cutting-edge, innovative technologies to address water leakages in their respective water distribution system. Next, we present the case of Sydney, to demonstrate the argument that the success of managing water loss does not need to rely on cutting-edge technologies. Sydney's water managers have made use of conventional methods and technologies to tackle the problem with tangible outcomes.

Finally, we look at the water loss control programs of Philadelphia, Tokyo and Halifax. The water managers in these three cities share the same belief: They attribute the success of their water loss management programs less to the technologies that they have used, but more to their water governance practices, organizational measures and effective coordination efforts among concerned stakeholders.

We conclude the report with a summary of key lessons that we have learnt from the six aforementioned cities. These lessons might offer some clues for us to contemplate on the way forward for Hong Kong.

Chapter 2

SEOUL

Case Report

SEOUL

Water provider

Seoul Waterworks Authority (SWA) (public).

Population served

More than ten million residents in Seoul and the metropolitan region.

Water supply

Han River.

Water loss concerns

Pipes installed before 1984 were prone to corrosion that caused frequent leakages and degraded water quality. Further, the mountainous terrain surrounding Seoul creates pressure and pipeline distribution issues.

Policies and programs:

- Launched the Seoul Waterworks Authority (SWA) in 1989 to coordinate water-related affairs.
- Implemented a three-phase project to improve the revenue water ratio (RWR)
- Established the Water Pipe Network Optimum Control System and Standard Maintenance Guidelines and Guidelines for Water Distribution Pipe Repair Works, which drive the city’s pipe replacement programs.

Methods and technologies:

- Consistently implemented pipe replacement programs dating back to 1962.
- Adopted a block system to improve management of the water distribution system.
- Maintain a geographic information system (GIS) that provides spatial information of waterworks, and can analyze and predict leakage.
- Implemented a multi-point leak noise correlation system to increase the precision of leak detection.
- Use a flow monitoring system to provide real-time data on water flow and pressure created during the supply process.

Accomplishments:

- Replaced 13,192 km out of 13,721 km of distribution pipes from 1984 to 2013.
- Improved the RWR from approximately 55% to above 95% within 30 years.
- Decreased the annual number of leak cases from 59,438 in 1989 to 10,421 in 2013.

Takeaways:

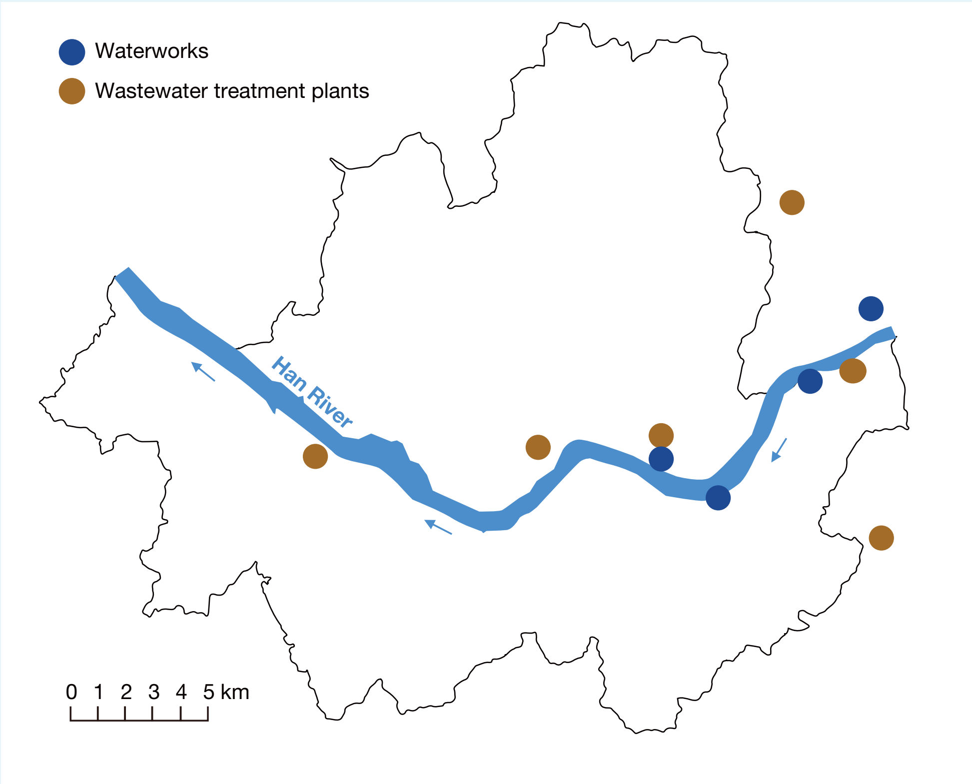
- Financially self-sufficient water agencies have significant incentive to minimize losses, as water loss equates to financial loss.
- Utilities should develop performance indicators and metrics targeted toward their objectives and the local conditions.
- Progressive research and development efforts, and implementation of technical advances can help facilitate consistent, gradual improvements in water loss control.
- Pipe replacement programs can provide both water loss control and water quality benefits.

1. INTRODUCTION

Seoul first introduced a modern waterworks system in 1908. Subsequently, it introduced the first modern water purification system to sustain clean and safe water for the public. The Han River, running through the center of Seoul, supplies all the city's water needs. Mountains surround all four sides of Seoul, located at 25-40m elevation, creating pressure and pipeline distribution issues that seriously impact Seoul's water supply and management system[29]. Moreover, many of the pipelines in Seoul's water distribution system are buried deep underground, resulting in challenging excavation projects to replace or rehabilitate pipes. Climate change, rapid urbanization, and population growth, also create water shortage problems in Seoul. Improving the water sector has been a national priority for many years in South Korea (Figure 2.1)[92].

Figure 2.1

Water supply system of Seoul



Source: Seoul City Hall, 2015

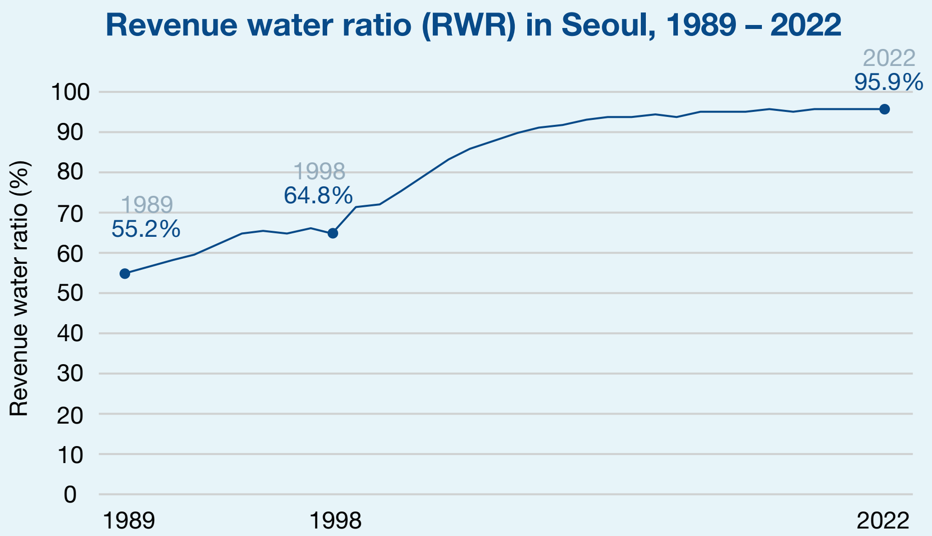
The Seoul Metropolitan Government launched the Seoul Waterworks Authority (SWA) in 1989 to coordinate affairs related to providing clean and safe drinking water as well as to improving the efficiency of water system. SWA is a public utility but operates as an independent local company with a self-supporting financial system dependent on water tariffs from customers. Through public-private-partnerships, SWA is increasingly engaging in overseas business with the goal to make the country a powerhouse in the global water market.

Water loss control has been a dominant business management goal of SWA as water loss equates to financial loss. SWA uses “Revenue water ratio (RWR)” as the performance indicators that take into consideration the financial losses associated with water loss:

Revenue water ratio (RWR)
the reverse of non-revenue water ratio, based on billed water used by customers[28]

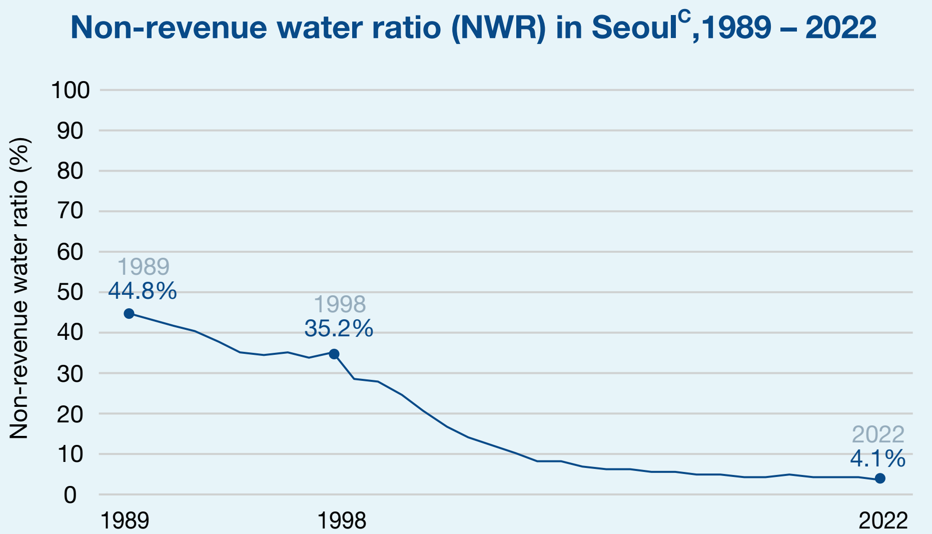
From 1989 to 2015, the RWR of Seoul improved from 55.2% to 95% (Figure 2.2a). This improvement is attributed to continuous pipe replacement and repairing, block management of the distribution system, systematic monitoring, and leak prevention.

Figure 2.2a



Source: Seoul Metropolitan Government, 2015c, KOSIS, 2021. Modified by authors.

Figure 2.2b



Source: Seoul Metropolitan Government, 2015c, KOSIS, 2021. Modified by authors.

[c] Unlike other cities featured in this Technical Report, Seoul is unique in its case for using the Revenue Water Ratio (RWR), which is the reverse of the non-revenue water ratio. For the reader's ease, we have generated another graph that plots the non-revenue water ratio (%) so that the reader may compare figures between different cities.

2. POLICIES AND PROGRAMS

Before 1998, SWA mainly focused water loss control efforts on pipe replacement and leak detection. The late 90's brought a new policy aimed at improving waterworks management via an increase of RWR, as well as controlling water quality[30]. The RWR improvement project included three phases – initial phase, development phase, and settlement phase – defined by the measures and projects in Table 2.1. The next section describes a selection of the most important methods and strategies included in the three phases.

Table 2.1 Process of RWR improvement project

Phase	Measures and projects
Phase 1: Initial phase of RWR improvement (1989~1995)	• Establishment of SWA (November, 1989) • Installation of district-level flow meters (1990s) • Intensive maintenance of old water distribution/supply pipes (4,200 km) (1991~1993) • Fully established the use of district flow meters at each of the waterworks offices to measure the system (1995)
Phase 2: Development phase of RWR improvement (1996~1999)	• Launch of RWR improvement team (October, 1998) • District-level measurement of supplied water and RWR initiated (1996 – 1997) • Installation of smaller diameter meters, meter replacement (1996~2000) • Minimum Night Flow (MNF) measured by dividing the Seoul pipeline network into 2,037 small blocks (1998) • Official district-level RWR statistics produced for the first time (1998) • Intensive management of waterworks facilities at the redevelopment and reconstruction sites (from 1999)
Phase 3: Settlement phase of RWR improvement (2000~present)	• Shifted to indirect supply system after reservoir establishment (2000~2003) • Office reshuffled and RWR management responsibility transferred from waterworks task force to RWR division (January 2001) • Meter-reading works entrusted to private entities (July, 2001) • Appropriate pressure of booster pumps managed in each period (from 2002) • Systematic management of disused pipes (359km) (from 2003) • Block-level RWR managed after introducing the medium block system (from 2004) • Scientific leak detection started using the multi-point leak noise correlation system (from 2004) • Amount of water supplied analyzed and flow controlled through the flow monitoring system (from 2005)

Note: MNF: Minimum night flow, RWR: revenue water ratio.
Source: Seoul Metropolitan Government, 2015c. Modified by authors.

In the early 20th century, Seoul launched a "*Comprehensive Water Management Plan*"[d] that included seven promotion strategies and 23 detailed tasks for the strategies. Building a smart water supply city was one of the promotion strategies, which aimed to establish a safe tap water production and supply system, as well as optimize water supply through the increased flow rate.

Several sets of guidelines address pipe replacement in Seoul. In 2014, the Ministry of Environment published the "*Water Pipe Network Optimum Control System and Standard Maintenance Guidelines*" to drive the city's replacement programs[94]. These Guidelines require that pipes over 30 years old or pipes that will soon exceed their lifespan be evaluated based on established assessment factors. Further, the city's "*Guidelines for Water Distribution Pipe Repair Works*" outlines priority replacement programs. These guidelines placed high priority on replacing old pipes buried underground near streets and main roads, and unused and abandoned pipes were removed.

[d] Comprehensive Water Management Plan was translated from 서울특별시 물환경 종합관리계획 , the original name of this plan.

3. METHODS AND TECHNOLOGIES

In Seoul, RWR denotes Revenue Water Ratio. This term refers to the proportion of tap water produced by Seoul Waterworks Authority that is billed to, and paid for by, its customers.

For the last three decades, Seoul has taken a phased approach to improving RWR (Table 2.1), including the following key methods and strategies described in this section: pipe replacement, block management, active leak detection, water pressure control using the water reservoir system, and automatic meter reading.

Pipe replacement

Seoul's pipe replacement efforts date back to 1962 and continue through today. The first program consisted of a "*5-year Plan to Prevent Leaks*" that included a target for reducing the leakage rate from 57% in 1961 to 35% in 1966. While only 113 km of drainpipes were replaced in the first five years, efforts expanded over time and also included supply pipe replacement[94].

In 1984, Seoul adopted the "*Old Pipe Maintenance Plan*" aimed at minimizing leaks, ensuring the cleanness of the supplied tap water for households, and establishing a stable inter-regional supply system. The Plan mainly targeted old pipes made of grey cast iron, steel, PVC, or galvanized steel, which were buried before 1984 and were prone to corrosion that caused frequent leakages and degraded water quality (Figure 2.3b). The Plan also addressed old corrosion-resistant pipes that have been in use for over 40 years or other pipes with frequent leak issues. Despite these early pipe replacement programs, Seoul didn't see significant improvements from pipe replacement until the 1990s when the old pipes were replaced in large numbers. From 1991 to 1993, Seoul replaced 4,200 km of pipes, with the rate reduced to 500-600 km every year since 2000[94].

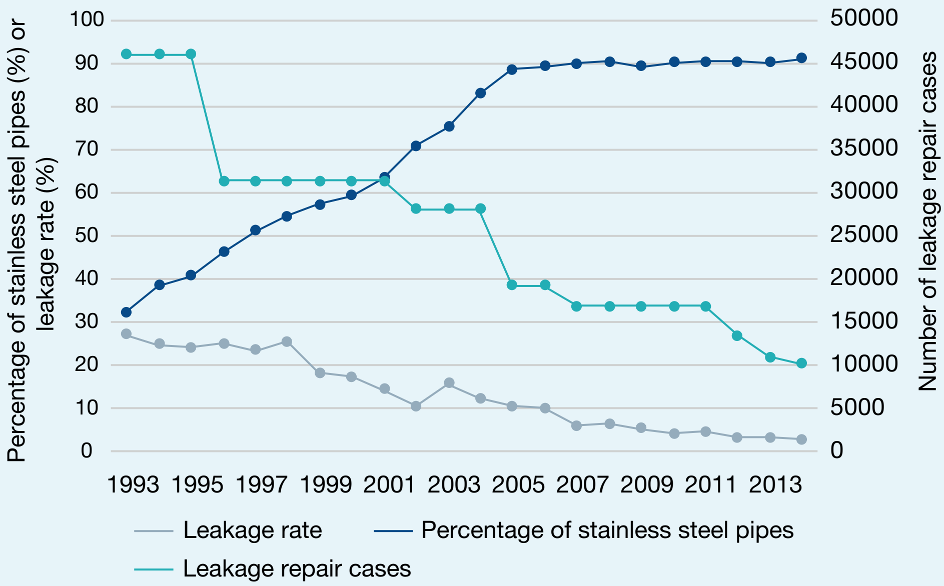
Seoul has also upgraded piping materials over time, with improved materials resulting in reductions in leakage rate and repair cases. Before 1987, Seoul mainly used galvanized steel pipes for supply lines, but they ceased using the material in 1994. From 1987 on, Seoul used stainless steel pipes and copper pipes for supply lines instead. By 2013, 90.6% of pipelines were stainless steel as well as 72.7% of transmission mains, while 81% of trunk mains were ductile cast iron pipes (Figure 2.3a). In 2001, SWA introduced corrugated pipes to reduce the joints in the water distribution system (Figure 2.4).

With the objectives of increasing RWR and improving water quality, between 1984 to 2013, Seoul replaced 13,192 km of 13,721 km of distribution pipes. The remaining old pipes were then replaced with corrosion-resistant cast iron pipe and stainless pipe by 2018[94,96]. The application of stainless steel pipes along with other technologies led to a steep decrease in annual numbers of leak cases from 59,438 in 1989 to 10,421 in 2013, and a reduction in the leakage rate from 27% to 2.5% from 1993 to 2014 reduced (Figure 2.3a).

An upgrade to using stainless steel pipes to build the water supply network has contributed to a significant reduction in the leakage rate in Seoul, suppressing it from 27.0% in 1993 to 2.5% in 2014.

Figure 2.3a

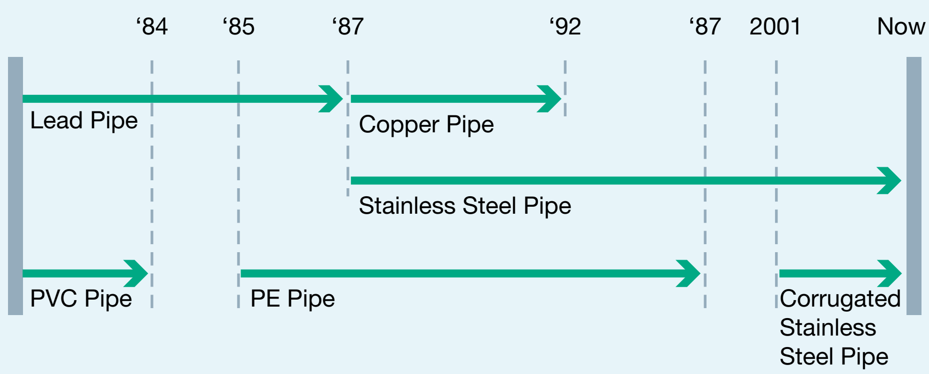
Percentage of stainless steel pipes, leakage rate and number of leakage repair cases in Seoul, 1993 – 2014



Source: International Stainless Steel Forum, 2018. Modified by authors.

Figure 2.3b

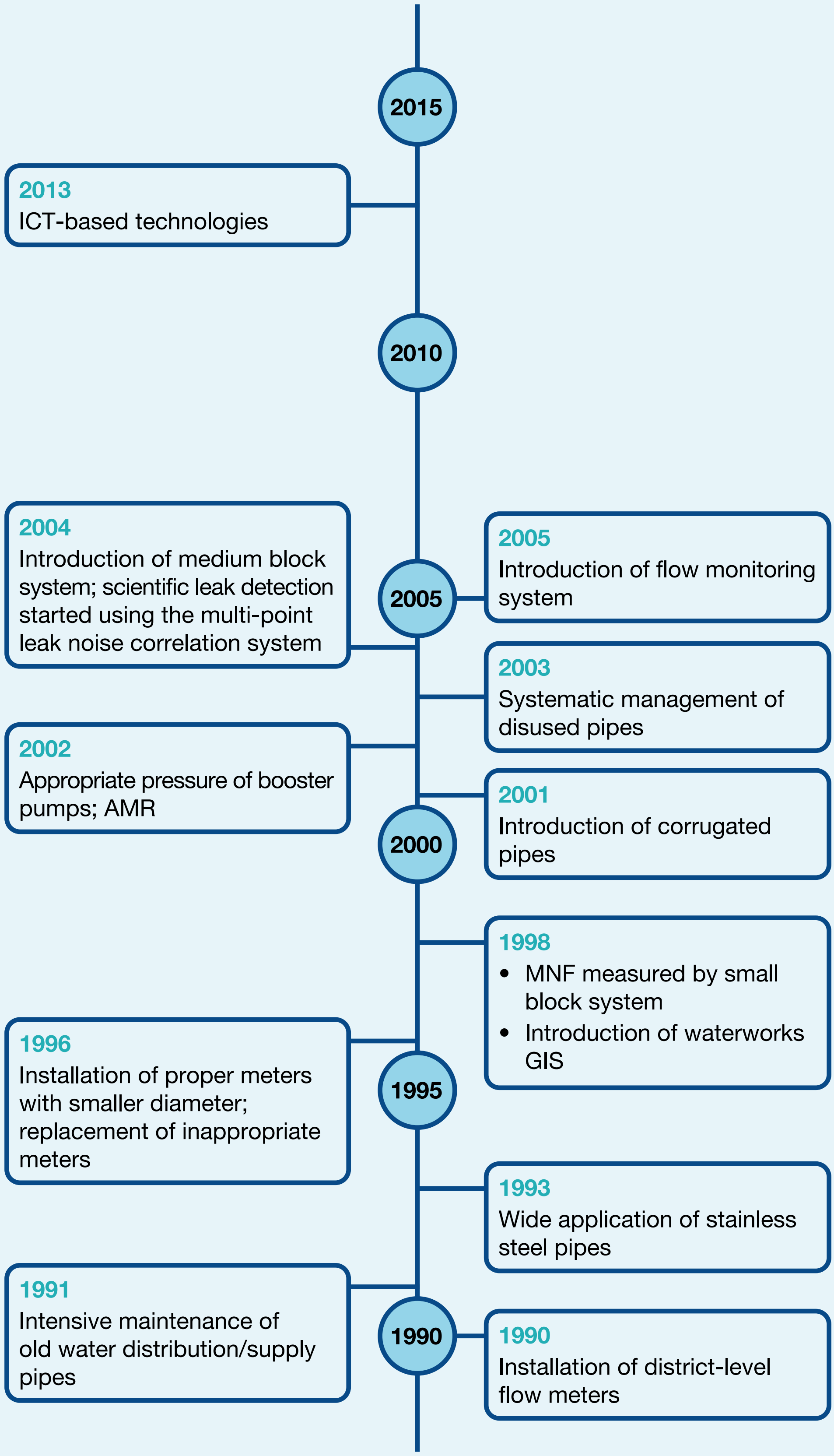
Transformation of service pipe



Source: International Stainless Steel Forum, 2018. Modified by authors.

Figure 2.4

Technologies applied in Seoul



Block management of the distribution system

To improve management of the water distribution system, SWA adopted a block system, dividing its pipeline network into 2,037 small blocks (sub-distribution network block) and 100 middle blocks (distribution block) (Table 2.2)[29]. The block system more effectively controlled water flow and pressure within a small block[31].

In addition, SWA first introduced minimum night flow (MNF) measurements in 1999 to selected blocks, aimed at helping the block system detect leaks and improve RWR. A team of 4-5 workers conducts water leak detection in the middle of the night (01:00-04:00) – one person measures the minimum flow at the flow meter-installed area, and the remaining 3-4 persons detect the leaks with listening sticks, visual inspection of roads, and water meter boxes.

Table 2.2 Process of RWR management for the small-size block

Step	Goal	Contents
Step 1	Fundamental investigation of the block	To make a list of the current condition of the block including separation of the block, characteristics of the block, and current conditions of facilities for water supply
Step 2	Selection of block	To select a relatively weak block with many leak cases among the separable blocks
Step 3	Measuring water supply and consumption	To measure water supply and consumption in the small-size block three times
Step 4	Estimation of the RWR; Plans and strategies for the RWR goal	To make strategies and plans to increase the RWR considering changes in water supply and consumption

Source: Choi, 2014. Modified by authors.

Active leak detection

For leak detection, SWA conducted precise detection in areas that recorded the greatest number of leak cases over the past three years based on a waterworks Geographic Information System (GIS), developed between 1998 and 2001[28]. The waterworks GIS provides spatial information of the common facilities, water pipes, and attached facilities. It can help identify the hotspots by correlating the flow data with pipe age, for example. Since the mid-2000s, SWA regularly conducts aerial surveys, checks underground facilities, and maintains a database for the equipment parameters. In addition, information and communications technology (ICT) was applied to the water supply system to collect more data. It allowed the remote monitoring of water quality and water flow.[94]

In 2004, Seoul introduced a multi-point leak noise correlation system to make leak detection more precise[95]. This system can pinpoint the locations of all leaks with high precision through the high-sensitivity sound sensors and the complete analysis of noise. SWA also uses a flow monitoring system to provide real-time data on water flow and pressure created during the supply process. Through installation of the flow monitoring system, Seoul can detect abnormal noise and the leaking point can be further identified with the accumulated statistical information[28].

Water pressure control using a service reservoir system

Urban drinking water supply systems need to maintain consistent water pressure to provide a continuous water supply. Often times, service reservoir facilities are used to store water from treatment plants. Seoul makes use of a service reservoir system to effectively manage water pressure based on elevation differences resulting from the hilly and mountainous terrain. As of 2015, Seoul maintained a total of 120 service reservoirs with a capacity of 2.4 million m^3. This system can control excessive water pressure, effectively reducing leakage.

Automatic Meter Reading (AMR)

Seoul introduced several automatic meter reading (AMR) pilot projects in 2002 to reduce labor force for meter recording and improve meter accuracy, which can reduce apparent loss (Table 2.2). Through the pilot projects, the average meter reading success rate improved from 67.8% in 2002 to 86.0% in 2006[129].

Due to the poor communication issues associated with a separated AMR system, Seoul implemented an integrated AMR pilot project from May 2007 to June 2009. This AMR integrated water, electricity, gas, and other utilities, and utilized power line infrastructure for networking and communication. Power line communication (PLC) technology reduced the cost for building communication networks, and was less sensitive to obstacles compared to wireless communication. In this integrated AMR system, the average meter reading success rate during the project period was 91.2%, and was more cost-effective than the separate AMR system.

However, Seoul faced great challenges in attempting to implement the AMR system. The unfavorable communication environment, high cost of AMR infrastructure, and unsuitable wet type registers for AMR sensors[e] have stalled pilot projects in Seoul. To promote the development of AMR system, Seoul is now researching the development of additional features to improve cost-effectiveness, incorporation of the AMR with smart pipe network, and establishment of procedures to ensure communication security.

[e] This refers to AMR sensors that can be immersed in water.

4. KEY LESSONS

The government's decision to turn the Seoul Waterworks Authority into a financially self-sufficient entity provided powerful incentives for utility managers to focus their attention on stemming water losses and the associated financial losses.

Seoul has successfully improved the RWR from approximately 55% to above 95% within 30 years. It has become one of the pioneering cities on water loss management in the world. Seoul can attribute some of the city's impressive improvement in RWR to the institutional framework, led by the Seoul Waterworks Authority. As a financially self-sufficient agency with stake in oversees public-private-partnerships, SWA faces enormous financial pressure. The corporatization of the public SWA triggered increased efforts towards controlling water losses, due to the associated financial losses. The performance indicator used by SWA – RWR – reflect the utility's business focus and illustrate the need to target indicators and metrics to a utility's objectives and the local conditions.

The use of Revenue Water Ratio as a performance indicator accentuates Seoul Waterworks Authority's business focus. This is a good illustration of the need to link performance indicators directly to a utility's objectives.

In the case of Seoul, research and development (R&D) efforts, and progressive implementation of technical advances for water loss control led to a steady increase in RWR and decline in leakage cases over time. Seoul's early efforts to control water loss in the water distribution system focused on replacing old pipes and leak detection. These pipe replacement programs also yielded water quality benefits, highlighting the potential to receive co-benefits from water loss control projects. The city then devoted much effort towards improving the RWR, which included establishment of a block system and flow monitoring system. To maintain a high RWR in Seoul's water distribution system, SWA is now promoting the development of smart technologies for water management. Further, R&D efforts have helped prioritize and define targets for water losses, such as through the GIS system and producing guidelines.

Despite the significant increase in RWR over time, the future may bring more challenges to Seoul's water systems due to climate change, rapid urbanization, and population growth. Thus, despite the significant increase in RWR, SWA will need to take additional measures to improve the cost-effectiveness of pipeline replacement and promote effective pressure management.

The Seoul Waterworks Authority has successfully reduced water losses caused by high water pressure in its water supply network, a problem usually associated with hilly topography, by effectively operating a network of service reservoirs to control the water pressure.

As one of the successful pioneering cities in addressing water leakages, Seoul has invested substantial efforts and resources towards pipe replacement technologies and leakage detection. In particular with Seoul's surrounding hilly terrain, the city's successes in tackling pipe distribution and pressure issues presents the city as an excellent reference for other global cities with similar topographies. Even though hilly terrains pose additional complications with pressure and pipeline distribution issues, the successes of Seoul show that with the right technologies and strategies, water loss can be effectively controlled by substantive amounts.

On this same thread on novel technologies, in the next section, we turn to another part of the world – Berlin – to explore the programs and strategies it has adopted in pipe replacement and asset management.

Chapter 3

BERLIN

Case Report

BERLIN

Water provider:
Berlin Water Company (BWC) (currently public, formally private).

Population served:
3.7 million Berliners.

Water supply:
Nine waterworks utilizing groundwater reserves.

Water loss concerns:
Following reunification, the Berlin municipal government faced a budget deficit and a deterioration of water infrastructure in the East due to a lack of investment before the reunification.

Policies and programs:
- Regulated by the Minister for Economic Affairs, Energy and Operations that oversees the water tariff and the Minister for Environment, Transport and Climate Protection that oversees water management planning, water quantity, and water quality control.
- Required to replace water meters once every six years under the Measurement and Calibration Law.
- Established standards and technical rules to guide the construction, operation, and maintenance of the water supply system based on guidelines established by the German Association of Gas and Water Experts (DVGW).

Methods and technologies:

- Deployed OptNet®, a software for determining optimal network rehabilitation strategies that factors in technical conditions such as age and pipe materials, hydraulic performance, and monetary valuation.
- Employs trenchless rehabilitation of pipes to repair or replace them.
- Developed W-Net 4.0, a user-friendly platform with geographic information, simulation, and data analysis tools.
- Carries out active leakage detection through checking the fittings in pipe networks annually and the water mains once every four years.

Accomplishments:

- Maintained a level of non-revenue water (NRW) below 7% since 1991, with a current rate near 5%.
- Cut systemwide pipe breakage in half between 1996 and 2008 from 0.187 to 0.088 breaks per km per year, with a decrease in East Berlin from 0.34 to 0.119 breakages per km.

Takeaways:

- Utilizing asset management software allowed BWC to strategically investigate and prioritize pipe repair and rehabilitation after reunification, significantly reducing breakage in East Berlin.
- Progressive implementation of technologies such as trenchless rehabilitation and geographic information systems have helped BWC maintain an extremely low NRW rate for the last thirty years.
- To ensure that its system will be able to perform at a high level in the future, BWC is in the process of assessing the potential impacts of climate change on its systems, including the impact of extreme heat or rainfall on pipes and breakage rates.

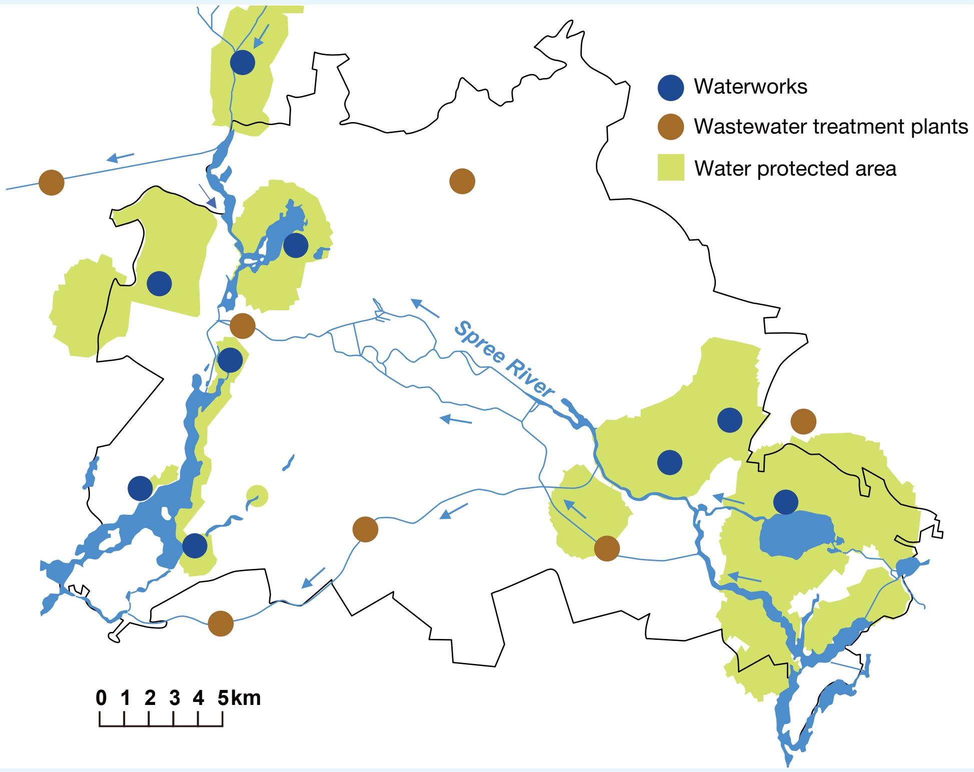
1. INTRODUCTION

After the reunification of Germany, the water utilities in East Berlin and West Berlin were “re-unified” in 1992, forming today’s Berlin Water Company (BWC)[14]. As a result of the unfavorable economic situation after reunification, the Berlin municipal government faced a budget deficit in the 1990s. Water infrastructure in East Berlin was deteriorating due to a lack of investment before the reunification. To consolidate Berlin’s budget, the city privatized its infrastructure systems and outsourced responsibilities, including selling 49.9% of its shares in BWC to a consortium of companies in 1999. However, the Senate of Berlin took back full control of BWC after remunicipalization in 2014.

Today, the Berlin Water Company provides drinking water and drainage services to 3.7 million Berliners. Utilizing groundwater reserves, nine waterworks supply Berlin and the surrounding areas with drinking water (Figure 3.1). The waterworks extract groundwater from over 700 wells between 30 m and 170 m deep and store the water in tanks before pumping it through the 7,824 km network of municipal water pipes[14]. To safeguard water quality, water protection areas have been specified as buffers around water extraction points (Figure 3.1)[12].

Figure 3.1

Water system in Berlin



Source: Berliner Wasserbetriebe, 2014b. Modified by the authors

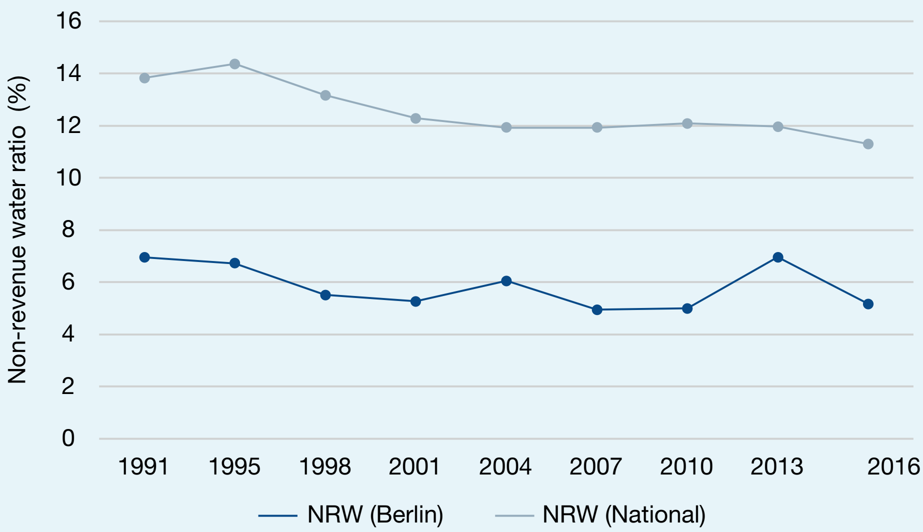
BWC assesses water loss based on non-revenue water (NRW), the water produced that is "lost" before it reaches the customer. Losses can be real losses (through leaks, sometimes also referred to as physical losses) or apparent losses (for example through theft or metering inaccuracies). The level of NRW in Berlin has fluctuated between 5% and 7% since 1991, far below the national level (Figure 3.2). From 2010 to 2013, when BWC was undergoing remunicipalization, NRW experienced a short rising blip from 4.9% to 6.9%.

The low level of NRW in Berlin was the outcome of cumulative efforts taken throughout the history of BWC, including rebuilding East Berlin's networks after World War II, investing in rehabilitating the water network in West Berlin in the 1970s, and engaging in asset management and pipe replacement efforts after reunification.

Berlin achieved low levels of non-revenue water ratio through cumulative efforts in four areas: Rebuilding East Berlin's network; rehabilitating West Berlin's network; replacing old pipes after reunification; and managing its assets.

Figure 3.2

Non-revenue water (NRW)[f] ratio
Berlin and Germany, 1991 – 2016



Source: StBA, 2016; Knobloch, 2014. Modified by the authors.

[f] The calculation of the NRW is based on the data obtained from the Germany Federal Statistics Office and calculated by the author. Non-revenue water = (Water supplied - water delivered to the users - waterworks own use) / Water supplied X 100%.

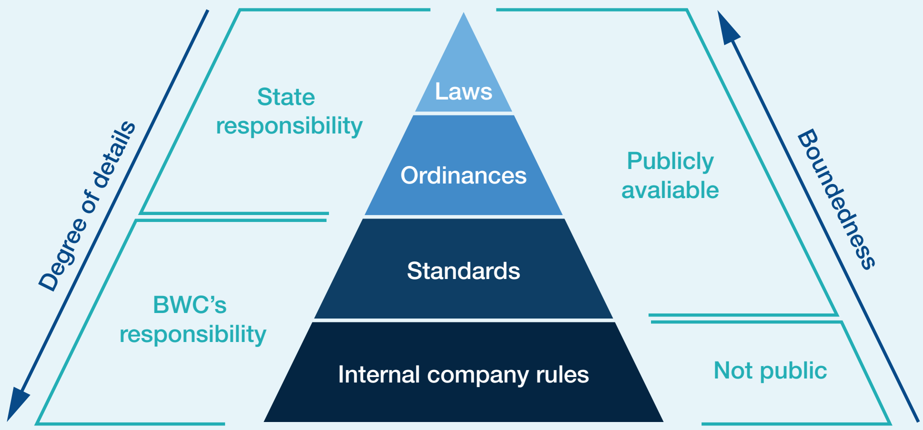
2. POLICIES AND PROGRAMS

When the State of Berlin remunicipalized the Berlin Water Company, the city placed the state-owned utility under the regulatory authority of two ministers in the Berlin Senate. The Minister for Economic Affairs, Energy and Operations regulates the water tariff, while the Minister for Environment, Transport and Climate Protection oversees water management planning, water quantity, and water quality control[10,90].

Apart from supervision by the Senate, various federal laws and ordinances place legal restrictions on the water utility (Figure 3.3). Most relevant to the BWC, the Measurement and Calibration Law requires the replacement of water meters once every six years to limit measurement deviations. It also specifies the quality and labeling of water measuring instruments[59,88]. The Antitrust Law empowers the Cartel Office to investigate the operation of the water utility for price abuse concerns. If these occur, the authority will request the water utility to readjust the price. Stringent application of this Law could restrict BWC ability to raise enough funds for project works. Lastly, the Drinking Water Ordinance stipulates the minimum requirements for the extraction, treatment, and distribution of drinking water as well as inspection, notification, action, monitoring, and reporting requirements[120].

Figure 3.3

Legal framework of water industry in Germany



Source: Jagodzinski and Schülken, 2014, p.6

In addition to the legally binding federal laws and ordinance, BWC has established standards and internal rules to guide the construction, operation, and maintenance of the water supply system (Figure 3.3). These derive from guidelines established by the German Association of Gas and Water Experts (DVGW), a professional body with a quasi-legal status. DVGW's duties include:

- Outlining technical specifications,
- Documenting the best available technology,
- Stipulating minimum qualifications required for employees in waterworks,
- Setting specifications for pipelines, conditions for pipe-laying, qualifications required for pipe installation enterprises, and
- Serving as the basis for voluntary product certifications[55]

Two sets of DVGW guidelines specifically relate to water loss management: W392 and W400-3. The W392 "Network inspection and water losses-activities, procedures and assessments" guidelines, published in 2003, outlined three pillars for a comprehensive maintenance strategy:

i. Inspection – regular, scheduled inspection of the system and its components;
ii. Maintenance – preventive and corrective; and
iii. Repair and rehabilitation[33]

3. METHODS AND TECHNOLOGIES

The technological measures adopted by Berlin mainly focused on pipe replacement and asset management, with more recent efforts to implement more innovative technologies. During the 40-year separation between East and West Berlin, the two water utilities adopted completely different strategies in pipe network maintenance. West Berlin consistently carried out pipe replacement in the event of damage or road construction. In contrast, East Berlin focused on repairing pipes; and only replaced pipes in exceptional cases[87]. As a result, the rate of pipe breakage in East Berlin has been higher than that in West Berlin since 1965.

From 1965 – 1995, pipe breakage in East Berlin rose steadily from 0.09 to 0.34 breakages per km per year. Meanwhile in West Berlin, the number never exceeded 0.1 breakages per km per year during the same period. With recent efforts to improve East Berlin's water infrastructure, the number of breakages has decreased to 0.119 per km in 2008.

OptNet® asset management software

After reunification in 1989, BWC invested in improving the network of East Berlin[87], which included deploying OptNet® asset management software. This software helps determine optimal network rehabilitation strategies by factoring in technical conditions such as pipe age and materials, hydraulic performance, and monetary valuation. BWC used OptNet® to conduct an initial evaluation of the pipe network conditions in East Berlin. The assessment information was then used to identify pipes that needed immediate replacement, and to predict those likely to experience future breakages[70].

Trenchless rehabilitation

BWC employs two trenchless rehabilitation methods to efficiently and cost- effectively repair, renew, or replace pipes. Trenchless methods eliminate the need to dig long trenches to access old or damaged pipes and don't disturb surfaces as much. The first method inserts flexible plastic pipes into the existing pipe from a manhole to reinforce the pipe's structural integrity. Secondly, BWC uses "micro-tunneling," in which they remotely bore a tunnel for the pipes, minimizing the disturbance to road traffic and other underground pipelines[54]. BWC renews around 54 km of pipe network every year, and the utility renewed 30% of water mains in the 2000s[13].

Service connection depth

When building a new service connection, BWC installs service pipes 1.6 m below ground to prevent them from freezing in winter, and to keep the water cool in the summer to prevent bacterial and pathogen growth. To contrast, telephone and electricity lines are installed at 0.6 m and 0.7 m depth respectively[16].

W-Net 4.0 digitized water network

The water loss control focus of the utility has shifted in recent years from pipe replacement to asset management and digitization of the water network. In 2018, BWC launched a project called “W-Net 4.0” to provide a centralized platform to manage and analyze the data and information obtained from the water system. The water mains network is completely digitally mapped and sensors systematically monitor parameters such as water quality, network utilization, and the functioning of the corresponding networks[35,36].

Active leak detection

The current drinking water system in Berlin is 52 years old on average, with pipes comprised of a variety of materials. The company carries out active leakage detection by checking the fittings in pipe networks annually and the water mains once every four years[12,16].

4. KEY LESSONS

BWC strategically investigated and prioritized effective management actions that led to its successful control of water loss. Results from an asset management assessment taken after the reunification persuaded BWC to prioritize the replacement of high-risk pipes in East Berlin. These efforts resulted in a decrease from 0.34 breakages per km in East Berlin in 1995 to 0.119 breakages per km in 2008. When the NRW ratio stabilized, BWC progressively investigated other technological measures to enhance the efficiency of the water loss control programs, including trenchless technology and a data analytics and mapping platform.

Clear guidelines from the German Association of Gas and Water Experts (DVGW) allow BWC to draw from established technical standards and the best available technologies to customize the city's standards and management strategies.

Despite successful efforts to maintain an extremely low NRW rate since the 1990s, climate change and drier, hotter, and longer summers will create new challenges for BWC. The water utility is currently working with the city government on a "Water Masterplan" that includes an assessment of whether the pipe network is flexible enough to deal with extreme heat and rainfall, and whether the capacity of its waterworks should be increased. Further, BWC is looking at where it should be investing. It is concerned that restrictions on tariff levels will make it difficult to raise additional funds necessary for addressing the impacts of climate change.

New technologies, effectively combined, could produce significant impacts on water loss management. Digital mapping and data analytics could complement pipe replacement technologies to create a centralized asset management system that offers improved efficiency and accuracy in leakage detection and control.

With the case of Seoul and Berlin, so far, we see the significant impacts of new technologies in water leakage control, such as in pipe replacement, rehabilitation of pipes, and active leakage detection. These mapping and data analytics platforms can complement pipe replacement technologies, and create centralized asset management systems that can facilitate coordinated, more effective approaches to water loss control. Having software platforms that determine optimal network rehabilitation strategies based on factors such as pipe age and materials, hydraulic performance, and cost effectiveness, will henceforth improve efficiency and accuracy in active leakage control and detection, and pipe replacement.

The successes of Seoul and Berlin may then lead one to think - are novel, cutting- edge technologies the only solution that can promise successes in addressing water leakages? To answer this case, we turn to look at Sydney. With strategic planning and tailored approaches, we learn that conventional methodologies and approaches can have their equivalent successes too.

Chapter 4

SYDNEY

Case Report

SYDNEY

Water provider:

Sydney Water Corporation (“Sydney Water”).

Population served:

Five million people in Sydney, the Illawarra and the Blue Mountains.

Water supply:

Blue Mountains and the Southern Highlands, with 80% supplied by the Warragamba Dam.

Water loss concerns:

Recent droughts and climate change-induced weather uncertainties represent a significant challenge for Sydney’s urban water supply management, making every drop count.

Policies and programs:

- Uses the International Water Association’s (IWA’s) water budget method to estimate leakage rate.
- Applies the concept of Economic Level of Leakage (ELL) to identify the optimum leakage level in economic terms.

Methods and technologies:

- Initiated an Active Leak Detection Program in 1999 and a Pressure Management Program in 2005.
- Introduced improved leak/break response time program in 2006.
- Applied or piloted several innovative technologies including: a Customer Hub, advanced pipe sensing technology, and LIDAR technology.

Accomplishments:

- Maintained a water leakage rate at approximately 10% or below since 2006.
- Reduced leakage by 20 billion liters of water per year, over the last two decades, attributed to the Active Leak Detection Program.
- Manage pressure in a quarter of Sydney Water's network

Takeaways:

- Water budgeting and accounting policies, such as the IWA water budget method and ELL, can drive the appropriate use of methods and technologies to meet benchmarks.
- Despite the limited use of innovative technologies to date, Sydney's water leakage rate is lower than 90% of water utilities globally.
- Climate change threatens to increase water scarcity in Sydney, requiring further research and design efforts to test and develop innovative technologies to effectively control water loss.
- Programs to increase the speed and quality of repair work have made a relatively small contribution to total water loss reduction in Sydney.

1. INTRODUCTION

Sydney Water Corporation (hereafter "Sydney Water") provides water services to more than five million people in Sydney, the Illawarra, and the Blue Mountains[22]. This is the largest metropolitan population served and the highest total water demand in Australia[117] (Figure 4.1). Most of Sydney's drinking water comes from the Blue Mountains and the Southern Highlands, with 80% of greater Sydney's water supplied by the Warragamba Dam that collects water from the Wollondilly and Coxs river systems.

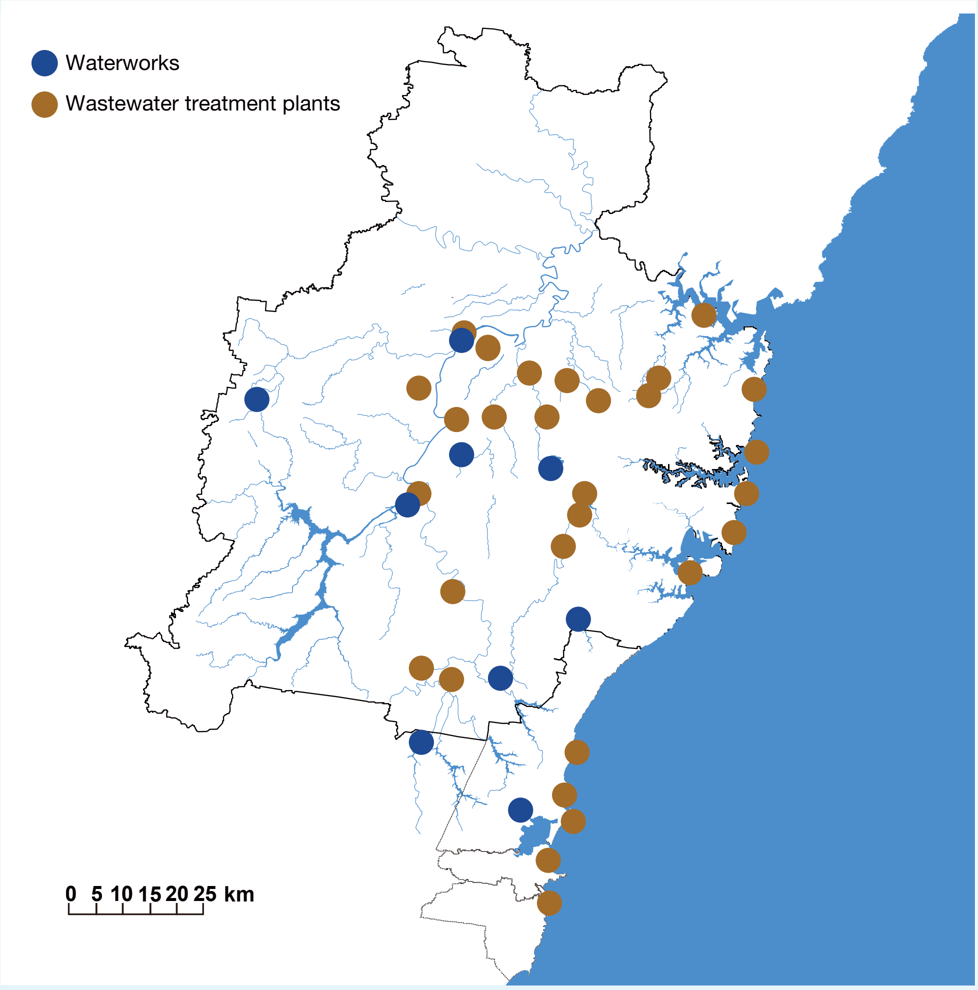
Sydney Water is a statutory corporation wholly owned by the New South Wales (NSW) government and operated under the provision of NSW's Water Management Act. Sydney Water has been instrumental in reducing the city's water leakage rate to less than 10% in recent years, placing the city among the top 10% of water utilities globally for minimizing leaks[117].

Sydney's water managers will need to pay more attention to water loss control in the future because climate change uncertainties will exacerbate that city's water variability and scarcity.

Climate change-induced weather uncertainties represent a significant challenge for urban water supply management in Sydney. High summer temperatures, coupled with increasing rainfall variabilities, have exacerbated drought conditions in and around Sydney since 2003. For example, reservoir levels dropped to 51% in 2019, placing significant pressure on the city's urban water supply system[117]. Water loss control will be even more important under future projections of increased water variability and scarcity.

Figure 4.1

Water delivery system in Sydney



Source: Sydney Water, 2016

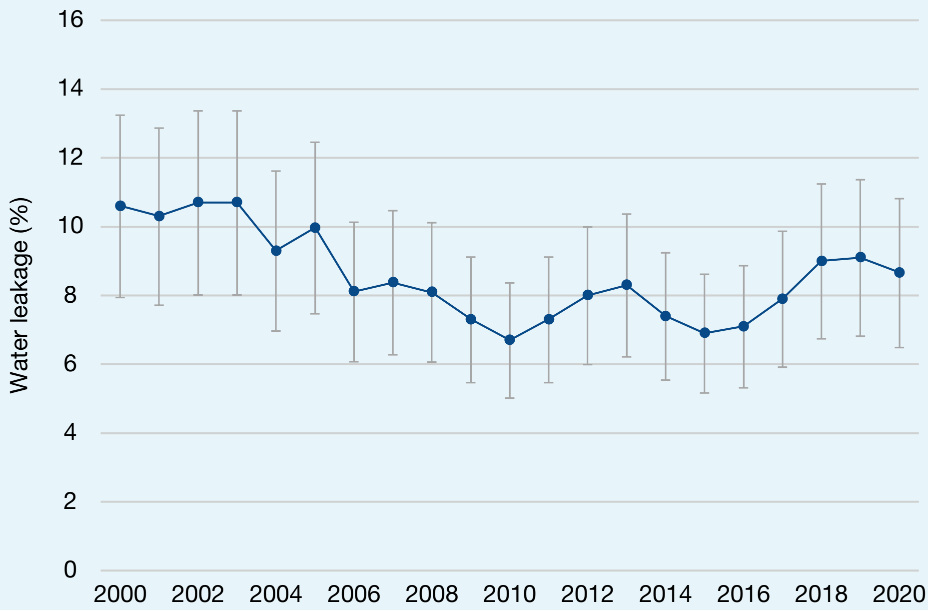
2. POLICIES AND PROGRAMS

Sydney Water began applying water budgeting and accounting methods to aid water loss control decision making in 2002. Sydney Water defines non-revenue water as "water that has been supplied and then lost from the network infrastructure, through either unbilled (authorized) consumption, apparent losses (unauthorized consumption – water theft – and meter inaccuracies) and real losses (leakage)"[130].

Sydney Water adopted the International Water Association (IWA) water balance approach to estimate the average leakage rate in 2003[106]. While the water balance method provides a simple method to estimate leakage, it has a large uncertainty band of around 25% of the total water leakage ratiog. Sydney Water has maintained a water leakage rate[g] at approximately 10% or below since 2006 (Figure 4.2) due to an array of water loss control measures (Figure 4.3).

Figure 4.2

Water leakage (expressed as a percentage of potable water drawn) in Sydney, 2000 – 2020

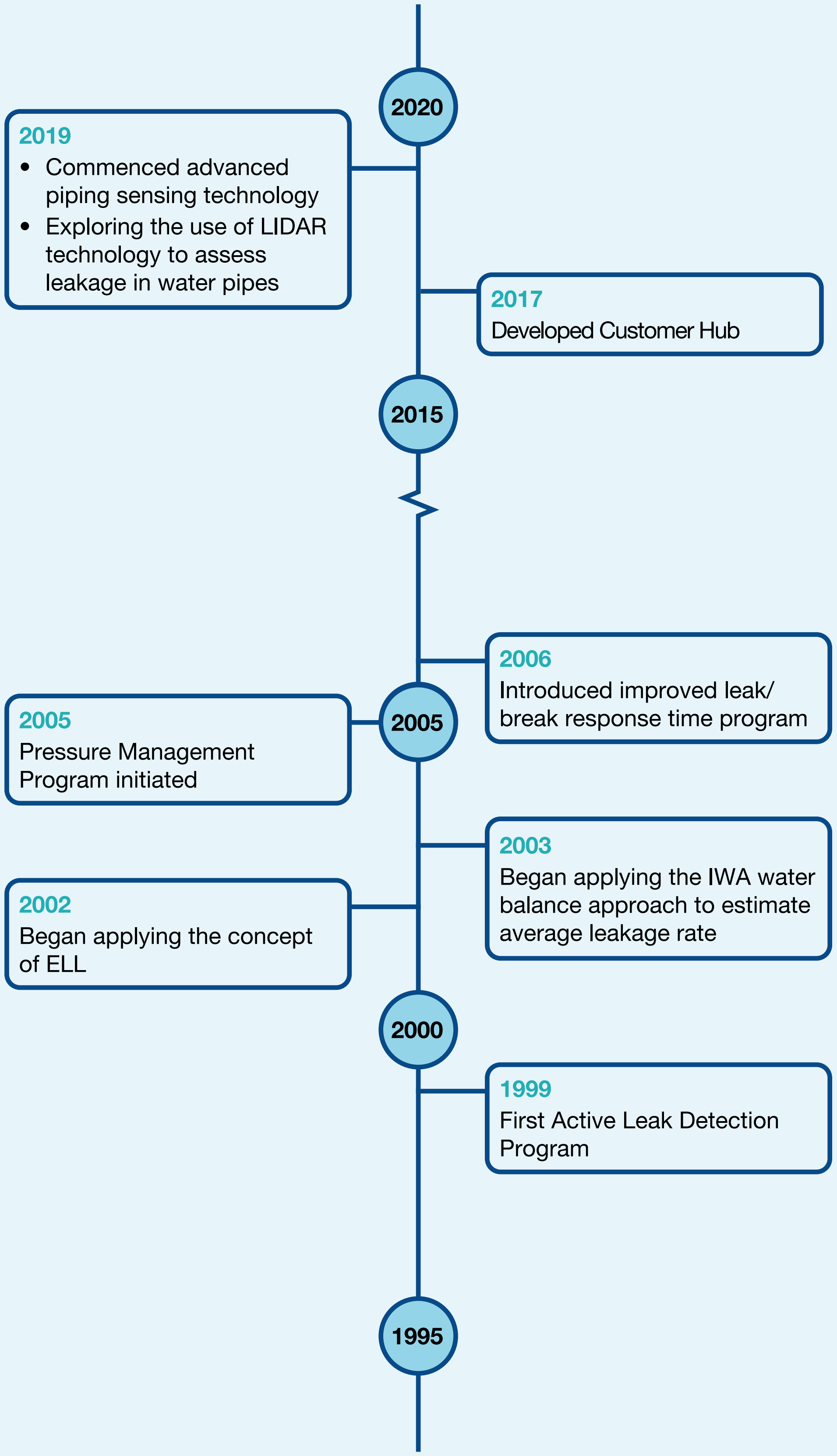


Sources: Water Conservation and Recycling Implementation Report 2003 – 2004, 2004 – 2005, 2005 – 2006, 2006 – 2007, 2007 – 2008, 2008 – 2009, 2010 – 2011, Water Efficiency Report 2011 – 2012, 2012 – 2013, 2013 – 2014, 2014 – 2015, Water Conservation Report 2017 – 2018, 2018 – 2019, 2019 – 2020

[g] All water balance calculations include data uncertainties, to a greater or lesser extent; and the uncertainty can be assessed by including confidence limits in the calculations.

Figure 4 .3

Timeline of measures to reduce water loss in Sydney



Sydney Water uses the Economic Level of Leakage (ELL) to identify the optimum leakage level in economic terms (Independent Pricing and Regulatory Tribunal, 2005). From 2003 to 2015, Sydney Water estimated ELL at 105 million liters per day (ML/day) (Figure 4.4). In 2016, the utility increased ELL to 108 ML/day, based on a consideration of the short-run cost of water, Warragamba Dam's level (65%~70%), and an uncertainty band set at ±16 ML/day.

Sydney Water managers have discovered that climate change has exacerbated the water leakage problem: Extreme changes in weather conditions have caused the ground to contract and swell, leading pipes to move around and thereby increasing the risk of bursts.

From 2015 onwards, the leakage percentage increased slightly from 7% to 9.1% (Figure 4.2). Sydney Water attributes this rise in leakage to a period of higher-than- average temperatures and increased rainfall variability, exacerbating the region's drought conditions. Alternating conditions from hot and dry weather to wet and cold (freezing) weather causes the ground to contract and swell, especially in reactive soils. This can cause pipes to move and can result in bursts. Managing intensifying drought conditions represents a significant challenge for Sydney Water, particularly in the context of increasing variability due to climate change.

3. METHODS AND TECHNOLOGIES

Sydney Water undertook three primary programs to save water and reduce real losses in the city's water network, namely, active leakage control, pressure management, and improved leak/break response times (Table 4.1). The most significant water savings resulted from the leakage control programs, which saved 24,018ML/year in 2009 – 2010, followed by the programs for pressure management and leak/break repairs.

Active leak control

Sydney Water initiated its first Active Leak Detection Program in 1999, under an operating license granted by the NSW Government.
The program included a host of measures to monitor flows in metered areas and evaluate the risks of potential leaks or breaks, including:

- Acoustic leak detection sensors and electronic equipment; and
- Active leak control measures along pipelines and assets including material selection, installation, maintenance, replacement, and infrastructure network renewal (Table 4.1).

Between 1999 and 2018, Sydney Water attributes a leakage reduction of 20 billion liters of water per year to this Active Leak Detection Program.

Table 4.1 Program investment and water savings

Program	Active leak detection	Pressure management	Improved leak/ break response time
Description	Acoustically scanning for concealed leaks in buried pipes, repairing pipes identified	Installing pressure reducing valves in the water system to reduce the incidence of leaks	Improving Sydney Water's response time to repair leaks and reduce water loss
Year started	1999	2005	2006
Year on hold	Ongoing	2013	2011
Reported number	217,635	179	N/A
Unit	km pipe surveyed	Pressure reduction schemes	N/A
Average annual water savings (million liters/ year)	20,000	10,000	730
Total investment (uncorrected) (000s $ gross, up to 2018/2019)	53,185	71,479	24,000
Remarks	Ongoing	A quarter of Sydney Water's network is now pressure managed. Additional investment in pressure management is unlikely to bring forth any further reductions in leakage rate.	Leaks reported by size and risk, repaired to standard practice.

Source: Sydney Water, Water Conservation Report, 2018 – 2019, Page 44-45

Pressure management

Following the successful implementation of active leak control measures and a three-year study on leakage and pressure management conducted by the Water Services Association of Australia (WSAA), in 2005, Sydney Water implemented a pressure management program (Table 4.1). The study highlighted the benefits of pressure management for flow reduction and an associated cost reduction for the water utility as well as improved service for the consumer. Sydney's pressure management program has helped reduce water loss, leading to a water-saving of 10 billion liters per year from 2005 to 2013.

Improved leak/break response times

In 2006, Sydney Water introduced its third measure—an improved leak/break response time program, managed by TakaDu's network monitoring and analytic services (Sydney Water, Water Conservation Report, 2018 – 2019, Page 44-45) (Table 4.1). Sydney Water measures the response time as the time from receiving a break/leak notification to the time the reported water loss incident is brought under control.

The Independent Pricing and Regulatory Tribunal (IPART) recommended that 90% of all leaks should be repaired within three days of a leak being detected or reported. In theory, promptly detecting leaks and completing quality repair jobs should reduce leakage volume. However, various evidence shows that the speed and quality of repair work have made a relatively small contribution to total water loss reduction in Sydney (IPART, 2005). At the same time, this may partly be due to the relatively small investment in this program compared to the investment in the active leak control and pressure management programs (Table 4.1).

Innovative technologies in leak detection and control

While Sydney Water has relied on conventional technologies to reduce real water losses, it has also explored the application of innovative technologies to improve its performance in managing water leakage.

Sydney Water has primarily relied upon conventional leakage control methods (e.g., active leak detection and pressure management) to reduce real water losses. However recently the utility has explored more innovative technologies, including:

- A Customer Hub for case management,
- Advanced pipe sensing technology for detecting leaks and breaks, and
- Light Detection and Ranging (LIDAR) technology to assess the wetness of around the water pipes.

The Customer Hub, established by Sydney Water in 2017, provides efficient communications and case management services for customers. A key component of this innovative technology is the digital meter, which can rapidly identify leaks in the water supply network. Unlike a traditional water meter, a digital meter contains a wireless communication device that can send the reading directly to the water utility without the need for a meter reader to take a reading on site. The meters can record and promptly transmit parameters, such as flow rate, water pressure, and temperature at 30-minute intervals.

Also, these devices do not require additional infrastructure, allowing for installation anywhere. In 2018, Sydney Water conducted its first and only test of the digital meters within the Liverpool area of Sydney, with only 100 meters installed across the region. In the next phase, Sydney Water will increase the number of digital meters in Liverpool to about 8,500.

In another example of technological innovation, Sydney Water introduced an advanced pipe sensing technology for detecting leaks and breaks in 2019, co-developed by NSW Smart Sensing Network and Sydney Water. This technology is based on acoustic and pressure transient sensing that measures the vibration on the pipe or in the water column created by water leakage. The technology is currently in trial in the Sydney Central Business District. An associated research program brings together four leading research universities from across NSW and five water utilities from Queensland, Victoria, and South Australia to assess the potential for advanced pipe sensing.

Further, Sydney Water is working closely with Hunter Water, a state-owned corporation in the Lower Hunter Region in New South Wales, and several research institutes from Australia to explore drone-mounted Light Detection and Ranging (LIDAR) technology to assess the wetness around water pipes. This technology compares light intensity with surface moisture to predict potential leakage in the pipelines.

Other novel technologies in the trial stage include quantum sensing and hydrophone arrays, which could also provide insights for improving efficiency in water loss control management. A network of smart monitoring devices, including a combination of advanced techniques under consideration by Sydney Water, could improve water leakage management and system performance.

4. KEY LESSONS

Sydney Water's programs and policies to account for water loss in the early 2000s, including the use of the IWA water budget approach and ELL, led to methods and technologies that aimed to keep water leakage at the optimum level. Sydney Water has tested and applied a variety of methods and technologies towards water loss, most prominently - active leak control, pressure management, and improved leak/break response time.

Rising water scarcity and drought conditions have also helped catalyze policies, programs, and technological innovation. This drove Sydney Water to improve water use efficiency, reduce leakage, and better manage urban water demand. Primarily using conventional leak control methods, Sydney has reduced its water supply system's leakage rate to 10%, ranking it in the top 10% of water utilities for minimizing leaks.

Climate change-induced weather uncertainties create many challenges for Sydney's urban water supply management. In terms of leakage, the increase in extremes and variability projected under climate change can cause Australia's reactive soils to swell and contract, causing pipes to move and potentially burst. Further, high summer temperatures, together with increasing rainfall variabilities place significant pressure on the city's urban water supply system[117]. The climate change impacts highlight the need for Sydney to continue (and potentially expand) current research and design efforts aimed at testing and developing innovative technologies to effectively control water loss.

One important lesson of Sydney's successful experience in controlling water losses: The effective application of technologies requires good management.

The case of Sydney illuminates that technologies do not necessarily need to be novel for effective water loss control. With a tailored approach, conventional leak control methods such as active leak control, pressure management, and improved leak/break response time can be just as successful. The success of conventional methodologies to tame complex problems such as water loss, requires good management. Having well-defined measures of water leakage, clarity of where priorities lie and how resources should be allocated would facilitate more efficient, accurate and targeted troubleshooting of water leakage points.

In the following case studies, we turn to examples that - we think - provide good management practices in water loss control. We first begin with the case of Philadelphia. Compared to other case studies, the successes of Philadelphia are not as significant. However, Philadelphia is a pioneer in leakage control efforts in the US, and one of the first utilities to adopt the full American Water Works Association (AWWA) water audit. The city of Philadelphia offers important insights on audit methodology as (1) a standard business practice for optimizing revenue, and (2) a means to evaluate the operational efficiency of water supply through analyzing sources of water losses.

We will now turn to look at Philadelphia.

Chapter 5

PHILADELPHIA

Case Report

PHILADELPHIA

Water provider:

Philadelphia Water Department (PWD) (public)

Population served:

1.7 million residents

Water supply:

Delaware and Schuylkill Rivers

Water loss concerns:

In the 1980s PWD discovered high levels of non-revenue water (NRW) resulting from leakage of treated water before it reached customers' meters. Customer service lines represent 55% of the real water losses.

Policies and programs:

- Established a Water Accountability Committee in 1992 to organize and sustain water loss reduction initiatives.
- First American water utility to, in 2000, employ American Water Works Association (AWWA)'s M36 Water Auditing Manual.
- Jointly launched the Water & Sewer Line Protection Program in 2018 to protect property owners from costly water and sewer service line repairs.

Methods and technologies:

- Installed the largest Automatic Meter Reading (AMR) system in the United States in 1999.
- Initiated a scoring system to prioritize water mains for replacement in 2014.
- Employs a traditional acoustic leak detection program with the goal to inspect the entire water systems every three years.
- Uses Sahara® inline leak sensor technology to identify leak events to address the leakage in large diameter transmission mains buried under roads with high traffic flow and CityworksTM to improve the tracking and reassessment of customer-arranged leak repairs.
- Implemented a full-scale DMA monitoring system, advanced pressure management system, and inline transmission main leak detection technology to identify leak events.

Accomplishments:

- Pioneer in implementing AMR technology and AWWA water audits.
- Incentivized customers to repair water and sewer service lines.

Takeaways:

- Philadelphia maintains access to a secure supply of cheap water to meet its demands, resulting in a lack of economic justification for obtaining low levels of leakage.
- Factors beyond those related to fiscal matters (e.g., water conservation, resource preservation) can motivate actions to drive the leakage rates to lower levels.
- Despite pioneering technological water loss control measures, non-revenue water has fluctuated between 30-40% for the last 40 years.

1. INTRODUCTION

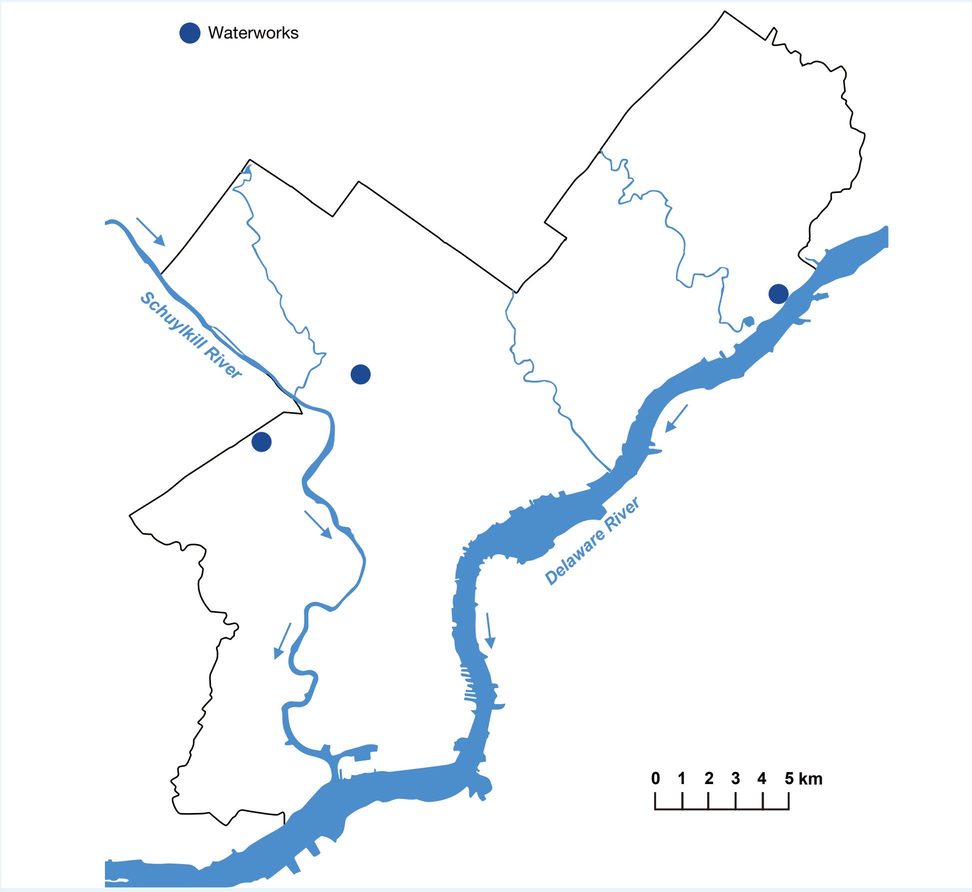
The Philadelphia Water Department (PWD) is responsible for operating, maintaining, and improving the water and wastewater systems in the City of Philadelphia, Pennsylvania, USA. The utility began operations in 1801 and currently serves over 1.7 million people. PWD extracts water from the Delaware and Schuylkill Rivers before distributing it through its 3,200-mile[h] water system, which includes 78-year-old water mains[72] (Figure 5.1).

Philadelphia Water Department was the first American water utility that put into practice, in 2000, the leakage control methods prescribed in American Water Works Association's *M36 Water Auditing Manual.*

PWD has a history as an early pioneer of implementing water loss control technology in the US. The utility installed the largest Automatic Meter Reading (AMR) system in the United States in 1999 and has also piloted many leakage control projects since then[3]. Further, PWD was the first American water utility to, in 2000, employ the American Water Works Association's (AWWA) *M36 Water Auditing Manual*.

Figure 5.1

Sources of water in Philadelphia

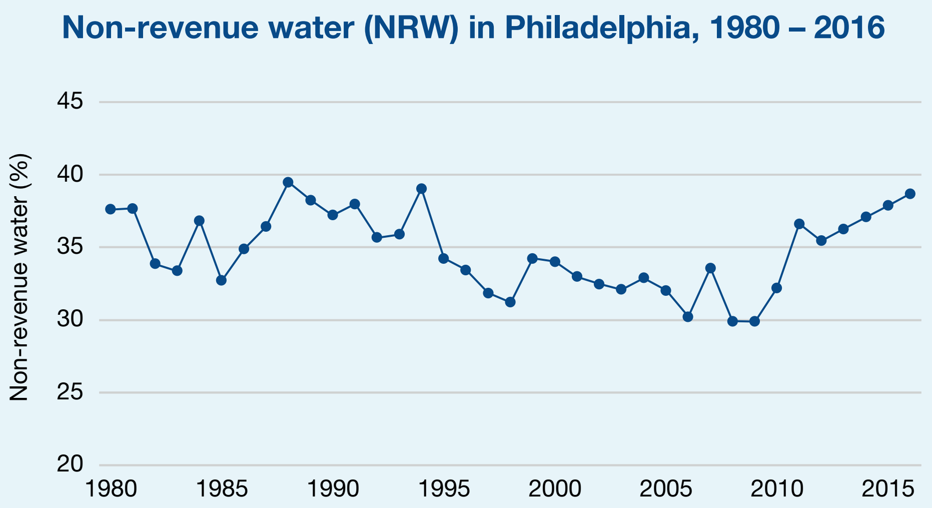


Source: Philadelphia Water Department, 2019, p.6

[h] 2,800 miles are small distribution mains. Their sizes are ranged from 6 to 12 inches while 400 miles are large transmission mains which range in size from 16 to 93 inches (Blumgart, 2018).

However, PWD faces high levels of non-revenue water, which they discovered in the 1980s when around 125 million gallons (equivalent to 473 million liters) treated water per day was not recorded by customer meters[26]. As shown in Figure 5.2, the non-revenue water ratio in Philadelphia has fluctuated between 30% and 40% from the 1980s to 2010s. It reached the lowest level, at 30%, in 2006, 2008, and 2009. Since 2012, the ratio went up again, reaching 38% in 2016.

Figure 5.2



Source: Philadelphia Water Department, 2012; AWWA, 2017; Modified by the authors.

2. POLICIES AND PROGRAMS

PWD is a municipal utility that operates under regulatory requirements from federal, state, and municipal agencies. The utility must comply with regulations on water quality set by the United States Environmental Protection Agency (EPA) and water resources planning requirements set by the Pennsylvania Department of Environment Protection. The Water Revenue Bureau (WRB), under the city's Department of Revenue, regulates water charges and fees. WRB also performs all functions relating to the reading of water meters, customer accounts, and water charge collection (Philadelphia Water Department 2011 and 2012). At the operational level, PWD and the WRB work closely to formulate and execute programs to promote water efficiency, including non-revenue water reduction. However, there is no hard target for water loss reduction[6].

PWD, together with WRB, established a multi-disciplinary Water Accountability Committee in 1992 to organize and sustain water loss reduction initiatives. The goal of the Water Accountability Committee is to promote a high level of efficiency in the water delivery and billing processes, and to perform strategic planning necessary to implement lasting improvements to water and revenue loss reduction.

The committee also networks with water industry professionals on water loss control. For instance, in 2001, they contracted international experts to conduct a Leakage Management Assessment project in the city.

Adopting AWWA M36 Water Audits and Leak Detection

Philadelphia Water Department issued its first comprehensive water audit in 2000. The water audit helped provide a complete and accurate picture of water consumption and losses in Philadelphia.

Annual water audits have been a standard business practice for PWD since 2000. To effectively measure internal leakage and revenue loss, in 1998, Philadelphia developed a water audit system based on the first edition of the American Water Works Association (AWWA)'s Manual M36. It then issued its first comprehensive water audit in 2000, which enabled PWD to gain a more complete picture of its system's operations, accurately track the city's water consumption and losses, and locate the leaks. The water audit itemizes the source and costs of real losses, such as tank overflows/ operator's errors, reported and unreported leaks, leakage from transmission main leaks and breaks, distribution main leaks and breaks, etc.

The collection of these audit data and the application of the Water Loss Control Planning Guide Worksheet in M36 have facilitated the development of a long-term water loss control program for Philadelphia. This program includes measures such as investing in an Automatic Meter Reading (AMR) system, identifying data gaps, and organizing leak detection surveys, described in Section 3.

Economic Level of Leakage

Philadelphia does not have much economic justification to attain low leakage levels, resulting in a high Infrastructure Leakage Index (ILI) - the ratio between actual real losses and an estimate of the minimum real losses that could be technically achieved in the system. In 2010, PWD experienced an ILI of 7.5, indicating real leakage levels 7.5 times greater than the minimum real losses that could be achieved. This means that any leakage reduction below an ILI of 7.5 was not financially justified based on the cost of water lost. PWD used this information to update its leakage component analysis and target-setting evaluation[i].

PWD managers use the optimum leakage level below which the costs of reducing leakage further exceed the benefits of saving water, known as the Economic Level of Leakage (ELL), to aid in decision-making[2].

In Philadelphia, leakages in customers' service pipes accounted for 55% of the city's total water losses in the 2010s. Customers, however, did not have any incentives to repair the service pipes because the losses caused by these leakages were not included in their water bills.

Philadelphia faces a high ELL, for three main reasons. First to investigate water leaks, Philadelphia charges a higher cost of USD 253 per km in comparison with USD 140 per km in Halifax and USD 124 per km for typical leak detection contractors. Second, PWD has faced low marginal costs of water, due to secure access to sufficient supplies in conjunction with decreasing demands due to a declining municipal population. Third, PWD does not own the water pipes connecting mains in the street to houses and businesses (Figure 5.3), thus the city doesn't have the authority to fix them. Since water meters are installed inside the premises of residences and not at points of connection with the water mains, leaks are often not reflected in customers' water bills and go undetected. Even if customers detect a leak outside their home, they do not have any incentive to repair the pipes since their the leakage does not affect their bill. Further, some of the pipes are buried underground with high repair costs[9]. As a result, customer service lines represent 55% of the real losses (Figure 5.4).

Importantly though, PWD is facing increasing pressure to reduce leakage. The marginal production costs of water increased substantially from USD 240/million gallons in 2010 to USD 345/million gallons in 2012[77]. Further, other factors (e.g., water conservation, resource preservation) seem to motivate PWD to drive the leakage rate to a lower level.

[i] Infrastructure Leakage Index (ILI) refers to the ratio between actual real losses and estimated minimum real losses, the latter of which is calculated through a formula developed by the International Water Association Water Loss Task Force. This is a performance indicator of real (physical) water losses from the supply networks, and was intended to be an index that can be used to compare leakage levels across different cities. However as the index was developed using European cities as case studies, the measure is not as relevant or accurate for Asian cities that have a much higher density.

Water & Sewer Line Protection Program

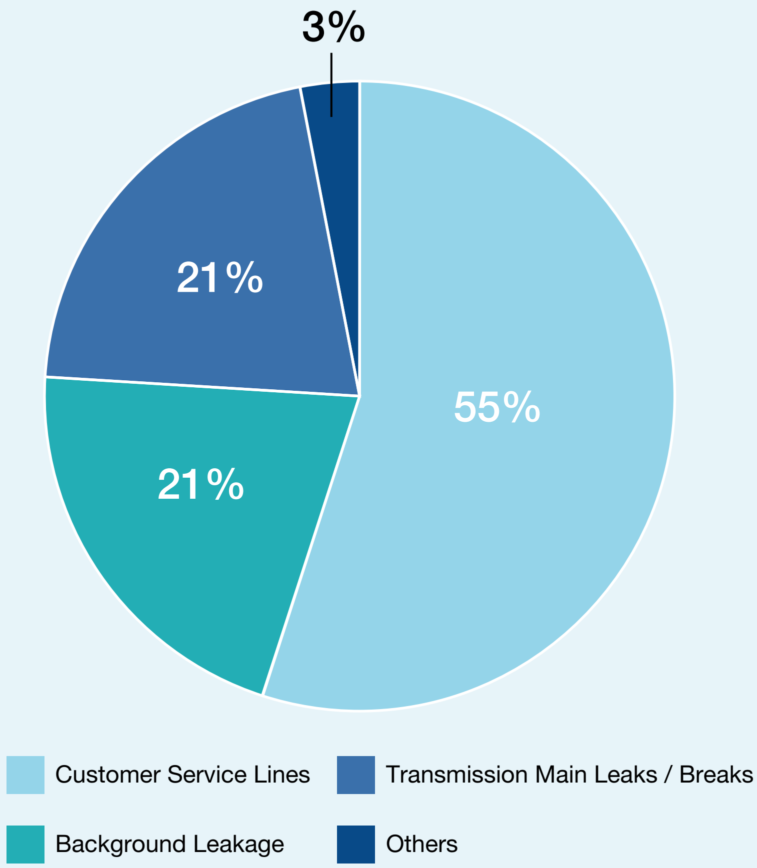
The high levels of service losses from customer service lines provoked PWD and Philadelphia Energy Authority to develop the Water & Sewer Line Protection Program to motivate customers to repair their pipes. The program allows property owners to sign up for a low-cost protection plan which covers the cost of repair and replacement of the service pipe. This program provides a subsidy to property owners to help pay for a portion of the cost of repair. In turn, it helps PWD manage the delivery cost of leaky service pipes.

Figure 5.3

Source: Philadelphia Water Department, 2014a, p. 2.

Figure 5.4

Distribution of water real losses in the City of Philadelphia in 2012



Source: Philadelphia Water Department, 2012; Modified by the authors.

3. METHODS AND TECHNOLOGIES

The City of Philadelphia operates one of the oldest water distribution systems in the United States. Approximately 71% of its pipelines are made of unlined cast iron and were installed between 1880 and 1930[72]. The leakage management efforts of the PWD focus on proactive leakage management, i.e., finding and repairing leaks while they exist in the unreported stage and minimizing excessive background leakage. Containing unreported leaks to economically low levels minimizes the time leaks go unnoticed, which can be weeks or months. This is particularly important since losses from many small, hidden, and long-running leaks can exceed the loss from large water mains breaks[61].

Philadelphia's Automatic Meter Reading system has helped reduce apparent losses by greatly reducing the number of inaccurate water bill estimates and identifying unauthorized uses of water.

Early water loss control efforts began in Philadelphia in the 1990s. An expansion of the water main replacement program and leak detection program, as well as a switch from quarterly to monthly billing, led to a notable decline in the NRW rate for the 1994 – 1998 period[2]. PWD also signed a contract in 1997 to install the largest AMR system in the United States. The AMR system reads meters remotely, greatly reducing data handling errors and the number of inaccurate water bill estimates, which has helped PWD address unauthorized uses of water and reduce apparent losses.

After these early efforts, the NRW rate increased in 1998, requiring further leak management and detection efforts. PWD piloted District Metered Areas (DMA) from 2006 to 2009 and subsequently implemented a full-scale DMA monitoring and advanced pressure management system. PWD also implemented a traditional acoustic leak detection program with an annual survey goal equivalent to one-third of the total length of the pipeline. In other words, over three years, PWD inspects the entire length of water mains[79]. To detect leakage in large diameter transmission mains buried under high traffic roads, PWD conducts Sahara® inline leak sensor technology pipeline inspections, which entail the insertion of a sensor into larger taps to locate leaks, pockets of trapped gas, and structural defects in large mains[60].

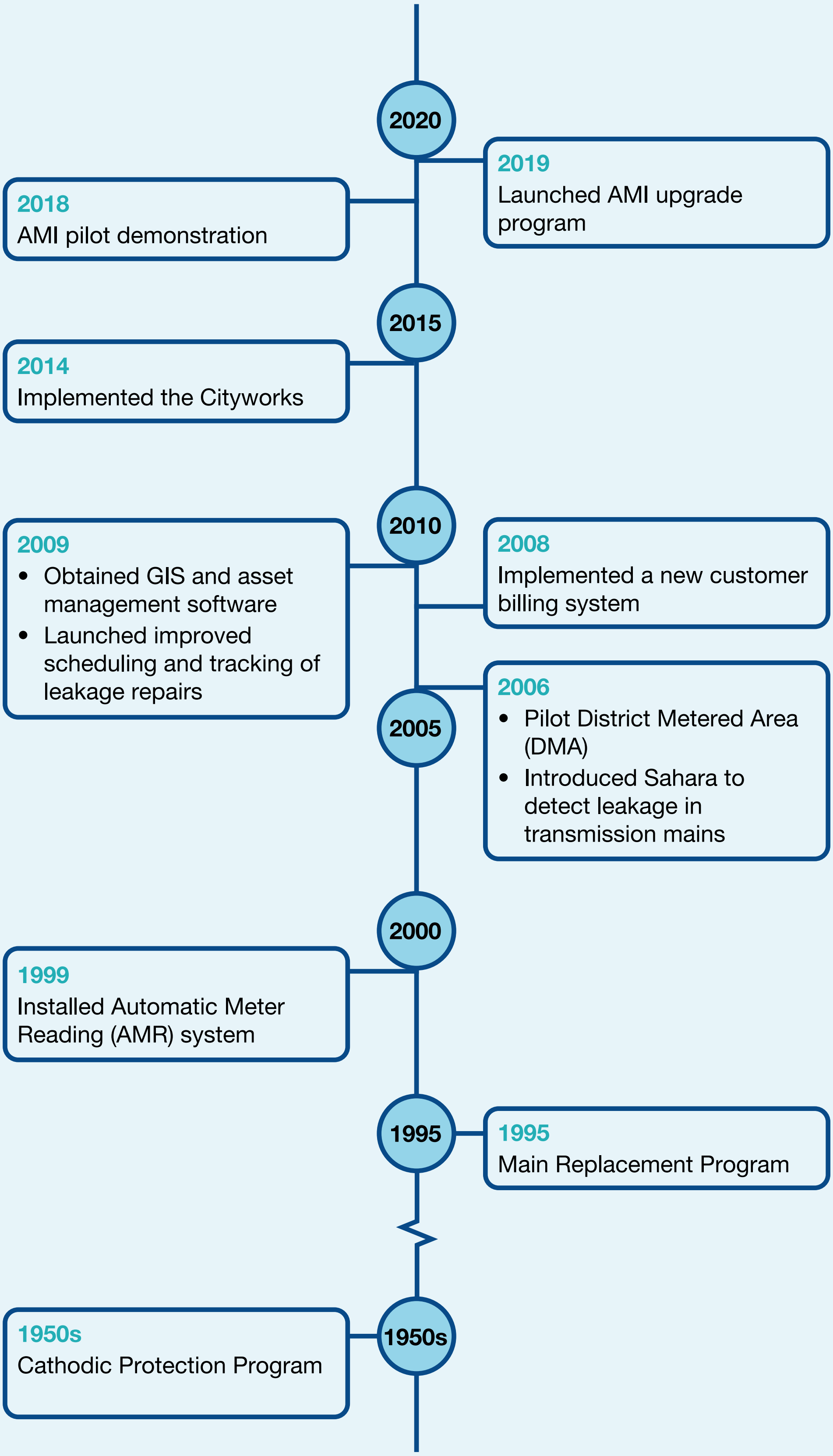
PWD has implemented more technologically advanced asset and data management activities over time. In 2014, PWD initiated a scoring system to prioritize water mains for replacement, based on pipe age and the number of recent leaks and breaks. The utility established a goal to replace 22 miles of high-priority water mains every year[18].

PWD also improved the tracking and reassessment of customer-arranged leak repairs with the application of Cityworks™, a GIS-centric management solution[77]. The Philadelphia Streets Department also uses Cityworks™, allowing the departments to compare maintenance activities and identify points of overlap and mutual involvement, such as when leak repairs affect streets and traffic.

Most recently, Philadelphia began deploying Advanced Metering Infrastructure (AMI) that automatically transmits daily water meter readings to PWD.

Figure 5.5

A summary of water supply system technologies deployed by the Philadelphia Water Department



Sources: Philadelphia Water Department, 2012, Philadelphia Water Department, 2014a, Centre for Neighbourhood Technology, 2014, Water Finance & Management, 2019

4. KEY LESSONS

Even though Philadelphia was a pioneer in adopting water loss control measures, the lack of economic incentives for both the utility and its customers to reduce leakages has resulted in relatively high levels of non-revenue water.

PWD and its customers have lacked economic incentives to significantly reduce leakage. Philadelphia maintains access to a secure supply of cheap water to meet its demands, resulting in a lack of economic justification for low levels of leakage. Until recently, customers lacked incentives to repair pipes outside their households, since the leaked water was not metered and did not affect their water bills. In response, PWD jointly developed the Water & Sewer Line Protection Program to provide economic incentives for customers to initiate repairs.

Despite the lack of fiscal motivation, PWD has invested substantial time, money, and effort into water loss control programs, policies, and technologies. This may indicate that the utility is more motivated by water conservation, resource preservation, or other factors. As the first utility in the US to adopt the AWWA water audit, Philadelphia has demonstrated the benefits of applying audit methodology as both a standard business practice for optimizing revenue, and a means to evaluate the operational efficiency of water supply through analyzing sources of water losses.

Despite pioneering technological water loss control measures, NRW has fluctuated between 30% and 40% for the last 40 years in Philadelphia. This likely relates to the high Economic Level of Leakage (ELL) – the optimum leakage level below which the costs of reducing leakage further exceed the benefits of saving water leakage. Nevertheless, as one of the first utilities to adopt the AWWA water audit, pioneer leakage control efforts and install the largest AMR facility in the US, the case of Philadelphia offers important foundational blocks for cities around the world to build upon in water loss control.

In the next section, we turn to Tokyo. Tokyo is one of the most successful cities in the world in addressing water leakages, with an impressive reduction in water leakages from 80% to 3.2% from 1945 to 2018. As we learn in the next chapter, the successes of Tokyo do lie in novel technologies, but also clear priorities, a phased approach and strong coordination between relevant enterprises, utilities and customers.

Chapter 6

TOKYO

Case Report

TOKYO

Water provider:

Tokyo Metropolitan Government Bureau of Waterworks (public)

Population served:

Approximately 13 million residents in Tokyo.

Water supply:

Tonegawa, Arakawa, and Tama River systems.

Water loss concerns:

Damage from World War II and frequent earthquakes resulted in a leakage rate of 80% in the 1940s prompting emergency leakage preventive measures. The aging system required significant pipe replacement and upgrades to further reduce water loss.

Policies and programs:

- Implements leakage prevention activities under three categories: corrective measures, preventive measures, and technological development following guidelines produced by the Japan Water Works Association.
- Required to replace domestic and industrial water service pipes when they reach their 40-year lifespan through the Local Public Enterprise Act.
- Required to replace water meters every eight years through the Japanese Measurement Act

Methods and technologies:

- Employs two types of leakage investigation methods – Minimum Night Flow (MNF) measurement method and acoustic leakage sound detection method.
- Established a mobile team for prompt repair of burst pipes and other visible leakages and for scheduling leakage detection and repair for citizens.
- Replaced aging pipes and fittings using a phased approach over several decades.

Accomplishments:

- Decreased the leakage rate from approximately 80% to 3.2% from 1945 to 2018.
- Replaced all lead pipes with stainless-steel pipes over twenty years.

Takeaways:

- Effective legislation and supervision by the government can help to promote leakage prevention.
- Replacement of aging pipes and fittings in the water distribution network not only enhances leakage preventions, but also provides safeguards for public health.
- Applying different measures according to the challenges defined in different stages over time can result in a gradual, but continual, reduction in leakage.
- Regular monitoring is important for identifying issues and taking appropriate corrective measures in a timely manner.

1. INTRODUCTION

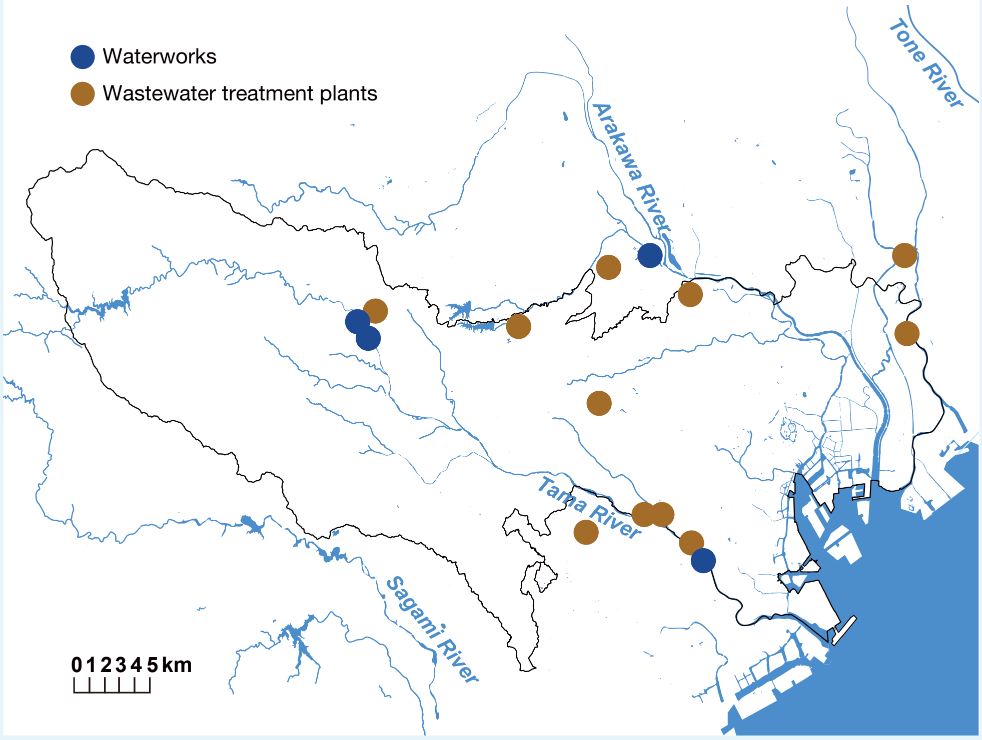
Tokyo Metropolitan Government Bureau of Waterworks, a city-owned public utility, provides water service to approximately 13 million residents of Tokyo. The city's water supply system has a long tradition that dates to the 16th century (Figure 6.1).The Tonegawa, Arakawa, and Tama River systems supply most of the water in Tokyo. With the prevalence of cholera in the 19th century, Tokyo underwent significant improvements to sustain a clean and stable water supply and modernize the water supply system. From then on, Tokyo advanced the construction of waterworks facilities to deal with increasing water consumption.

In Tokyo, Non-Revenue Water (NRW) includes unbilled authorized consumption, apparent losses, and real losses. Apparent loss include erroneous meter readings, faulty signal calibrations as well as unauthorized water consumption. Real losses are actual water leaks from storage systems, the transmission and distribution mains, as well as service lines. Illegal connections are rare and apparent loss is at the lowest possible level in Tokyo. Thus, the Bureau of Waterworks has focused on reducing leakage as a parameter for evaluating the efficiency of the water supply system. From 1945 to 2018, the leakage rate dropped from approximately 80% to 3.2%. The significant reduction was largely due to a phased technical approach for controlling water losses (Figure 6.2)[57].

In 1913, the Bureau of Waterworks began searching for and repairing leaks for the first time. Following these efforts, the Bureau emphasized different measures according to the challenges defined in different stages over time (Figure 6.2)[37]. Damages from World War II and the occurrence of frequent earthquakes resulted in a leakage rate of 80% in the 1940s, prompting the Bureau of Waterworks to carry out emergency leakage preventive measures to repair war damage. Through intensive repair activities and labor forces focused on reducing visible leakages above the ground, the leakage rate dropped to 30% within five years. After repairing the damages from the war, Tokyo shifted its focus from leakage detection to the prevention of leakage, particularly through piping upgrades and replacement. With these continual efforts to control leakages, overtime, this gradually led to a decreasing leakage rate of less than 5% today (Figure 6.2).

Figure 6.1

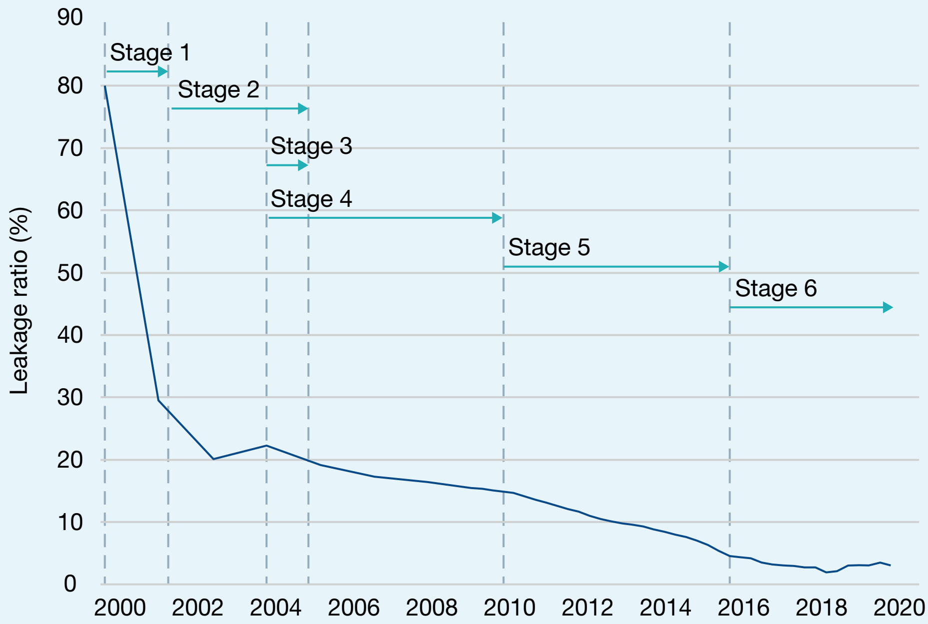
Water systems in Tokyo



Source: Bureau of Waterworks, 2018

Figure 6.2

Trends in leakage rate and time, and a staged approach to leakage management in Tokyo, 2000 – 2020



Stage	Period	Leakage rate	Focus/ Emphasis	Method
1	1945 – 1951	>30%	Decrease aboveground visible leakage	Intensive repair activities
2	1951 – 1960	30-20%	Decrease underground leakage	Zoning, accurate piping maps, training &utilizing good quality equipment for detection
3	1960 – 1964	25-20%	Prevention recurrence of leakage	Increase in leakage control work, starting replacement of deteriorated pipes, use of ductile cast iron pipe (DCIP)
4	1960 – 1982	20-12%	Leakage control work	Revision of working method & acceleration of pipe replacement work
5	1982 – 2003	12-5%	Improve service pipes	Introduction of stainless steel service pipes which are strong and durable
6	2003 – 2018	<5%	Maintain low NRW	Systematic pipe replacement and leakage control work

Source: Japan International Cooperation Agency, 2017. Modified by authors.

2. POLICIES AND PROGRAMS

In Japan, there are multiple levels of government agencies that have implemented several different policies to control water loss. The national government issues notices to promote leakage control. Most prominently, in 1950, the Ministry of Health and Welfare (MHW) tasked the Japan Water Works Association (JWWA) to prepare Water Leakage Prevention Guidelines and announced the Measures to Prevent Leakage in Water Supply Systems. Within these Guidelines, the Bureau of Waterworks implements three categories of leakage prevention activities on the ground: corrective measures, preventive measures, and technological development:

Corrective measures
included the establishment of a mobile team for prompt repair of burst pipes and other visible leakages and scheduling leakage detection and repair for citizens.

Preventive measures
generally include the replacement of old distribution pipes, material improvement work of service pipes, and the improvement of service pipe arrangement installed in private roads.

Technological development
entails the implementation of leak prevention technology and training programs.

Tokyo's water utility and its customers have fulfilled their respective share of the responsibilities in repairing leakages and broken pipes, thus equally contributing to improved performance levels of the city's water supply network.

In Tokyo, both the Bureau of Waterworks and customers have the responsibility of repairing leaks and broken pipes. Generally, the Bureau of Waterworks is responsible for the sections from the distribution pipe to the water meter, and customers or building owners are responsible for the areas between the meter and the building. Plumbers designated by the Bureau of Waterworks carry out repairs of waterworks infrastructure, under contracts with individual customers.

Tokyo has placed tremendous effort towards pipe repair and replacement, including policies to guide those practices. In 2004, JWWA prepared the "*Guidelines for Maintenance of Service Connection Facilities*" that describes the problems with maintenance and management of service connections. In 2001, the revised Local Public Enterprise Act notes that domestic and industrial water service pipes must be replaced every 40 years. Pipes that reach or exceed their lifespan are replaced according to a planned schedule.

In addition to pipe replacement and upgrades, the Japanese Measurement Act requires the replacement of water meters every eight years. The Water Supply Act requires utilities to ensure meters are in good working conditions. These strong legislative measures help keep pipes and meters up-to-date, and subsequently, minimize real and apparent losses.

3. METHODS AND TECHNOLOGIES

The corrective, preventive, and technological measures undertaken by Bureau of Waterworks primarily focus on leak investigation, and the replacement and improvement of pipes and meters.

Leak Investigation Methods

Tokyo currently uses two types of leak investigation methods – the Minimum Night Flow (MNF) measurement method and the acoustic leakage sound detection method. The Bureau of Waterworks and a private company developed the MNF measurement method, which monitors and records the water usage at midnight in a certain block, with gate valves that open and close at certain points in time. Each block contains 1,100 households, remotely monitored by a district flow meter. The measured minimum flow rate after closing the gate valves surrounding the block signifies leakage.

Secondly, Tokyo uses two acoustic leakage sound detection technologies that differentiate leak sounds from those of normal water flow through the distribution system. The two technologies are a leakage sound detection bar and an electronic leakage detector. The leakage sound detection bar is easy and convenient for leakage identification. However, it is difficult to detect the exact leak position. Electronic leakage detectors more precisely identify leak position through the amplification of an electrical signal.

Research institutions and universities in Tokyo offer formal training programs to water utility staff for them to gain expertise on both the technological and managerial aspects of leakage prevention methods.

To use these methods to properly identify leaks, training and well-skilled operators are needed. In Tokyo, human resources development has been essential to establish effective water management systems. Both research institutions and universities offer formal courses and programs for Bureau of Waterworks staff to gain expertise on the technical and management aspects of leakage prevention[56]. In addition, the Bureau of Waterworks established a trained mobile team for prompt repair of burst pipes and other visible leakages.

Pipe Replacement and Improvement of Pipe Materials

After repairing the damages from World War II, Tokyo shifted its focus to prevent leakages from occurring through piping upgrades and replacement. Early efforts from 1960 to 1964 focused on the replacement of deteriorated pipes in the distribution system with earthquake-resistant ductile cast iron pipes. In the subsequent two decades, the Bureau accelerated these efforts. Since 1960, the replacement of lead pipes greatly reduced the leakage rate from ~15% in 1982 to ~3.2% in 2018 (Figure 6.3). The replacement and advancement of pipe materials not only promotes leakage prevention, but also protects public health by preventing lead from leaching into the water supply. In addition, regular pipe replacement helps prevent debris and other containments from entering the pipes through cracks.

The replacement of lead pipes by stainless steel pipes has helped Tokyo to reduce its leakage rate from 15.0% in 1982 to 3.2% in 2018.

JWWA turned its efforts towards service pipes in the early 1980s. JWWA estimated that from the 1980s to 2000s, cracked or corroded service pipes caused 97% of leakage, with only 3% caused by aging distribution pipes (pipelines that deliver potable water to the fixtures). To address the leakage in service pipes, Tokyo began a water loss reduction program in the early 1980s to replace all the lead service piping in the network with Type 316L stainless-steel straight pipes. The stainless-steel service pipes are strong, durable, and greatly prolong the service life of the pipes used in the water supply network.

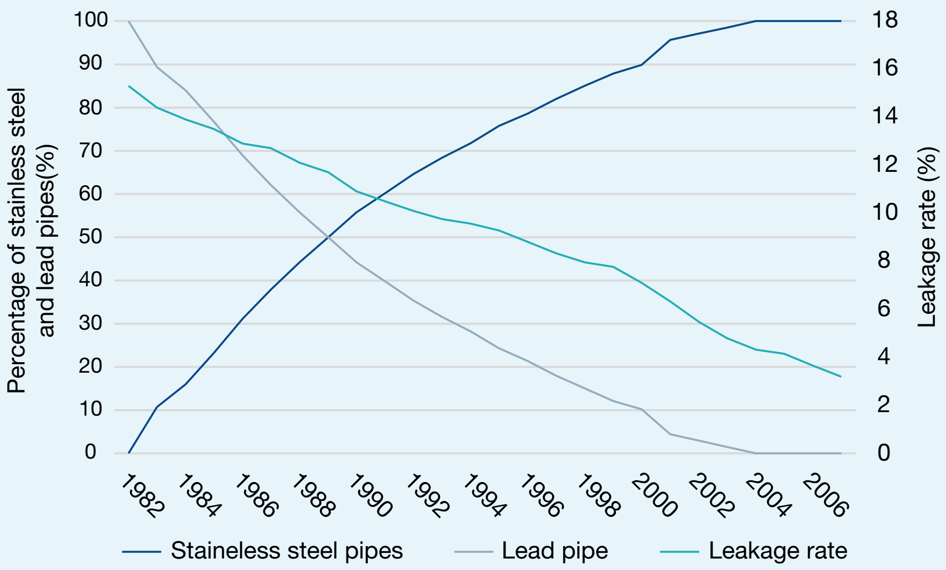
The Bureau of Waterworks also found that most leaks occurred at joints where the pipes connect. Using corrugated pipes can reduce the need for joints and elbows. These pipes are also flexible after installation, and can resist seismic shocks from earthquakes. From 1991 to 1998, Tokyo tested the performance of corrugated stainless-steel pipes and found the number of leaks and maintenances had greatly reduced. This led the Bureau of Waterworks to introduce corrugated stainless-steel for all pipe installations after 1998.

After Tokyo's water managers discovered that corrugated pipes could greatly reduce the number of leaks at joints where pipes connect, they applied this technology to all pipe installations.

To further improve the durability of the fittings towards high water pressure, earth load, earthquake forces, and chemical corrosion, the Bureau of Waterworks developed new components, such as ferrule with stainless steel saddle, flexible service connections, and saddle used in corrugated pipe system (Figure 6.3). Tokyo Waterworks has also cooperated with some private companies, and worked together to develop novel technologies for accurate leak detection and localization (Table 6.4 and Table 6.5).

Figure 6.3

Percentage of stainless steel and lead pipes and leakage rate in Tokyo, 1982 – 2006



Source: Bureau of Waterworks, Tokyo Metropolitan Government, 2019. Modified by authors.

Replacement of Water Meters

In addition to pipe replacement and upgrades, the Japanese Measurement Act requires the replacement of water meters every eight years, which helps to minimize the apparent loss caused by measurement error.

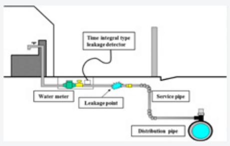
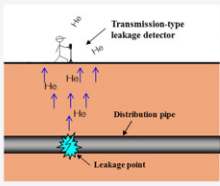
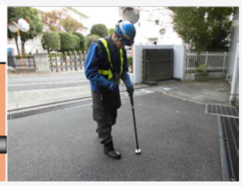
Figure 6.4

Novel components in the water supply system in Tokyo

Left to right: (a) Ferrule with stainless steel saddle, (b) Flexible service connection, (c) Saddle used with the stainless steel corrugated pipe system

Source: Japan International Cooperation Agency. 2017, International Stainless Steel Forum. 2018

Table 6.1 Technical developments in leakage prevention co-developed by the Tokyo Metropolitan Government and private companies

Leakage technology	Description	Image
Corrective leakage detector	This instrument locates the leakage by processing leakage noise picked up at two points on a pipe.	
Electronic leakage detector	This instrument can pick up the leakage noise electrically on the ground surface.	
Freezing method	This method suspends water by freezing up the water inside the pipe with liquid air during a repair.	
Portable minimum flow meter	This flow meter is used for the minimum night flow measurement.	
Time integral type leakage detector	This instrument can check whether leakage exists using the continuity of leakage noise.	 
Transmission-type leakage detector	This device locates leakage by detecting where helium gas injected into the water pipe discharges through the leakage spot to the soil.	 

Source: Bureau of Waterworks, 2019

4. KEY LESSONS

Tokyo is an excellent example of a city that successfully reduced an extremely high leakage rate (80%) to extremely low levels (3.2%). It accomplished this feat by having specific programmatic focuses over the last eighty years, and having a phased implementation of plans, programs, methods, and technologies. The rich experiences from Tokyo in controlling leakage provide three key lessons.

A combination of legislation, regulation and regulatory oversight has helped ensure Tokyo's water utility is held accountable for the effective operation of the city's water supply infrastructure.

First, effective legislation and government supervision can, and should support and promote leakage prevention in water loss management. Japan's regulations on the lifespans of water service pipes, and metering replacement periods ensure that the Bureau of Waterworks remains accountable for the maintenance of their engineering works. This is particularly important for a city, such as Tokyo, with a very old water system.

Secondly, replacing aging pipes and fittings in the water distribution network enhances leakage prevention, and protects public health by preventing lead and other pollutants from entering the water supply. The large decline in leakage rate is largely attributed to the phased approach in pipe replacement and upgrades. Guidelines and standards that require use of high-quality materials in the network assure the quality in pipe replacements.

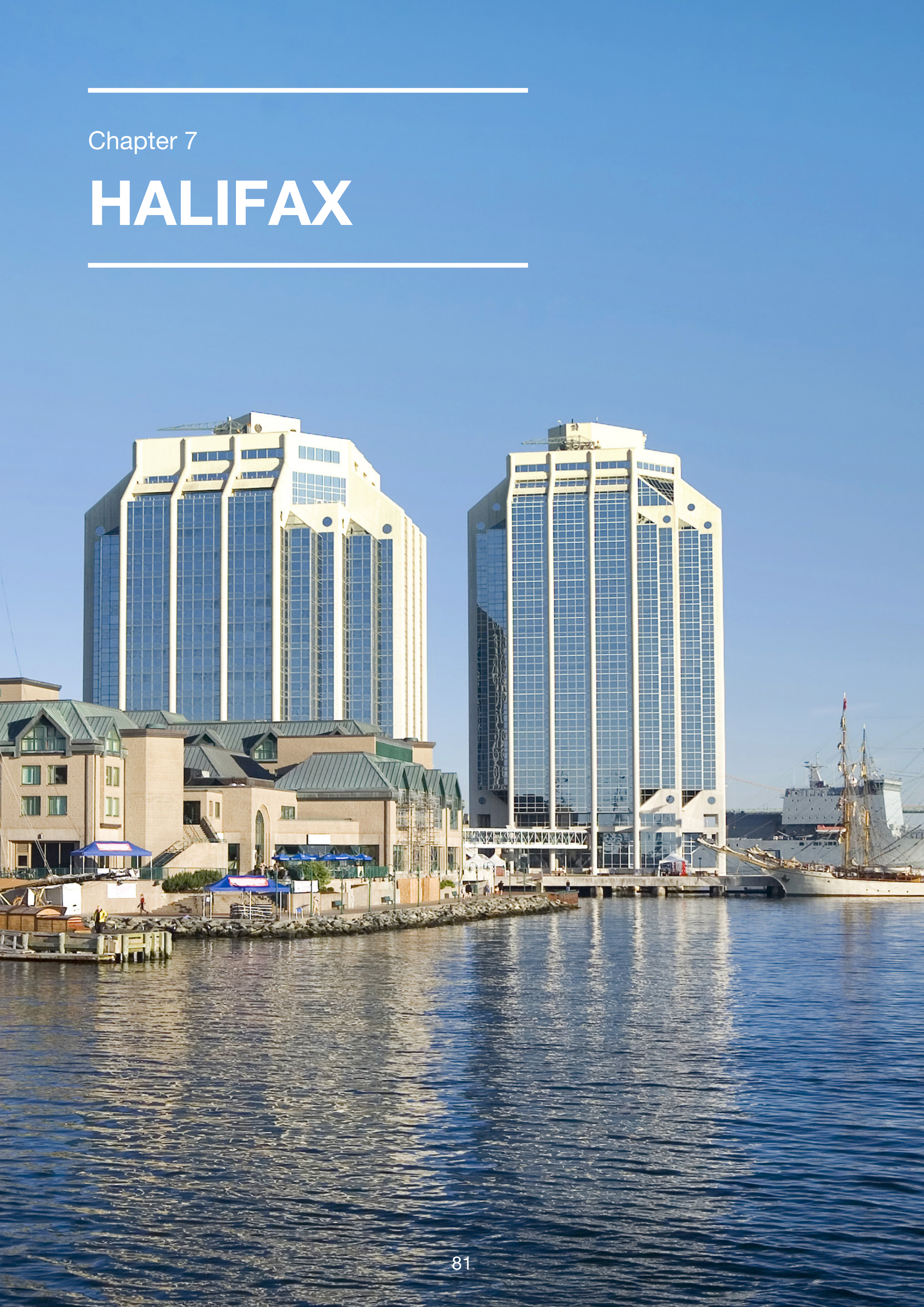
Lastly, applying different measures according to the challenges defined in different stages over time can lead to a gradual reduction in leakages. Regular monitoring is important for identifying issues and taking prompt corrective measures to address them. Tokyo developed some customized leakage investigation methods and technologies with a private company, highlighting the potential benefits of partnering with industry professionals to enhance technology development. Furthermore, formal water training programs have strengthened the human capacity at the Bureau of Waterworks, ensuring application of best management practices (BMPs) and more accurate leakage detection and management.

In sum, the Tokyo experience suggests that a phased technical approach can effectively control water loss. When cutting edge technologies in pipe replacement and leak investigation are paired together with strong coordination between enterprises, institutions and customers, the Tokyo case shows that water loss can be effectively addressed. This successful coordination between different actors is a very valuable lesson as this was what Philadelphia struggled with. Tokyo would henceforth be a strong reference as to how coordination was facilitated between different enterprises, customers and institutions.

For the final case study, we turn towards Halifax. Halifax is similar to previous case studies where conventional and novel technologies were an important component of tackling water loss effectively. However more predominantly, Halifax's significant reductions in water losses laid in the specific targets, organizational indicators and institutional measures it adopted to track water leakage. Following on from the key lessons we see with Tokyo, we will learn from Halifax that organizational measures, institutional roadmaps, and good governance are imperative considerations in effective water loss control.

Chapter 7

HALIFAX



Case Report

HALIFAX

Water provider:

Halifax Water

Population served:

360,000 residents; 109,000 connections

Water loss concerns:

In 1996, Halifax Water merged with three neighboring water utilities and discovered varying leakage levels. After the merger, Halifax Water prioritized the continuous reduction of leakage in the merged distribution system.

Policies and programs:

- Formulated an Integrated Resource Plan (IRP) with a 30-year roadmap for capital investment.
- Developed organizational indicators and targets that are reported in a Corporate Balanced Scorecard to track progress towards the company's vision statements.
- Implemented an Organizational Award Program that provides monetary incentives for employees who help meet the organizational indicator targets.

Methods and technologies:

- Implemented an Acoustic Leak Detection Program, Supervisory Control and Data Acquisition (SCADA), Master and Zone Metering, and Noise Correlators in the Central Region (before the merger).
- Developed a Comprehensive District Metered Area (DMA) design that includes 75 DMAs, each monitored by a SCADA system.
- Implemented Advanced Metering Infrastructure (AMI) in 2017 and installed 50,000 AMI meters by 2019.

Accomplishments:

- Experienced a substantial decline in unaccounted-for-water in the Central Region from 44.3% to 11.8%, before the merger (1982 – 1997).
- Reduced ILI in the West Region from 11.37 to 4.57 between 2001 – 2013.

Takeaways:

- The IWA methodology can be particularly effective at water loss control, when adopted in full, rather than in piecemeal fashion.
- Specific, measurable targets for water loss reduction are an effective method of tracking progress towards goals.
- Incentive programs can motivate employees to take more corrective actions to meet targets and improve the quality of services.

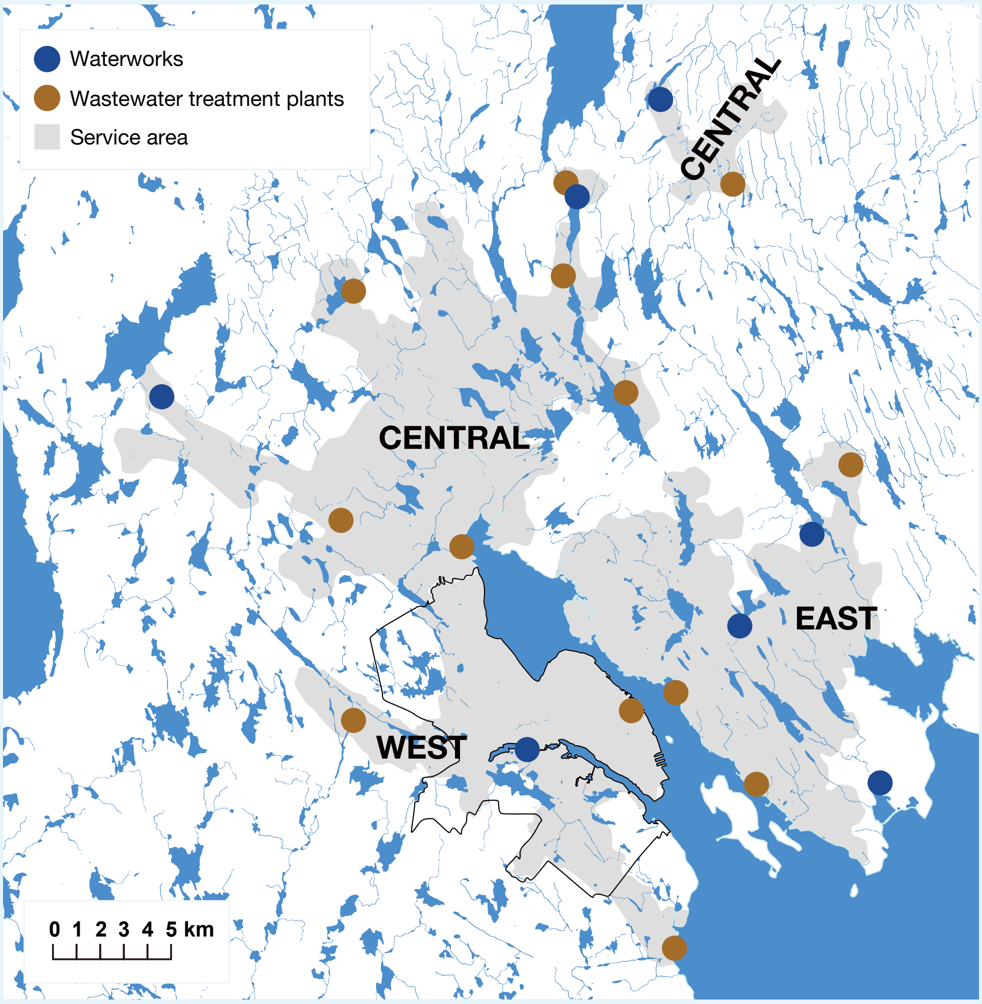
1. INTRODUCTION

Halifax Water has been serving residents in Halifax, the capital city of the Province of Nova Scotia, Canada, since 1946. In 1996, the provincial government pushed four municipal units – the City of Halifax, City of Dartmouth, Town of Bedford, and Halifax County—to form the Halifax Regional Municipality (HRM) [6,89]. Water utilities that served the original four municipal units[j] were merged into the Halifax Regional Water Commission (HRWC, "Halifax Water")[132]. In 2007, Halifax Water acquired Halifax's wastewater and stormwater assets, becoming a "one water" utility. Halifax Water is now an autonomous and self- financed utility owned by HRM that provides water, wastewater, and stormwater services to 360,000 customers. The current water supply system in HRM consists of three service areas – Central (formerly Halifax County), East (formerly Dartmouth), and West Regions (original Halifax Water) – comprised of 109,000 connections, and 1,558 k m of transmission and distribution mains (Figure 7.1).

[j] The three utilities included: Halifax Water Commission, Dartmouth Water Utility, and Halifax County Water utility.

Figure 7.1

Water system of Halifax Regional Municipality



Source: Halifax Water, 2020a

After the merger, HRWC discovered significant water losses in some of the new service areas under its service region. The three neighboring water utilities used different types of leak detection methods – such as Supervisory Control and Data Acquisition (SCADA) system development, zone master metering, and system sectorization, which led to disparate data collection and reporting. After the merger, it was a continued priority for the HRWC Commission managers to reduce leakage in the merged distribution system, and align the three different leak detection systems.

2. POLICIES AND PROGRAMS

Regulatory bodies

The Halifax Regional Water Commission's work is overseen by two Provincial government agencies: Nova Scotia Environment (NSE) and Nova Scotia Utility and Review Board (NSURB). NSE is responsible for monitoring water safety issues, such as drinking water quality, and municipal and industrial discharges from wastewater treatment facilities. NSURB, an independent body with both regulatory and adjudicative functions, regulates water rates, and has the authority to approve large capital expenditure projects. This regulator ensures that water utilities meet the financial requirements stated in the Public Utilities Act[47,86].

Full adoption of IWA methodology

After the merger in 1996 and the discovery of diverse levels of water loss in the new service areas, a steering committee comprised of representatives from all departments of Halifax Water, i.e., distribution system operations, engineering, finance, and customer service, was formed in 1999 to identify the best practice of leakage control.
The following year, HRWC decided to adopt the full set of International Water Association (IWA) best practices on water loss control, including measures of billed and unbilled, authorized and unauthorized consumption, as well as use of the infrastructure leakage index (ILI)[k]. ILI is a performance indicator of real water losses from water supply distribution systems.

Accordingly, they carried out a utility-wide water audit of the former water utilities to evaluate the ILI performance of each service area. The large variance of ILIs among the three service areas convinced HRWC managers to give top priority to water loss reduction.

[k] The complete manual on Performance Indicators for Water Supply Services can be found on the International Water Association (IWA) website: https://www.iwapublishing.com/books/book-series/manual-best-practice- series

Table 6.1 Initial ILI calculations in 2000, after the adoption of the IWA methodology.

Service Area	Infrastructure Leakage Index (ILI)
Central	1.6
East	4.8
West	12.2

Source: Yates, 2005

Since adopting the IWA methodology, Halifax's overall ILI has almost halved, from 6.04 in 2001 to 3.09 in 2017, just barely missing the target ILI of 3.00. The West Region has maintained the highest ILI over time, but also experienced the greatest decline of ILI in any region, from 11.37 in 2001 to 4.57 in 2013.

Plans and targets

In 2012, at the direction of NSURB, Halifax Water prepared an Integrated Resource Plan (IRP) laying out a 30-year roadmap for capital investment in both operations and maintenance. This plan considered the demands of regional growth (Infrastructure Master Plan), regulatory compliance (Compliance Plan), and asset renewal (Asset Management Plan) (Halifax Water, 2020c). The 2019 updated IRP recommends key performance indicators (KPI) of asset management, five of which relate to water loss control (Table 7.2).

Table 6.2 Key Performance Indicators (KPI) in the Halifax Water Integrated Resource Plan 2019 that were related to water loss control.

Measure	KPI
Active Leak Detection: % of leaks proactively detected (prior to reported customer issue or billing inquiry) versus total leakage incidents	>95%
Infrastructure Leakage Index (ILI) and total losses per service connection: ILI is the ratio between actual real losses and an estimate of the minimum real losses Total losses measure the sum of distribution losses and supply pipe losses per day and this is divided by total connections (liters per connection per day)	ILI <3.0 Losses <200 liters/ connection/day
Night Flow Analysis to assess possible leakage or unwanted customer internal plumbing losses: Average nighttime liters per residential service connection (liters/connection)	<50 liters/ service connection
Transmission Main Upgrades Meters replaced/year (m/yr): % of mains in poor condition	<5% in poor condition
Advanced Metering Infrastructure / Smart Metering: % of leaks proactively detected (prior to reported customer issue or billing inquiry) versus total leakage incidents	>95%

Source: Halifax Water, 2020c.

Halifax Water has developed a set of organizational indicators and targets to help measure and monitor the performance of its staff in regard to water loss control.

Halifax Water also developed eight "critical success factors" [l] to support the utility's vision statements[m]. To track the utility's performance, Halifax Water developed organizational indicators and targets that they annually report to the Halifax Regional Council (HRC) in a Corporate Balanced Scorecard. One of these indicators include Water Loss Control, which is measured in leakage liters per service connection per day. It is one of the organizational indicators used to evaluate "Effective asset management" (Table 7.3)[44].

To provide incentives for workers to maintain high levels of services, Halifax Water uses a subset of organizational indicators to determine monetary rewards for employees through an Organizational Award Program.

Table 6.3 Water Loss Control Target (2016 – 2021).

Year	**Target** [n] (Liters/Service Connection/ Day)	**Leakage Actual** (Liters/Service Connection/ Day)
2016/17	180-190	223
2017/18	180-190	198
2018/19	180-190	185
2019/20	N/A	177
2020/21	160-170	193

Source: Halifax Water, 2018a; 2020a. Actual leakage provided by Halifax Water. Compiled by the author.

[l] Critical success factors: 1. High Quality Drinking Water; 2. Service Excellence; 3. Responsible Financial Management; 4. Effective Asset Management; 5. Workplace Safety and Security; 6. Regulatory Compliance; 7. Environmental Stewardship; 8. Motivated and Satisfied Employees

[m] The vision statements are:

- We will provide our customers with high quality water, wastewater and stormwater services.
- Through the adoption of best practices, we will place the highest value on public health, customer service, fiscal responsibility, workplace safety and security, asset management, regulatory compliance, and stewardship of the environment.
- We will fully engage employees through teamwork, innovation, and professional development.

[n] This target is adjusted according to the latest IWA methodology. Of note, these indicators differ from the key performance indicators (KPI) of 200 liters/connection/day and should be reconciled to ensure consistency.

3. METHODS AND TECHNOLOGIES

Before the merger, Halifax Water and the regional systems used various degrees of technological measures, with the Central Region putting the greatest efforts towards leakage management). From 1982 – 1997 the Central Region experienced a substantial decline of unaccounted-for-water from 44.3% to 11.8%. This decrease resulted from the progressive application of leakage control technologies, including:

- An Acoustic Leak Detection Program
- District Metering Areas and SCADA, Master and Zone Metering, and
- Noise Correlators

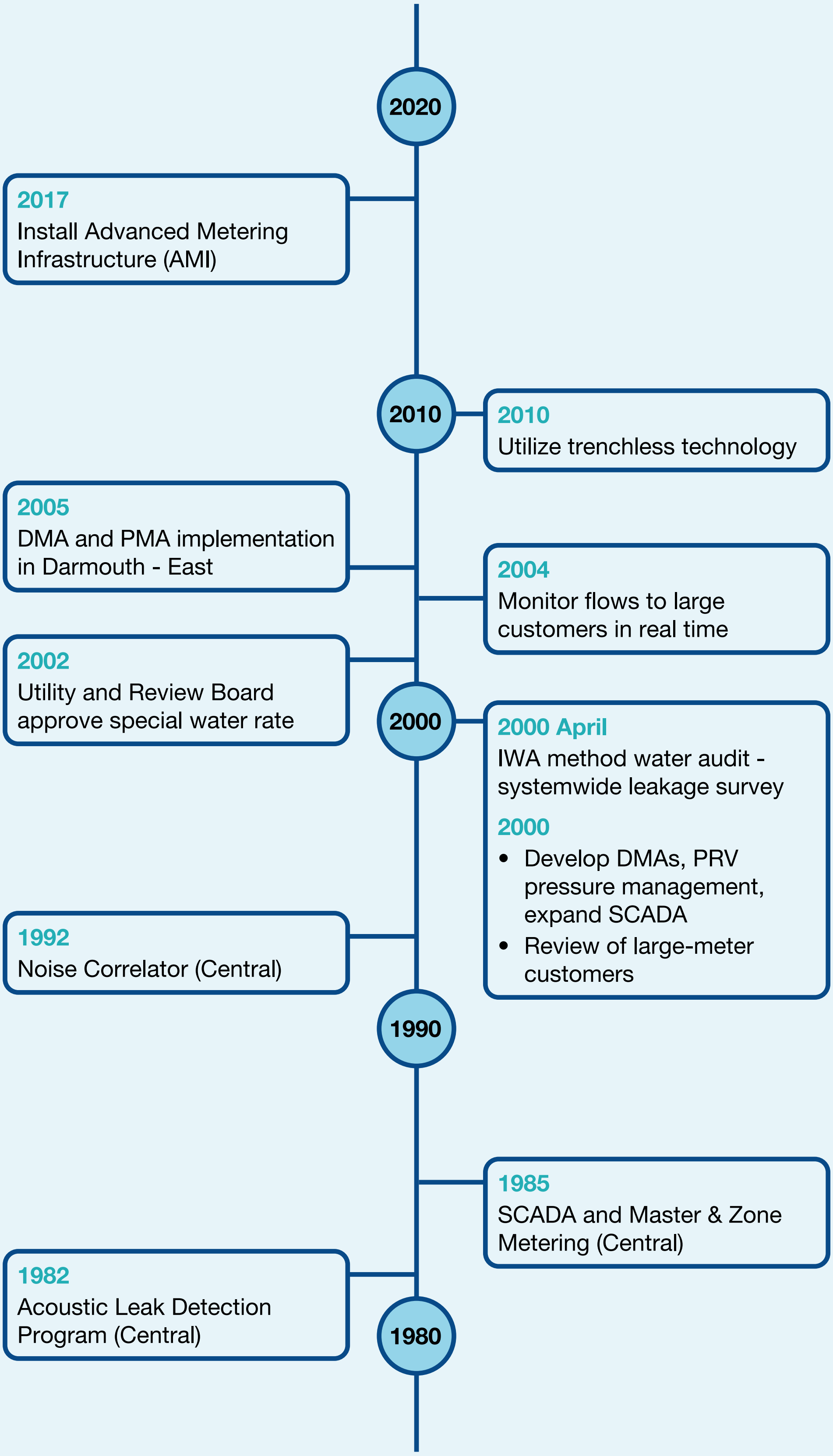
The timeline in Figure 7.2 shows other methods and technologies applied for water loss control, with the major efforts described below.

District Metered Area (DMA) and SCADA

Halifax Water adopted a comprehensive DMA design in 2000 that considered various factors, such as minimum nighttime flow velocities, water quality, and peak daytime demand[69]. The water system is divided into 75 DMAs, and each DMA is monitored by a SCADA system. A sudden increase in nighttime flow implies a possible leakage[21]. The SCADA offers real-time flow monitoring of large customers. The combined application of DMAs and SCADA enables active leak detection[19,132].

Figure 7.2

Timeline of technological measures adopted in Halifax since 1982 to reduce water losses



Sources: Brothers, 2001a; 2001b, Centre for Neighbourhood Technology, 2014, Halifax Water, 2018a, 2018b, 2018c; 2020c, Vassos, Huston and Blin, 2018.

Advanced Metering Infrastructure

In 2014, Halifax Water undertook a feasibility study of Advanced Metering Infrastructure (AMI) to investigate its costs and benefits[39]. The study found that AMI could improve meter accuracy by increasing the frequency of meter reading to every hour, versus the current quarterly manual meter readings. In addition, Halifax Water could bill monthly instead of quarterly, allowing customers to detect abnormal increases in water usage more quickly (a potential sign of a leak)[39]. The study also found that AMI could help reduce apparent losses in Halifax by 545,753 m^3 (545 million liters) in the first year of operation[39].

With these benefits, Halifax Water implemented AMI in 2017 and installed 50,000 AMI meters before the end of 2019[46]. As these installations are relatively new, data from the AMI meters on the reduction of water losses are not yet available.

4. KEY LESSONS

Halifax's success demonstrates the importance for water utilities to deploy the full set of IWA methodology, instead of adopting a piecemeal approach, to tackle the water loss problem.

Two key lessons could be drawn from the case of Halifax. First, the IWA methodology can be particularly effective at water loss control, when adopted in full. This includes using the IWA water balance approach and their recommended indicators to analyze water losses, and addressing those losses through asset management, pipe repair, pressure control, and active leakage detection. Halifax Water deployed the full set of IWA methodology in 2000, effectively reducing leakage in each of its service areas, particularly the West Region.

Secondly, the Halifax Water case demonstrates the value of setting specific, measurable targets for water loss reduction. The Integrated Water Plan includes Key Performance Indicators (KPI) of asset management. Halifax Water tracks organizational indicators and targets in an annual Corporate Balanced Scorecard submitted to the HRC. Uniquely, Halifax Water's Organizational Award Program ties leakage reduction targets to economic incentives for Halifax Water staff who help achieve those targets. Similar incentive programs could help other utilities motivate water staff to take more corrective actions to improve the quality of their services.

The case of Halifax continues to provide insightful lessons on good governance. While Tokyo was an exemplar study of the merits of strong coordination between different actors, we learn from Halifax the significant strides that can happen in water loss control when organizational goals are clear, and specific, measurable targets are set. The case studies of Philadelphia, Tokyo and Halifax offer different aspects of good management practices that can improve the day-to-day implementation work in water loss control.

Chapter 8

CONCLUSION

1. CONCLUSION

From a public policy analysis perspective, we can derive three lessons from reviewing the six cities' approaches to dealing with water losses in their municipal water distribution systems.

Water loss may be a complex issue. The problem, nevertheless, can be successfully tackled by a judicious combination of technologies and management methods.

First, water loss may be a complex issue, but it is no longer an insurmountable conundrum. The codification, as early as 1991, of mainstream water loss reduction methods by international bodies—such as the International Water Association and the American Water Works Association—signifies a consensus stance, shared among professional practitioners, that water loss has become a tame[o] problem that is amenable to a set of standardized methods of cure.

The combined chronicle of the water loss management practices contained in this report presents ample evidence that, despite challenging complexities, the extent of the problem *could* be suppressed and controlled, with skill, tact and determination on the part of teams of water managers who are given the required resources to do their job. In addition, it is not necessary for water agencies to pursue the so-called cutting-edge technologies that may sound promising but their efficacy has not yet been fully proven. As evidenced by the experiences in Berlin, Seoul and Sydney, many conventional technologies have matured and they are sufficiently robust to locate and plug the leakages.

For instance, while Seoul's water loss problem has been complicated by some attributes similar to those of Hong Kong, such as hilly terrain and high population density, the capital city of South Korea has attained impressive gains in water loss reductions by making use of such conventional technologies as multi-point leak nose correlation system and water pressure control-oriented reservoir system. Berlin has also demonstrated that discernible impacts could ensue from the application of mainstream methods and mature technologies, such as, respectively, asset management and geographic information systems.

Effective water loss control does not always require novel technologies. Many conventional technologies have matured and they are sufficiently robust to produce impacts.

Secondly, the varied trajectories of the six water agencies in tackling their respective water loss problem, with consequential outcomes, affirm an age-old maxim: There is no one-size-fits-all solution for many public policy problems. Research has taught us that what works perfectly well in one city might not pan out in another, for a number of reasons that are valid but could only be ascertained through a systematic inter-city comparative study. The consolidated experiences of the six cities cited in this report, nevertheless, strongly attest to the wisdom of formulating a fit-for-purpose approach to tackle the water loss problem by selecting a right mix of methods and technologies that match the specific nature of local challenges.

[o] A tame problem is a difficulty that has been understood and a known solution is available. It differs fundamentally from a wicked problem, which contains multiple layers of undefined difficulties and there is no known solution.

Sydney's approach offers an exemplary translation of the fit-for-purpose principle into practice. Without resorting to novel technologies, water managers in the most populous city of Australia have made use of water budgeting methods to determine an economic level of leakage that is considered an optimal level for their city, to respond to the vagaries of Sydney's local and its basin-wide hydrological conditions. This novel (regarded by water managers in most other cities) concept of economic level of leakage then helps inform the choices of water loss control methods and technologies. Philadelphia, likewise, has implemented this concept in their water loss control strategy.

The effective application of technical solutions depends on instituting a governance system that promotes accountability and provides incentives for adopting interventions that disrupt existing practices.

Thirdly, technology is a necessary but not sufficient condition for success. The effectual application of technical solutions often depends on an attendant governance regime that embodies an accountability system and an incentive structure that are conducive to the adoption of interventions that bring disruptions to existing practices. The need for decision-makers to pay attention to non-engineering causal factors such as governance ensues from the fact that the degree of complexity of controlling water loss is necessarily a function of the number of parameters that need to be managed by water utility managers in a coordinated fashion over a sustained period of time. It is, however, very rare to see the coordination matrix falling squarely within a water utility's perimeter. In most instances, the extent of complexity might be heightened because the dimensions of the coordination matrix could extend beyond the realm of a water agency and spill over into other public agencies' domains that water utility managers might have little sway over.

The records of both Halifax and Tokyo exemplify the significant role of an effective governance framework that brings together key stakeholders, from within and outside of the water utility to tackle the water loss challenge. For instance, Halifax Water has developed organization-wide indicators and targets to track progress made in achieving its vision statements, thus providing a clear direction, incentives and purpose for its employees in this regard. Tokyo's Bureau of Waterworks, on the other hand, through a well-tailored coordination and communication strategy, has effectively liaised with its customers to repair leaks and broken pipes.

To conclude, although there is no such wonder as a one-size-fits-all panacea, prima facie evidence gleaned from six overseas cities demonstrate that a right mix of technologies (constituting either the conventional or the novel) as well as an effectual water governance approach (underpinned by the accountability principle) that matches the peculiarities of the local context has produced some remarkable, tangible outcomes.

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