An Independent Study Commissioned by

RESIDENTIAL AND CIVIL CONSTRUCTION ALLIANCE OF ONTARIO

RCCAO

Constructing Ontario's Future



WATER INFRASTRUCTURE IN THE 21ST CENTURY:

Smart and Climate-Savvy Asset Management Policies

JUNE 2021


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The Residential and Civil Construction Alliance of Ontario (RCCAO) is composed of management and labour groups that represent a wide spectrum of the Ontario construction industry.

RCCAO's goal is to work in cooperation with governments and related stakeholders to offer realistic solutions to a variety of challenges facing the construction industry and which also have wider societal benefits.

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WATER INFRASTRUCTURE IN THE 21ST CENTURY:

Smart and Climate-Savvy Asset Management Policies

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TABLE OF CONTENTS

FIGURES AND TABLES

EXECUTIVE SUMMARY

Asset management in Ontario has come a long way since the days of Walkerton. This long journey has taught us many lessons. Chief among them is that deferring infrastructure investments leads to asset value loss, reduction of service quality, endangerment of public health and the environment, and higher premiums in upkeeping the assets. The more effective and prudent policy is to enhance municipal capacity in asset management and to implement proactive maintenance and upgrades for the assets. Given the advancement in asset management practices in Ontario, the looming challenges (of climate change), and the emerging opportunities (in the green and digital economy), Ontario should stay the course: there are significant gaps (especially in smaller municipalities) and largely untapped potential in our assets. With consideration of the asset-energy-carbon nexus, the return on investment (ROI) will not be only in terms of economic gains, but also in sustainability and resiliency.

> **Fixing leakage in a single section of the water system in York Region saved 139,000 m^3/year in water (the equivalent of 75 elevated tanks), $426,000/year in cost, and 102 MWh/year in energy (enough to power 11 homes for a year), and 4.1 tonnes of CO_2/year.**

In the medium term, Ontario policy makers should embrace a significant paradigm shift in the funding and business models for municipal utilities. Policies should invest and promote competency and capacity building to enable municipalities to justify the link between funding and gains in asset values, and, at the same time, transform assets into a propeller for regenerative sustainability, where public investments drive environmental enhancement (not degradation), generate economic opportunities, and optimize the wellbeing of citizens.

This study has three main recommendations:

Stay the course, realize higher ROIs

Ontario should stay the course and continue to provide sustained funding for Asset Management (AM) projects. There is room for improvement, and we can achieve these improvements at a higher level of efficiency and higher ROIs. Increasingly, from a financial perspective, every investment in Ontario AM is more rewarding than before. The reasons are threefold:

> 10-30% (in some cases, up to 50%) of all our water bills are paid for leaking water. If the Province invests (on our behalf) a fraction of this wasted money on system rehabilitation, our payments will decrease, and our property tax will not need to increase. Such funding has a payback period of 4-5 years.

1. **We are more knowledgeable and efficient:** thanks to years of hard work by the whole AM industry, we can plan better and achieve higher levels of success.
2. **We have better assets:** years of commitment to AM have brought a significant portion of our assets from the brink. Our task now is to prevent our deteriorating assets from reaching that level again.
3. We now have advanced decision and data analytics tools that can support a more optimal selection and design for projects.

Seizing the opportunities of green and digital economies

The changes in defining ROI beyond the financial aspects are more the reason to stay the course and sustain funding for AM. We are now aware of the environmental implications of inefficient assets. In the water sector, this means more unnecessary treatment chemicals, more energy waste, and more carbon emission. By investing in asset management, we create equally important ROI for the environment, climate action, and asset resiliency that were not recognized before.

Almost every other industrial sector is advancing to the digital economy at unprecedented speed. The municipal sector is by far the lowest/last adaptor and, due to its structure, will be the hardest to shift. If we embed advancing both the green and digital economies into AM funding, we will build significant momentum in our strategy to advance both economies.

Two key considerations are needed:

> The City of Hamilton (a leader in asset management practices) has seen a decline in its water and wastewater conditions. This is not because of lack of knowledge. It is because they have 23%-36% of all funds required to maintain the two systems.

1. **Reorient funding programs:** Adequate funding remains the most chronic problem in Ontario asset management. Stable funds should be allocated to support an extended asset-energy-carbon analysis; and, ultimately, to increase municipalities' abilities to lead and optimize the nexus of these three pillars. Some of the options in this regard include the following:

- Dedicate a category for projects that emphasize resilience in all funding programs.

- Shift parts of disaster recovery funds into disaster mitigation funds.
- Broaden the eligibility of key funding programs to include supporting asset management programs that focus on climate action and innovation.

2. **Knowledge creation and dissemination:** The sophistication of advanced technical and business analyses can be overwhelming to municipalities given the current state of their knowledge management systems. The Province can advance new economy practices in municipalities through a set of programs, for example:

- Create and support means for synthesizing scientific studies and technology best practices for easy use by municipalities and facilitate advanced education and hands-on training programs.
- Collate province-wide guidelines to help municipalities evaluate asset performance key indicators, including physical (leakage/corrosion), energy and carbon footprint, resiliency, and innovativeness.
- Develop databases and analytics tools to help municipalities conduct reliable basic data analytics, particularly regarding life cycle costing.
- Re-develop design standards to support formal quantification of climate change and objective consideration of resiliency.

Performance-driven policymaking

In the long term, the main question that is facing Ontario is: are we funding the rehabilitation of assets or are we funding sustained and effective management of assets? Are we funding municipalities to oversee projects or to become powerhouses in asset management knowledge and decision-making? Funding municipalities to support projects for assets, no matter how logical, effective, and well-designed these projects are, is a policy of the lowest hanging fruit. Funds should be provided to enhance the competency and capacity of municipalities to conduct the most effective analysis, develop reliable future scenarios, use best practices, lead innovation, and develop accountable plans for investment and performance optimization. Investing in competency creation along with project funding will transfer our assets to be key tools in regenerative sustainability, where the asset generates value to the local economy, the environment, and community; and, quite possibly, be a source of generating new types of financial income to the municipality. In the scope of this study, two fundamental principles should guide the Ontario asset management policy in the 21st century:

1. **Establish specific and quantifiable performance targets:** Create an objective expectation from every municipality—technical, financial, environmental, resiliency, and economic output and productivity. Technical support, training, incentive, and penalties should be used to encourage effective, long-term, and innovative plans for our assets. Province-wide standards on data quality and audits should be established to ensure that reported progress and planned actions are reliable.

2. **Reformulate the funding mentality to be adequate and sustained:** Holding every municipality to performance targets must be matched by commensurate funding. The funding frameworks should include a firm commitment from the government to provide its share of the funding, independent from politics. It should also include means for diversified funding sources (to make sure that municipalities have access to needed funds if the public funds do not materialize).

Ofwat (the water and wastewater regulator in the U.K.) provides valuable best practices. The regulator has a set of tests to evaluate the quality of plans presented by utilities. Those with lower scores are audited. They also established objective targets for utilities to achieve. When one utility did not achieve the benchmark for leakage, it was fined £8.55 million. The next year, the utility invested £200 million. That is £1 million/workday fixing leaky pipes. A wide set of means were deployed, including advanced detection systems, and a chlorine-sniffing dog.

Effectively establish a benchmarking-innovation-funding cycle: Providing knowledge, training to municipalities, provide financial support to develop reliable plans, benchmark the plans and the results against quantifiable targets, encourage innovation, productivity, and performance excellence. Tie funding to progressive enhancements of the benchmarks and, at the same time, penalize lower levels of benchmark achievement. Municipalities must have an incentive to keep building capacity for efficiency. Such a system will require shifts in public policy to be performance-based and to formally quantifying and firmly sustaining the required funding. Much like the U.K., this shift may require amalgamating utilities, introducing elements of private contributions to utility management, supporting community engagement, and (indeed) oversight over benchmarking and the role of the private sector (especially beyond funding) in holding utilities accountable. It is important to initiate further analysis and a dialogue about the needed changes and the means to exploit the emerging opportunities. This should be a collaborative work between key stakeholders, including the Government of Ontario, municipalities, construction industry, consultants, industry organizations, agencies promoting climate action and smart cities, and academia. The aim is to develop a roadmap for Ontario leadership in the water infrastructure systems of the 21st century.

1.0 INTRODUCTION

Asset management practices in Ontario have seen steady progress over the last two decades. We now have regulations mandating the development and use of asset management plans, including the consideration of levels of services. The adoption of asset management by larger municipalities has reached higher levels of sophistication. Ontario now has a set of industry organizations and experts who are at the forefront of asset management practices (for example, Asset Management Ontario, Ontario Good Roads Association, Municipal Finance Officers' Association of Ontario). The result: we saved our assets from the brink.

Yet, there is still much to do. The progress made should not be a reason to slow down. In fact, it should be the reason for doubling down. If we learned anything from the last two decades, it is that sustained attention and investments in infrastructure asset management and rehabilitation are the cheaper options. Inadequate investments deteriorate assets further and only exasperate future funding needs; hinder economic and environmental progress; reduce service quality; and erode the value we created in our assets.

A major study about North American water breakage levels (Folkman et al. 2018) showed that, between 2012 and 2018 and despite investments in asset management, the overall water main break rates increased by 27% from 11.0 to 14.0 breaks for every 100 miles every year. Even more concerning, the break rates of cast iron and asbestos cement pipes increased by more than 40% over the 6-year period. These pipes comprise about 40% of the installed water mains in the U.S. and Canada. Most of these pipes were installed decades ago. Given that there is no aggressive program to replace them, their breakage rates will only increase—draining more and more of our efforts, money, and energy.

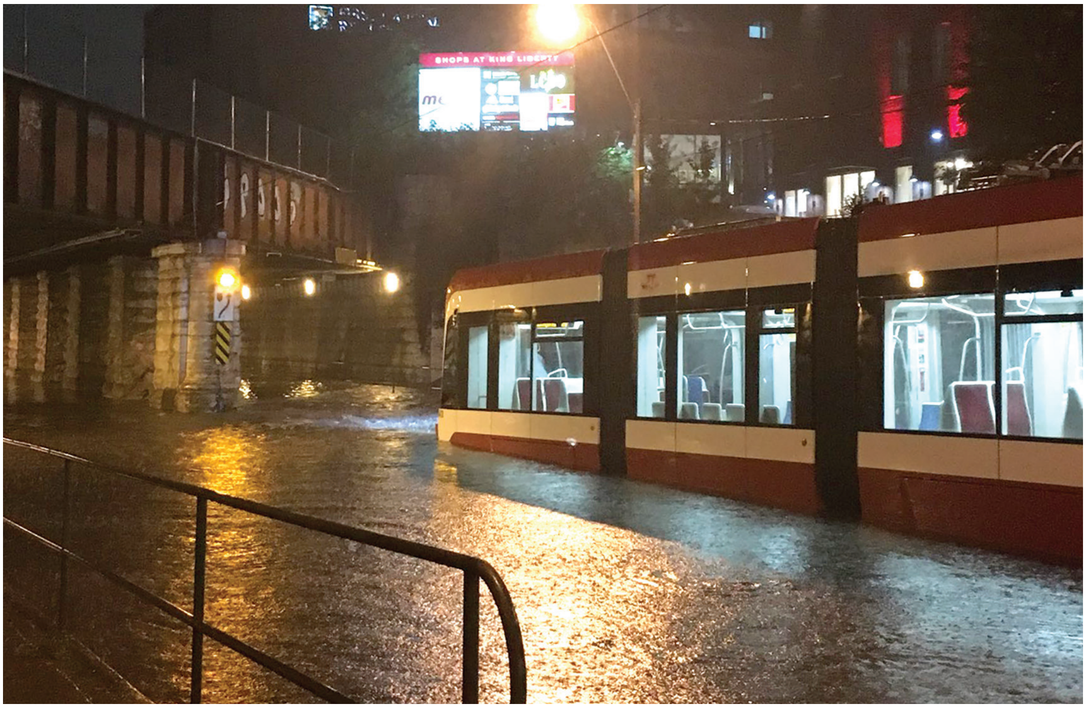
It is imperative that Ontario should stay the course to preserve the value we created in our assets. More importantly, we need to pivot our plans to face the more complex challenges of the 21st century. If we let our guard down, the repercussions will be much higher than the simple issue of crumbling assets and lower levels of services. Today, we are more aware of the implications of climate change on our health and overall economic advancement. Climate change is poised to exacerbate the deterioration of many of our assets. In the water sector, for example, more frequent and severe storms are going to test the capacity, efficiency and operational excellence of our systems. Conversely, the very nature and scale of our assets make them key contributors to climate change due to their high energy consumption and emission levels.

In contrast, if we reorient our asset management practices for exploiting the opportunities of the green economy and smart cities, we can make our assets more resilient, reduce their negative environmental footprint, access new sources of funding, and, interestingly, make our assets generate new income for municipalities. For example, the new practices of “pumps as turbines” (PAT) uses the kinetic energy from water pressure in water pipes to generate localized green energy. The payback period of some of these systems is as low as a few months.

Scope and organization of this report: This report is a follow-up to one that was published in 2009, which explored the importance and potential for considering water-energy nexus in Ontario. This report extends the analysis into the future: considering the water-energy-carbon nexus in light of the emerging opportunities and challenges of the green economy, artificial intelligence, and smart city technologies. The report takes managing leakage in water systems as an example case. What is the current status? How should we view leakage management in light of the water-energy-carbon nexus? What are the negative impacts of leakage? How can we redesign our technical systems as well as policymaking and the business model of utilities to better manage our water systems?

The report starts with an overview of the status, achievements and opportunities for asset management (AM) in Ontario. Then, the report explores the fundamentals of the water-energy-carbon nexus. This is followed by an analysis of the key reasons for leakage and means to detect and forecast them. After that, a section is dedicated to the returns on investing in leakage management from economic and environmental perspectives, as well as meeting the challenges and goals of climate action. The role of digital water, including smart hardware and advanced analytics is highlighted as a key factor and tool for advancing the role and use of artificial intelligence in the water infrastructure system. Finally, the last section discusses benchmarks for policymaking. The report does not aim at developing solutions and new policy suggestions as much as it aims to encourage a dialogue on these issues.

2.0 ONTARIO ASSET MANAGEMENT AT CROSSROADS



What is the future of asset management in Ontario? Can asset management practices in Ontario be part of regenerative sustainability, where assets become an engine for promoting the wellbeing of communities and the environment and, at the same time, their economic prosperity? Can asset management practices in Ontario be transformed from focusing on the limited view of putting out a fire (through rehabilitation projects) into a realm of promoting municipal competency and organizational excellence, where municipalities can develop and prove optimal returns on investments? How can asset management benefit and be a push for a green economy and for the realization of the smart city? How can the opportunities of the green economy help asset management?

To contextualize the analysis and findings of this report, the following sections attempt to synthesize the status of AM in Ontario through the prisms of legislation, investments and innovativeness.

Legislative progress: from introducing to assuring reliability and adequacy

In 2012, Ontario published *Building Together: Guide for Municipal Asset Management Plans (AMP)* to encourage and support municipalities in Ontario to develop AM plans in a consistent manner. In 2015, by passing the *Infrastructure for Jobs and Prosperity Act*, Ontario situated AM as a component of the economic and environmental prosperity of the province. After a year-long consultation, the Province created *Ontario Regulation 588/17-Asset Management Planning for Municipal Infrastructure*. O.Reg. 588/17 mandated specific requirements for municipal asset management plans—phased over five years. Core assets (water, wastewater, stormwater, roads, and bridges) and all city infrastructure assets will have an AM plan documenting current levels of service (LOS), as well as financial strategies to fund the enhancement of these LOS. Similarly, Ontario's Energy & Water Reporting and Benchmarking (EWRB) initiative represents a progressive step in creating and disseminating AM knowledge.

However, all legislations do not include two key ingredients: 1) reliability assessment: mechanisms to ensure the quality of the planning and estimation of LOS levels and the required budgets (particularly in relation to assessing the quality of data used); 2) adequacy: the suitableness of the targets set by each municipality—is this all that we can do? Are the LOS enhancement plans enough to help economic and environmental stewardship? To illustrate, Ofwat (regulator for water and wastewater sectors in the U.K.), uses several tests to examine the quality of data and plans submitted by utilities. Higher scores in the tests mean that the utility has more reliable plans and, as such, is given more freedom in setting their plans. Lower scores mean additional scrutiny and less freedom in planning. In addition to ensuring reliability, Ofwat uses a financial reward and penalty system to enforce ever-increasing standards/targets.

Progress of asset management in Ontario

While there has been significant progress in AM awareness and mastery of best practices in Ontario, there is significantly more work that needs to be done. A survey of 308 water utilities in North America showed that, in 2018, the typical age of a failing watermain is 50 years. This failure age is alarming because about 43% of all watermains have an age of 20-50 years; and 28% of them are 50 years or older. In 2012, the average age was 47 years. The expected age of an installed pipe did not change significantly between 2012 and 2018—still around 80 years. However, this age can be higher or lower based on soil corrosivity, installation practices, and traffic (Folkman 2018).

Against these benchmarks, here are some statistics for Ontario municipalities. A survey of Ontario municipalities (OSWCA 2018) found that, for example, the municipality of Chatham-Kent had the highest portion of its water infrastructure in poor or worse condition, including 37% that had expired. In Windsor, the asset portfolio includes 27% of assets that remain operational beyond their useful life. In contrast, the NA-wide survey (Folkman 2018) found that, in 2018, a total of 16% of installed watermains are beyond their useful lives (up from 8% reported in the 2012 study). The City of Hamilton can illustrate the progress and challenges of AM in Ontario. The city is a recognized leader in AM in Canada. Yet, the city reported that the overall grade for the water system in 2016 is a "C." The rating is based on three criteria: condition, capacity, and funding backlog/needs (see Table 1). This grade was a decrease from a B in the 2013 Report Card, which was a decrease from B+ grade in the 2009 report. The future outlook for the water system is neutral, indicating that the situation is expected to remain relatively constant in the near to medium future if the current plans are not changed (City of Hamilton 2017, 2019). The overall grade for the wastewater system is a C+. This grade has decreased from a B- in the 2009 Report Card, which is a decline from the B grade in 2005. The future outlook for the wastewater system is neutral.

Source: City of Hamilton

Table 1: The degradation of Water and Wastewater assets in Hamilton

	2005 Rating	2009 Rating	2016 Rating
Water	B	B+	C
Wastewater	B	B-	C+
Stormwater	C	C-	C+

One of the key indicators of AM efficiency in Ontario is leakage management. Watermain breaks can have multifaceted consequences. First, they can disturb the redundancy/vulnerability of the network. Second, they can impose economic pressure in terms of water loss, rehabilitation cost, and the cost of damage caused by watermain failure. Finally, the main breaks can directly have an impact on public safety and security (Phan et al. 2019). These events may have harmful effects on public health due to a deterioration in the quality of water (Martinez-Codina et al. 2016). The low and negative pressure resulting from water breaks potentially allows contamination of drinking water from adjacent soils (Shortridge and Guikema 2014). This is why the potable water system has been identified as a significant factor in waterborne disease outbreaks.

Despite investments in water system upgrades, there is still significant room for enhancement. To illustrate, it is estimated that in Canada and the United States, on average, there are 700 watermain breaks every day, costing more than (Cdn.) $10 billion/year (Kabir et al. 2015). The National Research Council found that social costs of water leakage ranged from 28% to 172% of direct project costs (Rahman et al. 2005). A British study concluded that the annual cost of traffic delays borne due to utility construction is estimated to be in excess of (U.S) $2.3 billion. If we consider the economic, social, and environmental costs, the total cost of a main break is (U.S.) $42,000 on average (Chen et al. 2018). The total cost of water loss due to watermain or pipe breaks is estimated to be (U.S.) $3.8 billion per year in North America (Snider and McBean 2020).

Funding asset management in Ontario

Funding still represents the most chronic problem for municipal asset management. In fact, of the recommendations of the Walkerton Inquiry Report and the Water Strategy Expert Panel Report, those related to financing and operational capacity of municipal water systems are the most lagging (ECO 2017).

Considering that 28% of all mains are over 50 years, significant change in funding levels and sources is essential. As a case in point, and in contrast to the declining trends listed above, the City of St. Catharines saw a significant decrease in watermain breaks, from a staggering average rate of nearly 45 breaks per 100 kilometres (km) in 2000 to approximately 15 breaks per 100 km in 2012. According to staff, this decrease was directly related to an increase in the city's watermain replacement budgets as well as prioritizing replacements (OSWCA 2018).

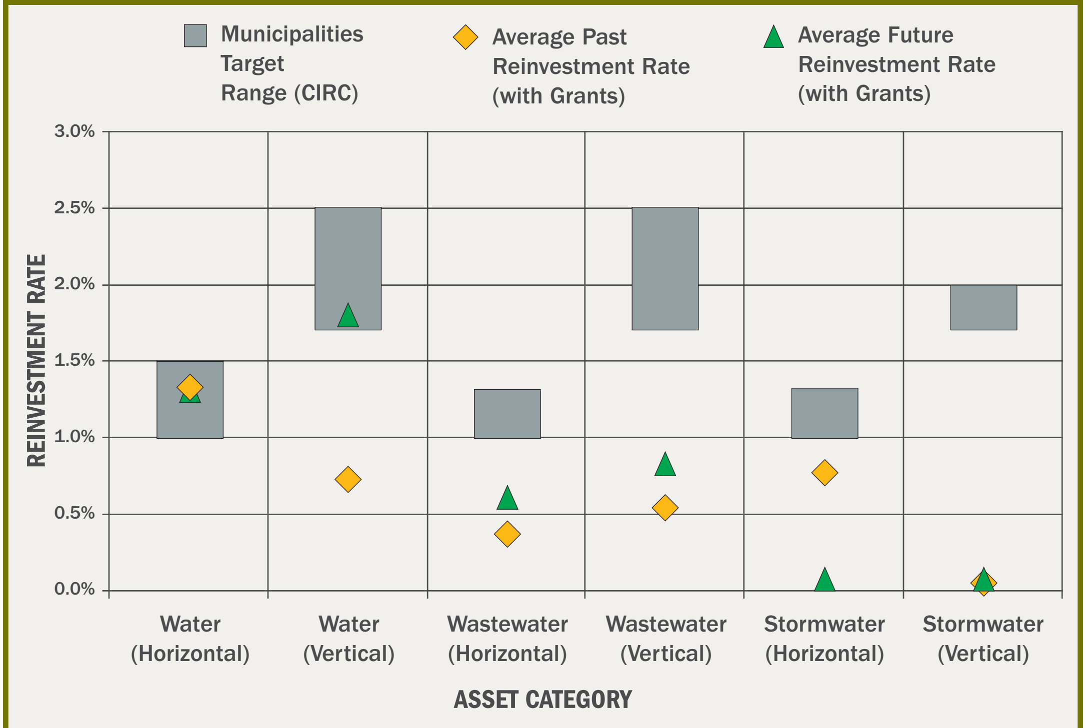
In Toronto, there are more than 6,000 km of watermains (13% are 80-100 years of age and 11% are more than 100 years old). The city experiences an average of 1,400 watermain breaks annually. The city replaces approximately 35 to 50 kms of watermains each year. This is a replacement rate of 0.6-.9% annually. This means that the city is working on the assumption that the service life of a watermain is between 110-166 years. To benchmark, the NA survey (Folkman 2018) reported an average replacement rate of 0.8%. This equates to a 125-year service life. The minimum pipe replacement rates for adequately maintained networks should be between 1% and 1.6%, equivalent to 100-year and 60-year useful life cycles, respectively. For deteriorated networks, the recommended replacement rate is 2% and could be as high as 4% (City of Hamilton 2016). At the start of AM implementation in Toronto, many were surprised that the oldest pipe in Toronto was installed in the 1880s—that is 140 years ago. With the current investment rate, we could be repeating the mistake.

In another example, the City of Hamilton will not be meeting its minimum funding requirements for several years to come. In the 2016 AMP, the city gross and net capital investment rates were 1.6% and 0.9% (City of Hamilton 2016). The average annual investment requirement for tax-funded categories was $7,808,000. The annual revenue allocated to these assets for capital purposes was $1,757,000, leaving an annual deficit of $6,051,000. To put it another way, these infrastructure categories are currently funded at 23% of their long-term requirements. The average annual investment requirement for water services was $152,000. The annual revenue allocated to these assets for capital purposes was $54,000, leaving an annual deficit of $98,000, i.e., the funding level was 36% of long-term requirements (see Figure 1).

There are concerns over the long-term funding of the system due to additional challenges. Declining water consumption is leading to falling revenues despite the increase in the water rate. In addition, many of the recent upgrades to the water facilities have been funded by external grants (i.e., stimulus funding) from higher levels of government. It should not be expected that external grants will be available to fund infrastructure renewal projects over the long term. The situation is worse in small municipalities, which, due to lower population densities, have more kilometres of water pipes per capita.

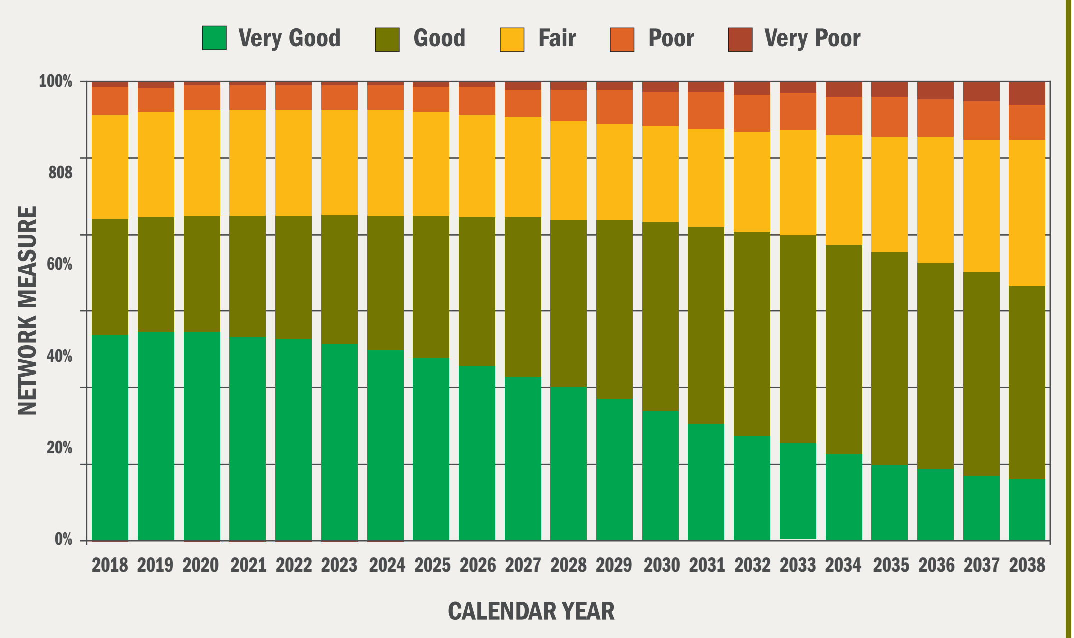
Source: City of Hamilton

Figure 1: Target and existing Reinvestment rates for Water and Wastewater



Simply put, we could be planning that our future pipes be older than the ones we inherited—despite them passing the normal expected life. Only, this time we could be doing it knowingly. Effectively, our benchmarks are below the minimum that we should aim for. The City of London, Ont., is a case in point. Between 2014 and 2019, higher competency and significant enhancement in AM planning have resulted in equally significant enhancement in asset conditions. In 2019, 45% of the water distribution system was rated at "Very Good," 25% rated at "Good." However, the current 20-year projection will see a decline in the "Very Good" category to about 12% and an increase in the "Good" category to about 45%. The current total of "Good+" will drop from 70% to around 57% (see Figure 2). Investment levels are the culprit. Investments are between 30-50% of the required levels (see Table 2). In the wastewater sector, about 38-41% of the assets are rated at "Very Good" and 24-28% at "Good." The current 20-year projection takes these to 7% and 35%, respectively. The "Good+" drops from around 70% to around 42%. Funding is at 24% of the recommended levels. More importantly, wastewater treatment plants are energy guzzlers and big CO_2 emitters. Being funded at only 14% of the recommended rate means very little enhancement can be expected in energy or carbon savings. It should be noted that the data accuracy/reliability is not optimal (but relatively high), which in itself is another issue that is overdue for substantial change—you cannot manage what you cannot measure.

Figure 2: 20-year projections for the water system at current investment levels



Source: City of London 2019

Table 2: Current vs. recommended investments rates

Water System			Wastewater System		
Sub-asset	Current Investment %	Recommended Investment %	Sub-asset	Current Investment %	Recommended Investment %
Linear mains	0.45%	1-1.5%	Collection	0.3%	1-1.3%
Water metres	4.6%	5%	Treatment	0.3%	1.7-2.5%
Water facilities	1.2%	1.7-2.5%	–	–	–
Overall water	0.5%	1-1.5%	Wastewater overall	0.3%	1.1-1.4%

Source: City of London 2019

Climate change

Climate change is having significant impacts on our infrastructure. For example, more high-intensity storms are becoming increasingly frequent. The July 2013 storm that resulted in flash flooding across the GTA caused $940 million of damage in Toronto alone, becoming the most expensive natural disaster in Ontario's history. Possibly related, in 2014, the city experienced a year's worth of watermain breaks in the first three months, resulting in a $1.6-million cost to the water utility (see Toronto Water website).

To protect homeowners from subsequent flood risk, insurance premiums have risen by as much as 20% in the GTA. In the summer of 2017, Windsor saw $124 million of damage due to storms with over 1,000 basements flooded. In February 2018, a state of emergency was declared in various parts of Southwestern Ontario, as people were forced to evacuate their homes due to heavy rain and melting snow. These previously rare 100-year storm events are becoming much more common, and current stormwater infrastructure is unable to cope. Such severe climate, combined with the deterioration of sewers, is hampering the capacity of the wastewater system, and increasing the inflow of harmful chemicals from the surrounding soil. The new changes to the *Fisheries Act*, which requires higher levels of water quality at the discharge locations, means we have to replace our pipes even faster (ECO 2017).

The challenges and high costs of Ontario carbon-neutral policies means that every tonne of GHG emissions between now and 2050 counts. Reducing GHG emissions and building resilience to climate impacts improves air quality, reduces noise pollution, provides space for recreation, physical activity, and social interaction, and generally beautifies a city. The result is improved health and wellbeing of residents. Adapting to the changing climate will strengthen emergency preparedness and infrastructure resilience and enhance natural habitats and biodiversity. Many of these are prudent measures that improve the quality of life in communities.

The need for innovation

Deep emission reductions require innovation, rapid diffusion of new technologies, and more importantly sustained focus on efficiency gains. To illustrate, there was a significant reduction in GHG emissions in many Ontario municipalities around 2015. But this was mainly due to the decommissioning of coal-powered plants. Since then, very limited reduction has been achieved. Each municipality should realize that increasing system efficiency and reducing water leakage is the way to contribute to GHG-emission reduction. Several tools are available to help such as advanced hardware like smart meters and pumps. Several software systems can also help. For example, Toronto implemented a system for water operations based on optimizing energy consumption.

Business model innovation: Ontario does not lack the technical expertise to develop plans for revamping its AM programs. There is also a political awareness of the need to upgrade our systems; and there are helpful policies in place. The Achilles heel of AM in Ontario is the business model of its utilities. Here we need some innovative thinking and revision of established norms. Ontario has a highly fragmented water infrastructure network, with a total of

466 wastewater systems and 665 drinking water systems varying in size and sophistication. Smaller municipalities do not have the resources (financial and human) to implement what they know is good for their assets. In fact, the NA survey (Folkman 2018) found that smaller utilities can have break rates more than twice as high as larger ones. A small or rural utility would typically have more pipe miles per customer. This can result in greater financial burdens in maintaining their water systems compared to larger or urban utilities.

The policy of amalgamation of utilities in the U.K. has been through ups and downs as it faced many problems and fears. But now it has evolved into a better, more efficient system. Such experience should be considered to evaluate the benefits of collating the resources of smaller municipalities to muster the required resource and benefit from economies of scale.

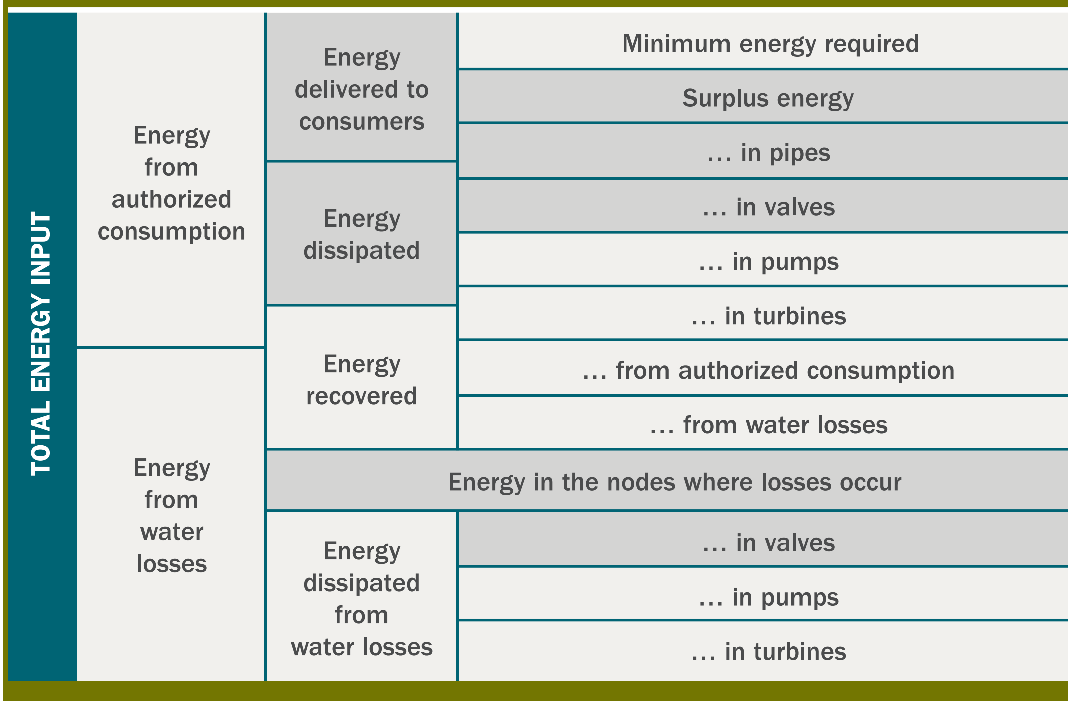
Similarly, the engagement of the private sector in the infrastructure domain in Ontario has come a long way. We should consider opportunities and new models for private-sector engagement in providing funding that respects the public nature of water utilities. The bi-directional link between climate and assets makes investments in asset management a win-win for assets, the environment, and green investors. The fact that Ontario has sustained a high level of attention and higher-than-before investments in our infrastructure assets makes them a well-suited target for private investments. For example, the Canada Infrastructure Bank has a very progressive policy for green infrastructure. It could be possible that the bank funds the installation of Pumps as Turbines (PAT) systems in our water infrastructure to charge electrical vehicles. The added revenues can fund pipe upgrades while installing the PAT or it can fund inspecting the pipes. This is not a call for privatization. It is a call to reach to the core problems and rethink new opportunities in funding.

3.0 THE WATER-ENERGY-CARBON NEXUS

The nexus between water and energy has been recognized by researchers and utility operators for decades. Water treatment and distribution are energy-intensive processes (see Figure 3). The estimates of energy used in water and wastewater utilities vary markedly. Some of the more reliable estimates set the global consumption at around 10.2 Exajoules (EJ) or 1.7 - 2.7% of primary energy (Liu et al., 2016). In the U.S., water utilities account for 1.0% of the total annual electricity consumption (2-3% in other estimates). The water and embedded energy loss associated with non-revenue water accounts for 9.1 billion m^3 of water and 3,100 gigawatt-hours (GWh), enough electricity to power 300,000 U.S. homes (Chini and Stillwell 2018).

Data about energy consumption by water utilities in Ontario is not easily found or regularly updated. Some of the most reliable data were reported by the ECO (Environmental Commissioner of Ontario) in 2017. It reported that Ontario water and wastewater treatment facilities used about 1,800 GWh of electricity (the equivalent of powering approximately 200,000 homes) and 40 million m^3 of natural gas (the amount needed to heat approximately 15,000 homes). This is equal to about 38% of reported municipal energy consumption. For example, water and wastewater systems (combined) are the largest source of GHG emissions for the City of Toronto—estimated at around 30-35%. The energy used to operate water and wastewater systems costs Ontario municipal taxpayers about $260 million each year (ECO 2017).

Figure 3: Breakdown of energy consumption in water systems



Source: AWWA

Water and wastewater systems are significant contributors to GHG emissions. In the U.S., it is estimated that moving, treating, and heating water produces at least 290 million metric tons of CO_2 a year. To better understand the scale of this undertaking, 1 Mt CO_2e is equivalent to the emissions from 216,000 cars driven for an entire year, or the emissions from driving around the world 99,650 times (EPA 2020). The CO_2 embedded in water systems represents 5% of all U.S. carbon emissions. This is equivalent to the emissions of over 62 coal-fired power plants. Lifecycle analyses of water infrastructure (Stokes and Horvath 2011) have indicated that the operational phase is responsible for most of the environmental impacts—around 67% of GHG emissions. Climate change will only exacerbate the problems. According to Brown et al. (2013), freshwater withdrawals in the U.S. are projected to increase by 3%, without considering climate change, and up to 34% (in some areas) when considering the changing climate, between the years 2005–2060.

In Toronto, according to the city's Greenhouse Gas Emissions inventory, electricity is the main source of power for water and wastewater facilities (76%). The smaller portion that uses natural gas (24%) is, however, responsible for 62% of emissions. Water and wastewater account for 32% of all energy used and 30% of all emissions in the city. The water system in Toronto uses very limited natural gas. Between 2013 and 2017, the electricity usage in the system remained almost constant. In 2014, there was a drop in GHG emissions (possibly because of the decommissioning of coal-powered electric plants). Since then, GHG emissions by the system have remained constant. Similar trends exist in sewage pumping facilities. However, in sewage treatment plants (typically powered by natural gas), both energy consumption and GHG emissions remained flat. This is another possible indicator that the greening of electricity can be the main reason why Toronto is exceeding its 2020 emission targets. As further evidence, for the City of Ottawa, in 2012-2019, emissions decreased 12%. However, total emissions have remained relatively flat after a significant drop in 2016. "This decline in emissions remains primarily attributable to the provincial phase-out of coal plants and a significant reduction in emissions from electricity generation (Ottawa Greenhouse Gas Emission Inventory)."

Toronto committed to reducing its emissions in 2020 by 30% of the 1990 levels. In 2018, Toronto achieved a 37% reduction. By 2030, Toronto is committed to reducing emissions by 65% from the 1990 levels. To achieve that, Toronto must reduce its 2018 emissions by 50% within 10 years. The net-zero-by-2050 target will require Toronto to remove all its emissions (estimated at 16.2 megatonnes in 2018). With such substantial challenges, we have to consider tougher measures, especially now that we cannot rely on the decommissioning of coal-powered plants. Genuine energy conservation through efficiency gains is needed. Given the technical difficulty of doing so, we should target every tonne of GHG. Buildings and transportation are the other biggest contributors to GHG emissions in a city. Significant changes in these sectors will require extended periods of time and massive investment given their scale, fragmentation and the essential need for behaviour change in achieving reduction goals. For a typical city, saving energy in water and wastewater facilities, in contrast, does not face the hurdles of fragmentation or behaviour change.

The first, and easiest way to save energy and GHG emissions in the water system is to rehabilitate leaky pipes. The ECO noted that "high leakage and infiltration rates are a symptom of underinvestment in both energy efficiency and infrastructure maintenance." A survey by the commission found that a leakage rate of 10% is typical in Ontario municipalities, with some reporting levels upwards of 40% (ECO, 2017).

Leakage is not just an economical issue as it is often perceived. It is also an environmental, sustainability, and potentially a health and safety issue. To manage leakages, municipalities have to increase water pressure to prevent infiltration. The extra energy and the associated carbon emissions are unnecessary impacts that can be avoided through adequate and proactive AM. In addition, leaking water is a waste of our valuable natural resources. It may come as a surprise to many that, while Canada is lucky to have 20% of global freshwater resources, only around 7% is considered renewable, and most of that drains north towards Hudson Bay and the Arctic Ocean—away from the 85% of Canadians that live along the southern border.

Energy-wise, in Ontario, electricity is consumed across 423 drinking water treatment plants, 340 wastewater treatment plants, and over 2,000 pumping stations, responsible for approximately 34% of municipal energy use (Posterity Group, 2018). In one study, it was found that, on average, approximately 28% of the energy supplied is delivered to junctions, 35% for overcoming differences in elevation, and 37% for overcoming friction, leaving a wide margin for savings (Dziedzic and Karney 2015). A 5% reduction in water distribution system leakage would save 270 million gallons per day (MGD) of water and 313 million kWh of electricity annually, equal to the electricity use of over 31,000 homes. In addition, approximately 225,000 metric tons of CO_2 emissions could be avoided (Griffiths-Sattenspiel and Wilson 2009).

On the emission front, while Canada is aiming to reduce its carbon emissions, between 1990 and 2019, emissions increased by 21.4% or 129 Mt CO_2 eq. Canada's emissions growth over this period was driven primarily by increased emissions from oil and gas extraction as well as the growth in the transportation sector. Despite that, emissions in the period of 2005-2019 have been reduced (for a total decrease of 8.5 Mt CO_2 eq or 1.1%). According to Natural Resources Canada, the 8.5 Mt CO_2 eq emission reduction is equivalent to removing over 2,600,000 passenger vehicles from the roads for one year, or the energy-based emissions from nearly 2,000,000 homes for one year (see ECCC 2021).

In 2018, it was estimated that Ontario municipalities can save between 1,176 and 2,620 GWh per year, representing a reduction of between 19% and 42% compared to 2014 consumption. A survey of Ontario municipalities suggested that the range of savings in electricity consumption for wastewater treatment, pumping operations, and water systems are 180-500, 80-420, and 100-310 GWh, respectively (ICF-Canada). The size of the savings provides a huge potential for a real reduction in GHG emissions if we enhance system efficiencies. An EPA (2013) report states that a large water utility in the U.S. can save about (U.S.) $400 million and 5 billion kWh annually through cost-effective energy conservation techniques. Energy consumption is expected to grow because of the ever-more-stringent treatment quality specifications. These costs are likely to rise, because:

- Energy prices are rising, particularly for electricity;
- Much of the existing water system infrastructure is aging, leaking, and increasingly inefficient;
- More stringent regulatory standards and poorer-quality water bodies necessitate more energy-intensive treatment;
- Populations across Ontario continue to grow, especially in the Greater Golden Horseshoe Area; and
- Interestingly, the reduction in consumption levels per capita will mean lower income for municipalities, too.

Conversely, wastewater treatment plants represent a significant opportunity for energy generation. Modern plants are capable of using 85% less energy than older ones (IFC 2018), and have been designed to be net-zero or energy-surplus facilities (for example, see the case of the City of Guelph in ICF 2018). The energy-generating potential of the existing wastewater treatment is difficult to quantify with the current data available, partly because it is self-reported, and the data quality is uncertain. However, extrapolating from available data, IFC (2018) estimated that Ontario municipalities may have the potential to generate 124 GWh of electricity from sewage sludge if existing plants can match the levels achieved in several European countries (0.12 kWh generated per m^3 of wastewater processed).

4.0 LEAKAGE IN URBAN WATER SYSTEMS

Leakage in water distribution systems can be caused by different factors. Some examples include bad pipe connections, internal or external pipe corrosion, or mechanical damage caused by excessive pipe load (i.e., by traffic). Other common factors that influence leakages are ground movement, high system pressure, damage due to excavation, pipe age, winter temperature, defects in pipes, ground conditions, and poor quality of workmanship. In addition to wasting water, the presence of leakage may damage other infrastructure and cause third-party damage, energy losses, and health risks. Leakage, no matter how small, wastes significant amount of water (see Table 3):

Table 3: Water leak costs and waste

Size of Hole	Amount and Cost of Water Wasted
● 1/16" hole	Wastes 3.57 m³ (3,570 litres) in 24 hours: Cost: $14.54/day or $1,745.09 in 120 days
● 1/8" hole	Wastes 14 m³ (14,000 litres) in 24 hours: Cost: $57.03/day or $6,843.48 in 120 days
● 3/16" hole	Wastes 32.13 m³ (32,130 litres) in 24 hours: Cost: $130.88/day or $15,705.79 in 120 days

Source: City of Toronto 2021

Defining leakage

There are several types of leakage—some of them are unavoidable. As shown in the following tables, produced water can be categorized as follows (see Figure 4):

AUTHORIZED CONSUMPTION

Billed authorized consumption:

- Billed metered consumption
- Billed unmetered consumption

Unbilled authorized consumption:

- Unbilled metered consumption
- Unbilled unmetered consumption

WATER LOSS

Apparent loss:

- Unauthorized consumption
- Customer metering inaccuracies

Real losses:

- Leakage on transmission mains
- Leakage and overflow at utility storage tanks
- Leakage at the service connections

Figure 4: Categories of Water loss

SYSTEM INPUT VOLUME	Authorized Consumption	Billed Authorized Consumption	Billed metered consumption	Revenue Water
			Billed unmetered consumption	
		Unbilled Authorized Consumption	Unbilled metered consumption	Non-Revenue Water
			Unbilled unmetered consumption	
	Water Losses	Apparent Losses	Unauthorized consumption	
			Customer metering inaccuracies	
		Real Losses	Leakage on transmission and distribution mains	
			Leakage on overflows at utility's storage tanks	
			Leakage on service connections up to the point of customer metering	

Source: AWWA

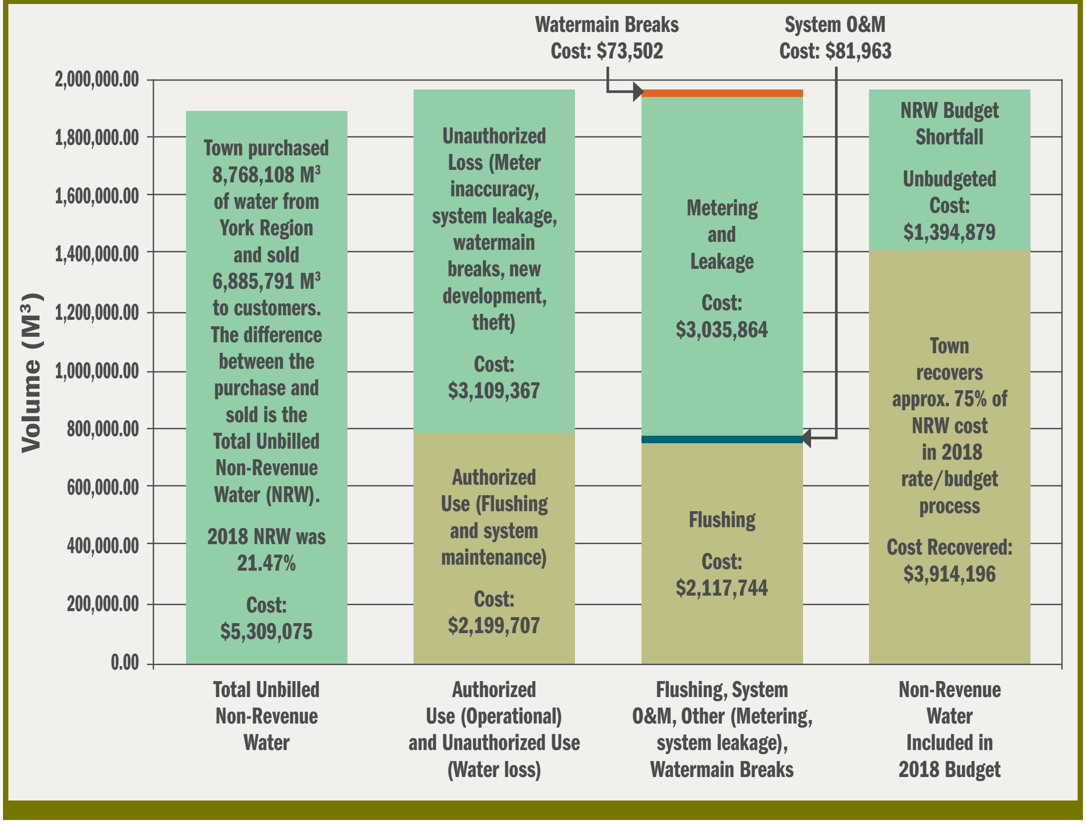
Non-revenue water (NRW) is water that has been produced and pumped into the network and is lost before it reaches the end-user. NRW is typically measured as the volume of water "lost" as a share of net water produced. Not all NRW is related to the system's physical conditions. Some water is lost due to the lack of metering or inaccuracies of metering. Some NRW is unavoidable—for example, water needed for new watermain commissioning and testing. Some are authorized but unbilled, such as water used for firefighting, while others are unauthorized and unbilled, such as theft.

Figure 5, produced by the town of Newmarket in 2018, illustrates the types and costs of NRW. In 2018, NRW was approximately 21.47% (the difference between the water volume billed by the Region and sold by Newmarket). The total lost revenues due to this leakage are $5.3 million/year, including the following:

- Water used for flushing to maintain water quality (approximately 750,840 m³, 8.56%)
- Routine maintenance activities (approximately 29,060 m³, 0.33%)
- Watermain breaks (approximately 26,060 m³, 0.30%)
- Other Water Loss, including water meter inaccuracies, system leakage, firefighting, theft, new watermain commissioning/testing (1,076,357 m³, 12.28%)

Source: Town of Newmarket

Figure 5: Town of Newmarket (2018) Non-Revenue Water Breakdown



Note that the valuation of water assets in Newmarket (in 2020) was estimated at $373 million. The average capital investment budget (5-year average) is $1.68 million. The replacement rate is 0.47%, which is below the typical industry thresholds. This means that the planned service life is over 200 years. The Canada Infrastructure Report Card recommends that a minimum of 1%-1.5% of the current replacement value (CRV) be allocated to annual capital expenditure. A suitable rate is typically estimated as high as 2-4% annually. In the case of Newmarket, the current estimated life expectancy of water infrastructure is 73 years. This is mainly because the system is relatively new. The average pipe has only reached 31% of this age. However, staying at a replacement rate of 0.47% means that the town is on track to triple that age (212 years). The conditions of wastewater and stormwater asset management are worse than water infrastructure: reinvestment value of 0.18% and 0.09% respectively.

The quality of the physical system is the main reason behind the leakage. By better asset management, a significant percentage of NRW can be recovered. Replacing older pipes can reduce corrosion and the need for frequent flushing. Typically, 75% of NRW is recoverable by proactive leak management. Potentially, this could mean that about 5-15% of all water produced in the Town of Newmarket can be saved (amounting to 16% of the total capital budget).

Infrastructure Leakage Index

AWWA traditionally tracked water loss as a percentage of the total water produced. The benchmark was 30%. This includes a target for an unaccounted NRW of 10%. Recently, AWWA shifted to a more meaningful benchmark: The Infrastructure Leakage Index (ILI). ILI is the ratio of current annual losses to the unavoidable annual real losses. An ILI close to 1.0 demonstrates excellent levels of leakage management. Each level of ILI defines the general conditions and is associated with some recommended best practices, which are classified in the International Leakage Performance Category (LPC). The LPC classification has 8 categories (A1 to D2); LPC boundary values of ILI for Low- and Middle-Income Countries (LAMICS) is twice as large as boundary values for High-Income Countries (HICs). Table 4 showcases the ILI and LPC benchmarks. Table 5 compares ILI values for Canada against other countries. Canada is second from last; and is above the North American average.

The AWWA database includes ILI values for 33 Canadian cities. More than 50% of the cities have an ILI above 4, and only less than 30% of the cities are in the excellent category of ILI<2.0.

Source: www.Leakssuitlibrary.com)

Table 4: Infrastructure Leakage Index and Leakage Performance Category

Low and Middle Income Countries ILI range	High Income Countries ILI range	Leakage Performance Category LPC	Calculated ILI for this System	General Description of LPCs A to D (LPC limits for Low and MIddle Income Countries are double those for High Income Countries)	Recommend Actions for each LPC range	A	B	C	D
					Investigate pressure management options	Yes	Yes	Yes	-
					Investigate speed and quality of repairs	Yes	Yes	Yes	-
					Check economic intervention frequency	Yes	Yes	-	-
Less than 3	< 1.5	A1	-	Further loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement	Introduce/improve active leakage control	Yes	Yes	Yes	-
3 to < 4	1.5 to < 2	A2	-		Identify options for improved maintenance	-	Yes	Yes	-
4 to < 6	2 to < 3	B1	-	Potential for marked improvements; consider pressure management, better active leakage control practices, and better network maintenance	Assess Economic Leakage Level	Yes	Yes	-	-
6 to < 8	3 to < 4	B2	-		Review burst frequencies	-	Yes	Yes	-
8 to < 12	4 to < 6	C1	-	Poor leakage record; tolerable only if water is plentiful and cheap; even then, analyze level and nature of leakage and intensify leakage reduction efforts	Review asset management policy	-	Yes	Yes	Yes
12 to < 16	6 to < 8	C2	-		Deal with deficiencies in manpower, training and communications	-	-	Yes	Yes
16 to < 24	8 to < 12	D1	-	Very inefficient use of resources; leakage reduction programs imperative and high priority	5-year plan to acheive next lowest band	-	-	Yes	Yes
24 or more	12 or more	D2	-		Fundamental peer review of all activities	-	-	-	Yes

Table 5: Global Infrastructure Leakage Index Comparison

A	B	C	D	E	F	G	H	I
Country or Region	Source of Data	Period	No. of Utilities in Group	% of Utilities in Sample	No. of Utilities in Sample	Median of Average Pressure (m)	Median ILI of Sample	% of Sample Utilities with ILI ≥ 2.0
The Netherlands	ILT	2015	10	100%	10	32	0.6	0%
Denmark	DANVA	2014	170	22%	37	34	0.7	3%
Belgium (Flanders)	AQUAFlanders	2014	7	100%	7	39	1.0	14%
Germany	Wasser-Praxis	2011	6,000	0.7%	44	40 to 50 (est)	1.0	25%
Austria	OVGW	2007/2011	5,500	0.9%	50	50	1.0	36%
Australia	WSAA	2014/15	70	93%	65	41	1.1	21%
England/ Wales	EU Ref. Doc	2011/12	26	35%	9	43	1.7	22%
Georgia (USA)	Env. Prot. Div	2011	107	100%	107	46	1.8	44%
North America	AWWA	2011	50,000	0.5%	25	51	2.4	64%
Portugal	Global ILIs	2013/15	129	11%	14	40	2.6	57%
Canada	Global ILIs	2003/14	33	100%	33	50	2.7	67%
Croatia	Global ILIs	2005/14	150	15%	23	50	4.5	80%

Source: www.Leakssuitlibrary.com)

Leakage in Ontario

There are no adequate estimates for leakage rates in Ontario. Leading jurisdictions, like Denmark, have achieved water loss rates as low as 7%. Some cities, such as Berlin, have reported even lower rates of 3-5%. However, significant leakage rates ranging from 10% to 50% have been reported in other European cities (European Environment Agency 2010). The American Water Works Association (AWWA) suggested an estimate of 15% average leakage in North American water utilities (AWWA, 2018). The U.S. infrastructure report card, by the American Society of Civil Engineers (ASCE), estimated that there is a water break every two minutes in the U.S. It is estimated that approximately 6 billion gallons of treated water are lost as a result of leaky pipes each day. That is equivalent to 9,000 swimming pools or 6-day water consumption in Toronto. According to the U.S. Environmental Protection Agency (EPA), the volume of water lost through distribution systems is 1.7 trillion gallons per year, at a cost of (U.S.) $2.6 billion. Many of these wasted gallons are lost through the 240,000 watermain breaks that take place annually across the United States. EPA estimated $97 billion (29% of $384 billion in infrastructure investments) will be needed nationally to control water loss over the coming two decades in the U.S. However, about 60% to 75% of leaked water is recoverable leakage (Vickers, 1999), which can create significant savings.

Naturally, leakage rates are expected to increase in the future due to the widening gap between aging water infrastructure and investments in system rehabilitation, and the implications of climate change.

Challenges with estimating leakage rates in Ontario

The City of Toronto has consistently reported an NRW rate of 10-15% since 2004 (Roshani and Filion 2015). Similarly, many Ontario municipalities report an estimated 10% of NRW. In contrast, ECO (2017) suggested that the rates in Ontario could be at least 10% and can reach up to 40%. Reports by consultants who conducted actual assessments show that NWR in Ontario ranges between 11-37%, with an average of 23%. For ILI, results of actual studies conducted by consultants estimate that the range is between 1.8-5.8, with an average of 3.7 (see Town of Tecumseh-Water audit and water balance, 2018). For the Town of Tecumseh, the consultant applied the standard AWWA/IWA software using data from the town. The results were ILI=1.27 and NRW=12.7%. ILI value indicates assets in near-mint conditions. They were rightly rejected by the consultant.

It is clear that data accuracy is an issue. Table 6 shows the inconsistency in the estimates of non-revenue water in the town of Newmarket as reported in 2018. The contrast of the leakage rate between 2009 and 2017 against that in 2018 obviously reflects an inaccurate data collection in 2009-2017.

Of the reliable estimates, there is a clear discrepancy that indicates that age alone is not the reason for higher ILI. The asset management program and the adequacy of funding make a big difference. An analysis for the Town of Smiths Falls estimated that NRW between 2003 and 2019 ranged between 41% and 67%. For ILI in the same period, the range was between 10 and 15.5. These are off-the-chart kind of numbers (Town of Smiths Falls Water systems non-revenue water reduction strategy, 2020).

Table 6: NRW in the Town of Newmarket

Year	Purchased volume from York Region (m^3)	Billed volume for Town of Newmarket (m^3)	% Difference – Purchase vs. Consumption (non-revenue water)
2009	8,741,611	7,368,900	15.70%
2010	9,129,588	7,539,311	17.42%
2011	8,479,472	7,345,696	13.37%
2012	8,598,676	7,191,412	16.37%
2013	8,613,261	7,080,899	17.79%
2014	8,130,411	7,011,144	13.77%
2015	8,242,358	6,940,811	15.79%
2016	8,175,016	7,045,890	13.81%
2017	8,061,649	6,669,617	17.27%
2018	8,768,108	6,885,791	21.47%

Source: Town of Newmarket

The difference between region-level and individual municipality level should also be considered. In 2016, the average non-revenue water percentage in the region of York was 11.3%, which is very good. However, the newly minted systems in Vaughan obscure the significant deterioration in other older municipalities in the Region. For example, East Gwillimbury had 22% and King had 30% (See Table 7 below).

Source: Region of York

Table 7: Region of York long term water conservation strategy (2018)

Municipality	2016 NRW (%)	ILI
Aurora	17.8	1.07
East Gwillimbury	21.9	1.75
Georgina	19.2	1.79
King	29.5	4.16
Markham	10.7	1.47
Newmarket	13.8	1.54
Richmond Hill	12.5	1.98
Vaughan	7.3	1.20
Whitchurch-Stouffville	12.8	1.34
Weighted Average	**11.3**	–

High leakage and infiltration rates are a symptom of underinvestment in both energy efficiency and infrastructure maintenance. The relationship between leakage rates and energy inefficiencies is not linear. The fraction of energy wasted is typically 30-80% higher than the percentage of water lost through leakage as pumps need to work harder to maintain desired pressure levels. The increased workload may shorten the lifetime of pumps, and increased upstream pipe pressure may trigger other leaks. Audits for energy "leakage" due to inefficiencies are hard to find. Outdated means for estimating deterioration are prone to errors, especially if manufacturer curves are without correcting for actual performance. 152 pumps currently used in Ontario were tested in 2013 (HydraTeck 2013). It was found that, on average, peak efficiencies were 9.3% lower than their original manufactured state. This gap further increases to 12.7% when accounting for operation away from peak efficiency

Progress in leak management in Ontario

When proper funding is applied, positive results are achieved. In Collingwood, which is as old as Smith Falls, the ILI is 2.4. In Ontario, the ECO report noted that leak-detection programs have shown that by reducing water pressure by 10%, 15% of water loss can be avoided. In one case, with the help of acoustic leak detection technology, finding and repairing leaks reduced 30 m^3/hr of reduced water loss, an annual reduction of about 262,000 m^3. This represents a significant energy reduction. Consistently using an International Water Audit by AWWA, the City of Guelph was able to save 3.7 million cubic metres of water and over $300,000 in electricity costs to treat and pump that water between 2006 and 2014.

Toronto, for example, has a relatively high per-capita water consumption—estimated at over 360 L/P/D (litres per person per day) in 2013. This is an advancement compared to its rates in 2002—estimated at over 430 L/P/D. Yet, the current rate is high compared to leading cities such as Copenhagen and Melbourne (at around 260 L/P/D). A world leader such as Berlin has a consumption rate of about 160L/P/D. Other cities, such as Tampa and Denver, have higher consumption rates than Toronto, estimated at 440 L/P/D and 540 L/P/D, respectively. However, the two cities have lower per capita energy usage—estimated at less than 50kWh/P/D compared to Toronto's estimated 80kWh/p/D (Lam et al. 2017)

Lessons from the top-performing cities for NRW management, such as Berlin, Tokyo, Denver, and Copenhagen (all reporting NRW between 3% and 7%) can be insightful. As an example, Tokyo managed water loss by replacing aged watermains systematically, conducting active leak detection, improving detection devices, and retaining experienced staff in leak detection. As a result, the city reduced its water loss rate from over 10% in 1990 to less than 3% in 2010 (see Lam et al. 2017; Ashida, 2014).

Is a drop from a supposed 10% to a hard-to-get 3% significant? Yes. The 2004 water audit and water balance study for the City of Toronto estimated NRW at 52,433,000 m^3, or 10% of the total system supply. From this, the system leakage or real losses were calculated at 103 MLD (million litres per day). This volume of real losses is equivalent to supplying the daily demand of a system servicing a population of approximately 250,000 people, or filling over 15,000 Olympic-sized swimming pools daily.

Is achieving such levels of reductions possible? Yes. The success of the Water Loss Program in Halifax is a case in point. Halifax Water determines yearly and quarterly ILI statistics. In 1999 the system registered a 6.4 ILI. With government support and through applying the AWWA audit program as well as an aggressive leak-management initiative, Halifax Water brought its ILI down to 3.8 in 2004. This represents a total water volume savings of 23,000 cubic metres per day (Halifax Water 2019). Staying the course, the overall ILI has been reduced from 6.1 in 2001 to 2.4 in 2014. The proud staff of Halifax Water is working towards savings of 27,000 cubic metres per day, by 2025.

5.0 THE ECONOMICS OF ENERGY AND CARBON FOOTPRINTS OF LEAKAGE

Leak management saves lost water and, as such, has a direct economic benefit. For example, at an assumed 10% leakage rate, Toronto wastes 100 MLD. This is equivalent to supplying the daily demand of 250,000 people or filling 15,000 Olympic-sized pools every year. It is estimated that investments in leakage reduction in Toronto will have a benefit-cost ratio between 4.1/1 to 6.3/1. The payback period for investments in leak and pressure management systems (in East York) is estimated to be between 4 and 4.5 years (Hydratek 2013). Bakker et al. (2014) combined water demand forecasting with pressure management to reduce pressure and leakage. The approach reduced pressure by 29%, the background leakage by 20%, and the total energy cost of the system by 11.5% on one network.

Reducing leakage makes business sense. For example, Thames Water in London, U.K., is investing £200 million to find and fix leaks. The project will reduce the leakage rate by 15% by 2025 (from 430 to 370 million litres of water a day). It is expected to save the equivalent of 172 Olympic-sized swimming pools of water every day (Hacket 2019).

In 2018, Yorkshire Water (a U.K. utility) hired over 170 additional leakage inspectors and started investing in the use of cutting-edge technology, including drones, satellites, and acoustic loggers. The utility has a target of cutting the pollution rate by 40% in two years. The company reviews all customer accounts every year and proactively contacts anyone who they believe may financially benefit from switching to a water meter. In the first two months of 2019, more than 14,000 leaks were repaired by the company, which is spending more than £1 million a day to tackle leakage and improve its customer service (see Yorkshire 2021). The utility adopted a campaign-based method to leakage detection using innovative approaches to best understand full water usage within specific geographical areas. "Reducing leakage is a top priority for the company and our customers, so it's vital we have the very best people working on it. Our partners will be challenged to be as innovative as possible to find leaks so we can get them fixed, especially those that are hidden underground and not visible from the surface. We are focused on ensuring our network is fit to serve our customers now and into the future, and I'm confident investment on this scale will help us to achieve our ambitious targets (Ofwat 2019)."

The benefits of leak detection go beyond direct monetary savings (Renzetti and Dupont 2013).

- "Reduced water losses from the system and the revenue losses they cause
- Reduced demand for energy, labour, chemicals, and other scarce inputs needed to purify, pressurize and deliver water
- Reduced CO_2 emissions associated with energy use
- Deferral of water treatment plant and system capacity expansions through water savings
- Reduced traffic congestion, inconvenience, and service outages arising from emergency repairs
- Reduced withdrawals of water from rivers and lakes and thus increased water for aquatic ecosystems, recreation, etc.
- Reduced risks of contamination of water supplies
- Reduced risk of future pipe and watermain breaks"

Forecasting or detecting leakages before they exist can have direct benefits to economic activities, the least of which is reducing traffic disruptions. To imagine the scale of disruptions, Toronto has around 1,400 breaks every year. That is about 24 breaks for every 100 kms or about four breaks per day. In the U.K., it was expected that 4 million holes need to be dug into its road network for pipe installations and leak repairs, every year. The monetary impact of the repairs is estimated to be at £7 billion (around (U.S.) $10 billion) annually. The overall cost can be divided into two main portions, £1.5 billion (around (U.S.) $2 billion) indirect damage costs and £5.5 billion (around (U.S.) $8 billion) in social impact costs (El-Zahab and Zayed 2019; Royal et al. 2011). At the wider economic view, The Bureau of Economic Analysis (BEA), Dept. of Commerce in the U.S. estimated that a dollar of revenue in the water and sewer industry increases revenue in all industries by $2.62 in that year. Further, adding one job in water and sewer creates 3.68 jobs in the national economy to support that job.

Managing Non-revenue Water

Leakage can be reduced and controlled through five main strategies, 1) PM; 2) ALC activities; 3) pipe rehabilitation; 4) asset management; and 5) District Metered Area/Zone (DMA/DMZ). The latter is the newest addition to the traditional four approaches. It is part of a new direction called digital water (see next section). These include the following mechanisms (Creaco et al. 2019):

"Pressure management

- Use of pressure-reducing valves (PRVs) (number of PRVs, its optimal localization, and settings)
- Use of pumps as turbines (PATs) (optimal locations and settings of PAT installations)

- Remote real-time control (RTC) of variable speed pumps (VSPs)/PRVs
- Use of pressure-reducing flexible storage (PRFS)
- Pressure distribution control plan
- Use of flow-modulated pressure control
- Use of plunger valve
- Selection of pipe diameter

Active leakage control

- Burst/leak localization and detection
- Smart water system
- Background leak estimation
- Optimal location for sensor placement
- Smart metering
- Online leakage detection and monitoring
- Step testing and hydraulic analysis

Pipe rehabilitation

- Optimal rehabilitation strategy
- Optimum pipe replacement
- Prioritizing the order of pipe replacement/rehabilitation
- Pipe repair

Asset management

- Prioritization of asset management plan
- Meter replacement/maintenance strategy
- Use of pipe material
- GIS and data of pipe burst
- 'Predict-and-prevent' mode of operation
- Risk-based asset management

DMA/DMZ

- Water network partitioning/sectorization
- DMA optimal design
- Water network clustering
- operation of DMA"

The general objectives of pressure management for leakage are:

- Reduce background leakage which is acoustically undetectable seeps at pipe joints and small cracks. It cannot be economically repaired on an individual basis.
- Reduce the rate of new leaks and breaks which occur on mains and service connections, due to diminished stress on the pipes.
- Reduce the flow rate from any leaks and breaks.

One of the most common and effective methods for pressure management is using Pressure Reducing Valves (PRVs). Additional approaches include establishing zone boundaries, fixed outlet pressure control valves, pump, and level control, time modulated control valves, and flow modulated control valves. The payback period on different pressure management schemes can be as low as 4-5 months, with a benefit/cost ratio of up to 3/1 (Samir et al. 2017). According to the U.S. Department of Energy (2006), about 10%–30% of energy savings can be achieved by optimizing the pump sizes. The use of variable speed drives can save an average of 10% of the total electricity used in water distribution. It also reported that "investing 8 cents/kWh on maintenance of pumping systems can: (i) increase pump performance by about 20%, (ii) provide savings of 145,100 kWh/year of energy and (U.S.) $11,800 in energy costs, and (iii) reduce emissions by around 98 tons CO_2 per annum. (Sharif et al. 2019)."

An energy conservation project in Sydney used pressure management, watermain renewal, and meter data monitoring. Between 2002 and 2009, the outcome was a reduction in leakage from 188 MLD to 105 MLD. The energy savings was 6,617 MWh during the same period (Brandt et al. 2012). Increasing pump efficiency by using new ozone cooling pumps to replace the old ones in Three Valleys Water, U.K., resulted in 267 kWh/year or 0.004 kWh/m^3 (or 0.08 kWh/m^3 within the ozone cooling system) energy savings. United Utilities implemented variable speed drives to control pumps close to maximum frequency. Their pumping rate reduced from 32 to 25 MLD, increasing pump operating times but reducing friction heads on the system, resulting in 115,000 kWh per year or 12% (0.020 kWh/ m^3) energy savings (Brandt, 2012).

The business case for leak management in Ontario

Investments in leak detection have valuable ROI and, as such, companies are exploring all possible options for doing it. In 2018, United Utilities, which supplies water to northwest England, utilized a dog that can sniff chlorine to detect leaks; the dog could survey 8 km/day (BBC 2018). More traditionally, in 2013, a study tested the efficiency of 152 pumps across Ontario. The testing program employed a thermodynamic testing methodology. The average wire-to-water pump efficiency was estimated to be nearly 70%, stemming from a 9.3% reduction in efficiency from the stated manufacturer efficiency and a 12.7% reduction in the best efficiency point (HydraTek & Associates, 2013). In a single section of York Region water distribution system, a mobile testing unit was used to examine leakage. The magnitude of the leak discovered and repaired resulted in 139,000 m^3/year in water savings (the equivalent of 75 elevated tanks); $426,000/year in cost savings; and 102 MWh/year energy savings, enough to power 11 homes in a year. The estimated mitigated environmental impacts: 4.1 tonnes of CO_2/year (see Jenks and Papa 2020).

Three fundamental reasons make the case for investing in leak management and detection in Ontario:

Water scarcity

We do not drink natural water. Rather, we drink treated natural water. So, the quality and size of our treatment and distribution infrastructure is what counts, not Canada's abundance of natural water resources. Given population growth, the more the pipes leak, the more we need to build brand new infrastructure, which is generally much more expensive than simply maintaining and rehabilitating current assets. As a case in point, the City of Collingwood, seeing a 53% increase in population over the last five years, is enacting a freeze on development because its water treatment infrastructure cannot catch up with demand. Oddly, one development site that was halted sits on the sixth largest Great Lake. The development freeze will stop the building of housing for seniors and a much-needed medical centre. In 2017 (at the start of the latest boom), the city water system had an ILI of 2.4. This means that there is enough leaked water to accommodate the increased needs in 2017-2021. If leakage mitigation measures were taken, a freeze on development would have not been necessary. The socio-economic impacts of such development freezes are not limited to wasted investments. The more important impact is in hampering Ontario's long-term efforts to sustain livable cities and vibrant communities in the North.

User fees

Effectively, the cost of leakage is paid by the end-users. We are all charged 10% to possibly 30% more for water that we do not use. If the municipalities invest a fraction of these extra costs to rehabilitate the system, we all save on our bills and our property taxes. The City of Halifax (recognized as a leader in water systems asset management) is a case in point. The city implemented a leak management program recommended by the International Water Association (IWA). The program resulted in saving the taxpayer $650,000 per year in treatment chemical and electricity costs and has reduced watermain breaks by 20%, saving $500,000 in repair costs annually (Halifax water 2019). In Warwick, Ont., in 2014, it was estimated that a one-time leak detection program would cost $22,150. It is estimated that the payback period would be 3 years—saving users significantly and quickly (Warwick 2014).

Every carbon tonne counts

Canada's ability to fight climate change is hampered by the harsh climate; the vast distances between cities in a country as large as Europe but with a population of only 38 million; sustained economic and population growth; a resource-rich economy of which almost a third is still comprised of goods-producing industries; and a very tightly integrated North American economy. Because of these challenges Canada does not have too many options to achieve its climate goals and the possibility of achieving our goals is less than certain. This is maybe why Canada, upon re-setting its GHG goals, put a range (40-45%) instead of a specific target. Therefore, every attempt should be made to save carbon. Focusing on reducing GHG emissions from water and wastewater utilities can be one of the easiest to implement—compare that to the efforts needed to rehabilitate the majority of our housing stock. Also, the investments needed are not as extensive as other domains (for example, the oil sands), with a very favourable ROI. In fact, Stokes et al. (2014) indicated that water-loss control was more cost-effective in mitigating GHG emissions than emission trading schemes (ETS) in the case of California water utilities.

6.0 DIGITAL WATER

The municipal water sector is undergoing a transformative change. New business models and new hardware and advanced analytics tools are opening new horizons of innovation and efficiency. The concept of digital water integrates the use of smart hardware and advanced data analytics to help optimize the operation and ROI of water systems. Upgrading existing systems through asset management and leak reduction is now a top priority for digital water systems. Some of the key digital water solutions that are being implemented include advanced metering infrastructure (AMI), water loss detection, water quality monitoring, SCADA modernization cybersecurity, condition-based monitoring, and digital twins.

Energy management and leakage control systems with Digital Water

The concept of "smart city," as related to technological innovations, is relatively recent. A smart city can be defined as "the city in which an investment in human and social capital is performed, by encouraging the use of information and communication technology as an enabler of sustainable economic growth, providing improvements in the city inhabitants' quality of life, and consequently allowing better management of water resources and energy. Importantly, a smart city aims to promote socio-economic development as the ultimate objective of any associated technological advancement (Ramos et al. 2020)."

Within this scope, digital water conceptualizes water as Physical-Cyber-Social (PCS) domain. Beyond installing smart hardware, PCS emphasizes the collection and use of big data and real-time data to enhance decision-making; and the formal inclusion of community needs/objective in the analysis, including socio-environmental considerations (such as equity or climate action) in the decision-making. Progressive utilities are investing in research, prototyping innovative solutions, and supporting the development of integrated PCS systems.

A digital twin of a smart water system provides a virtualization platform to collect data, conduct predictive (what can happen) and prescriptive (what should happen) analysis that can lead to more sustainable water services, reducing financial losses, enabling automated work processes to better serve the population. The aim of digital twins of water distribution systems is to reproduce disruption scenarios for resilience assessment purposes, to validate beforehand new solutions for network configurations, and to analyze asset prognosis and health status to determine proactive maintenance models.

The main advantage of smart water management is that a holistic and data-driven view of the whole system enables in-depth analysis of resources and system outputs. This provides for a better understanding of water flows and pressure patterns, early detection of leaks, and constant monitoring of water quality. Particularly for leak management, digital water can help track breakage patterns and identify areas where illegal connections occur. In addition to the economic benefits, digital water preserves energy and enhances the customer experience. This is why the International Water Association (IWA) emphasizes that digital water is not an option but an imperative (Giudicianni et al. 2020).

The manifestation of the transformative role of digital water mentality can be observed in the following areas:

Sustained network monitoring: Smart water systems are now the fifth approach to managing real losses (in addition to the traditional four: active leakage control, pressure management, asset management, and repair optimization). This includes technologies such as Internet of Things (IoT), mobile and fixed sensors, and even the use of drones and satellite imagery.

You cannot manage what you cannot measure. These systems can help solve one of the most chronic problems in city management: data collection rates and quality. There is a need for mandating rigorous data collection regarding our water and wastewater, much like the practice in highway systems. For example, O.Reg 239/02 mandates an annual inspection of roadway assets, such as sidewalks. If similar mandates were to be enacted for water and wastewater assets, IoT, which has advanced significantly in terms of quality and pricing, would significantly increase the ROI of such mandate.

Supporting innovation projects: Unlike traditional business practices, through digital water, utilities can study and develop advanced analytics for system efficiency; and simulate in the virtual world new technical and business scenarios—for example, contrasting different billing and operations options to support the reduction of per capita consumption or optimal reduction in GHG emissions. By analyzing pipe failure rates using big data leakage analytics and analysis of leak dynamics, pipe replacement becomes no longer based on age only, but on a multitude of factors, such as pipe failure rate, soil corrosivity, and pressure levels. We now can move from reactive to proactive decision-making regarding when to replace pipes. What are the options for minimal disruption or non-intrusive pipe repairs? What value can be generated through using smart systems?

Business best practices: Water utilities are at the centre of a greater, more complex, and interconnected ecosystem that includes stakeholders from across the water and wastewater spectrum, such as private and public utility peers, governmental bodies, local communities, other utilities, technology solution providers, and academic institutions. Utilities are starting to implement best practices in process automation that has been in use in other industries for decades. Intent-based networking (IBN) transforms a hardware-centric, manual network into a controller-led network that captures business intent and translates it into policies that can be automated and applied consistently across the network. The goal is for the network to continuously adjust its configuration to help assure desired business outcomes.

The market for digital water in the U.S. and Canada is expected to expand at a compound annual growth rate of 8.7% between 2019 and 2030 (Bluefield research 2019). This is higher than previous expectations, possibly because of the COVID impacts on virtual business. In one estimate (Maize 2020), the leakage management segment can see total operational expenditures of more than $1 billion by 2026, with smart water technologies continuing to grow in market share. It is not a surprise that the market is seeing high levels of mergers and acquisitions.

To this end, on April 29, 2021, the U.S. Senate approved the *Drinking Water and Wastewater Infrastructure Act* of 2021 (S.914). It allocates (U.S.) $35 billion over the next five years to invest in the nation's water systems. The bipartisan bill passed and included strong support for the use of digital water systems.

7.0 BENCHMARKING BEST PRACTICES IN PUBLIC POLICY

Leadership from policymakers matters and is needed. As we embark on the next phase of asset management practices in Ontario, public policy will play a major role in addressing the challenges of climate change and asset deterioration; the adoption of digital water concepts; and securing adequate and innovative funding schemes. However, the most impactful role of public policy in the next phase of AM in Ontario is to create the environment for a paradigm shift in the sector that promotes a more efficient industry structure and agile business and funding models.

As a case in point, evaluations of environmental performance in the EU27 showcase that policymaking and local conditions play a major role in overall energy and economic performance. The overall performance of the EU27 indicates an average water efficiency of 27 m^3/k€. The energy efficiency is 8.8 MJ/€. Both are better than the worldwide average (75 m^3/k€ and 13.9 MJ/€, respectively). The per capita indicators are higher than the world average in terms of consumption (1,332 m^3), energy used (at 0.43TJ), and carbon footprint (at 14 t). Within the EU27, variations in country-level policymaking created significant differences in the water-energy-carbon nexus. Some of the countries that consume the most energy such as France (0.42 TJ/cap), Sweden (0.7 TJ/cap), Lithuania (0.36 TJ/cap), and Portugal (0.29 TJ/cap), have less CO_2 emissions because of higher renewable energy share (Wang et al. 2020).

Objective benchmarks

So far, Ontario regulations provided general guidelines for mandated actions. For example, O. Reg 588/17 mandated the consideration and reporting of LOS and the funding needed to address any shortcomings. This was a very significant step forward that pushed AM practices in Ontario beyond analyzing the basics. Two important changes should guide future policymaking. But there are questions about the value of this regulation given that there are not clear mechanisms to enforce it or consistently advance LOS over time.

New policies should establish mechanisms for developing and enforcing specific benchmarks, such as acceptable ILI, maximum GHG levels, replacement rates, and leakage levels. The Ofwat site states, "We have scrutinized companies' (business) plans to make sure that they deliver more of matters for customers and the environment. Where they have fallen short, we will be stepping in." Ofwat goes even a step further by testing the quality of data upon which AM plans and targets are developed.

The management efficiency of the utility

It is not a prudent use of public finances to fund projects before funding the capacity to develop and manage the projects efficiently. Some benchmarks should be established for assessing the performance, capacity, and competency of the overall asset management program in a municipality. In a recent study in the U.K., researchers compared the performance of several utilities (water and wastewater companies). They found that, in perfect conditions, if the lower-performing companies adopt all the best practices in the industry, they can have the potential to decrease their energy inputs and their economic inputs (Walker et al. 2020).

In a progressive move, the City of Markham has conducted an audit of its water revenue. The audit evaluates the needs for enhancement in nine major business efficiency indicators—using a scale of low, medium and high. The 2017 audit graded one indicator as medium. The remaining eight were evaluated at low. In the following year, 2018, the same ratings were scored for the nine indicators (see City of Markham 2017 and 2018). Quantifying and tracking performance are the first steps to real efficiency gains.

For Ontario, the stakes are high. It is estimated that, over the next decade, Canadian municipal utilities are poised to invest (Cdn.) $64 billion in capital improvements in a wide range of projects in the collection and distribution of water and wastewater systems. Therefore, every enhancement counts.

The context of public policy in the new market

Our future plans should consider that operations and investments in water and wastewater utilities take place in a significantly changed world. This relates to the impact of climate change, opportunities for digital water, and the globalization of water services. For example, let us consider the management of severe storms. In 2021, an Arctic blast disrupted most utility services in 13 southern states in the U.S. In Texas, over five million people lost electricity and 14.4 million people lost access to drinking water (with 1,100 public water systems reporting disruptions).

In 2018, the British Isles were hit with a significant storm with unusually low temperatures and excessive snowfall—they called it the "The Beast from the East." Post-storm analysis by Ofwat found a set of common failings across several water companies, including the following:

- "Poor preparation and planning, with several companies lacking adequate emergency response plans and mainly reacting to events as they happened;
- A lack of coordination between companies to share resources such as bottled water suppliers or best practice in handling the incident;
- Limited or inaccurate data on where problems were occurring and whether they had been resolved, with several companies having limited capacity to remotely manage their networks and move resources which also hampered their response;
- An inconsistent approach to identifying and supporting customers in vulnerable circumstances, with some companies lacking accurate or up-to-date data on customers who needed priority help; and,
- Poor communication with customers and stakeholders, with only 60% of affected customers surveyed by the Consumer Council for Water receiving direct communication from their company and many priority stakeholders (councils, local resilience forums, emergency services, schools) receiving little or no proactive communication before, during or after the event (Ofwat 2018)."

Ofwat required four under-achieving water companies to submit a detailed, externally audited action plan. In releasing the report, the Ofwat CEO stated: "Four companies have three months to satisfy us … . We will take action if they don't rise to this challenge. We expect every water company to take action on the back of this review and the industry as a whole to transform how it works together in situations like these. Water is an essential service. Water companies must be prepared for whatever the weather brings."

Consequently, governments are reconsidering their role in setting specific targets to realize the goals of legislations on the ground. In California, SB 555 Bill allows the State Water Control Board to levy fines on urban water suppliers for water loss starting in 2019. In the U.K., Ofwat revised its performance measures to establish new climate-savvy benchmarks and incentive programs. The new program focused on two major benchmarks: Outcome Delivery Incentives (ODIs) as well as reducing leakage and Per Capita Consumption (PCC). The regulator showed its commitment to "putting a pricing on leakage" when, in 2017, it levied £8.6 million on Thames Water for missing a leakage target.

The result of Ofwat leadership was significant on corporate strategies. A spokesperson for one utility said: "The Government has made clear the water industry must raise its game. We want companies to invest more, reduce leakages and help customers to become more water-efficient, including through metering. Water companies are starting to rise to this challenge. The Environment Secretary has been clear that we will support regulators to secure a sustainable water supply for the future." (see Ofwat 2019)

Policymaking in the 21st century

Beyond redeveloping the benchmarks to be climate savvy, the true change in policymaking is in re-casting the role of public regulators. Public policy is not limited to setting technical benchmarks. It is increasingly being directed toward creating a healthy, innovative and resilient industry structure in the public assets domain.

The macro policy objectives in the sector did not change—for example (Haider et al. 2014):

- **Safety impacts:** How water supply services support the reduction of incidents or accidents that result in death and (or) injury and (or) property loss.
- **Health impacts:** The health impacts (both direct and indirect) can be beneficial or detrimental to consumers as well as to the general public.
- **Security impacts:** The performance of the water supply service in terms of protecting the security of the users, operators, and public at large.
- **Economic Impacts:** The direct and indirect impacts (beneficial or detrimental) of water/wastewater on local, regional, and national economies.
- **Environmental impacts:** The direct and indirect impacts of water supply service on the natural environment (air, water, soil, fauna, and flora) and climate change.
- **Quality of Service:** An assessment of how well the service meets established levels of service, regulatory requirements, industry standards, and customer satisfaction.
- **Access to service:** The geographical coverage and affordability of infrastructure services and provision of access to people with disabilities.
- **Adaptability:** The capacity of the service to adapt to short- and long-term changes and pressures.
- **Asset preservation, renewal, and decommissioning (Asset P/R/D):** The management of water supply assets to keep the service operations at their intended level of service through inspection, routine maintenance, repair, rehabilitation, renewal, and ultimately decommissioning.
- **Reliability of service:** The ability of the utility to perform its required function under stated conditions for specified periods.
- **Capacity to meet demand:** The capacity of the service to meet demand under current and future conditions, extreme events, and emergencies.

However, emerging new policies are operationalizing these objectives differently in light of the challenges and opportunities of the green economy and the advancement of smart city (digital water). These include (Brears, 2018):

- "Creating policy instruments that promote complimentary benefits (economic, environmental, social)
- Developing fiscal instruments that give a price to environmental goods
- Strengthening institutional arrangements that enable the management of water across sectoral silos and even political/administrative boundaries

- Developing financial instruments that share risks between governments and investors and make new water technology affordable
- Developing skills that support the sustainable management of water in the green economy
- Establishing information and monitoring systems that set targets, define trajectories, and monitor progress on water efficiencies
- Developing innovative plans that increase water productivity, protect groundwater and surface water resources, and ensure adequate levels of water quality"

Below are some key examples of the new policymaking landscape. This should guide the next phase of Ontario's policymaking and legislation.

Enhancing social considerations and equity

AM investments can create green jobs and support inclusiveness. Key among the actions needed are investments in education and training and outreach to all communities. The industry is suffering from a chronic lack of skills and training programs—especially at the level of smaller municipalities. It is also hard to recruit new talent in the industry—the average age of the labour force in the domain is typically over 40 years. The new realities of the economy also require different skills. The new labour force has to learn the skills of managing older facilities (in contrast to building new ones); they need to learn how to plan and evaluate the performance of their facilities to include energy and carbon footprint; they need to be informed about managing new risks such as severe storms; they need to have the skills to manage digital water systems, including data collection, analytics and cybersecurity issues.

Investments in education and training in this domain are, by default, investments into the green and digital economies. Such investments can make the domain more attractive to younger generations and provide opportunities to those who are shifting their careers from the traditional economy to higher-paying careers in the green/digital economy.

Governments and the AM industry should also rethink their community engagement practices. Instead of reactive delivery of information, our policies should be oriented towards proactive outreach and focus on empowering communities (as citizen scientists) to take ownership of their assets. Citizens should co-lead the definition of problems, developing alternatives, and take a lead in decision making.

Technology & digitization

Public policy regarding the data management processes in the domain is desperately needed. We need to invest in collecting data and in ensuring data quality and availability; promoting data sharing; and supporting the implementation of AI tools in the industry. As a case in point, to support the consideration of life cycle assessment, Germany enacted a policy that has two complementary instruments. First, mandating the consideration of LCA (life cycle analysis) in the contract-award laws. Second, supporting LCA consideration through establishing a portal to help contractors and public agencies conduct the analysis. Similarly, municipalities in Ontario (especially smaller ones) may not have the resources to exploit advances in data analytics. Ontario should support the transition to digital water in these municipalities through training (as above), setting benchmarks for data analytics, and possibly through creating a data analytics portal. Municipalities can upload simple files with key attributes about their infrastructure. The system can provide them with key basic analytics for such data.

The government in collaboration with the industry could support the creation, dissemination, and efficient deployment of new technologies (hardware or software). Collectively investing in a program to evaluate new technologies; developing guidelines for customizing technology use and adoption; provide incentives to municipalities to invest in research and training. For example, after being hit with a hefty penalty from Ofwat due to missing leakage targets, Thames Water enacted a £200-million program for leakage management. It requires suppliers to attend quarterly innovation forums to share the latest ideas, techniques and best practice.

Funding decision-making

Several changes are taking place in the way governments allocate funds. Some of the key best practices are listed below.

Switch to setting benchmarks along with incentive/penalty programs: Mandating that municipalities develop AM plans and mandating the consideration of LOS are significant steps. The next phase of Ontario legislations should advance AM practices by shifting regulatory mandates to be expressed in the form of common, objective, and measurable performance benchmarks—for example, acceptable replacement rate, ILI targets, specific GHG levels, and data quality standards. Similar to Ofwat best practices, funding and incentives are to be tied to progress towards achieving these targets. Penalties should be considered if these benchmarks are not met.

Considering energy/GHG reduction as a standalone decision criterion: Governments could mandate that, where applicable, any funding proposals must include energy or GHG reduction directly as planning objectives. See, for example, Matrosov et al. (2015), who examined the planning of London's future water supply, where energy consumption was included in the operating cost objective, together with capital cost.

Cross jurisdictional integration: Increased system complexity and the traditional silo approach to decision-making reduce the chances for integrated thinking. There is a need for establishing mechanisms and supporting analysis tools to promote collaborative, region-wide integration of water, energy, and emission plans. In Spain, for example, an integrated country-level model for tracking energy flows was created to help inform different organizations and support optimal usage of resources in water systems (Khan et al. 2016).

Encourage small, decentralized projects: Support the use of alternative water and energy sources in creating localized small-scale systems, such as rooftop rainwater systems. The use of pumps as turbines (PAT) systems can be also a good example of these types of projects.

Expanded finance sources

New sources of finance exist at the intersection of water, energy and carbon. Below are some examples.

Environmental Taxes: In addition to incentivizing investments in green practices, the government should consider a shift in the tax systems to address environmental "bads." Specifically, how to reconfigure and administer carbon taxes to reduce pollution, increase resource efficiency and promote behavioural change in consumers and economic sectors.

Partnerships: Public-private partnerships (PPPs) offer feasible solutions to complement or replace public responsibilities for infrastructure funding. This is not necessarily a call for privatization. Rather, this is a call for working with all stakeholders to investigate the increasing interest of the private sector in the green economy; and their newly developed partnership models. Many progressive private funds, eager to invest in the green economy, are offering innovative funding schemes that avoid previous public concerns. Take, for example, the Canada Infrastructure Bank program on project acceleration. The bank recognized that several hurdles and unknowns can stop green investments. Through this program, municipalities can apply for funding to study/enhance the feasibility of green or smart systems. The bank could also be a good partner in funding a PAT system for charging electric bicycles or cars.

Opportunities in Ontario

How can Ontario municipalities fund the next phase of their asset management systems? How can Ontario do this in a way that promotes the realization of the green/digital economy? In addition to the Canada Infrastructure Bank, some of the available funding sources in Ontario are listed below.

Green bonds: The increased realization by individuals and key financial industry players that the green economy is becoming more profitable provides opportunities to generate funding for energy and emission conservation projects. In 2018, the City of Toronto issued a green bond ($300 million) to raise the capital required to deliver projects in support of its climate action strategy. There were 30 investors who contributed to the bond and the City achieved the lowest interest rate since amalgamation, resulting in $600,000 in savings.

Green funds: Ontario should consider supporting innovation in greening of the water and wastewater sectors through awareness and funding (the *Water Opportunities and Water Conservation Act, 2010* provides a legal framework for prioritizing water-energy efficiency programs). Previously, Ontario created related programs, such as the Ontario Green Investment Fund, which provided support for climate action programs. Lessons learned from such programs can be helpful in charting future climate-oriented funding schemes. As part of the federal climate action initiatives, a multitude of funding opportunities can be used to encourage municipalities to embed the water-energy-carbon nexus into their Asset Management plans. For example, the Canada Healthy Communities Initiative (part of the Smart Cities Challenge) and the Municipal Asset Management Program (by the Federation of Canadian Municipalities) can provide funding for enhancing capacity (training, technology and software) in asset management and digital water.

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APPENDIX: EPA RECOMMENDATION ON BEST PRACTICES FOR CLIMATE ACTION

There are several strategies that municipalities can adopt to help combat climate change's negative impacts. Below is a sample of these strategies, which are extracted from EPA (2020):

Construct New Infrastructure

Build flood barriers to protect infrastructure: these include levees, dikes, and seawalls. A related strategy is floodproofing, which involves elevating critical equipment or placing it within waterproof containers or foundation systems.

Plan and establish alternative or on-site power supply: With future electricity demand forecasted to grow, localized energy shortages may occur. The development of "off-grid" sources can be a good strategy for electricity shortfalls. Moreover, the redundant power supply can provide resiliency for situations in which natural disasters cause power outages. On-site sources can include solar, wind, inline microturbines, and biogas (i.e., methane from wastewater treatment). New and backup electrical equipment should be located above potential flood levels.

Relocate facilities to higher elevations: Relocating utility infrastructure, such as treatment plants and pump stations, to higher elevations, would reduce risks from coastal flooding and exposure as a result of coastal erosion or wetland loss.

Model Climate Risk

Conduct extreme precipitation events analyses: Extreme event analyses or modeling can help develop a better understanding of the risks and consequences associated with these types of events.

Develop models to understand potential water quality changes: study, for example, the role of increased water temperatures on drinking water quality. The quality of drinking water sources may also be compromised by increased sediment or nutrient inputs due to extreme storm events. These impacts may be addressed with targeted watershed management plans.

Model and monitor groundwater conditions: Understanding and modeling groundwater conditions will inform aquifer management and projected water quantity and quality changes. Monitoring data for aquifer water level, changes in chemistry, and detection of saltwater intrusion can be incorporated into models to predict future supply. Climate change may lead to diminished groundwater recharge in some areas because of reduced precipitation and decreased runoff.

Model and reduce inflow/infiltration in the sewer system: More extreme storm events will increase the amount of wet weather infiltration and inflow into sanitary and combined sewers. Sewer models can estimate the impact of those increased wet weather flows on wastewater collection systems and treatment plant capacity and operations. Potential system modifications to reduce those impacts include infiltration reduction measures, additional collection system capacity, offline storage, or additional peak wet weather treatment capacity.

Modify Land Use

Acquire and manage ecosystems: Intact natural ecosystems have many benefits for utilities: reducing sediment and nutrient inputs into source water bodies, regulating runoff and streamflow, buffering against flooding, and reducing storm surge impacts and inundation on the coasts (e.g., mangroves, saltwater marshes, wetlands). Utilities can also work with regional floodplain managers and appropriate stakeholders to explore non-structural flood management techniques in the watershed. Protecting, acquiring, and managing ecosystems in buffer zones along rivers, lakes, reservoirs, and coasts can be cost-effective measures for flood control and water quality management.

Implement green infrastructure on-site and in municipalities: Green infrastructure can help reduce runoff and stormwater flow that may otherwise exceed system capacity. Examples of green infrastructure include bio-retention areas (rain gardens), low impact development methods, green roofs, swales (depressions to capture water), and the use of vegetation or pervious materials instead of impervious surfaces.

Integrate flood management and modeling into land-use planning: Future water utility infrastructure must be planned and built-in consideration of future flood risks. Infrastructure can be built in areas that do not have a high risk of future flooding. Alternately, appropriate flood management plans can be implemented that involve 'soft' adaptation measures such as conserving natural ecosystems or 'hard' measures such as dikes and flood walls.

Monitor Operational Capabilities

Monitor current weather conditions: A better understanding of weather conditions provides a utility with the ability to recognize possible changes in climate change and then identify the subsequent need to alter current operations to ensure resilient supply and services. Observations of precipitation, temperature, and storm events are particularly important for improving models of projected water quality and quantity.

Monitor flood events and drivers: Understanding and modeling the conditions that result in flooding is an important part of projecting how climate change may drive change in future flood occurrence. Monitoring data for sea level, precipitation, temperature, and runoff can be incorporated into flood models to improve predictions. The current flood magnitude and frequency of storm events represent a baseline for considering potential future flood conditions.

Plan for Climate Change

Develop coastal restoration plans: Coastal restoration plans may protect water utility infrastructure from damaging storm surge by increasing the protective habitat of coastal ecosystems such as mangroves and wetlands. Restoration plans should consider the impacts of sea-level rise and development on future ecosystem distribution. Successful strategies may also consider rolling easements and other measures identified by EPA's Climate Ready Estuaries program.

Identify and protect vulnerable facilities: Operational measures to isolate and protect the most vulnerable systems or assets at a utility should be considered. For example, critical pump stations would include those serving a large population and those located in a flood zone. Protection of these assets would then be prioritized based on the likelihood of flood damage and the consequence of service disruption.

Integrate climate-related risks into capital improvement plans: Plans to build or expand infrastructure should consider the vulnerability of the proposed locations to inland flooding, sea-level rise, storm surge, and other impacts associated with climate change.

Repair and Retrofit Facilities

Implement policies and procedures for post-flood and/or post-fire repairs: Post-disaster policies should minimize service disruption due to damaged infrastructure. These contingency plans should be incorporated into other planning efforts and updated regularly to remain consistent with any changes in utility services or assets.

Improve pumps for backflow prevention: Sea-level rise and coastal storm surge can cause wastewater outlets to backflow. To prevent this, stronger pumps may be necessary.

Increase capacity for wastewater and stormwater collection and treatment: Precipitation variability will increase in many areas. Even in areas where precipitation and runoff may decrease on average, the distribution of rainfall patterns (i.e., intensity and duration) can change in ways that impact water infrastructure. In particular, more extreme storms may overwhelm combined wastewater and stormwater systems.

Increase treatment capabilities: Existing water treatment systems may be inadequate to process water of significantly reduced quality. Significant improvement to existing treatment processes or implementation of additional treatment technologies may be necessary to ensure that the quality of water supply (or effluent) continues to meet standards as climate change impacts source or receiving water quality.

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