Management and maintenance practices of storm and sanitary sewers in Canadian Municipalities

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Executive Summary

Recent events that have taken place in Walkerton, Ontario and North Battleford, Saskatchewan, have brought the issue of the state of Canada's municipal water and wastewater systems to the forefront of public attention. Currently, most levels of government agree that there is an urgent need for the renewal of our municipal infrastructure. However, sources for the needed capital, estimated to be as much as $45 billion, are less apparent. (Sinha, 1999) Most of the funds needed will undoubtedly be generated through a combination of higher municipal taxes, higher user fees, provincial and federal grants, and low interest loans. Other efforts will focus on reducing overall costs through greater efficiency and the use of advanced technology. In particular, savings will be generated by optimizing the management and maintenance of municipal assets, developing and adopting more cost effective inspection and rehabilitation technologies, and a greater degree of integration among various construction activities.

This report focuses on the inspection, repair and management practices utilized by Canadian municipalities to maintain their buried storm and sanitary sewer systems. The report also examines several indicators of the current level of performance as well as the ability of Canadian municipalities to respond to emergency events such as natural disasters.

The results of a survey of preventative maintenance practices currently used by Canadian municipalities in managing their buried sanitary and storm sewer networks are presented. Survey results were collected from 26 municipalities of various sizes and in different geographical locations across Canada. The data collected include among others: the distribution in terms of spending per capita for new construction, inspection and rehabilitation; level of utilization of various pipe inspection and rehabilitation techniques; frequency of inspection; management of inspection data; material and diameter breakdowns; and frequency of basement flooding. The findings from the survey are compared with findings from a survey of the state-of-the-practice in sewer management of municipalities in the USA conducted by Malik et al. (1997), and a 1997 survey of the level of utilization of trenchless technologies in Canadian municipalities by Ariaratnam et al. (1999).

Analysis of the data collected reveals that Canadian municipalities spend approximately $20.00 per capita per annum on the inspection, replacement and rehabilitation of existing municipal sewer networks, an amount slightly higher than that reported for the 1996-97 construction season of $18.21 per capita (Ariaratnam et al., 1999). From this amount approximately 90% is spent on construction activities and 10% on condition assessment and evaluation. The per capita expenditure data are strongly skewed to the right (Figures 7, 8 and 9), an indication that the median value may be a better measure than the mean of the 'typical' level of expenditure. The data reveal a significant increase in expenditure for rehabilitation of buried infrastructure for mid-size and large municipalities in comparison to the 1996 levels.

Closed Circuit Television (CCTV) systems and smoke testing are by far the most common methods utilized by Canadian municipalities for the inspection of municipal sewer networks. Newer technologies such as sonar and ground penetrating radar have not been widely accepted in this market. The utilization of trenchless technologies by Canadian municipalities is on the rise, with 82% of municipalities using one or more pipe lining techniques in the year 2000 compared with only 66% in 1996 and 32% in 1991. Comparison of the composition of sewer networks in

Canada and the USA has shown significant differences in terms of the relative weight of various pipe materials. The most common pipe material in Canadian sewers is concrete (41%) while vitrified clay is most commonly used in the USA (56%). Canadian sewers also contain larger quantities of plastic and plastic pipes (PVC/HDPE). These findings imply that research and development efforts in the USA might not fully address the needs of Canada's municipal sewer systems.

The return period for inspection and assessment of sanitary and storm sewers in Canadian municipalities is between 25 and 30 years, which is nearly equal to the design life of many of these facilities. Computerized data management and record keeping systems are commonly used in Canadian municipalities, with 78% of respondents indicating the utilization of such systems compared to 71% in the USA. Forty-one percent of all municipalities use automated data management systems/GIS, compared with 44% in the USA. A pipe defect classification system developed by the Water Research Centre (WRc), a U.K. research organization, is commonly used by Canadian municipalities. Sixty-eight percent of all respondents use it exclusively or in combination with an internally developed system.

Basement flooding is a common event in Canadian municipalities with 42% of respondents indicating that storm surges and basement flooding occur several times each year in their jurisdictions. As for post-disaster management and recovery, only 15% of the municipalities with populations of less than 250,000 have guidelines in place for conducting post-disaster inspection of their buried municipal services. Forty-one percent of the municipalities indicated that such a post-disaster inspection would likely take more than 18 months, with only 23% being confident in their ability to accurately determine the damage inflicted on their buried networks in the aftermath of such an inspection.

The more advanced the inspection technologies and data management system that a municipality uses the greater is its appreciation of the complexity associated with a post-disaster inspection of its linear networks. When an aggregate measure of the municipality's level of sophistication was contrasted with its anticipated level of performance, it was found that the more sophisticated the municipality the longer the anticipated post-disaster inspection is expected to take, and the higher is the predictable percentage of determinable damage caused by the natural disaster. Additionally, municipalities possessing more sophisticated data management systems are more likely to have developed guidelines for post-disaster inspection of their storm and sewer networks.

No clear correlation was observed between the frequency of basement flooding and the average annual precipitation, implying that infiltration and inflow (I/I) contributions are more significant than the base flow with respect to the creation of overflow conditions. Direct correlation was observed between the level of investment in the inspection and management of the storm and wastewater collection system and the frequency of basement flooding.

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During the years following World War II, Canada experienced a surge of urban development that was characterized by a population shift from rural communities to urban centres. The increase in urban development was accompanied by large scale civil works that provided the infrastructure needed to support this growth. Many of these systems, originally designed for a useful life of thirty years, are still in place after almost fifty years. Furthermore, some municipalities are still operating sewer systems that are over one hundred years old. As a result of systems being operated beyond their intended design life and capacity, misuse and inadequate maintenance, the condition of buried municipal networks has declined rapidly over the past 15 years. Subsequently, many Canadian municipalities are currently faced with the need to renew extensive sections of their water and wastewater networks.

The average age of Canada's municipal infrastructure is 42 years. In particular, 6 percent of existing trunk sewers are 70 years or older, and 10 percent have been in service for more than 50 years. By the year 2010 approximately 80 percent of the municipal trunk sewers in Canada will reach or surpass the 50 year mark (Zhao, 1998), a value commonly designated as service life.

However, aging is but one contributor to the current poor state of our municipal networks. Other factors that have contributed to the rapid deterioration of Canada's buried assets include: poor construction practices and insufficient quality control during the original installation; little or no maintenance, primarily due to inadequate funding; a general lack of uniformity in design, operation practices; misuse in the form of discharge of various chemical mixtures at elevated temperatures to sewer systems; and, the operation of systems beyond their intended design capacities (NRC, 2000).

A recent report released by McGill University and the Federation of Canadian Municipalities suggests that nearly 55% of Canada's water and wastewater infrastructure can be classified as not meeting current standards. Direct costs associated with inadequate water and sewage infrastructure systems include:

- Higher treatment costs due to infiltration and inflow (I/I) of groundwater into the sewage system.
- Higher purification costs due to loss of treated water to pipeline leakage as well as higher energy costs incurred for pumping a larger volume of water.
- Rising insurance costs as a result of flooded basements and streets caused by overflowing sewer systems during periods of high precipitation.

It is estimated that 15% of the potable water that leaves the purification plants never reaches the tap. Considering the fact that pumping of potable water accounts for nearly 6% of the overall electrical power consumption in North America, a 15% loss translates into a waste of nearly 1% of North America's total electricity consumption (Colombo and Karney, 2001**).** In some cases an increase of up to 50% in the volume of wastewater takes place between the users and the treatment plant. Increasing the volume of water that must be treated not only increases operational costs but also hinders serviceability during peak flow periods (e.g., severe rainstorms). When the treatment facilities have been compromised this can cause discharges of untreated sewage into surface bodies of water to occur, while overflowing sewers lead to street and basement flooding. Street flooding represents a road hazard, while basement flooding is a

$140 million per annum item for insurance companies and can also represent a potential health hazard due to bacteria contamination (IICC, 1999a; IICC, 1999b).
Current obstacles for solving the infiltration and inflow (I/I) problem include the lack of ability to quantify the contribution of the various segments of the network to I/I as well as a standardized cost/benefit approach to evaluate and compare competing I/I reduction investments. Monitoring programs that can provide the data needed to answer these questions such as real time control (RTC) for combined sewer overflow (CSO) are uncommon in the Canadian municipal landscape.

Powell (1995) estimated the replacement value of the water and wastewater infrastructure in Ontario alone at over $50 billion, with the total replacement value for Canada's municipal services approximated at $140 billion. It has also been estimated that over the next 15 years the cost associated with upgrading and maintaining Canada's infrastructure systems to current standards will be approximately $75 billion (2000 dollars), or $160 per capita per year. This level of investment is more than double the current one (Andres and Collicott, 2001). The backlog is partially a result of the low priority assigned to buried infrastructure in the past by the municipal, provincial and federal levels of government. As a general rule, municipalities focus on those capital works required to support population growth, and subsequently expand their tax base. In addition, investment in buried infrastructure is significantly less visible to voters than community centres and sport arenas, and thus does not yield the same political attention. Finally, there is a resistance by municipal councils to substantially increase charges for municipal services. In fact, only a few Canadian municipalities charge fees for their municipal services that are based on full cost recovery including operations, maintenance, and replacement costs of all of the system's components.

At the provincial and federal levels focus is placed on other national priorities such as health care, education, and most recently defence, much to the detriment of infrastructure development. For example, the province of Ontario recently provided municipalities with access to $200 million under its three-year Water Protection Fund, an amount that translates into less than $6 per capita per year. The Federal government is currently allocating approximately $400 million per year to infrastructure (i.e., water, sewage, roads and affordable housing), representing an annual investment of less than $4 per capita (DiPede, 2001). This combined $10 per capita per year investment in infrastructure is less than one percent of the annual expenditure per capita in the province of Ontario for health care. Reassessment of funding priorities at all levels of government is essential for the renewal and long term sustainability of Canada's buried municipal infrastructure.

Recently, the Federal Government has announced the infrastructure Canada program through which $2.6 billion will be invested in infrastructure. While this amount significantly increases the current federal financial commitment to municipal infrastructure, it is still a far cry from the estimated $45 billion needed to bring Canada's infrastructure to an acceptable level.

Recent events that have taken place in Walkerton, Ontario and North Battleford, Saskatchewan, have brought the issue of the condition of municipal water and wastewater systems to the centre of public attention. The response of the various levels of government in the form of more stringent regulations capped a decade of increasingly tougher legislation with regard to environmental and quality issues associated with the operation of municipal infrastructure facilities. The net result is an ever growing gap between what can be considered to be an acceptable level from engineering and legislative points of view and the current state of Canada's buried municipal infrastructure. Canada must make a very substantial investment in its buried municipal services in order to bridge that gap.

Although most agencies agree that there is an urgent need for the renewal of municipal infrastructure, sources for the needed capital are less apparent. Many proposals have been put forward in an attempt to identify potential sources for financing the anticipated expenditures in the short term, while at the same time avoiding the recurrence of the current situation in the long term by securing the infrastructure's financial sustainability. The proposals range from dedicated reserve accounts as a means of dealing with ongoing maintenance, repair and eventual replacement, to full-cost recovery accounting practices where the depreciation and replacement costs of entire systems are factored into the unit cost charged to the consumers. A model commonly cited for such asset valuation is the GASB 34, which was introduced in the United States in 1999 (Andres and Collicot, 2001). Other proposals explore the possibility of a greater involvement of the private sector in the operation of municipal infrastructure networks and facilities. Privatization is deemed most suitable for potable water distribution systems, similar to business models developed in the U.K. over the past ten years (Lowdon and Saldarriage, 2001).

Whatever the final mechanism is determined to be, the majority of the needed funds will undoubtedly be generated through a combination of higher municipal taxes, higher user fees, special surcharges and provincial and federal grants and loans. The extent of these will be determined by the other potential source - savings obtained from greater efficiency and advanced technologies. In particular, these savings can be generated by the optimization of management and maintenance of municipal assets; the development and adoption of more cost effective inspection and rehabilitation technologies; a greater degree of integration among various construction activities; development of alternative income sources (e.g., reclaimed wastewater) and water conservation programs. To fully realize these potential savings the following issues need to be addressed:

- Training and continuing education at all levels must be given a stronger emphasis.
- A unified system is needed for approval of offshore technologies as well as for evaluating the suitability of competing rehabilitation construction methods.
- Decision-making processes must be streamlined in term of setting priorities according to a standard cost-benefit procedure within an integrated asset management strategy.

2. ASSESSMENT, INTERPRETATION, AND RESTORATION (TECHNIQUES AND TECHNOLOGIES)

2.1 Assessment Techniques for Buried Pipes

The emergency repair of a pipeline could cost up to 50% more than the same repair under normal circumstances (MacLeod et al., 2000). The need for emergency repairs of buried pipes can be significantly reduced if critical sections could be identified and repaired before a catastrophic failure occurs. Thus, the utilization of funds can be optimized to dramatically reduce the overall cost of maintenance.

The first technological methods of inspecting pipeline systems were developed during the aftermath of World War II. Over the past 50 years these methods have evolved continuously, incorporating the latest technological developments in order to increase the quality and quantity of the data collected. Currently, many methods for assessing the condition of underground infrastructure are available commercially. It is important that administrators of buried pipeline networks are aware of the various tools and techniques available for assessing the condition of buried infrastructure, their capabilities and limitations. A classification of the various condition assessment methods based on their method of operation is presented in *Figure 1*. This report focuses on those inspection methods that are, or can be, utilized for assessing the condition of municipal sanitary and storm sewers. Methods that are used primarily for watermain (e.g. acoustic leak detection) and liquid/gas transmission lines are not considered in this report.

The most elementary inspection method is man entry, involving the physical inspection of the pipe's interior by a trained technician. However, this method is becoming less popular due to associated high labour costs and safety issues. Furthermore, the ability of a worker to perform an inspection of the pipe's interior is limited by the diameter of the pipe being inspected. To overcome these limitations a variety of tools and technologies have been developed to aid in the condition assessment of buried pipes either from within the pipe or from the surface. The choice of the most suitable inspection method for a particular pipeline depends on the host pipe's material, diameter, buried depth, fluid level and the nature of the suspected problem.

The following sections describe methods used commercially for the condition assessment of buried storm and wastewater sewer pipes.

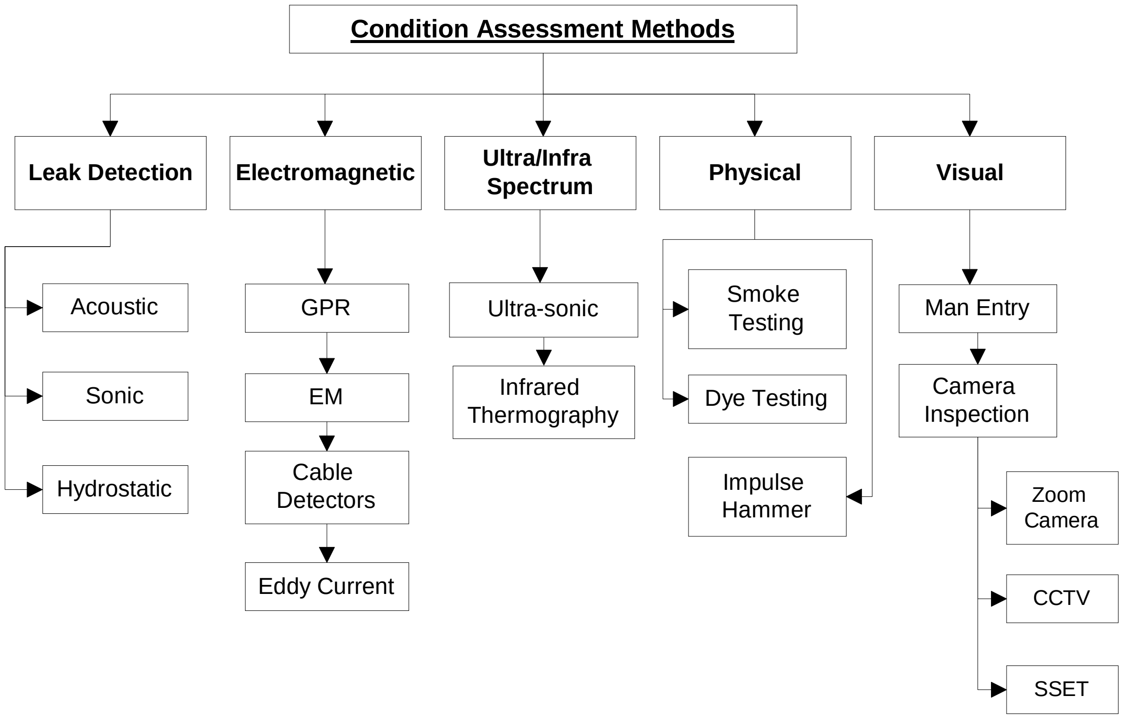


Figure 1: Condition Assessment Methods

<u>2.2 Smoke Testing</u>

Smoke testing is a quick and inexpensive method of inspecting a sewer system. Smoke testing of sewer systems began in the early 1960s and has proven to be an effective tool for determining leaks as it requires little equipment and manpower. A non-toxic smoke bomb or liquid smoke is placed in a manhole along with a blower. The blower pushes the smoke through the system. Cracks or improper connections are exposed when the smoke is seen filtering out of the pipe. Sections must be isolated to ensure that there is a high enough concentration of smoke to be detected. The system can be isolated through the use of sand bags or a stopper, or with a rubber flange to confine the smoke as shown in *Figure 2.*

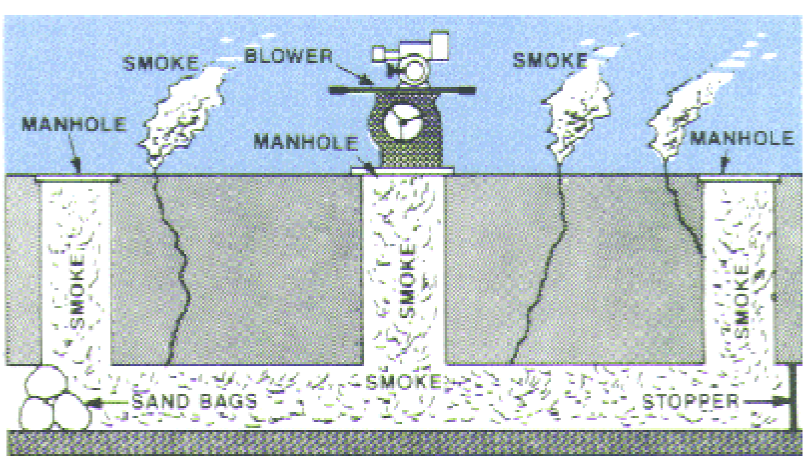


Figure 2. A Typical Smoke Testing Operation.

2.3 Dye Testing

The main purpose of dye testing is to trace the flow of effluent through the sewer system. Dye testing can be used to check if stormwater drains are connected to sanitary sewers through illegal or unrecorded connections. A non-toxic powder dye is added to drains and mixes with fluid carried by the pipe, giving it a highly visible colour (e.g., fluorescent green) that can be easily traced. The flow of the fluid through the sewer system is then monitored by inspecting manholes located downstream from the point of the dye application.

2.4 Closed Circuit Television

The most common technique used for the inspection of sewer pipelines is Closed Circuit Television (CCTV). CCTV as a method of pipeline inspection was first used in post-World War II Europe where cameras mounted on carts were used to assess the condition of damaged underground pipes. The technology has advanced considerably since then, although the basic concept has remained the same. A camera is placed into a pipeline and the picture is relayed to an operator located above ground who interprets the images and records the location and nature of the observed deficiencies. *Figure 3* shows a typical CCTV scan of a damaged pipe section. The images are stored on videotape or in CD-ROM format, allowing for further reviews by the engineering staff at a later date.

CCTVs are limited to providing visual information regarding the condition of the interior surface of the pipe being inspected. Contemporary mobile CCTVs are either pulled on a sled or navigated through a pipe using a robotic vehicle. Illumination inside the pipe is provided by an arrangement of small, high intensity lights that surround the camera lens. More advanced cameras are equipped with zoom lenses and pivot points that allow operators to get close-up pictures of damaged sections. Stationary CCTV systems are commonly used to perform initial inspections. The collected data is then used to determine which sections of pipe need to be inspected using more sophisticated equipment.

Figure 3. CCTV Scan of a Pipe Section from the City of Winnipeg, MB.

There are several limitations associated with this type of inspection procedure. The operator’s experience and level of awareness during inspection are still the determining factors in the success or failure of this process. The operator needs to record his/her observations as well as interpret the images transmitted by the camera while the filming is in progress. This limits the speed at which the camera can move through the pipe as well as the efficiency of the results. The detection of minor defects is difficult as they can be hidden by biofilm or mud. The effectiveness of a CCTV survey tends to decline with increasing pipe diameter due to increased lighting requirements and difficulty in achieving adequate resolution of details due to large camera-to-subject distances. Mistakes due to reflections caused by poor lighting or an inattentive operator can have an adverse effect on design decisions.

2.5 Zoom Camera Technology

Truck-mounted camera equipment with long-range zoom lens and powerful halogen spotlights are used to conduct visual inspections of manholes and sewers. The camera is lowered into the manhole from the back of a truck to the elevation of the first pipe and remotely aligned with the pipe's longitudinal axis. Powerful halogen lights are used to illuminate the interior of the pipe, as the camera zooms into the pipe providing a continuous image of the pipe's interior surface. The image is displayed on a monitor located in the truck while at the same time being recorded for subsequent review and analysis. All of the sewer lines connected to the manhole are viewed in the same fashion. After reviewing all of the pipes the manhole itself can be inspected before removing the equipment and moving on to the next manhole. The advantages of this method include significantly reduced inspection time and cost in comparison with conventional CCTV, since prior cleaning of the pipes and manhole entries are no longer needed. In addition, the manhole condition can also be evaluated, which is not the case with many CCTV inspections. The main limitation of this method is the range of operation, which is limited by the depth of penetration of the illumination equipment. The typical operating range for zoom cameras within pipes smaller then 250mm diameter is 25m, while the operating range can reach up to 50m in larger diameter pipes (Gunn, 2000).

2.6 Sewer Scanners and Evaluation Technology (SSET)

Sewer Scanners and Evaluation Technology (SSET) is a multi-sensor, non-destructive, pipeline inspection system developed to overcome some of the limitations of standard CCTV systems by providing multi-source data obtained through a scan of the pipe's circumference. (Kusumoh et. al., 1998) A SSET system scans the entire diameter of the pipe as it moves through the system, recording a 360-degree view of the pipe's interior. The information collected is processed and presented to the operator as uniform, high-resolution 2D images (See *Figure 4)*. SSET systems are more effective than traditional CCTVs because there is no need for the operator to slow down in damaged sections to ensure that all of the damage is recorded. Another advantage of the SSET system is the fact that it can measure horizontal and vertical pipe deflections using the gyroscope system (Iseley et al., 1997).

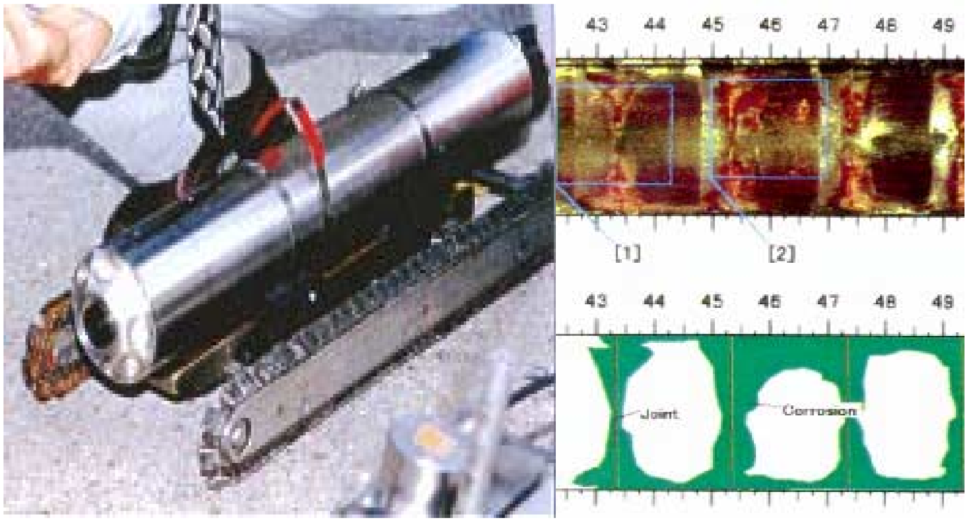


Figure 4. SSET Survey Machine and Some Typical Output (Blackhawk Inc., 2000).

2.7 Ground Penetrating Radar

Ground Penetrating Radar (GPR) works by emitting a pulse of radio waves into the ground or any other non-metallic medium (Sensors & Software Inc., 2001). An image can then be generated by measuring the strength and delay time of the refraction waves (echoes). The primary application of GPR for buried infrastructure is to identify the location and depth of buried pipes and conduits. GPR is also used to locate existing voids surrounding the pipe when the host medium permits adequate penetration. A more recent application is the utilization of specialized GPR units that are inserted into the pipe to evaluate the quality of rehabilitation projects using various lining methods such as slip lining and cure-in-place liners.

The depth of penetration and image definition quality of a GPR system are affected by the medium (e.g. concrete, soil, rock) and by the radio frequency emitted by the transmitter (typically 100 – 800 MHz). Low frequencies provide better penetration depths, while higher frequencies are used when high definition images are required (e.g. higher resolution). As a general rule, utility lines can be detected at a depth equal to 8–12 times their diameter (e.g. a 200mm diameter pipe can be detected at a maximum depth of 2m). However, the actual detection depth is a function of not only the pipe diameter but also its composition and the properties of the fluid/gas that flows through it. The reflectivity of a metal pipe is 80% higher than a non-metallic pipe that conveys water, and 250% higher than a non-metallic pipe that conveys gas (*Figure 5).* The detection capabilities of GPR are also greatly influenced by the electromagnetic properties of the host medium. The presence of highly conductive materials, such as clay minerals, causes severe attenuation of the GPR signal significantly restricting penetration depth (Mellet, 1995). *Figure 6* presents typical exploration depths of GPR in various host materials.

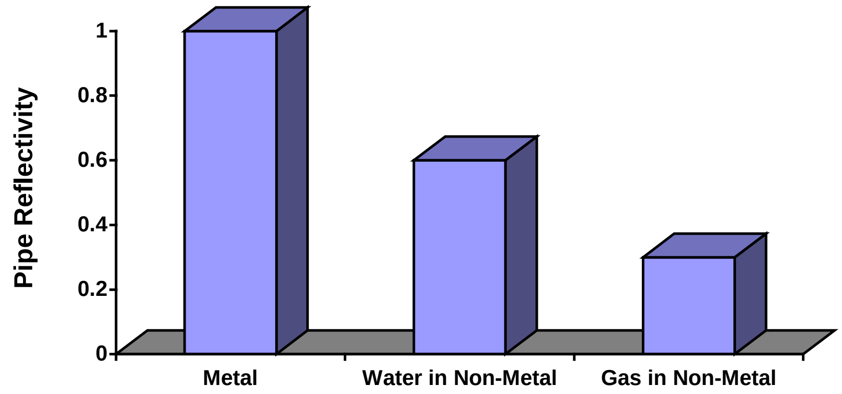


Figure 5. Pipe Composition vs. Pipe Reflectivity (Sensors & Software Inc., 2001)

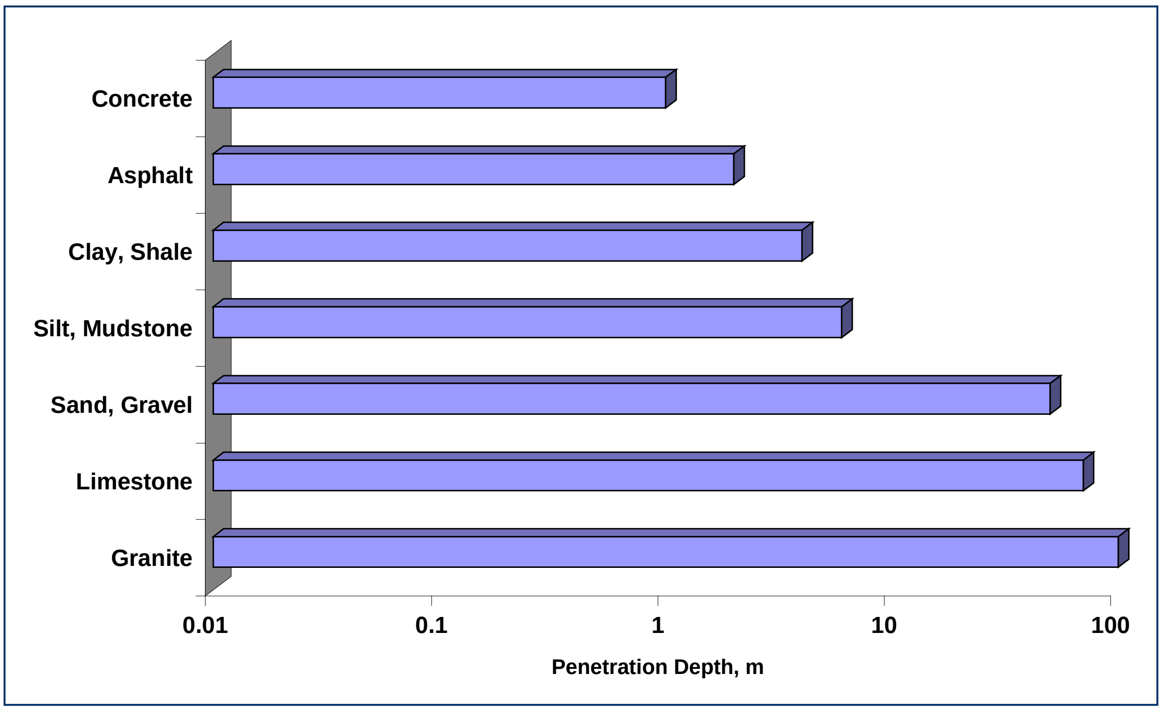


Figure 6. Typical GPR Exploration Depths (Sensors & Software Inc., 2001)

2.8 Ultrasonic Inspection (Sonar)

Wall thickness, crack depth, and condition of the backfill surrounding the pipe are all important aspects of a comprehensive condition assessment that cannot be examined using CCTV inspection. Thus, in order to fully assess the condition of a buried pipe it is necessary to look beyond the inner surface of the pipe at the cross-section of the pipe wall and the supporting backfill. In addition, debris, corrosion and biological film can make it difficult to assess the degree of deterioration of the pipe's wall when using a simple visual image.

Ultrasonic inspection devices utilize bursts of well-defined, high frequency sound waves that are sent towards the surface of the object of interest (Cascante et al., 2001). The sound waves are reflected back towards the source at the interface of adjacent surfaces or when it encounters materials with different densities and elastic behaviours. Variations in the amount of energy that is returned to the mechanism for analysis and the period of time it takes for the sound waves to travel to the target and return to the source are used to estimate the location (i.e. orientation and distance with respect to the source) of the various targets. The system is able to detect pipe-wall deflection, corrosion losses, and cracks/pits in the cross-section of the pipe wall. In addition, ultrasound inspection can provide information regarding the volume of debris in the invert. Ultrasound inspection is not well suited to analyzing the interior of brick sewers due to the random edges that characterize the brick-mortar interface. Ultrasound detection methods can be used in plastic, concrete and clay pipes that are either filled or empty. If used in partially filled pipes, information can be collected regarding either the empty, or submerged portion of the pipe only.

2.9 Laser Interferometer

Lasers are currently being used to measure the shapes of pipes so that excessive deflections and other defects, including cracks and joint displacements, can be identified and measured three dimensionally. The system is based on the principle that a smooth pipe wall will reflect the greatest amount of light, while a cracked surface will reflect a reduced amount of light back to the sensor (Makar, 1999). These systems can only function in empty pipes or completely full pipes, if the pipeline remains in use during the inspection.

2.10 Infrared Thermography

Infrared thermography is the science of measuring temperature variations over a specific area. Heat energy that flows from warmer to cooler areas is slowed down by the insulating effects of the material through which it is flowing. All measurements are made using a reference temperature of –196°C, with heat detectors that are accurate to +/- 0.05°C. The sun provides the energy source needed for initiating the energy flow. The technology is effective in detecting leaks, voids around the pipe, and poor backfill. Usually, the results of scans are displayed as pictures that use a range of colours and intensities to distinguish between areas of varying temperature.

The major drawbacks of this technology are the heavy reliance on the operator’s experience at interpreting the results and the lack of specific information regarding the location and extent of the defects. These surveys can be performed quite rapidly from an elevated position, such as the rooftop of a nearby building. Information displayed on the output screen is reviewed by the operator and can be shown to engineers at a later time (Weil, 1998). This method is susceptible to the surrounding local meteorological conditions (e.g. rain and snow) that tend to mask the heat signature of a leak.

2.11 Impulse Hammer

The Impulse Hammer is a technique developed to evaluate the structural integrity of brick sewers. The evaluation is conducted from a manhole, where a dynamic hammer is used to generate a broadband frequency excitation of the structure being tested. The dynamic response of the sewer structure is monitored by an accelerometer attached to the structure. The hammer’s force input and the accelerometer’s output are used to evaluate the structural soundness of the sewer (Sibbald et. al., 1995).

2.12 Summary of Inspection Technologies

Table 1 compares the approximate unit costs of the inspection methods used by Canadian municipalities. The capabilities of the inspection and condition assessment technologies discussed above are summarized in *Tables 2 and 3*. *Table 2* describes adverse conditions not directly associated with the physical condition of the pipe that can be detected by each of the inspection technologies. *Table 3* describes common types of pipe defects that each of the inspection technologies covered in this section is capable of detecting.

Table 1. Inspection Methods Used (Zhao, 1998)

Methods Used	Approximate Unit Cost ($/m)	Unit Cost (l.m./mm diameter)
CCTV	$1.75 - $14.00	$0.009
Sonar	$6.00 - $10.00	$0.03
Man-Entry	$1.33 - $20.00	$0.007
Combined CCTV/Sonar	$6.6	$0.013
Zoom Camera	$44.25 per MH	$0.033

Table 2. Inspection Technologies and Adverse Conditions

	Adverse Conditions					
	Debris	**Infiltration**	**Presence / Location of Voids**	**Cross Connections**	**Unmarked Pipe**	**Remarks**
CCTV	✓	✓	x	✓	x	Internal inspection can be used with all pipe types.
SSET	✓	✓	x	✓	x	Multi sensor device.
GPR	x	x	✓	✓	✓	Applied from surface or from within pipe.
Ultra-sonic	✓	x	✓	x	x	Not suitable for brick sewers.
Laser Interfero-metry	✓	x	x	x	x	Cannot be used in partially filled pipes.
Infrared Thermo-graphy	x	✓	✓	✓	✓	Limited by environmental conditions (i.e. weather).

Dye Testing	x	x	x	✓	x	Used to identify for cross connections between storm and sanitary sewers.
Man Entry	✓	✓	x	✓	x	Limited by pipe diameter and type of fluid/gas being transported.
Smoke Testing	x	✓	x	✓	x	Used mainly for brick and segmental pipes.

Table 3. Determinable Damage Types for Inspection Technologies.

Method of Inspection	**Type of Damage / Defects That Can be Detected**						
	Off-Set Joints	**Deteriorating Mortar**	**Cracks**	**Corrosion**	**Wall Thinning (Steel Pipe)**	**Lateral Deflection**	**Crown Sag**
CCTV	✓	✓	✓	✓	x	✓	✓
SSET	✓	✓	✓	✓	x	✓	✓
GPR	x	x	x	x	x	x	x
Ultra-sonic	✓	x	✓	✓	✓	✓	✓
Laser Interfero-metry	✓	x	✓	x	x	✓	✓
Infrared Thermo-graphy	✓	x	✓	x	x	x	x
Dye Testing	x	x	x	x	x	x	x
Man Entry	✓	✓	✓	✓	x	✓	x
Smoke Testing	✓	x	✓	x	x	x	x

2.13 Data Analysis

2.13.1 Data Analysis - An Overview

Sewer condition assessments are most commonly done based on the experience of the operator. Aid in the form of a comparative guide that can be used by the technician to classify damages by comparing pictures to what is on the display screen is also available. However, to date there are no established national standards for the classification and rating of damages to sewer systems. Most Canadian municipalities use loosely defined guidelines to interpret CCTV images that were developed based on internal experience. A recent trend, strongly promoted by industry associations such as the North American Association of Pipeline Inspectors (NAAPI), is a move towards a unified standardized classification system developed by the United Kingdom based Water Research Centre (WRc). The WRc has developed a set of standard methods for measuring damages and then taking these measurements and comparing them with an index of photographs depicting and labelling various forms of damage in different stages of progression. If an assessment technology other than CCTV is utilized, the operator of the inspection technology being implemented is usually requested to give each defect a designation (e.g. longitudinal fracture) and a severity rating (e.g. moderate) based on his/her own experience. The severity and extent of the observed defects are used to determine the magnitude of the problem and subsequently the priority of the remediation action and its nature (e.g. spot repair, full rehabilitation or replacement). The severity classification of any given damage is a function of its impact on the structural integrity and functionality of the pipe structure, which in turn is a function of the structure's operating conditions (i.e. pipe material, diameter, gravity driven/pressurized).

2.13.2 WRc – Sewer Rehabilitation Manual (SRM)

In addition to providing a guide for the interpretation of CCTV data, WRc's Sewer Rehabilitation Manual (SRM) also provides procedures that aid in prioritization of the needed repairs and upgrades. The SRM method of prioritizing is based on a "worst first" basis, meaning that the damage that is scaled to be the worst will receive priority and will be repaired/replaced as funds become available. Many of the municipalities using SRM find it necessary to modify it to suit their specific needs to better deal with their unique situations.

2.13.3 Sanitary Sewer Management System (SSMS)

The Trenchless Technology Center at Louisiana Technical University has developed a Sanitary Sewer Management System (SSMS) based on the results of standard CCTV inspections (Trenchless Technology Center, 1998). The SSMS is a tool used to prioritize the existing needs of a given sewer system for decision making purposes. Unlike the WRc method that is designed to prioritize on a "worst-first" basis, SSMS promotes the utilization of many small investments during critical points along the deterioration curve to reduce long-term future expenses by minimizing/delaying large expenditures.

2.13.4 NRC Guidelines for Large Sewers

In the late 1990s the National Research Council of Canada together with ten municipal partners developed guidelines for condition assessment and rehabilitation of large sewers (over 900mm diameter) (Zhao, 2000). The NRC model uses acronyms to designate the type of defect, its orientation, and severity (e.g. FCM = Moderate Circumferential Fracture). Separate sets of codes are used for service conditions (e.g., RS = severe root intrusion; IM = moderate infiltration). Each structural and performance defect is assigned a numerical value between 5 (e.g., moderate infiltration) and 20 (e.g., structural collapse). The condition rating for each given pipe segment is equated to the highest score assigned to a defect located within the length of that segment. A decision-making algorithm is then used to determine the priority of the needed remediation action (if any) based first on the segment's condition rating and secondly a parameter named the 'impact rating'. The latter is a rough measure of the likelihood and consequences of failure based on several attributes including: pipe location; buried depth; embedment soil; pipe diameter; and functionality (e.g. storm vs. sanitary).

2.13.5 City of Indianapolis Classification System

In 1996, the City of Indianapolis conducted a complete assessment of its large combined sewers (1500mm and larger in diameter) (Greeley and Hansen, 1996). The Department of Capital Asset Management (DCAM) developed a structural condition rating system to support the development of a priority list for rehabilitation. For each of the four dominant pipe material types (brick, clay, concrete, and reinforced concrete) a list of common defects was developed (e.g. for bricks sewers = cracking; deflection; missing bricks; and dropped inverts). During inspection, each type of defect was assigned a score ranging from 0 for "no visible sign" to 3 for "high evidence". The rating system shown in *Table 4* was used to compile the structural condition scores and determine the condition rating for each segment. The rating from the sewer inspection is then adjusted based on performance factors (e.g. signs of infiltration) and external factors (e.g. soil type, depth of cover) to obtain the overall structural grade (OSG). Sewer sections with OSGs of 4 or 5 are considered candidates for rehabilitation.

Table 4. Structural Condition Rating System

If the segment received the following combination for structural condition scores:			Which is a structural condition total of:	Then the sewer condition rating was set at: (5 is the worst)
Number of 3's	Number of 2's	Number of 1's		
0	0	1	1	1
0	0	2	2	1
0	0	3	3	1
0	0	4	4	2
0	1	x	At least 2	3
0	2	x	At least 4	4
1	0	x	At least 3	4
1	1	0	5	4
1	1	At least 1	At least 6	5
0	3	x	At least 6	5
2	x	x	At least 6	5
3	x	x	At least 9	5

x = any number of structural condition scores
structural condition scores: 3 = excessive, 2 = moderate, 1 = minor
condition rating: 1 = good, 2 = fair, 3 = moderate, 4 = poor, 5 = severe.

2.13.6 Others

Many individual municipalities use simple classification systems that have been developed internally by their respective public works departments. These systems reflect the individual characteristics of their own networks (pipe material, diameter, soil conditions) and the most common defects and deficiencies that prevail in their systems. The drawback associated with such an approach is the inability to transfer "lessons learned" and "best practices" among municipalities, which discourages regional and national efforts to improve the state-of-practice via knowledge sharing. *Table 5* summarizes the characteristics of the condition rating systems discussed in this section.

Table 5. Condition Rating Systems

	Empasis is put on:			**Additional Factors**	**Method of Prioritization**	**Supported**	
	Structural Condition	**Hydraulic Condition**	**External Factors**			**Inspection Methods**	**Types of Sewers**
WRc	High	Medium – High	Low	None	Worst First	Mainly CCTV	All
SSMS	High	Medium – High	Low	None	Life-Cycle Optimization	Mainly CCTV	All
NRC	High	Medium – High	Medium – High	Location Depth, Soil, Pipe Diameter, Functionality	Worst First / Failure Probability of Impact	All	Large Sewers (>1200)
City of Indiana-polis	High	Medium	Medium	Depth, Location, Soil, Ground Water Table	Worst First / Probability of Failure	Mainly CCTV	Large Sewers (>1500)

<u>2.14 Data Storage and Management</u>

2.14.1 General

The goal of an infrastructure management system is to create a basis upon which management decisions can be made with respect to operation, maintenance and development. One of the basic requirements for an effective management system is the availability of an accurate inventory of the existing infrastructure, including its function, physical properties (e.g. material, size, location (alignment and profile), condition, age, embedded soil, and repair history). Additional information is also needed for components supporting the linear system including manholes and various mechanical systems (e.g. CSO regulators). The large volume of data associated with the management of large storm and wastewater collection systems, as well as the variety of data formats (i.e. technical reports, inspection sheets, still images, videos) requires an ever increasing level of sophistication in terms of data management technology. The development of new condition assessment technologies (e.g. sonar) adds new types of data that need to be stored and managed. Consequently, over the last five to ten years many municipalities have been gradually automating their data management systems. The following sections describe four categories of data management systems used by Canadian municipalities for the storage and management of the data associated with fixed municipal assets.

2.14.2 Paper Archives

Paper archives represent the earliest and simplest form of sewer system management and data storage system. Usually they include maps, plan drawings, service records, and CCTV videotapes for the entire system. The limiting factor with paper archives is accessibility and limited ability to share information. A significant amount of time is spent searching through filing cabinets for specific items. In addition, to use this system one must have physical access to material and must travel to the physical location of the archive or request that the files be delivered. Large scale cross referencing of information for the purpose of decision-making is a very tedious, time consuming and costly proposition making efficient management of large sewer systems difficult.

2.14.3 Computerized Database

Electronic databases and computerized map systems were among the first advancements to occur in data management with regards to sewer systems. These systems allowed easy access to records of inventory and repair history from various locations at the same time. Retrieval of files is much faster and can be done remotely. Another advantage of a computerized database includes the user’s ability to prompt the system, using a set of criteria, to locate and cross reference information needed to support management decisions. The system also enables multiple users to access the same data simultaneously. The stored data can include reports, digital images, video footage, and other forms of output from sewer condition assessment inspections.

2.14.4 Geographic Information Systems (GIS)

GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information (i.e. data identified according to their locations) that is stored in multiple relational databases. The primary requirement for the source data is that the location of the variables are known. Location may be annotated by x, y, and z coordinates (longitude, latitude, and elevation), or by established reference systems such as zip codes or highway mile marks. In addition to their ability to accept information from various sources and in multiple formats, GIS systems are capable of recognizing spatial relationships among the various objects being mapped (i.e., sewer segment S3483 connects manholes MH7462 and MH7453). Its ability to integrate information from various sources allows GIS to use combinations of mapped variables to build and analyze new variables.

GIS systems are capable of storing massive amounts of data in multiple formats. For example, the physical properties, hydraulic performance, and inspection data for each element in the linear collection system (i.e., individual section of pipeline and manholes) can be stored in different layers within the system. CCTV scans and still images can be stored as another layer within the GIS system. All the information related to a particular element of the system (e.g. sewer segment S3483) can then be revisited simply by searching for all available information corresponding to its geographic location. Maps and plans of sewer systems stored within the GIS database can be quickly overlapped with other buried services in the area and geotechnical data, simplifying the development of drawings and specifications for construction bid packages.

2.14.5 Integrated Asset Management Systems

The most advanced level of data management comes under the title of Integrated Asset Management Systems (IAMS). The concept of IAMS evolved as a response to the need to optimize the operation and maintenance of vast, highly interrelated infrastructure networks. In other words, the need arose to accurately identify those improvements that will ensure long-term renewal at the lowest possible cost. This is accomplished via an integrated management of these networks (e.g. water distribution, sewers, and roads). These databases take into account not only the condition rating of individual pipe segments, but are also capable of cross-referencing proposed repairs of adjacent utilities and repaving/resurfacing operations in an effort to optimize the utilization of funds. Segments of the different services within a given geographical location can be combined to create "integrated segments" (Lalonde, 2001). These "integrated segments" can be looked upon as a way to determine the optimal time to perform repairs on more than one utility at a time in a given area.

IAMS may also incorporate risk analysis algorithms (e.g. probability of a burst based on burst history) and holisitic estimates of the consequences of a failure into the prioritization process. Through the use of decision support systems it can suggest the most appropriate method of rehabilitation/replacement for each pipe segment and then prioritize the repairs in order of urgency based on budget restraints, acceptable levels of service, liability considerations and other relevant criteria.

In addition, IAMS represents an important step towards meeting recent regulatory requirements in the transition to accrual based accounting methods for the costing of all municipal assets, and support decision-making based on life cycle cost analysis by providing a detailed inventory of municipal assets, their current condition, and their anticipated rate of deterioration (Andres and Collicott, 2001).

Table 6 summarizes the capabilities of the four categories of data management systems described above with respect to seven attributes: ease of data storage/retrieval; ability to store multi-format data; support of inventory control; ease of cross reference searches; data integration capabilities; ability to support and assist in making operational decisions; and ability to support conversion to an accrual accounting method. *Table 6* can be viewed as a guide for municipal administrators for evaluating the enhancement in capabilities gained by the additional investment associated with a higher level of data management system. It is also important to realize that aside from the purchasing of the hardware, software, and technical support associated with a GIS or IAMS system, a significant investment must also be made in data collection. For a GIS or IAMS system to be effective, extensive current data regarding all of the elements in the system is needed. In many cases, an extensive data collection effort is required to supplement existing databases. While the magnitude of the "data gap" varies from one municipality to another, a typical value for such an investment ranges between $13 and $20 per capita.

Table 6. Attributes of Various Data Management Systems

	Ability to Store Data in Multi Format	Ease of Storage/ Retrieval	Inventory Control	Cross Reference Search	Data Integration	Support Operational Decisions	Support of Accrual Accounting Method
Paper Archive	M	L	L	L	L	L	L
Computer Database	H	H	M	M	M	L	L – M
GIS	H	H	H	H	H	M	L – M
IAMS	H	H	H	H	H	H	H

H = High; M = Medium; L = Low

2.15 Decision Support System

After receiving all of the data collected through the sewer inspection and monitoring programs, decisions need to be made concerning the appropriate remedial actions to be taken. The aim of the decision-making process is to identify the course of action that will most benefit the system's state and performance within pre-determined economical, time, and resource constraints. Based on an engineering assessment, a decision should be made as to:

1. Which sections of the system require immediate attention.
2. Nature of the needed action (e.g., replacement; rehabilitation; frequent flushing).
3. Which projects are to get priority for rehabilitation/replacement (based on conditions; consequences of a delay; cost; available budget).
4. The rehabilitation/replacement methods that best suit the physical reality of each of the deficient pipe sections (e.g., full rehab vs. point repairs).

Decision-making processes typically include consideration of several criteria, such as: hydraulic capacity, physical characteristics, unit repair cost, functional integrity, condition of related assets, ratio of length of point repairs to total length of the segment, and extent of surface restoration. Another essential aspect in the decision-making process is the ability to anticipate the future rate of deterioration of sewers based on their current condition (Kathula, 1999).

In recent years, a number of automated and semi-automated decision-support systems have been developed by various researchers to assist construction practitioners in the assessment of anticipated project conditions. These systems consider the capabilities, limitations, and benefits of available rehabilitation and replacement construction techniques in order to determine the best construction method for a specific project. Methodologies utilized for the evaluation of competing construction technologies may be classified using two general categories, namely: algorithmic procedures (i.e. rate of return, utility theory, analytical hierarchy process, constraint satisfaction technique); and reasoning by deduction (i.e. expert systems).

A comparison of the features of nine models proposed in the literature in recent years for selection of replacement/rehabilitation construction methods for buried pipes and conduits is given in *Table 7*. The models are evaluated in terms of their flexibility (ability to incorporate new construction methods/attributes); their capability to simultaneously evaluate multiple construction methods; ability to account for tangible and intangible attributes; ability to account for risk; and, allowing trade-offs among preference attributes to be conducted in a quantitative manner.

Table 7. Comparison of Various Method Evaluation Models (Allouche et. al., 2000)

Model	Method	Flexibility	Handle multiple methods	Tangible / intangible attributes	Trade-off Among Attribute	Account for Risk
Hastak, 1998	AHP	High	**x**	✓	**x**	**x**
AbouRizk et al., 1994b	AHP	High	**x**	✓	**x**	✓
Iseley et al., 1997	---	Low	✓	**x**	**x**	**x**
Moselhi and Sigurdardottir, 1998	Utility	High	✓	✓	**x**	**x**
Stein, 1994	Expert-system	Medium	✓	✓	**x**	**x**
Russell et al., 1997	Expert-system	Medium	✓	✓	**x**	**x**
McKim, 1997	AHP	Low	✓	**x**	**x**	**x**
Ueki et al., 1999	Expert-system	Low	**x**	✓	**x**	**x**
Allouche, 2000	Utility / CST	High	✓	✓	✓	✓

✓ = Capable; **x** = Not Capable
AHP = Analytical hierarchy process
CST = constraint satisfaction technique

2.16 RC / CFM National "Best Practices" Guide

Currently, the Federation of Canadian Municipalities (FCM) and the National Research Council (NRC) are working together to develop a technical guide for best practices in municipal infrastructure (NRC, 2001). When completed, the guide will provide Canadian municipalities with a common knowledge base regarding best practices ranging from the development of capital investment programs to manhole inspection and rehabilitation procedures. The $26 million program is being funded by the Infrastructure Canada Program, NRC, and the FCM and is expected to take four years to complete. It is an attempt to help prevent the further deterioration of infrastructure networks across the country by establishing state-of-the-practice decision–making processes and rehabilitation technologies. The overall goal of this project is "the protection and enhancement of quality of life" by providing support through best practices and innovation for "sustainable municipal infrastructure" (NRC, 2001).

3. SURVEY OF CANADIAN MUNICIPALITIES

To date, limited data has been collected regarding the ability of Canadian municipalities to properly inspect and maintain their underground infrastructure. The results of a survey conducted to examine current practices used by Canadian municipalities for inspecting, maintaining and managing their storm and sanitary sewer systems are given below. In addition, the study examined the capability of municipalities to respond to catastrophic events such as natural disasters. The correlation between the level of resources municipalities invest in the maintenance of their storm and wastewater collection systems and their vulnerability to basement flooding and ability to respond to a natural disaster was also studied.

The main objective of this research was to gain insight into the maintenance and management practices of storm and sanitary sewers by Canadian municipalities. To achieve this objective surveys were mailed to 38 municipalities across Canada. The sample selected represents a wide range of geographical locations, geological conditions, historical developments and populations. Survey responses were received from 24 of the municipalities contacted, giving a 62 percent response rate. Responses were received from major metropolitan centres including Toronto, Edmonton, and Calgary, along with smaller municipalities. The combined population represented by the responding municipalities is approximately 5.2 million people, or roughly 17 percent of the population of Canada. The survey used a range of values as possible responses for each question. The middle value of each range provided by each municipality was used as a representative value to produce the per capita values. Population sizes were obtained from the 2000 Canadian census.

3.1 Expenditures

Responding municipalities have been grouped throughout this section by population size. The annual expenditures of the responding municipalities has been broken down into three categories, namely new construction, rehabilitation, and condition assessment is shown in *Table 8*. To compare the overall expenditure trends for all the participating municipalities sizes, the budgets for the three categories were converted to a per capita yearly expenditure.

It is interesting to note that the total expenditure per capita increases slightly with the size of the municipality. Also, the data reveals that on average municipalities spend more on new construction than condition assessment and rehabilitation, combined. The data also indicates that Canadian municipalities invest approximately $1.6 billion per year maintaining and expanding their linear storm and wastewater infrastructure. Some key factors that determine a municipality’s budget for storm and sanitary sewers are the overall adequacy of the system’s performance and the structure of municipal taxes and user fees. Due to Canada’s large landmass, there is a great range of conditions that play a role in determining how long pipes will last (e.g. temperature, soil conditions). These factors will affect the individual municipalities budgetary needs to maintain their storm and sanitary sewer systems.

Table 8. Average Annual Expenditures for Storm and Sanitary Sewers

		Annual Budgets				
Population Size	Number of Responses in Category	New Construction	Rehabilitation	Existing Condition Assessment	Total	$/Person
<100 000	10	$2,416,667	$1,050,000	$120,000	$3,586,667	$48.62
100 000 - 500 000	8	$9,231,250	$4,312,500	$265,625	$13,809,375	$53.49
>500 000	4	$17,062,500	$11,875,000	$1,093,750	$30,031,250	$55.30

Tables 9, 10, and 11 list the minimum value, maximum value, mean and median values for each population group as related to new construction, rehabilitation, and condition assessment expenditures, respectively. Expenditure ratios for condition assessment versus rehabilitation were calculated and the results are shown in *Table 12.* The amount of money spent annually on inspection of existing infrastructure is approximately 11 percent of that spent on the rehabilitation of sewer systems. The mean and median values, on a per capita basis, for the condition assessment were calculated to be $1.51 and $1.01, while the mean and median values for rehabilitation expenditures were found to be $16.96 and $10.18, respectively. The range of per capita budgets ($0.34 - $5.39) is similar to that reported by Zhao (1998) of $1.03 to $6.56.

Table 9. Budget Per Capita for New Construction (by Municipality Size)

Population**	<100,000	100,000 - 500,000	>500,000
Minimum	$10.20	$5	$28.39
Maximum	$53.47	$93.20	$42.40
Mean	$31.46	$34.54	$34.45
Median	$37.32	$23.83	$32.55
Data Points*	9	8	3

** Three municipalities claim all New Construction is done by developers*
*** Population Determined by Statistics Canada 1996*

Table 10. Budget Per Capita for Rehabilitation (by Municipal Size)

Population	<100,000	100,000 - 500,000	>500,000
Minimum	$2.61	$2.46	$9.76
	($5.33)	($0.48)	($1.34)
Maximum	$53.93	$65.24	$42.40
	($624.96)	($22.81)	($52.63)
Mean	$15.51	$17.71	$19.11
	($67.71)	($8.61)	($18.48)
Median	$10.22	$9.14	$12.15
	($25.17)	($3.74)	($12.13)
Data Points	10	8	4
	(34)	(9)	(9)

* Values in brackets were reported for 1996-7 construction season (Ariaratnam et al., 1999)

Table 11. Budget Per Capita for Condition Assessment (by Municipality Size)

Population	<100,000	100,000 - 500,000	>500,000
Minimum	$0.52	$0.34	$0.61
Maximum	$5.39	$3.26	$3.23
Mean	$1.64	$1.23	$1.73
Median	$0.97	$0.79	$1.55
Data Points	10	8	4

Table 12. Expenditure Ratio - Condition Assessment/Rehabilitation

Population	Mean (%)	Median (%)	Average (%)
<100,000	13.04	13.33	13.19
100,000 – 500,000	6.64	10.00	8.32
>500,000	9.18	13.33	11.25

The histograms of the expenditure data as related to new construction, rehabilitation, and condition assessment are shown in *Figures 7, 8, and 9*, respectively. All three histograms are strongly skewed to the right, implying that the median might be a better representation of the "typical" value than the mean (which is effected by outlying values). *Figure 7* reveals that the shape and median values for new construction expenditures recorded in 1996 and 2001 are very similar and believed to reflect a growth rate that is steady overall. In *Figure 8* the annual expenditures per capita by the responding municipalities on the rehabilitation of existing services is compared to the 1996 survey of Canadian municipalities. The general trend of the two plots is very similar with the data from the 1996 survey being skewed more strongly to the right. The median values for 2001 survey was $10.2 per capita in comparison with a mean value of $17.33 per capita calculated for the 1996 survey.

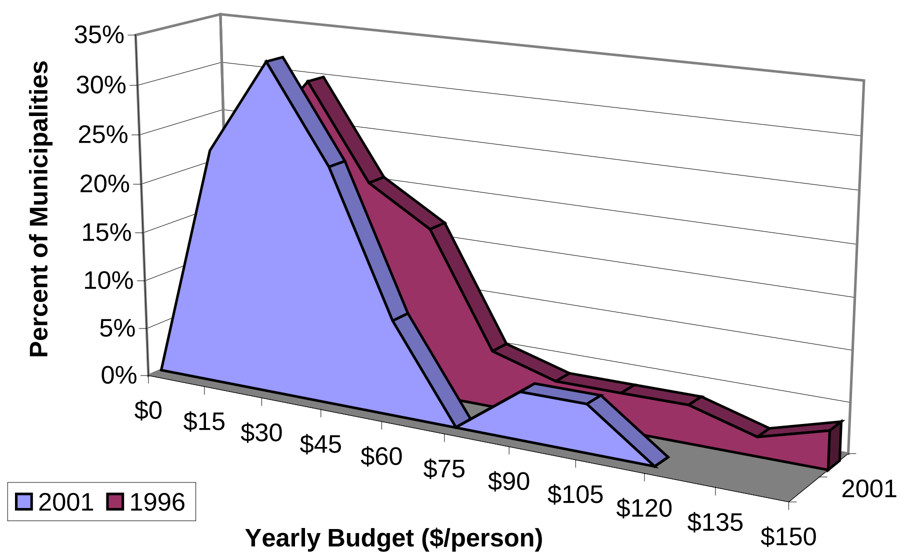


Figure 7. Distribution of Expenditures per Capita for New Construction

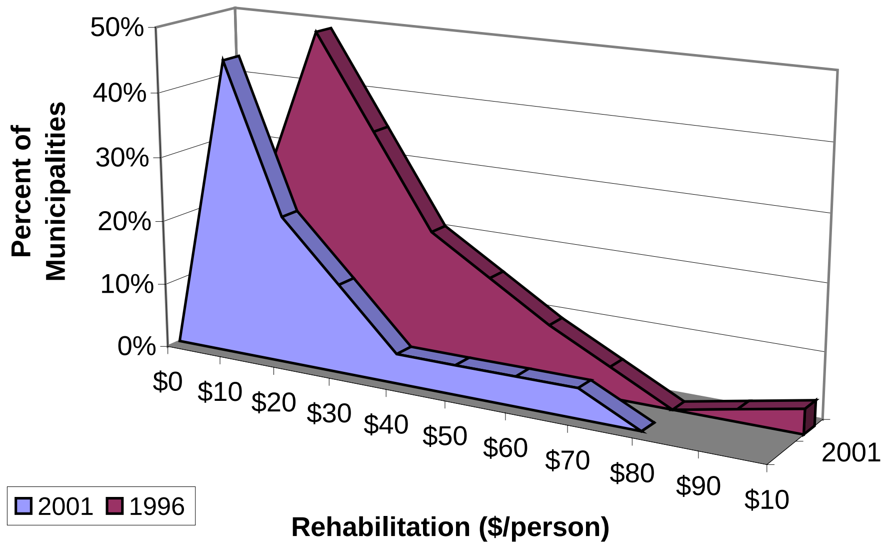


Figure 8. Distribution of Expenditures per Capita for Rehabilitation of Existing Services

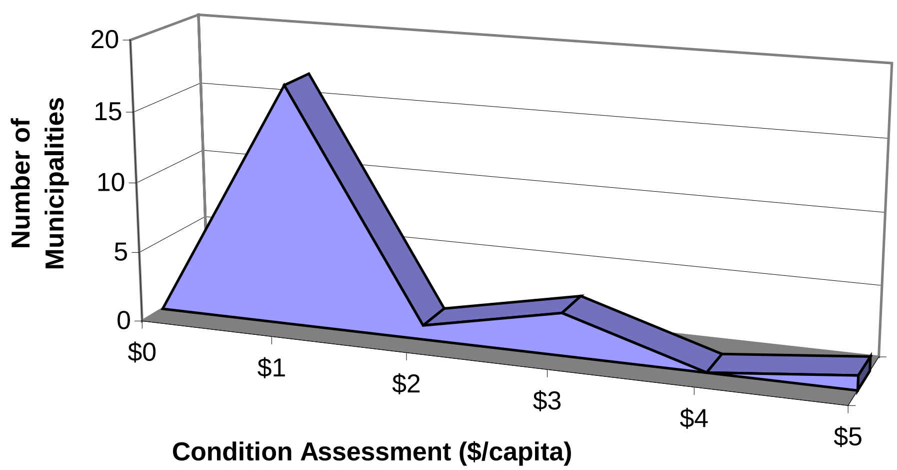


Figure 9. Distribution of Expenditure per Capita for Condition Assessment

The presence of outlying values for upgrades and rehabilitation expenses in small Canadian municipalities considered in the 1996 survey resulted in unrealistically high mean and median values for this group (See *Table 10*). Also, most of the small municipalities that participated in the 1996 survey are located in Western Canada, while those surveyed in 2000 are mainly located in Ontario, thus a comparison of the values is difficult. Medium sized municipalities experienced significant increases in expenditures, while expenditures by the largest municipalities surveyed remained nearly constant (many of the municipalities in those groups were surveyed in 1996 and 2001). While some municipalities spend little on rehabilitation projects others spend large sums. This could possibly be explained by some municipalities including the budget for one time large expenditures in their response while others are "between" projects. Larger municipalities tend to spend more per capita on rehabilitation and inspection. While the number of residents per linear kilometre of pipe might be higher, pipes are typically larger and harder to access. Results from the Canadian surveys contrast those reported by Malik et al (1996) who observed a decline in the expenditure per capita as the size of the municipality increases. A potential reason for these differences is the lower population density in Canadian municipalities, 5.7m of storm and wastewater sewer per capita (McDonald et al., 1994) in comparison with 4.3m per capita in the United States (Malik et al., 1997). Another contributing factor is the fact that the Canadian mid-size group includes a high proportion of municipalities with relatively recent urban development (e.g., Newmarket, Brampton). In such municipalities only a small portion of the storm and wastewater collection system is older than 30 years and the need for rehabilitation is limited.

3.2 Assessments and Rehabilitation Technologies

The percentage of municipalities using the various inspection technologies are given in *Figure 10*, which clearly shows that CCTV scans are a standard practice nation-wide with 100 percent of the responding municipalities making use of this technology. Over 50 percent of respondents are using man entry and smoke testing. These findings are in agreement with those reported by Zhao (1998).

GPR and ultrasonic inspection techniques represent some of the newer condition assessment technologies being utilized by about 13 percent of Canadian municipalities. Reasons for the low rate of utilization of advanced inspection techniques might include availability of local contractors, cost and lack of knowledge regarding the potential benefits of these methods. Laser scanning and surface tomography are two other technologies listed in the survey, but do not appear to currently be used by Canadian municipalities on a regular basis. Inspection techniques not included in the survey, but used by some of the respondents, are dye testing, flow monitoring (I/I programs), and sonde locate.

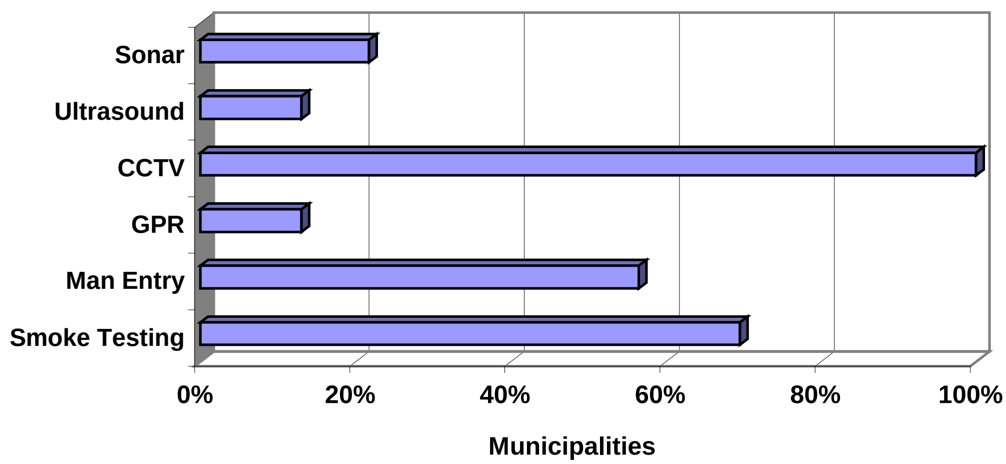


Figure 10. Percent Utilization of Pipeline Inspection Techniques (Overall)

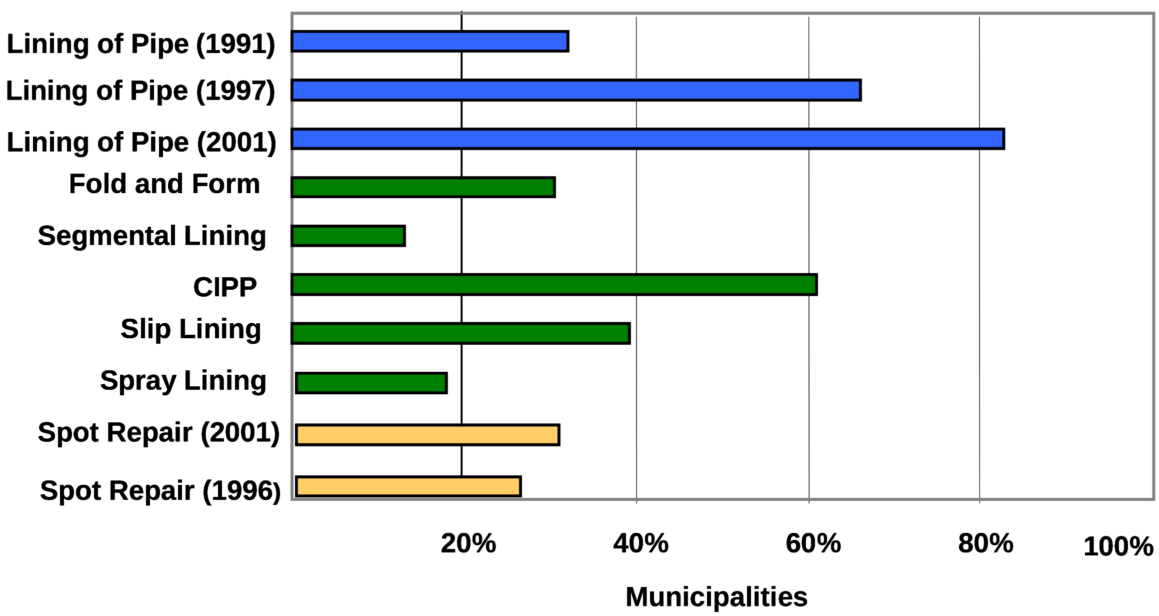
The utilization of the different inspection technologies was analyzed for the different population categories to see if there are any significant trends. It is apparent from *Table 13* that the municipalities with populations above 500,000 have made use of the widest array of inspection technologies. Among the smaller municipalities CCTV, smoke testing, and man entry are the most common. The utilization rate of the more modern technologies, such as GPR and sonar, is significantly lower.

Table 13. Utilization of Inspection Technologies (by Municipality Size)

Population Size (k)	Smoke Testing	Man Entry	Ground Penetrating Radar	CCTV	Ultrasound	Sonar
50 – 99	100.0%	85.7%	14.3%	100.0%	14.3%	0.0%
100- 499	63.6%	27.3%	0.0%	100.0%	0.0%	18.2%
> 500	60.0%	80.0%	40.0%	100.0%	40.0%	40.0%

Information regarding the type of rehabilitation techniques used by the survey respondents is shown in *Figure 11*. The various technologies that fall under the category of pipe lining are gaining a solid foothold in Canadian municipalities with over 80 percent of respondents reporting use of one or more of these technologies compared with 66 percent and 32 percent in 1996 and 1991, respectively. Cure-in-place pipe (CIPP) is the most widely used method followed by slip-lining, fold and form and robotic spot repair (up to 32% in 2001 from 26% in 1996).

Figure 11. Percent Utilization of Rehabilitation Techniques (Overall)



3.3 Distribution of Pipe Materials and Diameters (Canada and USA)

Information was requested from the municipalities regarding the composition of their storm and sanitary collection systems. The average percentage of each type of pipe in use, as a national average, is shown in *Figure 12*. Concrete pipes are the most common pipe material constituting 41 percent of pipes in use. PVC pipes make up 22 percent, vitrified clay tile (VCT) pipes make up 16%, while HDPE pipes make up 5 percent of the sewer networks in Canadian municipalities. Three percent of Canada's storm and sanitary sewers are made of brick. These sections were most likely built before the 1930s and in some cases may be over 100 years old. Plastics are the preferred material for the smaller diameter sewers (> 600mm diameter) due to their lightweight and ease of handling, while concrete pipes are commonly used for pipes larger then 600mm in diameter.

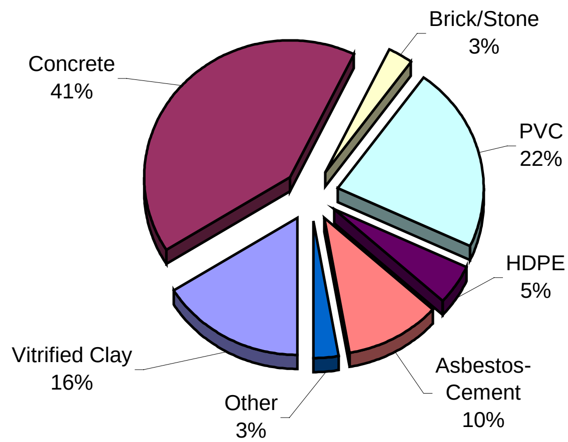


Figure 12. Percent of Pipe Composition in Canada

Comparisons between the results of this survey and the survey performed by Malik et al. (1997) (See *Figure 13*) show a large difference in the proportion of pipe material composition found between Canadian and U.S. municipalities. While vitrified clay pipes in Canada account for only 16 percent, in the United States this material constitutes 58 percent of the total length of sewer pipes. In return, Canadian municipalities have a significantly larger percentage of concrete and plastic pipes in their networks. There are many possible reasons for these differences including: availability of materials, time of construction, strength of local industries, and local design codes. The vast difference in the composition of the U.S. and Canadian municipal storm and wastewater networks implies that inspection methods, and damage classification and rating systems are likely to be developed in a non-uniform fashion, as challenges facing Canadian and U.S. municipalities do not necessarily coincide.

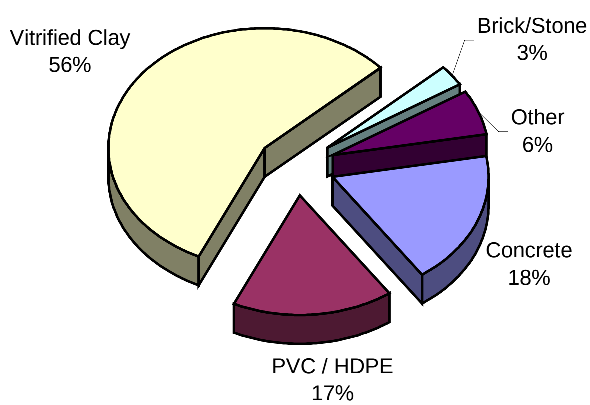


Figure 13. Percent of Pipe Composition in the U.S. (after Malik et al., 1996)

The distribution of pipe sizes, as a percentage of overall system length, is displayed in *Table 14.* As anticipated, the municipalities get larger, they have a tendency to utilize a higher percentage of large diameter pipes. This trend is anticipated as a result of servicing areas with higher population densities, a challenge that is met most effectively through larger capacity sewer systems. Nevertheless, regardless of size, all of the municipalities have at least 75 percent of their systems consist of pipes with diameters smaller than 750 mm (defined in this report as regular sewer). The percentage of trunk sewers (pipes > 750mm) varies from 11 percent in small municipalities to 25 percent in larger urban centres.

Table 14. Pipe Size Distribution

Population Size (k)	Pipe Size (mm)						
	100 - 250	250 – 500	500 - 750	750 - 1200	1200 - 1800	1800 - 2400	>2400
50 – 99	54.7%	28.8%	5.0%	5.0%	2.2%	2.2%	2.2%
100 – 249	31.8%	26.4%	15.5%	10.0%	7.3%	2.7%	6.4%
250 – 499	25.7%	30.5%	19.7%	7.8%	4.2%	7.8%	4.2%
500 – 999	23.1%	49.2%	10.8%	4.6%	4.6%	4.6%	3.1%

3.4 Frequency of Inspection

Table 15 shows the percentage of the storm and wastewater collection systems that were inspected within the last three years, five years, and ten years. A graphical presentation of the results is given in *Figure 14*. The results of the survey show that less than five percent of the responding municipalities were able to inspect 50 percent of their systems within the last three years. In the last ten years, less than 40 percent of the responding municipalities were able to accomplish this task. Eighty percent of the responding municipalities had inspected less then 25 percent of their systems in the last three years, while 25 percent of respondents were still in this category after ten years. The overall average turnover time for a full inspection of a typical municipal sewer system in Canada is 25 years, a value deemed inadequate considering the fact that many of these systems have a design life of 50 years. This statistic raises concerns about the availability of sufficient current information to enable engineers and technicians to make informed decisions regarding prioritization of maintenance efforts. A comparison of the population groupings shows that mid-size populations have outperformed the larger municipalities by 15 to 20 percent over the past decade. Overall, the rate of inspection has been increasing in recent years. These findings are significantly less favourable than the 2 to 15 year range for the inspection cycles reported by Zhao (1998).

Table 15. Percentage of Storm and Wastewater Sewers Inspected

Population Size (k)	Within the last 3 years	Within the last 5 years	Within the last 10 years
50 – 99	17.9%	22.1%	37.9%
100– 249	26.7%	38.3%	46.7%
250 – 499	29.0%	43.0%	49.0%
500 – 999	12.5%	22.5%	30.0%
> 1 M	5.0%	15.0%	15.0%

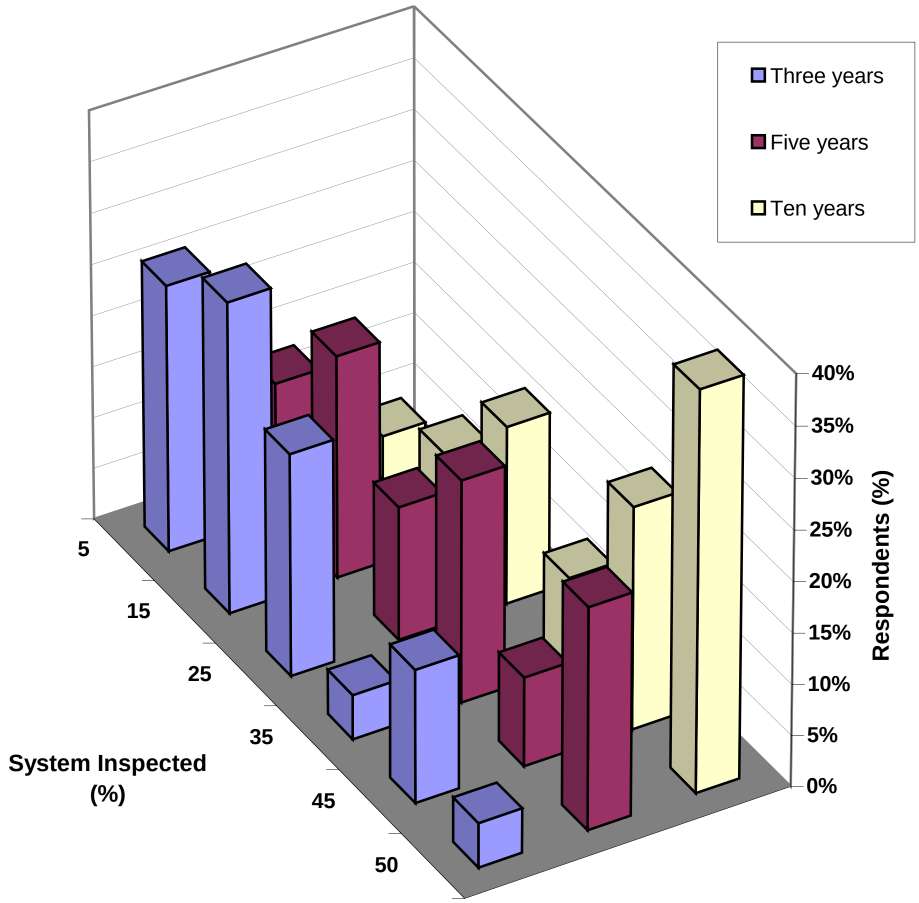


Figure 14. Percentage of Sanitary and Storm Sewers Inspected by Responding Municipalities Over the Last 10 Years.

3.5 Management of Inventory, Inspection and Performance Data (Canada vs. USA)

It is essential for any asset-based organization to maintain an accurate database regarding the assets under its control for the purposes of needs-assessment, development of an investment plan, and the preparation of construction documents. In the past ten years there have been significant changes in the way Canadian municipalities store and manage their buried asset inventory data as well as the data collected during sewer inspections. These changes came about in an effort to address problematic issues such as an increase in the volume of inspection data; new formats in which inspection data is collected; the need to improve uniformity in data collection and storage to allow for better sharing of information among municipalities; and the desire to increase integration of activities performed by various departments (i.e., roads, water distribution and wastewater); and, a growing pressure to improve efficiency by adopting business practices from the private sector.

Paper archives represent the earliest and simplest form of data storage and management for storm and wastewater collection systems. The limiting factor with paper archives is accessibility and a limited ability to share information, as one must have physical access to the material. In addition, large scale cross references of information for the purpose of decision making is tedious, time consuming and costly as a significant amount of time needs to be devoted to manually searching through filing cabinets, thus making efficient management of large networks strenuous. In *Figure 15*, it can be seen that 22 percent of the responding municipalities are still solely dependent on this form of data storage. The majority of the municipalities in this category service populations that are smaller than 250,000 (See *Table 16*).

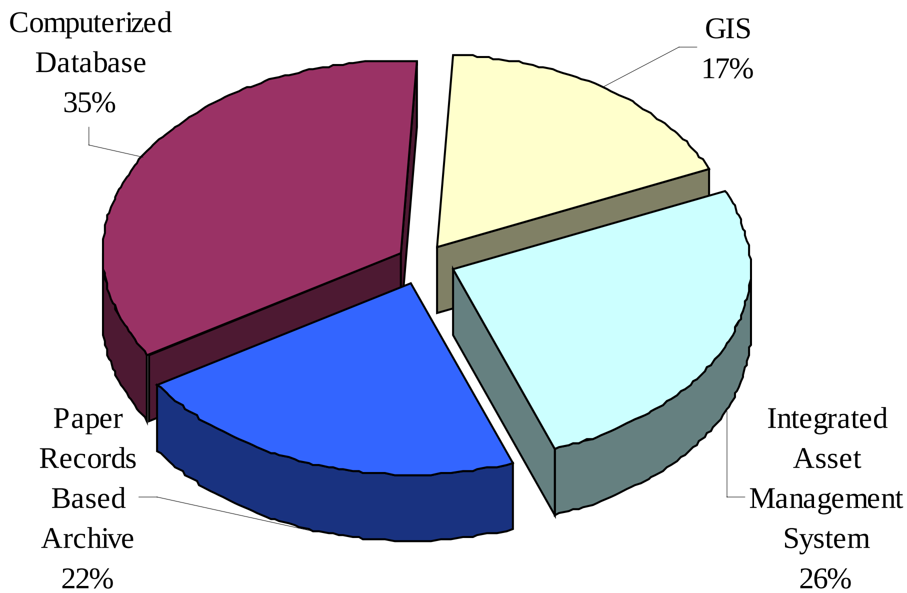


Figure 15. Data Management Systems in Canadian Municipalities

Table 16. Data Management Systems (Breakdown by Municipality Size)

Population Size (k)	Paper Records Based Archive	Computerized Database	Integrated Asset Management System
50 – 99	43%	57%	0%
100- 249	50%	17%	33%
250 – 499	20%	60%	20%
> 500	0%	60%	40%

The middle level of storage and management of infrastructure inventory and inspection data is a computerized database system (2D/3D CAD Drawings, and Computerized/Digitized records database). Of the four data management categories commonly used, computerized database systems are the most popular with 35 percent of the survey respondents using them. One of the main advantages of a computerized database system is the speed and efficiency of data retrieval. Queries can be made regarding individual manholes or pipe segments or about the entire network. Improved access to information is available online via the Internet and through local networks (LAN) from remote computer stations. Geographic Information Systems (GIS) represent yet another improvement in terms of data management and manipulation. GIS enables the user to overlap different types of information, such as construction data, geotechnical data, and inspection data to support decision-making processes. GIS also provides enhanced visual display capabilities of data stored in relational databases (RDB).

Integrated Asset Management Systems (IAMS) represent the top category of data storage and management systems. These databases not only store physical and inspection data, but are also capable of supporting the integration of proposed repairs of adjacent utilities (e.g. storm sewers and water mains), repaving/resurfacing operations, and in some cases risk analysis algorithms (e.g. probability of a burst based on burst history). Another common feature of such software systems would be the ability to assist in the development of schedules for the network's inspection and flushing programs based on previous inspection data. Twenty six percent of the respondents reported that they operate automated data management systems that utilize a degree of data integration at the operational level.

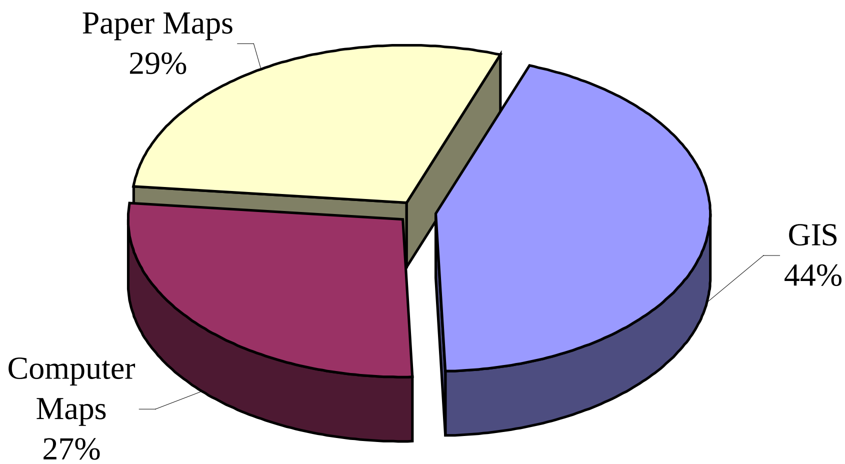


Figure 16. Data Management Systems Utilized by U.S. Municipalities (Malik et al., 1996)

The breakdown of data management systems for Canadian municipalities presented in *Figure 15* is similar to that reported by Malik et al. (1997) for U.S. municipalities (see *Figure 16*). The slightly higher overall level of automation reported by Canadian municipalities can be explained by the five-year time lag between the two surveys. Additionally, it appears from *Table 16* that the level of automation in a municipality's data management system is directly related to its size. A similar observation was made for U.S. municipalities (Malek et al., 1997).

3.6 Information Recorded for Pipe Damage

Information was also gathered from the responding municipalities about methodologies used to classify defects encountered during condition assessment inspections of their sewer systems. Thirty two percent of the survey respondents rely solely on an internally developed system of damage classification. Use of these internally developed systems has generated problems with consistency of damage classification and rating, especially when contractors perform work for more then one municipality. Zhao (1998) suggests that the lack of standards and guidelines for condition assessment of municipal sewers have resulted not only in inconsistencies among neighbouring municipalities, but also within the same city from one year to the next. A recent trend, strongly promoted by industry associations such as the Association of Pipe Inspectors of Ontario (APIO) and the North American Association of Pipeline Inspectors (NAAPI), is a move towards a unified standardized classification system developed by Water Research Centre (WRc) based in the U.K. Currently, the WRc method is the damage classification system most commonly used by Canadian municipalities with 68% of the respondents using this methodology exclusively or in combination with their internally developed systems (see *Figure 17*).

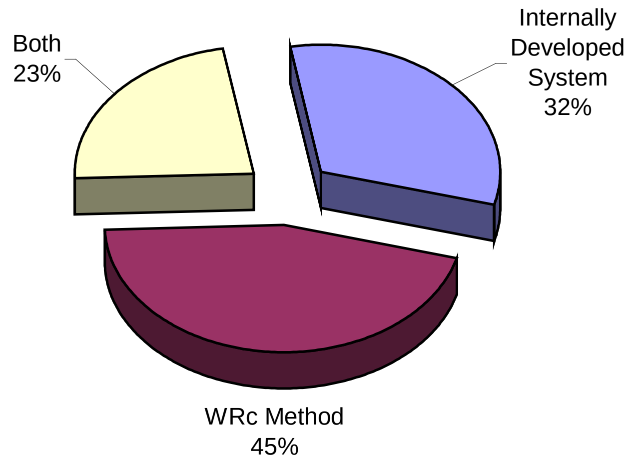


Figure 17. Utilization of Various Defect Classification Systems

Further information was collected from the respondents as to the exact information recorded during a routine inspection of their buried infrastructure. This was done to gain an insight into the nature of the information available to the municipalities for their decision making process. *Figures 18* and *19* show the information municipalities record during their inspection processes regarding the host pipe and observed defects, respectively. Efforts have been made to standardize data collection methods during pipeline inspections. For example, standardized inspection sheets have been developed and implemented to provide better uniformity in data storage and allow for better sharing of information among adjacent municipalities for purposes such as the development of deterioration curves for specific pipe types**.**

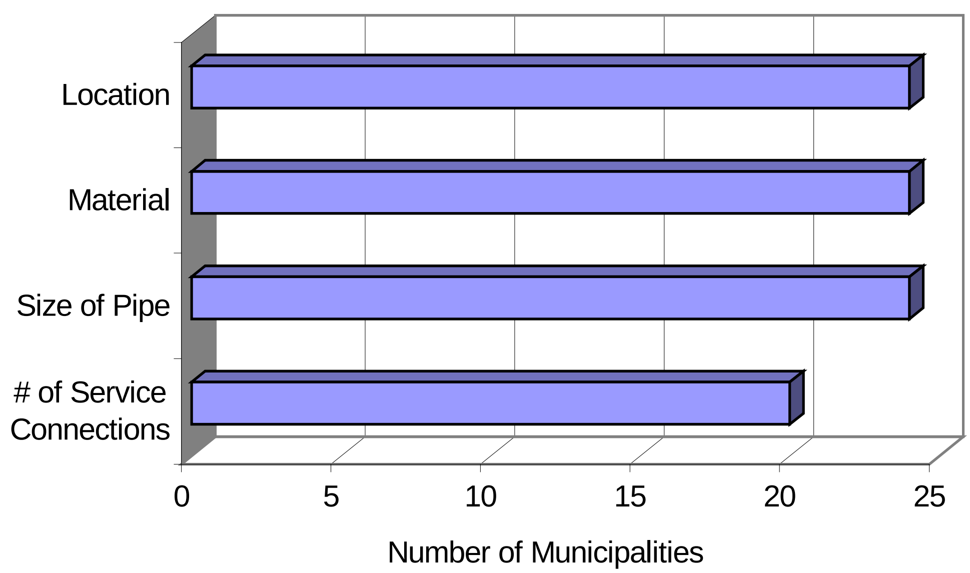


Figure 18. Pipe Information Recorded in Database

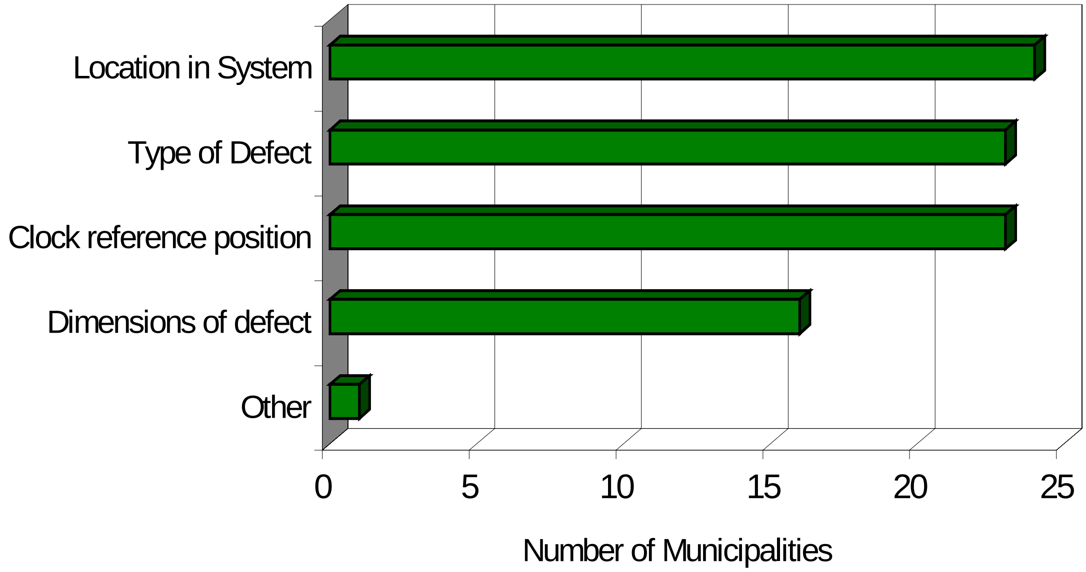


Figure 19. Damage Information Recorded During an Inspection

3.7 Flooding / Emergency Response

The flooding frequency within the responding municipalities shown in *Figure 20* demonstrates how prevalent storm surges and basement flooding are across the country. Both types of events are good indicators of the adequacy (i.e., capacity) and condition (i.e., hydraulic performance, I/I) of local storm and wastewater collection systems. The results of the survey show that 62 percent of responding municipalities are affected at least once each year by some form of basement flooding or storm surge, suggesting that many Canadian communities are served by a sewer collection infrastructure that lacks the capacity to adequately handle moderate storm events.

Basement flooding is associated with health hazards, negative physiological impacts, and economical losses. The first two issues are of significant importance but lay outside the scope of this report. As for economical losses, basement flooding claims are a major item for Canadian insurance companies. This is commonly attributed to the fact that Canadians are 'living in their basements'. In many Canadian households a significant portion of the high value possessions are kept in basement areas (e.g. TVs, DVDs, PCs, entertainment centres). As a result, the average claim value for basement flooding across Canada ranges between $3000 and $5000, depending on the province, and is rising. In terms of value per claim, water damage is second only to fire and roof collapse (IICC, 1999a; IICC, 1999b). According to statistics collected by the Insurance Information Centre of Canada (IICC) water damage related insurance claims across Canada between 1995 and 1999 totalled approximately $1.2B. While IICC statistical data does not distinguish between basements flooding and other water related damage claims, discussions with industry experts suggests that a conservative allocation to basement flooding will be in the order of 60%. Thus, basement flooding related insurance claims in Canada are in the order of $140 million per year based on a multi-year average.

A recent report prepared by the consulting firm Cumming Cockburn (2000) for the Institute for Catastrophic Loss Reduction estimates that the potential losses associated with a Hurricane

Hazel-type event in the Toronto area would exceed $640 million, from which over $400 millions were attributed to basement flooding. While a tropical storm of the magnitude of Hurricane Hazel is an unlikely event, a series of severe torrential rainstorms could yield a similar level of damage. The report also suggests that municipalities with smaller original design capacity and direct basement connections to storm or combined sewers are at the greatest risk for widespread basement flooding. In addition, overflowing sewers might also result in flooded roads, potentially increasing traffic accident rates. In the case of wide spread basement flooding or frequent basement flooding the municipality is risking liability-related law suites from the private insurance sector and/or very high premiums for basement flooding insurance in high-risk areas within their jurisdiction, both undesirable outcomes.

As for storm surges, when sections of sewer networks have been subjected to storm surges or other forms of unusually high volumes of water, 48 percent of the respondents felt that in the future these sections would exhibit an accelerated rate of deterioration. Fifty-five percent of the responding municipalities agreed with the statement that storm surges negatively affect the life expectancy of gravity-driven pipes. The comments included with the answers to this question suggested that little information has been collected, and that there was no consensus on the issue. In general, it is felt that gravity driven pipes are designed to carry flows and damage is not to the "pipes" specifically, but to the "system" as a whole (Survey respondent). Storm surges and floods can severely affect the life expectancy of a system that has already sustained damage, particularly by exposure to increased internal pressures and loss of ground support due to infiltration of fines soil particles (Sacher, 2000). This response is supported by the findings of the City of Indianapolis, Department of Capital Assessment study (Wirahadikasumah and Abraham, 1999), and is believed to be prevalent mainly for clay pipes.

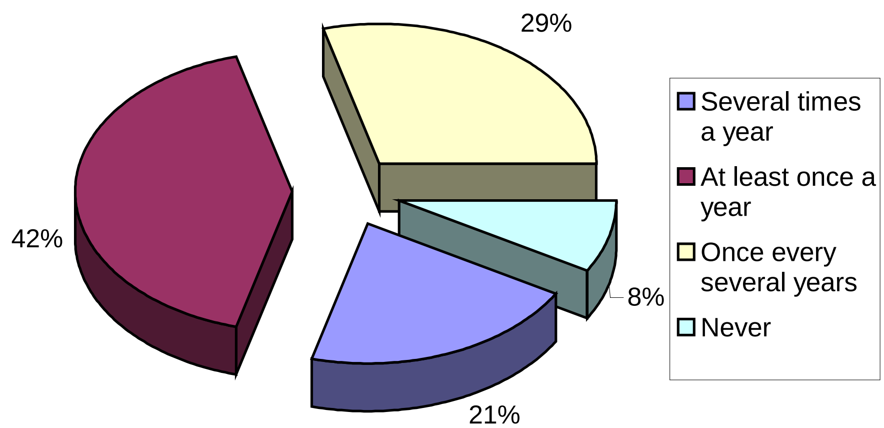


Figure 20. Frequency of Storm Surges/Basement Flooding in Canadian Municipalities

Municipalities were questioned regarding their ability to respond to the needs of their buried infrastructure in the event of a natural disaster. Two-thirds of the respondents claimed that they have no guidelines or emergency procedures for dealing with the inspection of their buried infrastructure in the aftermath of a natural disaster. This response was analyzed according to population size, as shown in *Table 17.* The results suggest that large municipalities are more prepared to respond to a natural disaster than are the smaller communities. *Figure 21* shows the amount of time required by the municipalities to complete a full condition assessment of their storm and wastewater sewer systems. Each sector of the pie chart represents the percentage of respondents that believed they could accomplish a full condition assessment within the corresponding time period.

Table 17. Time Needed for a Post-Disaster Inspection

Population Size (k)	Municipalities with Guidelines to Deal with Post Disaster Inspection	How long would assessment of system take? (Months)					
		1	3	6	12	18	> 18
50 – 99	14.3%	0.0%	0.0%	14.3%	42.9%	0.0%	42.9%
100 - 249	16.7%	0.0%	20.0%	20.0%	0.0%	0.0%	60.0%
250 - 499	60.0%	0.0%	20.0%	20.0%	20.0%	0.0%	40.0%
> 500	60.0%	0.0%	0.0%	40.0%	20.0%	0.0%	20.0%

Forty-one percent of the responding municipalities felt that it would take them longer than 18 months to complete the assessment. This suggests that these municipalities would not be fully aware of potential problems with their system for two years or more. There is no clear correlation between the size of a municipality and its rate of response (see *Table 16*).

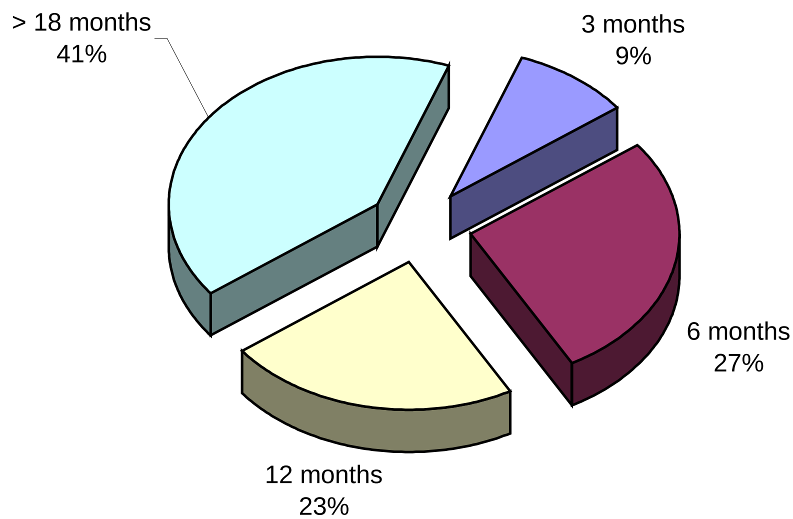


Figure 21. Time Required to Complete Post-Disaster Inspection of Sewer Systems

The ability to quantify the extent of damage caused by a natural disaster would be very helpful during the planning and prioritization of post disaster recovery efforts. In addition, being able to clearly demonstrate the amount of damage caused by an isolated event would make soliciting funds for condition assessment and repairs of the buried infrastructure from different levels of governments an easier task. A relevant example is the $1M requested by the City of Winnipeg to inspect its buried infrastructure system in the aftermath of the 1997 Red River flood. The municipality was awarded only $70 000. Members of the engineering staff argued that storm surges have the potential to cause an increase in the deterioration rate of their storm and wastewater collection systems, but were unable to prove it due to a lack of prior inspection data. *Figure 22* shows the response to the question "what percentage of the total damage to the underground infrastructure caused by a natural disaster is your agency able to determine." Eighteen percent of the respondents believed that less than half of the damage could be identified. Twenty three percent expect that 50 – 70 % of the damage could be determined, thirty six percent believe that 70 –90 % of the damage is determinable. Twenty three percent of the respondents foresee that they will be able to determine at least 90 % of the damage caused by a natural disaster, such as a flood. Based on documented case histories from several recent earthquake events that hit urban centres in North America, Central Asia, and Japan, (Allouche and Bowman, 2002) the authors feel that survey respondents might be alarmingly optimistic.

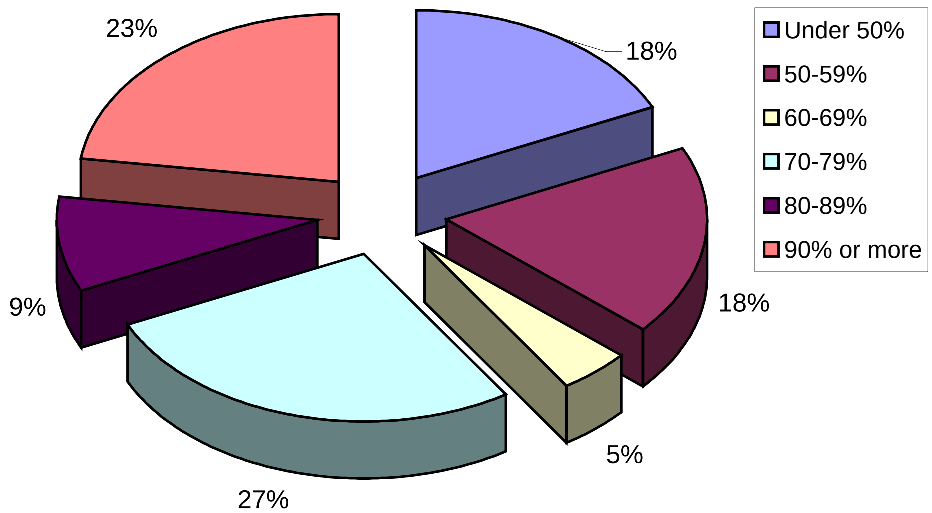


Figure 22. Ability of Municipalities to Determine Damage to Buried Infrastructure Caused by a Natural Disaster

3.8 Trends Derived from Multi-Variable Correlations

In the previous sections the survey data for each question was analyzed and presented individually. In this section trends and correlations that relate answers provided for multiple questions were explored. This second level analysis focused on the preparedness of municipalities for dealing with natural disasters with respect to their buried lifelines.

3.8.1 Level of Data Management as an Indicator of Preparedness

The more sophisticated the data management system employed by the municipality, the greater confidence the respondent had in its ability to determine the damage caused by a natural disaster (see *Figure 23*). Overall, municipalities with paper-based data management systems have a lower confidence in their ability to determine the extent or degree of damage than municipalities with more sophisticated data management systems. In contrast, no clear correlation was observed between the utilization of sophisticated inspection technologies and the ability to determine post-disaster damage. Municipalities were classified as "sophisticated" if they reported using at least one of the following inspection technologies: ground penetrating radar, ultrasound or sonar. No clear correlation was observed between the type of data management system and the predicted time required to perform the post-disaster inspection.

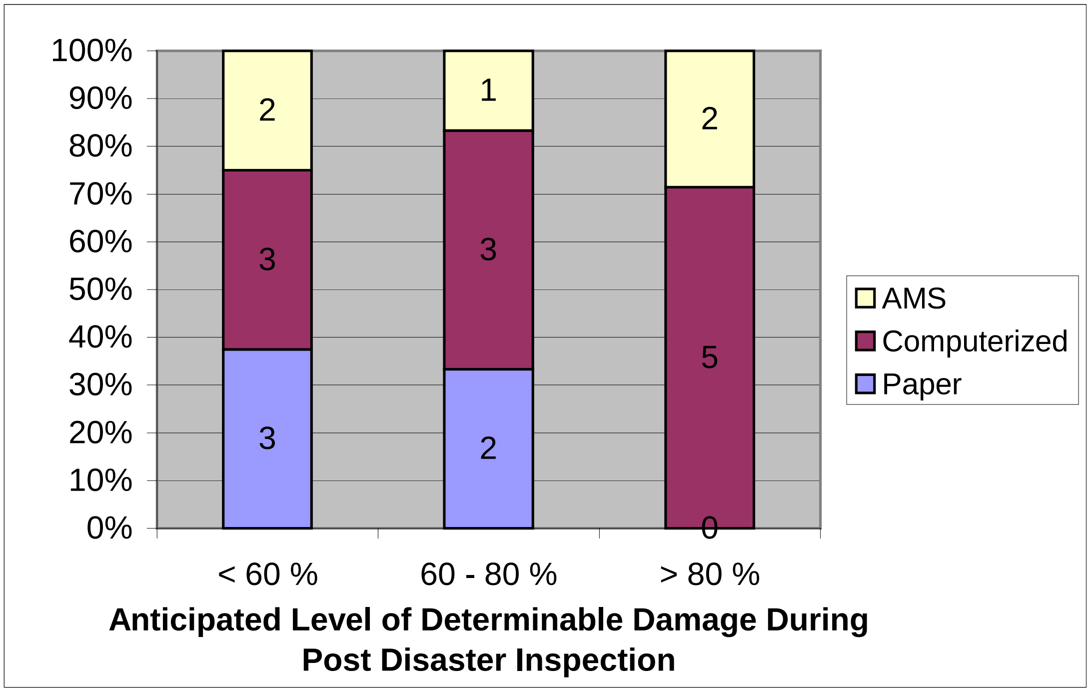


Figure 23. Level of Data Management System Vs. Percentage of Anticipated Level of Determinable Damage

Municipalities with more sophisticated data management systems are more likely to have guidelines for the inspection of their storm and sanitary sewer networks in the aftermath of a natural disaster (See *Figure 24).* This suggests that the level of commitment to adequate maintenance of buried infrastructure network reflects the level of preparedness for dealing with the potential impact of a natural disaster on these networks.

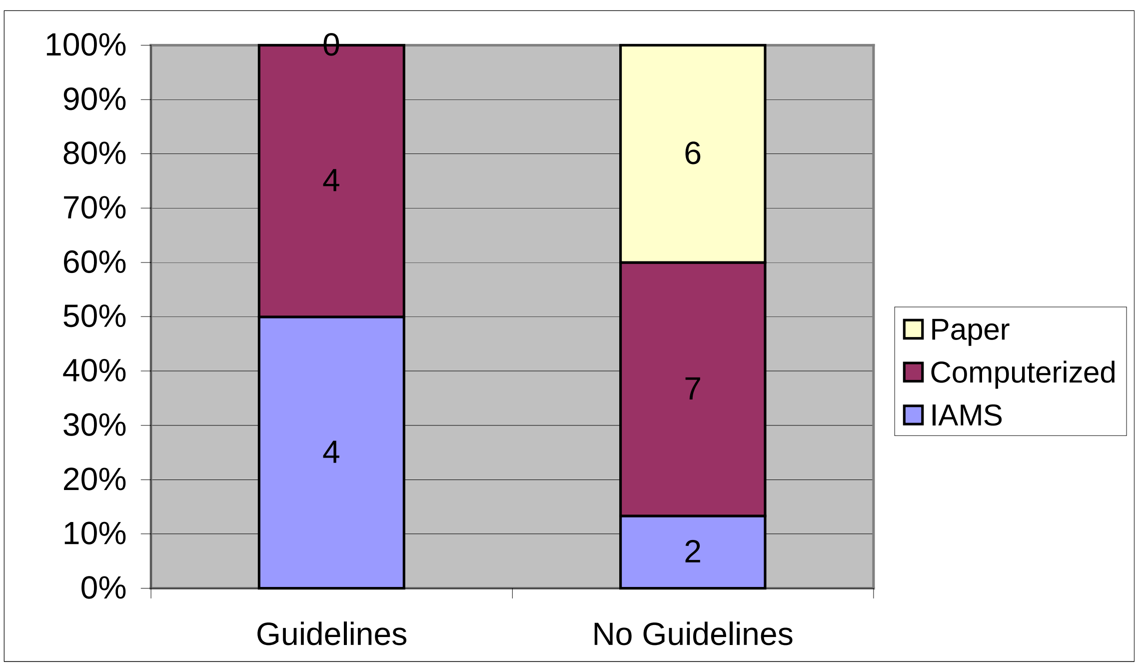


Figure 24. Availability of Post Disaster Guidelines Vs. Level of Data Management

3.8.2 Guideline for Post-Disaster Inspection of Linear Networks

Municipalities that have post disaster inspection guidelines in place have a higher confidence in their ability to determine the degree of damage inflicted upon their networks due to a natural disaster event (See *Figure 25*). However, no clear trend was observed between the availability of post-disaster inspection guidelines and the anticipated duration the post-disaster inspection.

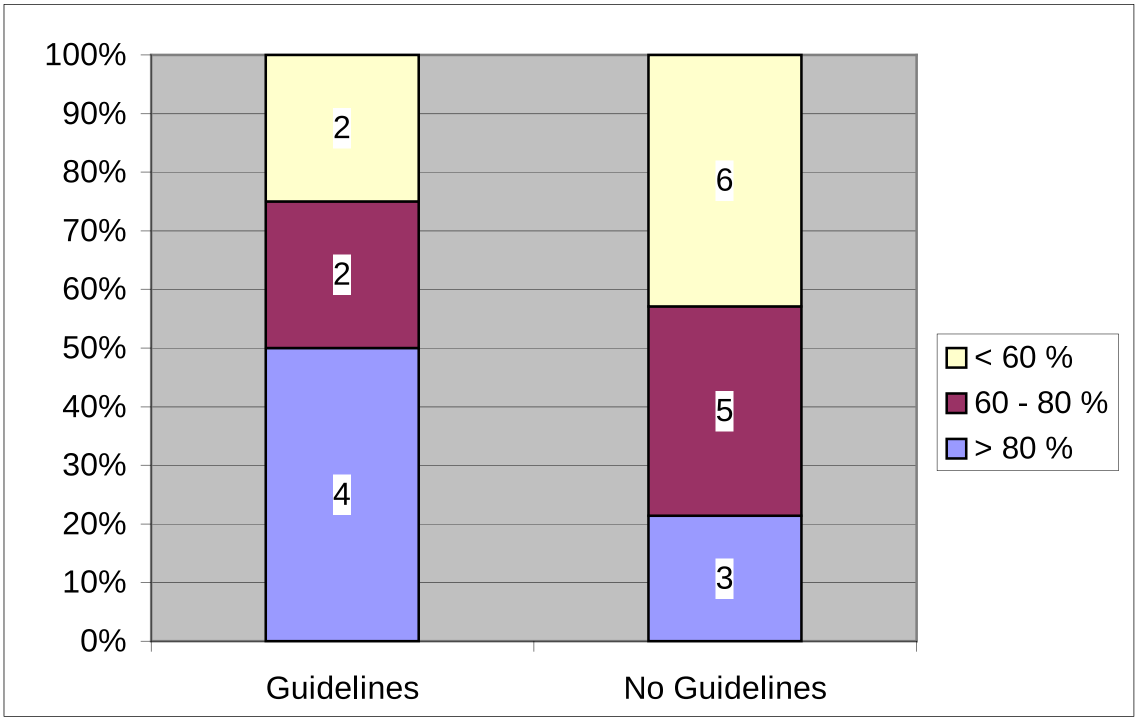


Figure 25. Availability of Post Disaster Guidelines Vs. Percentage of Anticipated Level of Determinable Damage

3.8.3 Frequency of Basement Flooding And The Average Annual Precipitation

Multi-annual average precipitation data for the twenty-six municipalities that participated in the survey was obtained from a database maintained by Environment Canada. No correlation was found between the average annual precipitation and the frequency of basement flooding expressed as Low (= once every several years), Medium (= once a year) or High (= several times per year), as suggested by the respondents (see *Figure 26*). This somewhat surprising finding could be explained by the fact that the average annual precipitation is a key parameter during the design process. Thus, its effect is cancelled by a larger initial capacity (sewers typically designed for a two or a five year storm). A second possible explanation is that the contribution of infiltration and inflow (I/I) rather than the base flow tends to govern the frequency of overflow conditions.

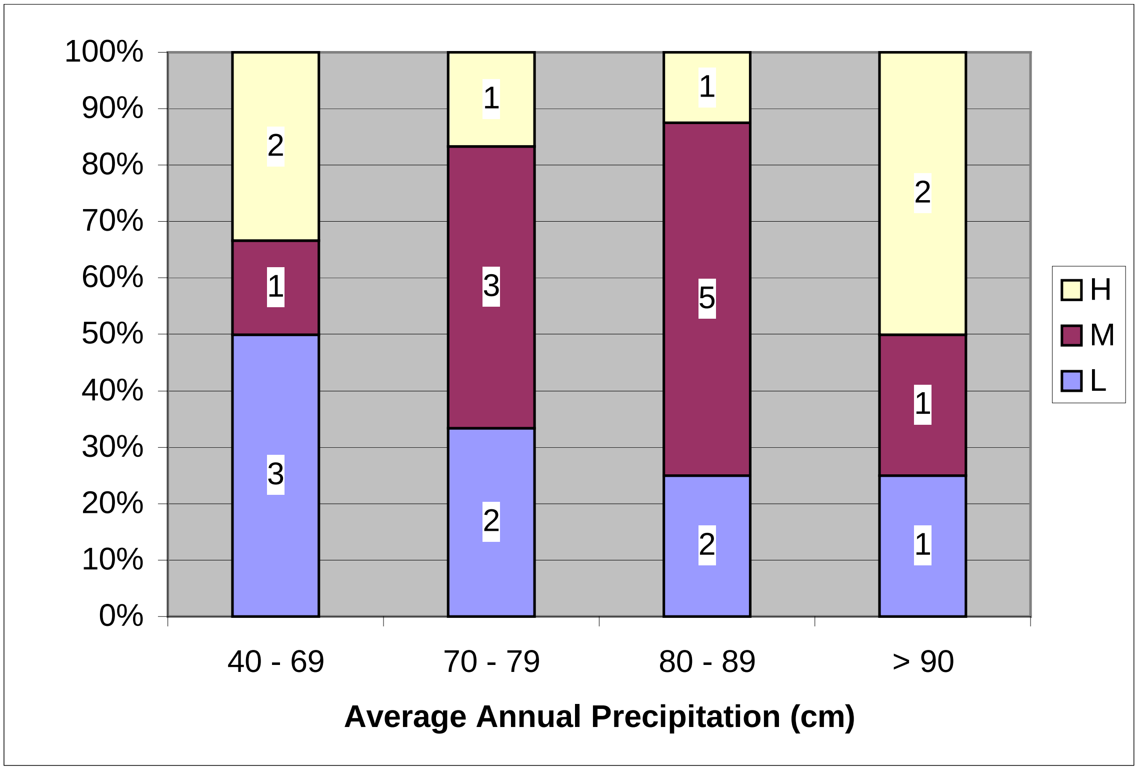


Figure 26. Frequency of Basement Flooding Vs. Average Annual Precipitation

Qualitative attributes that indicate the level of progression of a particular municipality (i.e., level of data management; degree of utilization of advanced inspection technology; availability of post-disaster buried infrastructure inspection guidelines) were contrasted with the frequency of basement flooding. The score for each municipality was calculated by assigning a point for each level of progression (e.g., paper archive = 1; computerized archive = 2, etc.). The overall scores, which ranged between 3 and 8, were then grouped into three classes (A≥7; 7>B≥5; 5>C). Figure *27* implies that the motivation of a municipality to improve its capabilities for inspecting and managing its storm and wastewater collection systems is driven, at least partially, by the frequency of basement flooding.

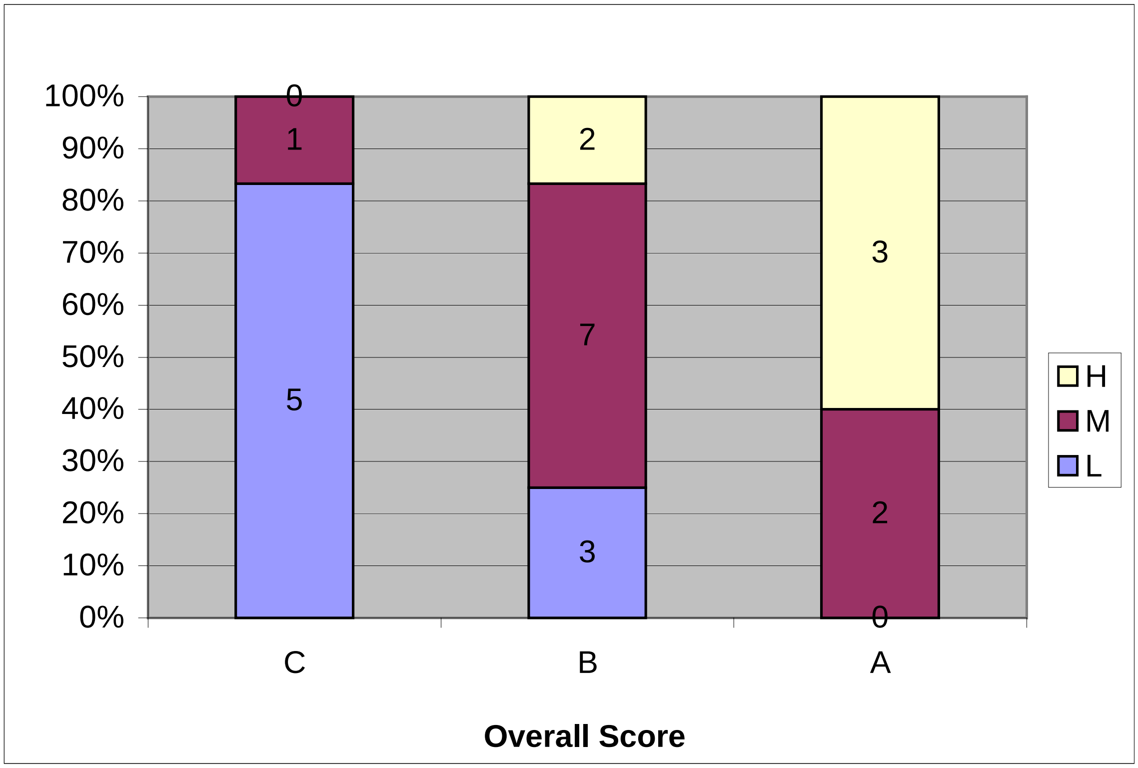


Figure 27. Frequency of Basement Flooding Vs. Overall Progression Score

4. CONCLUSIONS

1. While most levels of government agree that there is an urgent need for the renewal of Canada’s municipal infrastructure, sources for the needed capital, estimated to be as much as $45 billion, are less apparent.

2. Some of the needed capital can be generated through greater efficiency and advanced technology. In particular, optimizing the management and maintenance of municipal assets, the development and adoption of more cost effective inspection and rehabilitation technologies, a greater degree of integration among various construction activities and the development of alternative income sources (e.g., reclaimed wastewater) and water conservation programs.

3. To fully realize these potential savings the three key issues need to be addressed: a) training and continuing education at all levels must be given a stronger emphasis; b) a unified system is needed for approval of offshore technologies as well as for the evaluating the suitability of competing rehabilitation construction methods; and, c) decision-making processes must be streamlined in term of setting priorities according to a standard cost-benefit procedure within an integrated asset management strategy.

4. Canadian municipalities spend approximately $19.2 per capita per annum on the replacement and rehabilitation of existing municipal sewer networks, an amount slightly higher than that reported for the 1996-97 construction season of $18.21 per capita.

5. Only 10% of rehabilitation budgets are spent on condition assessment programs (approximately $1.5 per capita per year).

6. Closed Circuit Television (CCTV) systems and smoke testing are the most common methods utilized by Canadian municipalities for the inspection of municipal sewer networks. Newer technologies such as sonar and ground penetrating radar have not been widely accepted to date in this market.

7. The utilization of trenchless technologies by Canadian municipalities is on the rise, with 82% of municipalities using one or more pipe lining techniques in the year 2000 compared with only 66% in 1996 and 32% in 1991.

8. Comparison of the composition of sewer networks in Canada and the USA has shown significant differences in terms of the relative weight of various pipe materials. The most common pipe material in Canadian sewers is concrete (41%) while vitrified clay is most commonly used in the USA (56%). Canadian sewers also contain larger quantities of plastic and plastic pipes (PVC/HDPE). These findings imply that research and development efforts in the USA might not fully address the needs of Canada’s municipal sewer systems.

9. The return period for inspection and assessment of sanitary and storm sewers in Canadian municipalities is between 25 and 30 years, which is nearly equal to the design life of many of these facilities.

10. Computerized data management and record keeping systems are commonly used in Canadian municipalities, with 78% of respondents indicating the utilization of such systems compared to 71% in the USA.

11. A pipe defect/deficiency classification system developed by the Water Research Centre (WRc), a U.K. research organization, is commonly used by Canadian municipalities. Sixty-eight percent of all respondents are using the WRc system either exclusively or in combination with an internally developed system.

12. Basement flooding is a major ticket item for Canadian insurance companies, with annual payouts valued at approximately $140 million.

13. Basement flooding is a common event in Canadian municipalities with 42% of respondents indicating that storm surges and basement flooding occur several times each year in their jurisdictions.

14. Only 15% of the municipalities with populations less than 250,000 have guidelines in place for conducting post-disaster inspection of their buried municipal services. Forty-one percent of the municipalities indicated that such a post-disaster inspection is likely to take more than 18 months, with only 23% being confident of their ability to accurately determine the damage inflicted on their buried networks in the aftermath of such an inspection.

15. The more progressive is the municipality in its management and maintenance practices, the more likely it is to have guidelines for post-disaster inspection of its linear lifeline networks.

16. The more progressive is the municipality in its management and maintenance practices, the longer it expects the post-disaster inspection to take and the higher is the anticipated percentage of determinable damage.

17. No clear trend exists between the frequency of basement flooding in a particular municipality and the average annual precipitation for that municipality. Thus, the relative contribution of infiltration and inflow (I/I) appears to be more significant than the absolute volume of the precipitation.

18. There is a strong correlation between the level of investment a municipality made in the management capabilities of its linear sewer networks and the frequency of basement flooding.

5. RECOMMENDATIONS

1. Liability in terms of basement flooding frequency might be considered as an external factor in the overall assessment of the urgency of the action needed to repair/upgrade sewer systems, as it is a key performance parameter.

2. Among the costs associated with the upgrading of a municipality's data management system, the most significant one is the bridging of the "data gap" between the available data and the quality and quantity of data believed to be necessary to effectively operate the new system. It is recommended to develop methodology for determining the expected cost of bridging this gap and the most cost effective manner for doing so.

3. The condition assessment market in Canada for linear sewer system is approximately $50M per year, an amount believed to be insufficient for supporting a coast-to-coast specialized private sector that own and operate advanced condition assessment technologies. It is recommended to investigate various mechanisms, policies and incentives that will make advanced inspection and assessment technologies more readily available to medium size Canadian municipalities.

4. The relationship between the return period for inspection and assessment of buried pipe systems and the life cycle costs of such systems is currently ill-defined. There is a need to further research this area to determine the optimum return period for inspection that will minimise the life cycle costs of the system.

5. Additional research is needed to support the establishment of national standards and guidelines for post-disaster inspection of linear lifeline networks. Additionally, an educational effort should be made across the municipal engineering community to raise awareness of the importance of a comprehensive and properly documented lifelines emergency response strategy (LERS).

6. It is the accumulative effect of responses to immediate and short-term needs (e.g., basement flooding) that enhances the resilience of a municipal system to potentially catastrophic, but infrequent, events such as natural disasters. It is suggested to study the relationships between localized improvements of lifeline management and maintenance practices and the overall resilience of the system to natural disasters, in order to maximize the benefits of the latter from the former.

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Interview

Mrs. Dianne Sacher, P.Eng, Water and Waste Department, City of Winnipeg, August 28, 2000.

APPENDIX I: PARTICIPATING MUNICIPALITIES

The authors would like to acknowledge the following municipalities for participating in the survey. Their input and insight were invaluable in completing this research project

City of Brampton, Ontario
City of Brantford, Ontario
City of Burlington, Ontario
City of Calgary, Alberta
City of Edmonton, Alberta
City of Guelph, Ontario
City of Hamilton, Ontario
City of Hamilton, Ontario
City of London, Ontario
Town of Markham, Ontario
City of Nanaimo, British Columbia
Nepean, Ontario
New Market, Ontario
Regional Municipality of Niagra, Ontario
City of North York, Ontario
Corporation of The City of Peterborough, Ontario
City of Richmond, British Columbia
City of St. Albert, Alberta
City of Sudbury, Ontario
City of Surrey, British Columbia
Victoria/Capital Regional District, British Columbia
City of Victoria/Water and Environment Division, British Columbia
City of Waterloo, Ontario
City of Winnipeg, Manitoba