An Introduction to Asset Management Tools Municipal Water, Wastewater and Stormwater Systems

A white paper prepared for the Canadian Water Network research project:
"An Integrated Risk Management Framework for Municipal Water Systems"

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- Ontario Clean Water Agency
- Southern Ontario Water Consortium
- Clean Nova Scotia
- British Columbia Ministry of Transportation and Infrastructure
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- Engineers Canada
- West Coast Environmental Law
- Watson and Associates
- AECOM
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- City of North Vancouver
- University of British Columbia
- Carleton University

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overview

The following white paper provides an introduction to select tools and practices that are helping municipalities in Canada make the shift towards an integrated approach to managing water, wastewater and stormwater infrastructure assets.

Part 1 - Asset Management

Strategic, risk-based municipal asset management practices are important during an era of infrastructure replacement. Asset Management Plans (AMPs) can be developed to document how groups of assets will be managed to provide a satisfactory service level in a sustainable and environmentally responsible manner.

Part 2 - Condition Assessment

A critical component of the AMP structure involves risk management, where information on the physical condition of existing infrastructure is collected and recorded. Although many municipalities have traditionally relied solely on expert opinion when determining asset condition, a wide range of advanced inspection technology and condition assessment tools are now available for those municipalities seeking accurate and reliable condition data.

Part 3 - Defining Levels of Service (LoS)

Defining an appropriate LoS for water system infrastructure requires input from stakeholders, the municipality, technical analysis, and risk analysis. Existing LoS systems can help ensure established LoS performance indicators are not only focused on the customer but are also relevant and attainable.

Part 4 - Software Trends

The ability for a municipality or utility to effectively manage its water and wastewater infrastructure assets will largely be controlled by its ability to organize large amounts of data. A wide variety of technologies that support asset management are now available to municipalities and utilities.

Part 5 – Conclusion

A series of barriers to asset management still exist in Canada. Embracing standardization of asset management practice and state-of-the-art software tools is a necessity for sustainable growth and development.

pt 1. asset management

≈75% of the respondents in a 2012 survey of 451 utilities in North America's water and wastewater infrastructure sector chose aging infrastructure as one of the most important factors leading to the implementation of asset management practices [1].

Click here to see the report.

Widespread concern for the state of water and sewer infrastructure in North America has motivated a push over the past few years for wide-spread adoption of advanced management practices developed with an intention to maintain infrastructure assets at an acceptable level of risk while continuously delivering established levels of service. A wide-range of benefits are received when municipalities adopt advanced techniques for asset management. When considering infrastructure assets (those stationary water, wastewater and stormwater components with an independent physical and functional identity and age), asset management practices effectively lower the cost of infrastructure renewal, extend the life of existing assets and will ultimately help ensure adequate funding for the activities essential for a municipality's sustained growth and development over time.

1.1 STANDARDS FOR MUNICIPAL ASSET MANAGEMENT

Click here to learn more about the ISO 55000 series of standards for asset management [2].

For many years, one of the major obstacles preventing widespread adoption of advanced asset management practices at the municipal-level has been a lack of consistent standards and terminology among practitioners. Fortunately, the ISO 55000 series of standards introduced in 2014 now provides practitioners with a standardized overview of the subject of asset management, and the key requirements for the establishment, implementation, maintenance and improvement of an effective asset management system.

Defining Key Terms

- Asset: something that has potential or actual value to an organization.
- Asset Management (AM): coordinated activity to realize asset value.
- Asset Management Objective (AMO): result required from an asset.
- Asset management Plan (AMP): documents the strategic activities, resources, and timescales required for an individual asset or a grouping of assets to achieve defined AMOs [3].

1.2 ASSET MANAGEMENT GUIDANCE/EDUCATION

Click here for a "Quick Guide" to using the IIMM to meet the requirements of ISO 55000 [5].

While the ISO 55000 standards provide useful information on "what" is required of an asset management system, they do not provide asset-specific guidance on "how" an organization should achieve ISO requirements. Municipalities seeking a practical approach to implementing effective management practices for a range of infrastructure assets can refer to the International Infrastructure Management Manual (IIMM) developed by the Institute of Public Works Engineering Australasia (IPWEA) [4]. The IIMM contains over 100 case studies collected from a range of countries demonstrating good asset management practice and is used by a number of Canadian municipalities (e.g. Cambridge, Ontario).

Click here to access the IPWEA's Practice Notes for Asset Management and Financial Planning [6].

The IPWEA also develops and maintains a series of Practice Notes that can assist practitioners with asset management and financial planning [6]. Although primarily developed using input from practitioners in Australia and New Zealand, these Practice Notes are internationally applicable (with some containing Canadian case study applications:

Click to access the free, on-line copy of Practice Note 6: Long-term Financial Planning [7].

- PN 4 Asset Management for Small, Rural or Remote Communities (Version 1 published in 2011, 140 pages, available free to small Australian councils): provides access to on-line templates for managing assets with knowledge, understanding and commitment.
- PN 5 Stormwater Drainage (Version 1 published in 2011, $150 excluding taxes): assists practitioners in applying best practice for asset management, condition assessment and performance inspection for various stormwater systems (e.g. traditional underground conduit systems and lined open channel systems).
- PN 6 Long-term Financial Planning (Version 1 published in 2012, free on-line access): provides guidance and a tool-kit that can help an organization prepare a long-term financial plan without use of proprietary software (simple excel model with 15 worksheets with a how to guide to assist with the setup).
- PN 7 Water Supply and Sewerage (Version 2 published in 2014, 124 pages, $220 excluding taxes): provides guidance for condition and performance assessment. Sections included that specifically relate to ISO 55000 compliance. Provides access to a spreadsheet that can help select the priority and timing of renewals.
- PN 8 Levels of Service (Version 1 published in 2014, $220 excluding taxes): practice note examines in detail the purpose of community engagement, developing levels of service (and service options), developing a community engagement plan, determining affordable and acceptable service levels, and delivering agreed service). Provides access to a case study of the Township of Langley, British Columbia.

Tom's Bad Day:
Click to discover the EPA's storyline approach for interactive asset management training [8].

The United States Environmental Protection Agency (EPA) has developed interactive training material covering the fundamentals of discovering and applying advanced asset management practices to a utility environment. Recognizing the reality that utilities and municipalities increasingly need to do more with existing resources, the training material highlights the real savings asset management provides via efficiency gains, cost avoidance and cost effectiveness and redirection. The EPA's training material (PDF and flash videos) is structured as a hands-on approach to learning holistic asset management practices that aim to maintain a level of service at the lowest life-cycle cost at an acceptable level of risk. A real-world storyline referred to as "Tom's Bad Day" (a utility director dealing with management problems – e.g. pump station issues, sanitary sewer overflows, maintenance budget short-falls, and broadly with utility management) is used to help users think about the principles and objectives of asset management within the context of a realistic setting [8].

Click to access the EPA's Best Practices Guide for Asset Management [9].

The EPA has also made available a Best Practices Guide for asset management for water systems [9]. Released in 2008, the guide was developed for owners, managers, and operators of water systems, local officials, and technical assistance providers. Although released before ISO 55000 standardization, the material is still relevant and of utility when gaining familiarity with aspects of asset management. It covers:

- Challenges faced by water systems (e.g. increasing demands for services, overcoming resistance to rate increases, etc.).
- Benefits of asset management (e.g. prolonging asset life, meeting consumer demands with a focus on system sustainability, meeting service expectations and regulatory requirements, etc.).
- A framework for implementing asset management based around five core questions: (1) Current state of Assets, (2) Level of Service, (3) Critical Assets, (4) Minimum life cycle cost, and (5) Long-term funding plan.

SIMPLE:
Click to discover the WERF's web-based asset management learning environment [10].

The Water Environment Research Foundation (WERF) and the Water Research Foundation (WRF) have been active in the field of advanced asset management. They have made available a range of tools to facilitate asset management at the utility/municipal level. Their Sustainable Infrastructure Management Program Learning Environment (SIMPLE) serves as a web-based resource existing at two levels – an "Introductory Level" provides free, basic asset management information. The "Practitioner Level" is available to WERF and WRF subscribers and provides more advanced guidance, case studies and information on processes and that can be used for tasks such as risk assessment and establishing levels of service [10].

1.3 CANADIAN RECOMMENDATIONS FOR AMPs

Although nation-wide standards for asset management planning are not currently enforced, there has been a move towards standardization and consistency in municipal asset management in some provinces. Considering Ontario as an example, the province has made it a requirement that any municipality seeking provincial capital funding needs a detailed asset management plan (AMP) and must be able to show how the intended project falls within that plan. In general, AMPs contain information related to the characteristics and conditions of infrastructure assets owned by a municipality, levels of service expected for those assets, clear actions that ensure assets are providing the expected level of service, and financing strategies for sustainability.

Click to discover the CNAM's Asset Management Primer [11].

Click to discover the MOI's guidance on developing effective AMPs [12].

The Canadian Network of Asset Managers released an "Asset Management Primer" in support of the Canadian Infrastructure Report Card [11]. The primer provides recommendations for AMP structure based partly on guidance provided in the Ontario Ministry of Infrastructure's "Building Together – Guide for Municipal Asset Management Plans" [12]. Following that guidance, an effective AMP would contain the following six sections:

1. Introduction: documents assets that are within the scope of the AMP, the goals of the municipality and clarifies the relationship between the AMP and other corporate planning documents.
2. State of the Infrastructure: documents the inventory, age, condition, and replacement value of assets owned by the municipality.
3. Levels of Service: Documents the current level of service being provided and describes what the municipality is measuring to ensure level of service targets are being effectively met.
4. Plan Monitoring and Improvements: key asset renewal projects and changes that might impact the next round of AMP goals.
5. Asset Strategies: establishes 10 year and longer term renewal plans, strategies used to reduce cost of rehabilitation, etc.
6. Financing Strategy: how the municipality will reach a point where available revenues equal asset renewal needs [11].

> "Asset management planning will allow needs to be prioritized over wants. It will help ensure that investments are made at the right time to minimize future repair and rehabilitation costs and maintain municipal assets."
>
> --- "Building Together: Guide for Municipal Asset Management Plans" [12]

Ontario MOI's Asset Management Toolkit

The province of Ontario released a long-term infrastructure plan/strategy in the summer of 2011 to ensure province-wide implementation of effective asset management practices [13]. The goals of this strategy include making good asset management planning universal, moving toward optimal use of a full range of infrastructure financing tools, and addressing structural challenges facing small communities. The strategy indicates how, over a ten year period, the province will work with municipalities to ensure financial and environmental sustainability of water, wastewater, and stormwater systems through activities on several fronts, including:

- **Enforcing the requirements of the Water Opportunities Act, first passed in the summer of 2010 to improve the efficiency of municipal infrastructure. This legislation requires the preparation of municipal water sustainability plans that include performance measures and targets for municipal water, wastewater and stormwater systems.**
- **Making improved asset and financial management practices, preconditions for provincial infrastructure grants. The strategy makes the development of comprehensive AMPs a requirement for municipalities requesting provincial infrastructure funding.**

Click to access "Building Together" - Ontario's long-term infrastructure strategy [13].

More than 80% of drinking water systems in the province serve fewer than 10,000 people and these smaller municipalities often lack the technical capacity or financial resources necessary for the preparation of detailed AMPs. In addition to funding strategies (e.g. the $100-million per year Ontario Community Infrastructure Fund (OCIF) launched in the summer of 2014 to support the revitalization and repair of critical infrastructure in small, rural and northern communities), the province has also developed a guide to preparing municipal AMPs [9].

Click to access the MOI's Guide to Developing Municipal Asset Management Plans [12].

The MOI's guide is part of a web-based toolkit [14] that contains a variety of tools designed to help municipalities with the execution of their AMP:

- **A communications tip-sheet designed to help municipalities effectively communicate the benefits of asset management planning to a broad range of audiences.**
- **A self-assessment checklist/questionnaire intended to start a review of current asset management practices.**
- **Sample state of the infrastructure reports that cover asset types, financial accounting valuation, replacement cost valuation, asset age distribution and asset condition.**
- **A risk management primer covering aspects related to consequence and likelihood of failure, identification of critical assets and strategies for managing risk.**
- **A life-cycle costing primer covering the fundamentals of estimating the life-cycle cost of various asset management strategies.**

Click to access the MOI's management tookit [14].

http://www.moi.gov.on.ca/en/infrastructure/building_together_mis/tools.asp

Saskatchewan's Website Dedicated to Improving Municipal Stakeholder Capability for Asset Management

The province of Saskatchewan maintains a website designed to increase municipal stakeholder knowledge of municipal asset management practices. Managed through a collaborate effort of several associations (e.g. the Saskatchewan Urban Municipalities Association, Ministry of Municipal Affairs, and individual municipalities throughout the province),

The website provides access to a variety of useful asset management resources, including a series of videos that were developed to raise awareness about why asset management is important for municipalities. The videos are structured around a set of chapters consisting of interviews with industry professionals:

- **Chapter 1 – State of Affairs (2 minutes): identifies the threat posed by aging infrastructure and the need to rehabilitate assets for use by future generations [12].**
- **Chapter 2 – Asset Management Principles (6 minutes): covers integrated asset management planning for achieving long-term sustainability, full-cost accounting of an asset, the benefit of developing asset registers that form the starting point for asset management plans, choosing levels of service and communicating the challenges around asset management.**
- **Chapter 3 – Asset Management Process (5 minutes): the relationship between municipal stewardship, asset management planning and financial planning.**
- **Chapter 4 – Call to Action (2 minutes): the benefits received when asset management planning practices are adopted at the municipal-level.**

Click to watch Saskatchewan's asset management videos [15].

The asset management videos can be viewed used in tandem with Saskatchewan's Guide to Getting Started with Asset Management that provides a general introduction to asset management practices at the municipal level [16].

Click to access the Guide to Getting Started with Asset Management [16].

The asset management website also contains a number of links to presentations and case studies covering topics related to the Public Sector Accounting Board's PS 3150 Tangible Capital Asset (TCA) implementation. First introduced in 2009, PS 3150 was considered to be one of the biggest changes in the history of Canadian municipal accounting as tangible capital assets had to be identified, counted, valued, and amortized.

http://assetmanagementsk.ca/index

Asset Management British Columbia

Asset Management British Columbia represents a group of local government representatives in administrative, technical, operational, financial, planning, and political disciplines as well as key industry associations [17]. In September 2010 the organization released the "State of Asset Management in British Columbia" - containing the results of interviews with key representatives from 39 local British Columbia governments on the state of asset management in the province [18].

Like many other Canadian provinces at the time, the interviews suggested the state of asset management in British Columbia varied widely across communities and that asset management practices often vary across services within the same local government. No two governments were found to have identical circumstances nor did they take identical approaches to asset management. One of the key challenges facing local governments with respect to asset management was found to be a limited amount of financial resources [18].

Click to access the 2010 report: "State of Asset Management in British Columbia" [18].

The opportunities identified in the State of Asset Management report were then prioritized and incorporated into Asset Management B.C.'s recently released framework for Sustainable Service Delivery [19]. The framework represents a high-level, systematic approach that will support the move local governments in British Columbia are making towards service, asset and financial sustainability. It highlights the reality that asset management is an ongoing process that is incremental and scalable and that effective internal and external communication of progress is of critical importance. A short-version of the framework is currently available (the long-version is scheduled to be released in 2015 (click image on the right to go to the framework).

Asset management B.C.'s website also provides links to a wide variety of resources related to understanding sustainable service delivery, asset management planning, and long-term financial planning. As an example, the "AssetSMART" tool (prepared by the professional consulting firm Urban Systems for B.C.'s Ministry of Community and Rural Development" helps local governments evaluate their capacity to manage their assets [20].

Click to access AssetSMART [20].

http://www.assetmanagementbc.ca/

British Columbia's Master Municipal Construction Documents Association (MMCDA)

The Master Municipal Construction Documents Association (MMCDA) represents a collaborative collection of government, consultants, contractors and owners that have worked together since 1989 to solve challenges facing municipal infrastructure projects in British Columbia [21].

The MMCDA has developed the free-to-use Asset Management Data Repository (AMDR) to bring standardization to the way local governments work with infrastructure data. The AMDR contains two core components:

- **Infrastructure Data Schema (IDS): containing standards for infrastructure naming conventions, physical description of attributes and life-cycle management. The IDS is open-source and compliant with the Public Sector Accounting Board's Statement 3150.**
- **Infrastructure Data Management Utility: a tool that can be used to create, manage and report infrastructure data in a manner that is consistent with accounting guidelines for tangible capital assets.**

The AMDR schema incorporates a variety of infrastructure types including storm drainage, sanitary sewers, water distribution systems, transportation and electrical infrastructure [22]. The MMCDA website also contains a set of video resources related to infrastructure asset management, including webinars dealing directly with:

- **The asset management data repository project (49 minutes - an introduction to the AMDR)**
- **Perspectives on asset management in British Columbia (8 minutes - a brief introduction to difficult challenges).**
- **Engineering Challenges in Asset Management (38 minutes - exploring questions such as "What do you own and what is it worth?")**
- **Planning Strategies for Asset Management (47 minutes - topics such as how asset management fits with official community plans and the overall planning process).**
- **Financial Management Challenges for Asset Management (31 minutes - covering topics related to challenges often faced when integrating existing financial systems with asset management systems).**
- **Leadership and Management for Asset Management (45 minutes - addresses questions related "How do we integrate all our processes? What is the role of council and staff? What has to change to make it work?") [23].**

https://www.mmcd.net/

Click to access the free-to-use Asset Management Data Repository (AMDR) [22].

Click to access the MMCDA's video series on infrastructure asset management [23].

pt 2. condition assessment

Condition assessment is a critical component of the asset management process as it provides the data necessary to evaluate the risk of failure of individual assets. In this way, it helps utilities make informed decisions and is one of the most effective strategies for allocating funds for the repair, maintenance and replacement of existing water and wastewater assets [1].

2.1 A LACK OF CANADIAN INFRASTRUCTURE DATA

The 2012 Canadian Infrastructure Report Card (CIRC) indicates that of the 346 surveyed municipalities:

> Less than 15% of municipalities in the 2012 CIRC survey were able to provide asset condition data derived from an established asset management process [24].

- 41% had no data on the condition of their water distribution pipes
- 17% had reliable data on water distribution pipe condition.
- 48% had no data on water transmission pipe condition.
- 14% used reliable data to assess water transmission pipe condition.
- 33% had no data on their wastewater linear assets.
- 53% had no data on their stormwater linear assets.
- 4.5% use complete and reliable assessment data when assessing stormwater system capacity [24].

Many municipalities use purely age-based assumptions of condition when assessing the current state of their infrastructure assets. There is a significant amount of risk associated with this practice as rehabilitation/replacement decisions based only on age will provide a number that if funded, might result in misleading projections of condition and unnecessary allocation of funds to replace older assets that actually have a significant amount of useful life remaining despite their age. In general, the concept of conducting condition assessment through established asset management practices is still an emerging issue in Canada – with municipalities increasingly aware of the necessity to take action, but the level of action taken is still in the early stages.

STAGE 1 Review available data (historical, environmental & operational) relating to the asset in question. Identify data gaps & prioritize assets.

STAGE 2 Evaluate consequence of failure. Condition assessment will identify likelihood of failure. Risk assessment provides clear idea of which assets to inspect.

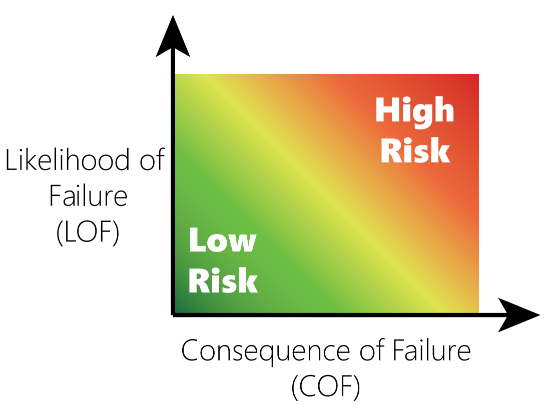
STAGE 3 Evaluate appropriateness of different methods of inspection. Select suitable technology and perform asset inspection.

STAGE 4 Final condition assessment based previous stages Define condition of the asset and capability to achieved required level of service.

2.2 STAGES OF CONDITION ASSESSMENT

The infrastructure condition assessment process for linear water and wastewater infrastructure essentially consists of four stages [25]. The first stage entails a review of all the information a municipality has maintained for the asset in question (e.g. as-built drawings, operating data, maintenance history, previous failures, rehabilitation actions, and interviews with experienced personnel). A key outcome of this stage in the process is the identification of any particular gaps in knowledge (i.e. the provision of a general indication of the extent of asset inspection that might be required).

The second stage of the process consists of evaluating the risks associated with the failure of an infrastructure asset. Every failure is unique, and quite often, risks are not always well defined (with most information on consequences being anecdotal). One of the more versatile approaches for defining risk is centered on risk matrices that establish both the consequence of failure (COF) and probability of failure (POF).



COF is typically established by considering a range of dimensions, including the cost of repair, health and safety, costs associated with damage to surrounding infrastructure, environmental impacts and reduction in level of service [13]. Based on this evaluation, COF for an asset may take the form of a classification - e.g. 1 - insignificant, 2 - low, 3 - moderate, 4 - high, and 5 - severe [27].

If no previous condition assessment data is available for an individual asset, LOF classes may initially be estimated using age-based metrics or a more technically evolved predictive model.

The manner in which the probability and consequence of failure are combined at this stage in the condition assessment process reflects the degree-of-caution being exercised by the analyst [27]. Traditionally, avoidance of significant/catastrophic failures has been the prime driver for condition assessment carried out for linear assets in water, wastewater and stormwater systems [28]. In general, it is important to accurately define failure likelihood for those assets with a high COF - and this can be achieved through asset inspection. Lower risk assets may require either a low-resolution screening tool or in some cases, no assessment as inspection costs would be higher than the cost of just replacing the entire asset [29]. It is during the third stage of the condition assessment process that the municipality evaluates the various options for asset inspection and chooses the most suitable inspection option.

Upon completion of the inspection, the fourth and final stage of the process involves defining the current condition of the asset and its ability to achieve the required level of service. The final results of the condition assessment are then typically fed into asset management software and evaluated with respect to other components of the AMP to determine necessary and cost effective interventions to achieve the desired level of service [25].

2.3 INSPECTING LINEAR WATER DISTRIBUTION ASSETS

Over 8% of all installed water mains in North America are beyond their useful life and the amount of pipe needing immediate replacement is growing rapidly [30].

Click here for the results of the first Canadian Municipal Buried Infrastructure Survey conducted by the Centre for the Advancement of Trenchless Technologies (CATT) [31]

The most common type of defect in water distribution systems is leakage through points of structural damage or faulty connections – and 70% of respondents in the first Canadian Municipal Infrastructure Survey indicate reducing leakage and breaks, and improving water quality as critical or very critical [31]. These pipe failures are tied to a wide range of associated consequences including increased O&M costs, decreased hydraulic capacity, contaminant ingress through points of failure, opportunities foregone to sell potable water, the inevitable damage to surrounding infrastructure that occurs during pipe burst events.

Click here for the WERF's public-use risk-screening tool for predicting consequence of failure for water pipes [32]

Condition assessment for water pipelines is still an evolving field and there is still considerable uncertainty when quantifying both the likelihood and consequence of water main failure. With this mind, a public-use risk-based screening tool was recently developed by the WRF, WERF and EPA to help municipalities prioritize individual water pipeline assets for action based on their likelihood and consequence of failure. The spreadsheet-based tool can be used to establish orders-of-magnitude risk costs that improve the information given to decision makers about the need for pipeline renewal [32].

Click here to access the open-source community edition of AWARE-P [33].

The AWARE-P suite of software tools recently made available for managing and planning urban water supply, wastewater and stormwater systems provides another option for assessing failure-likelihood and quantifying the impact of asset management interventions. AWARE-P was designed to integrate with existing asset management tools and is structured around an asset management methodology that builds upon two decades of leading-edge research conducted in Europe. The range of tools contained within the software suite support service-oriented asset management practices that meet key ISO 55000 standard requirements for full consideration of system behavior for linear assets and facilities [33]. Select tools include:

- "PLAN" tool: the centerpiece of AWARE-P that provides a central planning framework for integrated infrastructure asset management. It can be used to evaluate social, economic and service impacts of planning alternatives over the long term [34].
- "Infrastructure Value Index" tool: used to determine infrastructure value over time and to evaluate the impact of investment policies on service availability and financial sustainability.
- "Fail" tool: used to predict the probability of failure and the number of future failures for each pipe in a network based on a history of past failures and asset information (e.g. length, installation year, material and diameter) [35].
- "Component Importance" tool: used to evaluate the consequence of failure for an individual pipe. Using a working EPANET model (public-domain software developed by the EPA to model water distribution systems [36]), pipe importance is calculated by comparing the total demand that the network is hydraulically capable of satisfying when the pipe has failed to the total demand supplied by an intact network [37].
- "Unmet Demand" tool: combines the results of the "Failure Analysis" and "Component Importance" tools to provide a service interruption risk metric (expected volume of water that the system will be unable to satisfy over the course of one year caused by the failure of each individual pipe, calculated by multiplying a pipe's expected number of failures in 1 year by the average downtime and the average reduced service caused by its failure) [38].

Click here to access EPANET - software that models the hydraulic and water quality behavior of water distribution piping systems [36].

Although leaks on large-diameter water transmission pipelines make up less than 5% of the total number of leaks in a system, they typically account for more than 50% of the total water being lost to leaks (transmission mains are typically several times larger than distribution mains and operate at higher pressures) [39]. Consequently, most municipalities tend to focus leak detection and condition inspection programs on the largest diameter pipes in their system. Proactive inspection of linear water infrastructure can provide significant benefits as it is estimated that $3 can be saved for every $1 spent on the proactive prevention of failures and breaks [40].

Click here to see the EPA's summary of 70 current and emerging technologies for linear water system infrastructure inspection [41].

Section 5.0 includes a detailed description of 17 physically-based and 31 statistical asset deterioration models. Section 6.0 provides an overview of 29 decision support tools.

A large variety of existing and emerging technologies are currently available for assessing the condition of linear water system infrastructure. The EPA recently conducted a comprehensive study of condition assessment technologies and decision support tools that are available for water transmission and distribution systems [28]. That report provides descriptions of approximately 70 current and emerging technologies/techniques/methods for the inspection and evaluation of water main condition (e.g. visual, ultrasonic, laser-based technologies, etc.). Although no single technology is universally applicable, the benefits of non-disruptive inspection technology with a capacity for accurate leak-detection are highlighted within the report - e.g. no excavation, water shut-offs or physical entry required. The EPA notes "information on the current structural condition of the individual water main, combined with good understanding of failure modes and deterioration models, will greatly enhance the ability of water utilities to manage these assets in a cost-effective manner" [41].

A lack of cost information is often indicated as being a barrier to the inspection of water and wastewater system assets.

Click here to connect to WATERiD to find data compiled by WERF on costs associated with common assessment tools [42].

A significant barrier to the implementation of condition assessment for water distribution and transmission pipes has been perceived high cost and cost uncertainty associated with available inspection technology. Additional insight into the total costs associated with common condition assessment tools can be found in the web-based Water Environment Research Foundation's Water Infrastructure Database (WERF WATERiD) [42]. Developed through the participation of a wide-variety of utilities (located in the USA and internationally – e.g. Calgary, Hamilton, and Toronto Water), WATERiD provides information on state-of-the-art management practices for buried pipe location, predicting pipe condition, analyzing risks of failure and the prioritization of renewal activities for water and wastewater infrastructure. WATERiD also provides a single point information center for utilities looking for case studies of real-world application of condition assessment technology for water and wastewater pipelines – with a list of vendors, consultants and contractors that can provide a particular technology of interest.

Pure Technologies' Tools for Inspecting Water and Wastewater Linear Assets

Headquartered in Calgary, Alberta, Pure Technologies is a world leader in state-of-the-art solutions for pipeline condition assessment for proactive asset management.

Visual Inspection of Internal Condition:

- **PureRobotics™ Pipeline Inspection – a modular robotic system that can be configured to inspect any pipe with a diameter of at least 300 mm. Capable of providing a variety of high-quality data including closed circuit television (CCTV), profiling SONAR, and laser profiling.**

Electromagnetic Inspection:

- **PipeDiver® platform: electromagnetic inspection technology for large diameter pre-stressed concrete cylinder pipe (PCCP), lined cylinder pipe (LCP) and bar-wrapped pipe (BWP).**

Click here for a PipeDiver application on a high-risk 30″ main in Halifax, Nova Scotia [43].

In-Line Leak Detection Systems:

- **SmartBall Free-swimming Acoustic Sensor: used to identify leaks and gas pockets in large diameter pressurized pipe (all material types) with a diameter greater than 150 mm. Consisting of a sensor and data-recording device mounted within a foam ball, the technology is capable of detecting leaks less than 0.026 L/hour.**
- **Sahara Tethered Acoustic Sensor – consisting of a sensor attached to the end of a cable tether, the device allows for extended listening for defects at a particular location along the pipe length and can be removed when unexpected flow conditions are encountered.**
- **SmartBall Pipe Wall Assessment (PWA) Tool: used to identify wall stress in metallic pipelines. Capable of performing long-inspections without disruption of regular pipeline service, this free-swimming technology can precisely indicate the position and severity of damage.**

Near Real-Time Risk Assessment of Large Diameter PCCP Mains:

- **Proven to the most reliable acoustic fiber optic monitoring technology for monitoring acoustic activity associated with the failure of pre-stressing wires in water and wastewater PCCP pipelines with a diameter larger than 600 mm.**

PureNET Integrated Non Revenue Water and Asset Management Software:

- **Developed to allow municipalities to manage their water and wastewater system data.**

Although Pure Technologies has traditionally focused on the inspection of large diameter pipes, they are expanding their available suite of technologies to include options for assessing the condition of smaller diameter distribution mains.

www.puretechltd.com

Managing Risk via Drinking Water Safety Plans

Effective management of the risks present in a drinking water supply system can be achieved by identifying weaknesses in a system and addressing risks before they cause problems [44]. A number of options exist for adopting a proactive approach to water system management based around risk monitoring and mitigation. According to the World Health Organization:

"The most effective means of securing the safety of a drinking water supply is through use of a comprehensive risk assessment and risk management approach that encompasses all steps in the water supply from catchment to consumer" [45].

Click here for the WHO's Training Package for WSPs (structured around 13 learning modules) [46].

The first jurisdiction in North America to require water suppliers to implement a Drinking Water Safety Plan (DWSP) was the province of Alberta [47]. Alberta's DWSP approach was designed to be adaptable to any water system (regardless of size) and is based around four principles:

1. **Collect and evaluate the best information available about a water supply**
2. **Analyze and understand the potential risks**
3. **Assess risk mitigation options (i.e. how can risks be reduced to an acceptable level?)**
4. **Determine what resources and actions are necessary to ensure risks are reduced [48].**

Alberta offers training on the development of DWSPs and provides an Excel-based template to guide comprehensive assessment of all aspects of risk in a drinking water system (i.e. risks related to the source, treatment, storage, the distribution network, and customer risks) [49]. The template is used to establish overall risk by considering both likelihood and consequence descriptors.

Click for training on preparing DWSPs provided by the Government of Alberta [49].

			Consequence Descriptor				
	Score	Not Applicable	Insignificant	Minor	Moderate	Severe	Catastrophic
Likelihood Descriptor	Not Applicable	0	1	2	4	8	16
	Most Unlikely	1	1	2	4	8	16
	Unlikely	2	2	4	8	16	32
	Medium	4	4	8	16	32	64
	Probable	8	8	16	32	64	128
	Almost Certain	16	16	32	64	128	256

Some small communities (e.g. those with less than 5,000 people) may lack the resources to accurately complete these DWSPs. Research into the capacity of DWSPs to influence a change within small communities (e.g. those serving less than 5,000 people) is currently being conducted by Dalhousie University (through funding provided by the Canadian Water Network) [47].

http://environment.alberta.ca/apps/regulateddwq/DWSP.aspx

No standards are currently in place for assessing water force main condition and this poses a significant obstacle for condition assessment.

Click here to learn more about the standards being developed by the CATT (via WERF funding) [50].

Another barrier to condition inspection and assessment of pressurized water distribution and transmission infrastructure is a lack of any standardized defect coding and condition rating system. The Centre for Advancement of Trenchless Technologies (CATT – located in Waterloo, Ontario, Canada) is currently developing a framework and contents of a North American drinking water pipeline defect coding and condition rating standard (via funding through the Water Research Foundation RFP 4498 - project duration 2014 – 2017). The project involves a number of North American utilities and municipalities (e.g. Greater Cincinnati Water Works, Calgary, London, and City of Waterloo), organizations (e.g. the Ontario Clean Water Agency), and technology providers (e.g. Pure Technologies) [50].

2.4 INSPECTING LINEAR SEWER ASSETS

Click to go to the EPA's comprehensive overview of wastewater condition assessment tools [52].

A systematic approach to sewer condition evaluation and rehabilitation is critical as it results in the efficient use of limited financial resources [51]. Unlike above ground sanitary sewer and stormwater system assets (e.g. vertical treatment plant infrastructure), determining the condition of those linear assets that are buried underground tends to be much more difficult as these assets are out-of-sight and out-of-mind.

Whenever a detailed evaluation of the interior condition of a sewer pipe is required, municipalities most commonly use closed circuit television (CCTV) technology, consisting of a small camera mounted on a robot capable of traveling the length of the pipe. Standardized systems exist for gravity wastewater pipe inspection that minimize subjective evaluation of the camera footage.

Canadian municipalities have traditionally used a variety of condition grading systems. There has been a recent push for widespread adoption of NASSCO's Pipeline Assessment and Certification Program (PACP) for consistency.

Click to learn more about NASSCO PACP [53].

Operators trained in the use of these standards review the CCTV footage to identify defects (e.g. cracks, fractures, root penetration, etc.) and assign each inspected pipe structural and operational condition (e.g. 1 - minor defects, 2, 3, 4 or 5 - collapsed or collapse imminent). Municipalities typically use the assigned condition grade to evaluate the necessity of rehabilitation (e.g. some municipalities set a goal to ensure all sanitary sewer pipes currently in operation have a structural condition grade no higher than 3, as pipes in condition grades 4 or 5 are considered to be in critical condition).

Although CCTV inspections provide valuable information, they are time-consuming and expensive. Consequently, most municipalities are forced to limit CCTV work to small portions of their sanitary sewer and stormwater systems (in other words, a significant number of assets remain uninspected).

These municipalities benefit from a strategic approach to planning inspections based around the predicted likelihood of an uninspected asset being in critical condition. Although a wide variety of tools and models have been developed to provide a generalized/overall condition for a network of pipes (e.g. age-based estimated-rate of deterioration curves), validated models for reliably predicting the condition of individual pipes in a network are less common. Pipe-level models developed using novel techniques derived from the field of data-mining show considerable promise for integration into inspection planning activities [54, 55]. A tool currently under development and scheduled for release in the near future as part of the AWARE-P software environment will provide municipalities with a method of using CCTV inspections (and other condition assessment records) to predict present and future sewer condition and guide future inspection efforts.

Some municipalities benefit from an adopted strategy of using screening technologies to identify assets that should or should not be further evaluated using in-depth evaluation technologies. One very effective option for condition screening is the "zoom-camera", which consists of a camera mounted on a pole that is lowered into a manhole. Zoom-cameras have a site distance of 10-30 m and are capable of inspecting up to 1,800 m of pipe per day at a cost of approximately $0.90/m [52]. Although the technology is incapable of providing the same level of visual detail as CCTV, the technology is particularly useful for quickly visualizing pipe blockages. In this way, zoom-cameras can serve as a valuable tool in a program that aims to isolate areas within a sewer system that do not require cleaning and can be left out of flushing and cleaning maintenance programs.

Click to go to the EPA's field-test comparison of the overall complexity and cost of zoom-cameras, CCTV, electro-scanning, laser profiling, and sonar [57]

CCTV often misses defects that are hidden from the camera by obstructions inside the pipe and are incapable of imaging below the water-line. Municipalities are not limited to CCTV, as technological advances have introduced a new suite of inspection tools, including:

- Digital Scanning: representing the state-of-the-art in camera inspection technology. Uses 360-degree high-definition digital cameras to scan the pipe to form an unfolded spherical image of the complete pipe interior.
- Laser Profiling: used to identify the integrity of the pipe wall and the potential for infiltration. Capable of generating a profile of the pipe interior, which is useful for identifying reductions in cross-sectional area, corrosion, grease build-up, etc. Increasingly used in tandem with traditional CCTV.
- Sonar: ultrasonic signals used to identify corrosion, pits, voids and cracks in the pipe wall below the water service (most other techniques cannot provide a detailed overview of condition below the waterline).
- Electrical methods for leak location: suitable for non-ferrous materials (clay, plastic, concrete and brick). Typically used for small diameter pipes (e.g. locating leaks in service laterals).
- Autonomous technology: representing a cutting-edge advance in condition inspection, where unmanned condition assessment robots collect 360 degree visual records of the internal surface of small diameter pipes. RedZone Robotics' Solo System, currently the world's The only self-operating inspection robot, is NASSCO PACP compliant, capable of inspecting pipes from 200 – 300 mm in diameter and has five times the inspection throughput and half the cost of conventional CCTV [56].

Suitability of Various Sewer Condition Inspection Systems (Gravity Pipes)

	Zoom Camera	CCTV	Electro-scanning	Milti-sensor (camera, laser & sonar)
Training Requirements	Medium	Medium	Low	Medium
National Certification	PACP	PACP	None required	PACP Scanning
Equipment Operation	Low	Low	Medium	Medium
Pipe Preparation	None required	Possible cleaning	None required	None required
Data Analysis	Low to medium	Low to medium	Low	High
Overall Complexity	Low to medium	Low to medium	Low to medium	Medium to high
Cost per foot	$0.99	$2.80	$2.95	$4.21

Source: EPA Report EPA/600/R-11/078 [57]

Water, Wastewater and Stormwater Condition Assessment in Hamilton, Ontario

The City of Hamilton, Ontario owns and operates more than $14.4 billion in core public works infrastructure (water, wastewater, stormwater, roads and bridges). A Canadian pioneer in asset management, the City first established an asset management section within its Public Works Department supporting infrastructure stewardship in 2001. By combining responsibility for inspection, condition assessment and renewal planning for right-of-way assets within a single group has enabled a holistic approach to managing risk.

Their AMP serves as a "living document" that follows the framework established in the Ontario Ministry of Infrastructure's Guide for Municipal Asset Management Plans. The AMP outlines a variety of formal and informal practices that are used to assess the condition of their water, wastewater and stormwater infrastructure.

Click to access the first iteration of the City's AMP (prepared by CH2M Hill and Stantec) that was released in 2014 [58].

Gravity sewers are assessed using either stationary/zoom cameras or CCTV:

- **1597 km (94%) of the sanitary sewer network assessed by either zoom cameras or CCTV.**
- **1008 km (90%) of the stormwater network assessed by either zoom camera or CCTV.**
- **A lack of cost-effective condition assessment technologies for water infrastructure is cited as a barrier to inspecting their 2000 km water distribution network.**

Assessment methods for water pipe assets are selected based on criticality/consequence of failure. The City considers factors such as pipe diameter, material type, road type, surrounding land use and type of customer served to calculate the social, economic, environmental and operational consequence of failure.

- **For low criticality/consequence of failure) water pipe assets, a theoretical water main condition index (TWCI) is used as a proxy. This TWCI is on a scale of 0-100 and is based on the number of previous pipe breaks, soil type, pipe material and age.**
- **For high criticality/consequence of failure) water pipes, the City uses direct assessment methods including acoustic and electromagnetic technology designed to identify leaks.**

A suite of asset deterioration models are currently in use by the City:

- **Analysis of historical water main failures used to develop deterioration models that provide an estimated probability of failure for any specific pipe segment.**
- **Markov models and transition state models based on survival analysis for sewer mains (calibrated using condition grades as determined by CCTV). Used to forecast long-term expenditures needed to maintain a certain overall condition rating for the sewer network.**
- **Sustained collection of asset condition data helps improve the predictive capabilities of the models over time so that the City can carry out capital improvements that targets assets in actual need of intervention [58].**

www.hamilton.ca

Managing Inflow and Infiltration in Metro Vancouver's Sanitary Sewers

The Greater Vancouver Sewerage & Drainage District (GVS&DD) of Metro Vancouver serves a population of approximately 2.2 million people. A Liquid Waste Management Plan titled "Integrated Liquid Waste and Resource Management (ILWRM)" was adopted by the GVS&DD board and its member municipalities in 2010 and the plan was approved by the Minister of Environment in 2011. A key strategy of the ILWRM is to reduce the occurrence and impacts sanitary sewer overflows (SSOs). In 2013, there were 16 wet weather SSOs (caused by excessive inflow and infiltration (I&I) of groundwater into sanitary sewer systems during periods of wet weather) and 15 dry weather emergency SSOs (typically the result of power or equipment failures at pumping stations or broken sewage pipes).

Metro Vancouver and its GVS&DD members have worked to reduce the likelihood of SSOs through the adoption of strategies such as sewer capacity improvements, SSO containment facilities and I&I reduction programs. In 2011 Kerr Wood Leidal Associates Ltd. developed a template for the preparation of a formalized Inflow and Infiltration Management Plans (I&IMPs) for the GVS&DD and its member municipalities [59]. The template provides guidance on:

Click for the 2011 template for preparing a formalized Inflow and Infiltration Management Plan (I&IMP) [46].

The template provides guidance on:

- **Management Context: provides a rationale for whole system management (private lateral, municipal collector and regional trunk sewers).**
- **I&I Quantification: indicates the importance of accurate, reliable and repeatable sewer flow data. Provides guidance principles and the knowledge needed to plan and execute a flow monitoring program with subsequent analysis for I&I values. Recommends the "I&I Envelope Method" that has been used with various modifications by many agencies and consultants throughout North America to assess I&I magnitude using data from a flow monitoring program.**
- **I&I Sources: information on techniques such as age curves and field investigation efforts.**
- **Goal-based plans for municipalities where I&I targets are being exceeded or where limited capacity is restricting growth activity. Seeks to achieve a specific target (e.g. 11,200 L/ha/d city-wide) through incremental work-plans.**
- **Prescriptive-based plans for municipalities where I&I targets are currently being met. Applies best practices based on available assessment data to either reduce or maintain current I&I rates. Municipalities may specifically develop scheduled inspection programs using mainline CCTV, manhole inspection and smoke testing [46].**

www.metrovancouver.org

Another option for quantifying I&I is the EPA's public domain sanitary sewer overflow analysis and planning (SSOAP) toolbox. The toolbox is structured around six tools (Database management, Rainfall-derived Infiltration and Inflow (RDII) Analysis, EPA's Storm Water Management Model Version 5 (SWMM5) Tool, the SWMM5 Interfacing Tool and a Condition Assessment Support Tool) [60].

Click to access the SSOAP toolbox for quantifying I&I and developing SSO mitigation plans [60].

2.5 THE NEED TO INSPECT WASTEWATER FORCE MAINS

Traditionally, municipalities have taken a reactive approach to managing pressurized wastewater force mains (i.e. failures were dealt with after their occurrence).

This flawed approach could have severe consequences, as an unexpected force main failure could release millions of gallons of raw sewage into the environment posing serious health risks. Inspecting force mains can allow defective areas to be repaired before serious failure incidents occur.

While camera-based technologies are suitable for gravity pipes, the cost of utilizing those same inspection techniques for pressurized wastewater pipes are prohibitive (e.g. the time and cost of taking the force main off-line so it can be drained and inspected). Identification of defects in force mains typically requires multiple inspection techniques and technologies [61], including:

- External evaluation of corrosion along the length of the pipeline (e.g. above ground electromagnetic inspections).
- Electromagnetic Inspection of Force mains: used to identify broken pre-stressing wires in PCCP that need repair.
- Acoustic Inspection of PCCP Deterioration: usually follows electromagnetic inspection. Fiber optic sensors installed inside the pipe record the time and location that pre-stressing wires fail.
- Acoustic Detection of Leaks: free-swimming sensors are used to acoustically detect leaks and pockets of trapped gas in pressurized mains.

The average cost of condition assessment and localized rehabilitation of damage pipe sections is only 5% of the total cost associated with a full replacement [62].

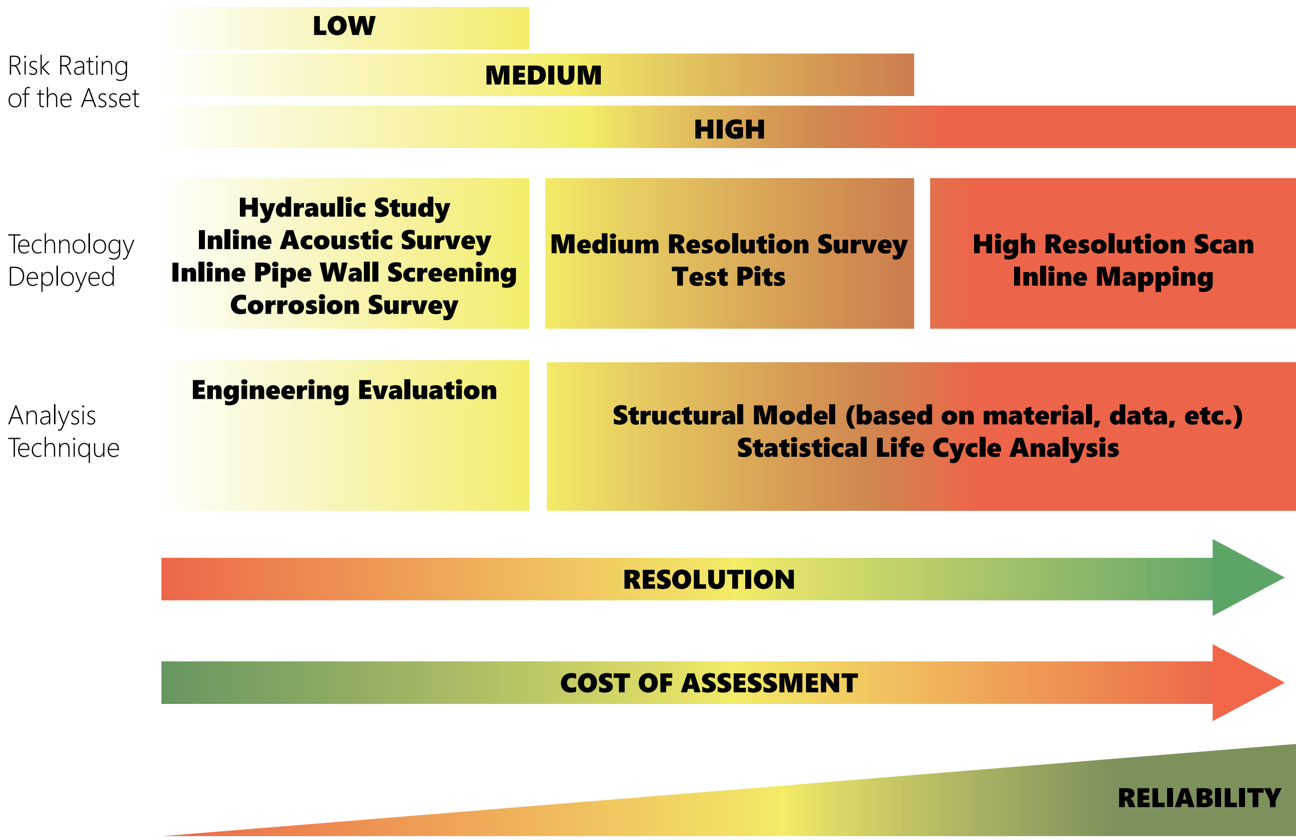
Research has shown that less than 10% of surveyed force mains have any indications of distress and only 1% require repair/rehabilitation to extend their service life [48]. These inspection tools can effectively identify points along the length of a force main that require localized rehabilitation. This can result in considerable cost savings for municipalities as the average cost of condition assessment and subsequent localized rehabilitation of damaged pipe sections are approximately 5% of the total capital costs associated with a full replacement [62].

Click here to access a worked example of establishing a risk profile of a pressurized sewer pipe contained in the WERF's SIMPLE Business Risk Exposure Tool [63

Some municipalities have established their own set of working protocols for wastewater force main inspection based on a holistic, risk-based approach that considers the combined impact of consequence and likelihood of failure. Analysis within a risk framework is essential for the selection of the most suitable inspection technologies. Consequence of failure (COF) for wastewater force mains can be established based around a triple bottom line (TBL) analysis of:

- Social consequences: number of critical customers affected, roadway impacts, public perception of failure, etc.
- Economic consequences: repair difficulty, pipe diameter, replacement cost, compensation for damage to surrounding infrastructure, etc.
- Environmental consequences: sensitivity of the failure discharge area, fines that are the result of failure-induced damage, etc. [48].

Likelihood of failure (LOF) for wastewater force mains may be based initially on the asset's age/the expected useful life remaining, the type of material, history of previous failures, and the date of the last inspection (if any). Rating scales are typically used to quantify COF and LOF - these scales are often municipality-specific, developed to meet the needs of the pipeline owner/operator and their intentions/ goals for infrastructure asset management.



One option for taking a risk based approach for force main condition assessment [61].

The Centre for Advancement of Trenchless Technologies (CATT) in Waterloo, Ontario

The Centre for Advancement of Trenchless Technologies (CATT) was founded in 1994 to help municipalities address critical issues facing underground infrastructure installation, assessment, repair, renewal and management. Located at the University of Waterloo.

CATT is a grouping of university, municipal, industrial, business and government agencies with a mandate to "address infrastructure needs faced by both public sector end-users and industry by providing a common forum for research, education and technology transfer in the area of trenchless technologies" [64]. CATT frequently hosts technical workshops, short courses and conference to provide various end-users with an opportunity to both contribute and learn about advanced underground infrastructure management practices.

CATT is heavily involved in research in such areas as buried infrastructure asset management, condition assessment of water and wastewater infrastructure, etc. One recent project includes the Plastics Pipe Institute's Pipeline Analysis and Calculation Environment (PPI-PACE): a free on-line tool developed to help industry professionals complete design calculations for high-density polyethylene (PE) pipe used in pressurized water distribution and transmission systems [65].

Click to connect to the free Plastic Pipe Institute's Pipeline Analysis and Calculation Environment (PPI-PACE) [65].

CATT has been working with Canadian municipalities to develop an integrated water and wastewater-specific decision support tool based on system-dynamics. Recent publications in this field include:

- **System Dynamics Model for Financially Sustainable Management of Municipal Water main Networks [66]: provides the first known causal loop diagrams for financially sustainable water systems. These diagrams illustrate feedback loops involving physical condition of assets, consumer behavior, and finances. The developed system dynamics model captures cost drivers and revenue sources in a system and can be used to achieve a variety of short and long-term objectives and develop defensible policies.**
- **Financially Sustainable Management Strategies for Urban Wastewater Collection Infrastructure – Implementation of a System Dynamics Model [67]: describes how a system dynamics model can be used by utility managers to ensure financial sustainability while maintaining customer expectations for service performance. Demonstrates the inter-relationships that exist between asset condition, total life-cycle costs, user fees, etc. for a case study area of a medium-sized municipality in Ontario.**

http://cattevents.ca/

pt 3. defining levels of service

Once condition assessments are complete (e.g. using tools for visual inspection, predictive analytics, etc.) the municipality then should seek to match the levels of service (LoS) provided by an asset with customer expectations of the quality of service, balanced against the price the customer is willing and able to pay. Generally customer levels of service outline the overall quality, function, capacity and safety of the service being provided. Technical levels of service outline the operating, maintenance, rehabilitation, renewal and upgrade activities expected to occur within the municipality [68].

Many municipalities consult with external engineering firms when developing a triple-bottom-line approach for water, wastewater and stormwater LoS that considers financial, environmental, and social/community/organizational perspectives. By doing so, the resulting levels of service “reflect social and economic goals of the community and may include any of the following parameters - safety, customer satisfaction, quality, quantity, capacity, reliability, responsiveness, environmental acceptability, cost and availability” [69]. Defining LoS for water, wastewater and stormwater systems can be complex - as trade-offs occur based on the opinion and priorities of the various stakeholders. As an example “The importance of public perception may require an enhanced environmental service level but in increase in servicing cost, creating a potential negative feedback on public perception” [70]. Consequently, guidance on developing and monitoring levels of service can be of significant utility.

> " Defining levels of service can be complex; there are no right or wrong answers. Levels of Service are a compromise based on the views and opinions of an array of stakeholders, whose input is critical if the outcome is to be successful. "
>
> --- AECOM’s Level of Service Workshop for the City of Cambridge, Ontario [70]

Section 2.2 of the IIMM provides a methodology for determing LoS and appropriate performance measures [4].

3.1 GUIDANCE

An effective strategy for developing LoS can be found in the International Infrastructure Management Manual.

- IIMM 2.1.6 Understanding the Customer Perspective: outlines a process for identifying customer groups and what they value ('customer' is treated in the IIMM in the wider sense to include all potential stakeholders).
- IIMM 2.2.2 Developing Levels of Service: covers the analysis of customer requirements.
- IIMM 2.2.3 Developing Effective Performance Measures
- IIMM 2.2.4 Customer Consultation Process and IIMM 2.2.5 Consultation Techniques: provides guidance on when to consult, who should be consulted and how to decide on what needs to be covered (including a table of the advantages and disadvantages of various consultation techniques).
- IIMM 2.2.6 Consultation Plan: details processes for engaging with customer to identify their requirements and priorities.
- IIMM 2.2.7 Developing Customer Charters: defines the scope and benefits of using customer charters for communication purposes.
- IIMM 2.2.8 Performance Monitoring and Reporting: describes how the effectiveness of assets and asset management performance can be reviewed by developing a performance monitoring programme, rating system and reporting to both internal and external stakeholders [4].

3.2 PERFORMANCE MEASURES

According to the IIMM, performance measures used to report levels of service should be SMART, in that they need to be specific, measurable, achievable, realistic and timely. Municipalities responsible for water, wastewater or stormwater systems may be tempted to start from scratch and establish their own unique performance measures. Considerable time and effort can be saved by making use of existing systems designed to measure performance that are already recognized as an international reference and in use by other municipalities [71]. Utilizing existing performance indicator systems also provides an opportunity to compare and benchmark performance against other municipalities that have adopted the same metrics.

Click to access the 2013 National Benchmarking Results for Water, Wastewater and Stormwater [72].

Municipalities should work with a set of performance indicators that are appropriate, relevant, and attainable if they want to make effective asset management decisions. Many North American asset management practitioners cite a lack of data on effective LoS targets remains a top barrier to the adoption of asset management practices for water and wastewater systems [1].

In Canada, many municipalities evaluate system performance through membership in the National Water and Wastewater Benchmarking Initiative (NWWBI). Since its inception in 1997, the benchmarking initiative has included 50 water utilities, 53 wastewater utilities and 28 stormwater management programs.

The NWWBI now represents 43 of Canada's leading municipalities and regional districts (representing over 60% of the Canadian population). The NWWBI uses a standardized utility management model to establish a framework for the selection and definition of performance measures for a set of seven generic goals that are common to all water and wastewater utilities:

National Water and Wastewater Benchmarking Initiative
Utility Management Model

	Utility Goals						
	Reliability & Sustainability	Infrastructure Adequacy	Cost Efficiency	Public Health & Safety	Safe & Productive Work Environment	Customer Satisfaction	Environmental Protection
	Performance Measures (PM's)						
WATER	**12 PMs e.g.** Capital Reinvestment / Replacement Value	**4 PM's e.g.** Number of Hours of Storage / Capacity at ADD	**23 PM's e.g.** O&M Cost / Ml Treated	**9 PM's e.g.** Length of Main Cleaned / Length	**8 PM's e.g.** Number of Sick Days Taken per FTE	**2 PM's e.g.** Number of Water Quality Complaints / 1,000 Customers	**3 PM's e.g.** Volume of Treated Water / Volume of Raw Water
WASTEWATER	**18 PM's e.g.** Length CCTV Inspected / 100 km	**3 PM's e.g.** % of Design AAF Utilized	**37 PM's e.g.** Per-Unit Biosolids Cost	**5 PM's e.g.** Number of Reported Surcharges	**4 PM's e.g.** Number of Accidents / 1,000 Labour Hours	**2 PM's e.g.** Number of Odour Complaints / 1,000 Customers	**3 PM's e.g.** kg BOD Discharged to Environment per Capita
STORMWATER	**4 PM's e.g.** Length of Eroded Stream / Length of Streams	**4 PM's e.g.** Stormwater Fees / Serviced Population	**3 PM's e.g.** O&M + Indirect Costs / 100 km Length of Drainage	**4 PM's e.g.** Value of Damage due to Flooding / Serviced Population	**3 PM's e.g.** Number of Training Hours for SW Employees / Employee	**2 PM's e.g.** Are there Stormwater Regulations?	**3 PM's e.g.** % of Effective Impervious Area

Data Collection → Data Analysis and Evaluation → Closing Workshops → Report and Database → Annual Review

The NWWBI Utility Management Model [56].

Click to access the NWWBI Water Performance Measures [73].

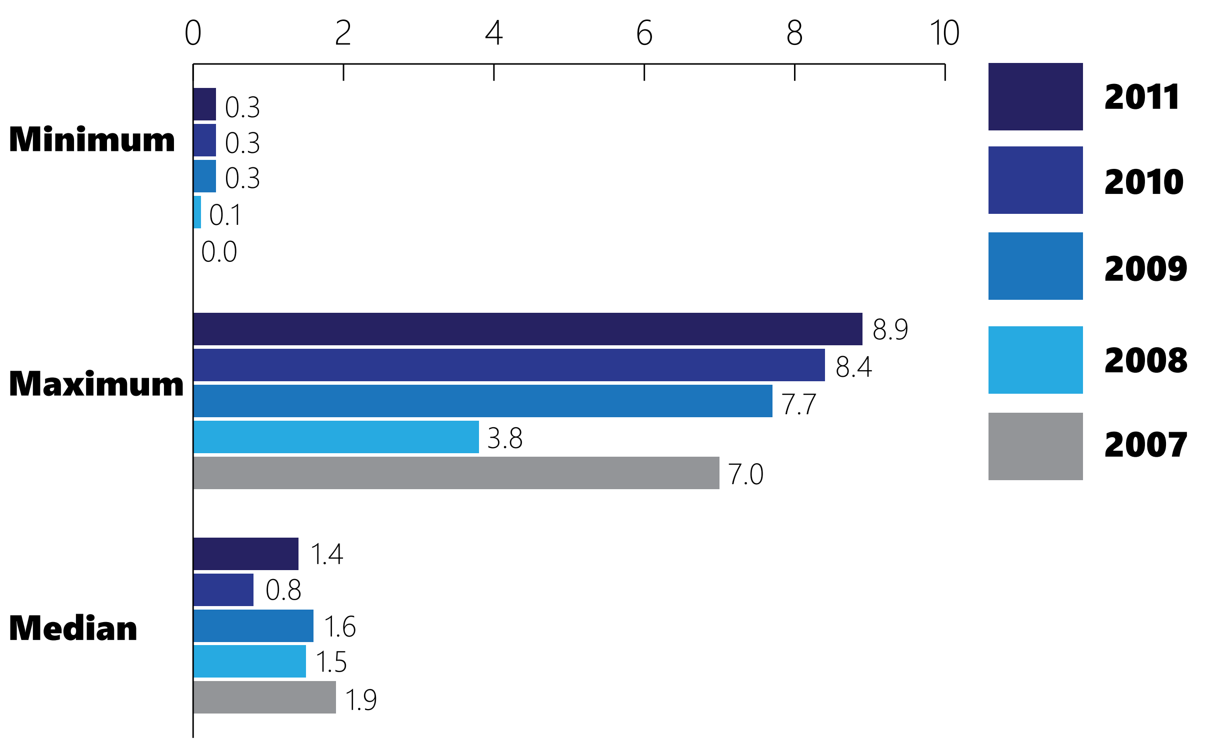
Click to access the NWWBI Table of Wastewater Performance Measures [74].

Click to access the NWWBI Table of Stormwater Performance Measures [75].

Currently, the NWWBI has benchmarked approximately 50 performance measures for each of the water and wastewater treatment, water distribution and wastewater collection utilities and approximately 15 performance measures for stormwater & drainage utilities. The measures typically consist of a numerator that expresses the level of goal attainment and a denominator that serves as a normalization factor to enable comparisons amongst different utilities.

Benchmarking analysis not only provides participating municipalities and utilities an opportunity to gauge their own system-performance against others in Canada, but it also provides an opportunity to track nation-wide progress made over time in addressing system risks and areas of concern. As an example, the figure below indicates the minimum, maximum and median performance of all participating utilities for one of the stormwater performance measures that was developed as part of the goal of having satisfied and informed customers:

# of Stormwater Related Customer Complaints / 1,000 People Served [72]



Click to learn more about AWARE-P's performance indicator tool [76]

An extensive list of performance indicators for water, wastewater and stormwater systems can be found within AWARE-P's "Performance Indicator" tool [76].

This objective-driven tool contains some of the world's most relevant organized libraries for measuring concepts related to LoS, network effectiveness and efficiency - including the International Water Association (IWA) library of performance indicators that are now standard for many utilities around the world.

The existing IWA library contains 70 precisely defined performance for water supply grouped under seven objectives (with each objective associated with a set of criterion groups):

1. Adequacy of the service provided (3 criterion groups)
2. Meeting user's needs and expectations (5 criterion groups)
   - e.g. "Criterion group 4: continuity of the service" which is linked to 17 performance indicators.
   - e.g. Performance Indicator "OP5 Active Leakage Control Repairs" which can be calculated using three input variables (number of leaks detected and repaired due to active leakage control during the assessment period, period of time adopted for the assessment of the data and of the performance indicator, and the total transmission and distribution mains length (service lines not included) at the reference date).
3. Promotion of sustainable development (9 criterion groups)
4. Protection of the environment (2 criterion groups)
5. Provision of the service under normal and emergency situations (7 criterion groups)
6. Public Health and Safety (8 criterion groups)
7. Sustainability of the Undertaking (11 criterion groups

The IWA library also contains 76 performance indicators for wastewater and stormwater grouped under seven objectives:

1. Meeting user's needs and expectations (6 criterion groups)
2. Occupational health protection and safety (2 criterion groups)
3. Promotion of sustainable development of the community (15 criterion groups)
4. Protection of the environment (9 criterion groups)
5. Provision of the service under normal and emergency situations (7 criterion groups)
6. Public Health and Safety (9 criterion groups)
7. Sustainability of the Undertaking (11 criterion groups)

Regina's Service-Level Approach to Asset Management

Regina is the capital of Saskatchewan Water and Sewer utility is responsible for water mains (over 900 km), storage reservoirs, pumping stations, building service connections, a wastewater treatment plant, wastewater sewers (over 600 km) and storm drainage sewers (more than 850 km) as well as drainage channels and creeks. The City's water, wastewater and stormwater systems are worth over $2 billion - and many of these assets have been in operation for more than 50 years [77].

The City launched an asset management program in 2010 after realizing its aging infrastructure had a growing need for urgent repair. Instead of the traditional "asset stewardship approach" (where capital investment decisions are based on the age and condition of assets), Regina has adopted a level of service approach for their water, wastewater and stormwater systems that focuses on the customer. A framework was developed to define and connect programs, services, service definitions and customer level of service measures.

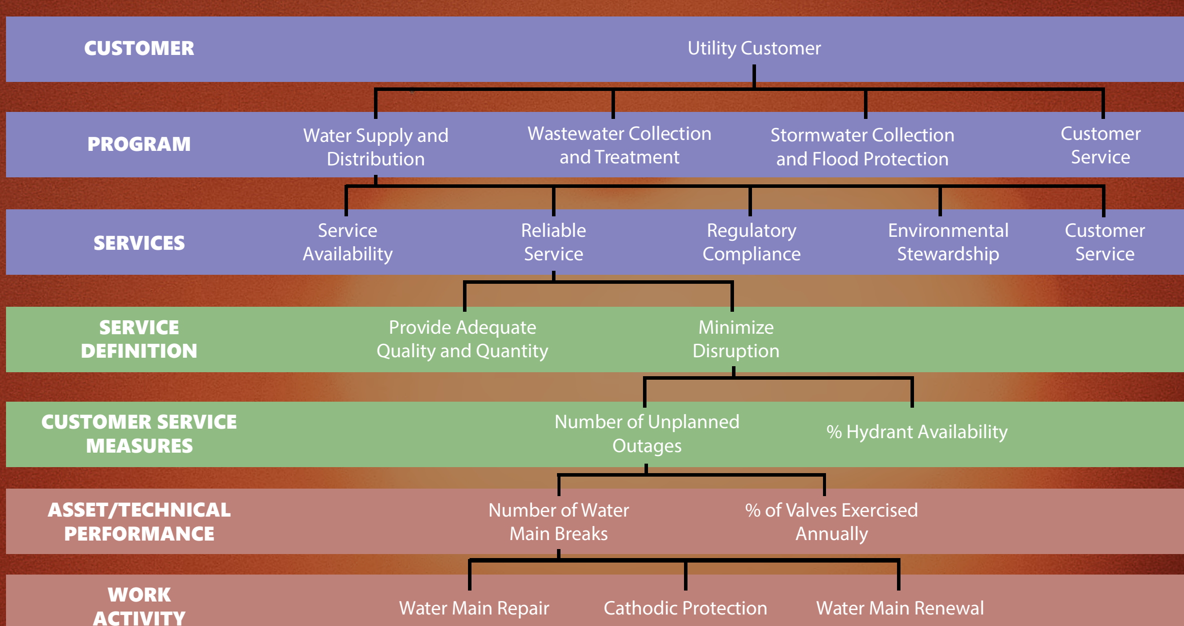
A key part of this process was establishing baseline LoS indicators to determine if service levels in the City were increasing, decreasing or remaining constant. This baseline work was also an essential component in the process of identifying gaps that might exist in the data and that would need to be addressed to ensure the City was being responsive to customer service requests and ensure the length of service disruptions were kept to a minimum [78]. Their Serviceability Approach is structured around the:

- **Capital maintenance based on risk to service delivery**
- **Considers the consequences of asset failure**
- **Considers the capability of a system of assets and operators to deliver services.**

http://www.regina.ca

Click for a profile of Regina in McGraw Hill Construction's Smart Market Report on Water Infrastructure Asset Management (page 30 of [1]).

Click here to access Regina's Water and Sewer Utility 2015 Operating Budget and 2015-19 Capital Budget [77].



pt 4. software trends

Asset management systems "can range from complex integrated Enterprise Asset Management (EAM) suites to mixed environments of best of breed software, bespoke applications and spreadsheet based analytics" [3].

In general, the software tools adopted by a municipality for managing infrastructure assets should consist of:

1. The Computerized Maintenance Management Systems (CMMS): a type of management software that supports operations and maintenance programs. Use of a CMMS is currently the most widely adopted asset management practice by water utilities in North America [1].
2. A system for managing asset inspection and monitoring where the collected data can be analyzed to enable identification of appropriate solutions for rehabilitation that will ensure continued provision of the desired level of service.

4.1 THE GIS-CENTRIC APPROACH

Historically, drinking water, wastewater, stormwater and road networks were managed in isolation from one another (with co-ordination of projects carried out manually though high-level meetings amongst the management groups). At that point in time, the primary function of GIS was purely to map capital assets.

Fortunately, today's modern GIS systems are capable than much more than pure mapping as they now offer extensive sets of tools to categorize, classify, explore, visualize and analyze infrastructure assets in their spatial context [79].

GIS is of increasing importance when managing water, wastewater and stormwater assets as it has become an essential component of municipal hydraulic modeling activities. Click here to learn more about integrating GIS with hydraulic modeling [80].

www.esri.com/

ArcGIS (Esri) is currently the world's leading platform for developing an asset data management repository. "As organizations accept that assets are central to their business purpose, realize the importance of knowing location, and recognize ArcGIS as a superior tool for creating an inventory of assets, they readily view ArcGIS as more than a mapping system. They recognize the powerful geodatabase is the best and only needed asset data management repository, and they recognize the benefits ArcGIS provides to optimize their maintenance and operations" [81].

4.2 THE WFRF's REVIEW OF MANAGEMENT SYSTEMS

The first major review of major CMMS and asset management systems currently being used by water and wastewater utilities in North America was conducted in 2012 by the Water Finance Research Foundation (WFRF) [82]. The WFRF study evaluated 14 different suppliers (in alphabetic order): Accela, Agile Assets, Azteca System's Cityworks, Cartegraph, Cityview, EnerGov, IBM's Maximo, Infor/Hansen, Lucity/GBA, Maintenance Connection, Novotx's Elements, Oracle, Pubworks and Vueworks. Those 14 systems were compared using four major functional categories:

Click to access the WFRF's 2012 Review of Municipal Asset Management Systems [82].

- Company Services: services/implementation, support/training and specialization.
- Asset Management: condition assessment, risk management, and asset inventory/hierarchy.
- Work Orders: a robust CMMS with work orders and work flow, inventory, licensing and permits.
- GIS: GIS mapping, Esri GIS integration, 311 citizen-information systems, mobile devices, and Esri GIS return on investment (ROI).

Each major component was assigned a rank from 1 to 5 (with 5 being the highest score and a zero assigned whenever a particular function was not contained within the software). An overall functional score was then established (assuming even weighting across the four major functional areas). A price score was assigned based on common cost factors (basic user licenses, software and maintenance costs, etc.).

> "In recent years, a number of software products have come into the water and wastewater market, each with its own set of features and benefits designed to help utilities make smart, informed decisions with regard to managing assets. But sifting through to find the one that meets a utility's specific needs can be daunting."
>
> --- The Water Research Finance Research Foundation's Review of Municipal Asset Management Systems [82].

A comparison of the overall functional score and the price score for each software tool evaluated in the WFRF study is shown below.

Software	Functional Score	Price Score *
Cityworks	99	91
Oracle	94	79
IBM Maximo	93	78
Accela	92	82
Infor/Hansen	89	79
Energov	88	82
Cartegraph	87	81
Lucity (GBA)	82	78
Pubworks	65	68
Maintenance	61	61
Vueworks	61	61
Agile Assets	52	58
Elements	50	56
Cityview	33	42

* Adjusted price score weighted 20%. Source: [82].

Cityworks received a 99% functional score in the WFRF 2012 review of asset management systems. Distributed exclusively in Canada by ESRI Canada, Cityworks provides tight integration with GIS and is currently in-use by numerous municipalities [83].

The overall winner of the WFRF comparison was Azteca System's Cityworks, which received a 99% functional rating due its superior capabilities for managing work at the municipal-level. A pioneer in GIS-centric asset management, Cityworks is a genuine GIS-centric CMMS (validated by the Esri Platinum Tier Partnership designation and the National Association of GIS-centric Solutions certification) that has a highly developed work-order management system capable of fully leveraging leverage an organization's return on investment in implementation of a GIS-based asset repository [82].

Vendors are continuously updating and revising their asset management software to improve capability. Competition for market-share has also introduced new software tools that were not included as part of the original WFRF study (e.g. Pure Technologies' PureNet software for integrated non-revenue water and pipeline management). In many respects, vendors often provide comparable tool sets (e.g. Cityworks, Accela, Energov, IBM's Maximo, and Oracle all received perfect scores in the WFRF study when only considering capabilities for condition assessment, risk management, and asset inventory). In general, the tool (or mix of tools) adopted by a municipality "will depend of the size and complexity of the organization and the nature of the regulatory environment it operates in" [3].

Cambridge, Ontario - Canada's First IBM Smarter City

The City of Cambridge is located in southwestern Ontario. In 2005, the Cambridge City Council supported the development of an Asset Management Division that would operate within the Department of Transportation and Public Works and would be responsible for the systematic collection of infrastructure data that would support a long-term approach to the maintenance, operation, rehabilitation and replacement of the City's infrastructure assets. Cambridge's infrastructure is valued at over $1.6 billion (500 km of roads and more than 2000 km of water mains, sanitary sewer pipes, stormwater pipes and tens of thousands of control devices).

Cambridge adopted the International Infrastructure Management Manual (IIMM) in 2012 as their methodology for comprehensive asset management. The IIMM, ISO 55001 standards and the Ontario Ministry of Infrastructure's Guide for Municipal Asset Management Plans are all being used to implement comprehensive and sustainable asset management practice within the City [84].

Click here for Cambridge's 2013 Asset Management Plan [84].

Cambridge relies on a suite of some of the industry's most sophisticated tools for asset management, including:

- **Esri GIS - corporate-level and can be utilized by all departments. Construction activity is circulated and posted on GIS and there is on-going, continuous improvement to push (and automate) information to staff so that they can identify and avoid conflicts in day-to-day business decisions.**
- **IBM's Maximo Asset Management - implemented in 2008 for full integration of service requests, complain management, etc. The system is used to track all re-active and pro-active work. The software incorporates extensive business intelligence and automation to minimize effort and maximize quality of data records.**
- **IBM Intelligent Operations Suite - offers integrated data visualization, real-time collaboration and analytics aimed at enhancing the efficiency of municipal operations.**

Cambridge was recognized in 2010 as being Canada's first IBM Smarter City (smarter cities take advantage of the increasing amount of instrumentation and advanced analytics tools). The combined adoption of state-of-the-art technology with forward-thinking leaders has resulted in a number of significant benefits including:

Click here for an overview of IBM's Smarter Cities Initiative [85].

- **Reduced inflow and infiltration into wastewater system by 22% between 2009 and 2012.**
- **Water loss reduced by 22% between 2009 and 2012 (saved the City $1.6 million in revenue)**
- **Water main breaks down to only 27 in 2012 (from a peak of 52 in 2007) [86].**
- **Better project coordination and improved asset management is expected to save at least $100,000 per year [87].**

www.cambridge.ca

Coordinated Decision Making in Hamilton, Ontario

Hamilton's Asset Management Section (formed in 2001) is responsible for the stewardship of the City's right-of-way infrastructure (6300 lane km of road network, 390 bridge and culvert structures, 1000 km of stormwater mains, 1600 km of wastewater mains and 1900 km of water mains. The City traditionally managed these water, wastewater, stormwater and road network assets in isolation from one another (with co-ordination of projects carried out manually though high-level meetings amongst the management groups).

Hamilton recently deployed a more coordinated decision-making approach based around an "Integrated Right-of-Way Infrastructure Support System (IRISS)" that interfaces with existing individual infrastructure management systems (e.g. Hansen) so that an integrated right-of-way (ROW) analysis can be carried out that aggregate the needs of water, sewer and road infrastructure (e.g. maintaining an acceptable level of risk, maintaining an acceptable level of service, optimal scheduling, best technology, financial constraints, etc.).

IRISS (developed in collaboration with InfraModex and Integraph) is currently used to evaluate all life cycle interventions for road, sewer and water assets. The system optimizes each investment in the short-term for immediate needs as well as in the long-term for strategic planning. The analysis results are visualized within GIS and this provides immense benefit - e.g. IRISS helps save money by coordinating work activities along individual right-of-way segments to avoid reworking the same section of road multiple times (e.g. avoiding the all too familiar scenario of repaving a road one year and then digging up the same section one year later to replace a sewer main) [88].

Click here for more information on IRISS (contained within the City of Hamilton's Public Works Asset Management Plan) [44].

In addition to IRISS, all involved groups (development, road operations, water operations, underground capacity, cycling, asset management, design and construction) attend monthly capital project coordination meetings to further ensure the needs of water, sewer and road infrastructure are aggregated. This level of coordinated analysis is unique within Canada and is critical for evaluating the overall risk and level of service that is achieved by completing (or not completing) rehabilitation, replacement and construction work. The overall outcome of this integration activity is an optimized infrastructure master plan that improves performance, reliability and ensures capital investments are made where the greatest needs exist.

www.hamilton.ca

Rothesay's GIS-Based Asset Management Tools

Historically, the Town of Rothesay (population of 11,947) managed utility service requests using a legacy IT system that was not integrated with the town's existing GIS database. The system was far from efficient, as a significant amount of time was spent manually importing and exporting data to view asset information (and only five users had access to asset-related data). This led to significant delays in the maintenance and repair activities of their aging infrastructure.

With the introduction of PSAB's Statement 3150 requirement to report Tangible Capital Assets on the Statement of Financial Position, the town recognized a need to upgrade the existing systems and embrace a more strategic approach to asset management.

Rothesay began working with Cityworks in 2012 to automate their approach to asset management [84]. The Cityworks platform allows the town to leverage the benefits of GIS so that infrastructure-related issues can be more quickly resolved. Field managers equipped with tablets remotely connect to Cityworks in the field to view, update, and complete service requests. Rothesay also implemented ESRI Canada s Asset Valuation Toolkit (AVT) to improve their asset inventory.

ESRI's AVT provides small to medium-sized municipalities with a population less than 50,000 with the tools and support they need to manage the valuation of infrastructure assets for Public Sector Accounting Board (PSAB) PS3150 compliance. Accounting rules built into the AVT tool allows the town to determine the expected life of individual assets, measure depreciation, and view current and projected costs related to capital, repair, and maintenance at-a-glance (without relying on an external contractor) [89].

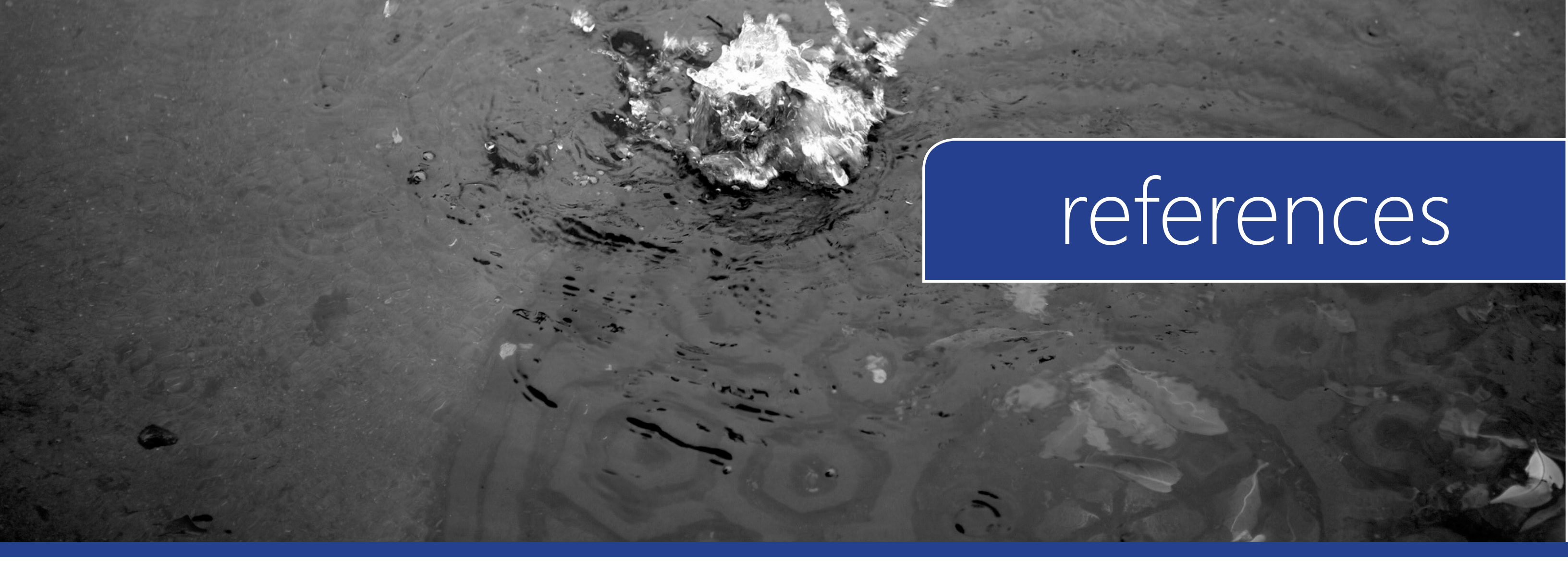
www.rothesay.ca

pt 5. conclusion

The 2013 Water Infrastructure Asset Management survey of 451 respondents from the USA and Canada (population range of 3,300 to more than 500,000) indicated the biggest obstacle preventing widespread implementation of advanced asset management practices is organizational resistance to change [1]. Such organizational resistance is closed tied to the "silo effect" - where overlapping activities related to managing water, wastewater, stormwater and watershed have typically been managed by different departments that operate in isolation from one another.

Existing silos need to be broken down to achieve sustainable asset management. Municipal water managers, watershed groups, conservation authorities, local businesses and governments need to start coordinating so that decisions are considered in the full context of actions from various other groups and levels of government.

Asset Management Plans structured around industry standards for infrastructure management are an invaluable tool for achieving sustainability at the municipal-level and overcoming problems associated with silos. Many of the goals and initiatives defined in these plans will only be achieved if municipalities seek-out and adopt leading-edge software tools that can break-down communication barriers. This white paper has explored a select set of practices that can assist with communication and ensure asset management operations are integrated across all departments.



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