3.2. Inspection/Assessment

There is no Canadian standard applicable for all types of sewer inspection/assessment. The Institute for Research in Construction (IRC) published guidelines for practitioners and sewer system managers but only addressed large diameter pipes (those over 900mm in diameter) [4].

A commonly used inspection and assessment protocol was developed by the Water Research Centre (WRC). It is detailed in the WRC Sewerage Rehabilitation Manual. A National Research Council (NRC) study utilized the WRC method to analyze several Canadian regions and municipalities [5]. The WRC guidelines and NRC study are premised on distress-based structural evaluation - a common industry practice. Generally, cracks are a common structural defect. Approximately 58% of all structural defects in Canadian sewer pipes involve cracking of some sort (longitudinal, 4-point, etc.). The next most common is spalling/wear (i.e. corrosion), usually associated with chemical attack from soil or the effluent.

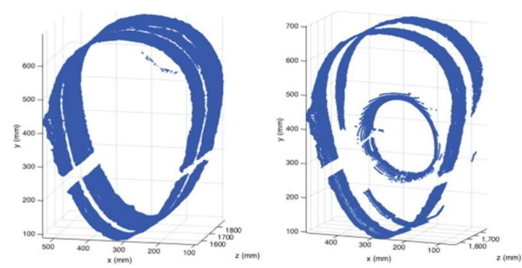
Most of [redacted]'s current network is mineral-based: concrete (48%), or VC (30%). Generally these material types are subject to chemically induced corrosion. The next largest category is synthetic: CIPP (11%) or PVC (4%). Both mineral and synthetic types are susceptible to cracking or ovality.

It is worth noting that data from the 2006 NRC is Canada-wide, and while [redacted] contributed inventory and structural grade data, it did not contribute defect data. This is important because the larger study suggests more variety throughout the supply chain which may signify differences in material or pipe quality, and installation. This asset management plan is targeted at a smaller scale for [redacted] and represents a highly localized community of suppliers or installers. A primary assumption is that quality differences from local to nationwide dataset are negligible. However, in the local setting, supplier or installer data may be a valuable metric to track relative to certain assets (see descriptions in section 2.1 attribute data, and relationships in section 2.2 data model).

Visual Inspection Techniques

Given the prevalence of cracking or ovality, and corrosion defects, visual inspection techniques are recommended as part of most inspection protocols. Visual inspection allows for subjective grading and distress-based evaluation of structural defects. Visual inspection techniques are also effective for identification of unique emergent operational defects, such as obstruction by roots or debris, encrustation, etc. A cursory comparison of visual inspection techniques follows.

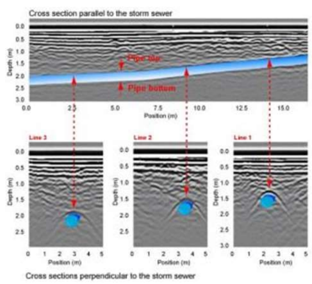
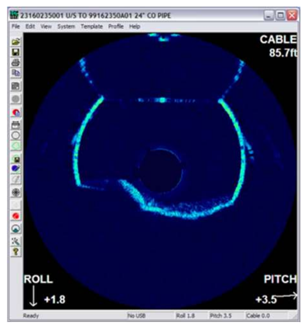
Table [5]: Comparison of Visual Inspection Techniques

Metric	**Visual Technique**		
	Direct Visual	**Closed Circuit Tele-vision (CCTV)**	**3D Imaging**
Pipe Diam.	>= 1600 mm diameter (human-Entry Size)	200-1200 mm diameter or 75-150 mm (mini camera)	Most firms perform "large diameter" pipe inspection
Data Interpretation	On-site, Most Legible	Manual/Auto, Legible	Manual/Auto, Requires Interpretation
Data Example [6]			

In addition to the techniques listed above, non-destructive testing (NDT) should be employed. Generally, NDT can identify defects that may develop or worsen from an initial defect, such as a crack or corrosion, without risking further damage to the asset. Such cracks can manifest infiltration or exfiltration relative to the surrounding soil and are difficult to visually detect. Therefore, geophysical techniques are another important class of inspection technique that provides necessary supplementary data about pipes and pipe surroundings.

<u>Geophysical Inspection Techniques</u>
Infiltration can result in operational defects, such as soil buildup, which may impede flow or speed up any chemical degradation distress. Exfiltration can result in soil voids near the pipe, which can manifest unique structural defects or exacerbate current defects. Geophysical inspection techniques allow for identification of soil structural stability and can be used to confirm pipe thickness and structural stability. A cursory comparison of geophysical techniques follows.

Table [6]: Geophysical Techniques

Metric	**Geophysical Technique**		
	Ground Penetrating Radar	**Sonar**	**Infrared Thermography**
Pipe Diam.	Any	Any	Depends on Usage
Data Interpretation	Manual/Auto, Requires Interpretation	Manual/Auto, Legible	Manual/Auto, Legible
Data Example [7]	 (features superimposed)		 (aerial use for SSO)

It is worth noting that sewer networks are often deeply embedded, and the effectiveness of certain techniques may be affected by depth. The ability to automatically interpret and 'flag' defects is a valuable time-saving process, especially when compared to manually revisiting CCTV, 3D scan, or NDT results. Speed of data collection plays an important role in determining cost of any data-collection technique. However, it is worth noting that auto-interpretive methods require their own unique up front time and development costs to properly design and tune models.

Visual inspection by closed circuit tele-vision (CCTV) is seen as the industry standard for sewer pipe inspection. CCTV is often the benchmark against which other visual or geophysical inspection techniques measure their feasibility. For example, a UK study of acoustic defect detection technology concluded a good level of feasibility due to a 79% defect capture rate relative to CCTV inspection, but at less cost [8]. Cost information is sparse. This is likely a result of strategic control by inspection consulting companies. In short, CCTV as the industry standard should be viewed critically, especially given the emergence of new technologies, and considerations such as their capture rate, and the skill requirements to operate. This recommendation is supported by a Dutch study that concluded that wastewater practitioners tend to show consistency as a group but that their decision making is not always based on pertinent information [9]. The versatility of these studies given the local North American, or Canadian context is unknown.

Finally, consideration should also be given to composite techniques which employ multiple sensors. Combined physical/chemical/biological inspection provides a large amount of varied data per inspection and may be especially valuable for critical assets.

[4] Rahman & Vanier (2004). "MIIP Report: An Evaluation of Condition Assessment Protocols for Sewer Management". [Online]. Retrieved August 16, 2017. Available: http://nparc.cisti-icist.nrc-cnrc.gc.ca/eng/view/fulltext/?id=93ed3e91-be5e-452d-b79d-c20d4ac77002

[5] National Research Council Canada (2006). "MIIP Report: The State of Canadian Sewers – Analysis of Asset Inventory and Condition," [Online]. Retrieved August 16, 2017. http://nparc.cisti-icist.nrc-cnrc.gc.ca/eng/view/fulltext/?id=52c8f131-5d40-4e96-a2e2-69c00da90833

[6] Lepot et al. (2017). "A Technology for Sewer Pipe Inspection (Part 2): Experimental Assessment of a New Laser Profiler for Sewer Defect Detection and Quantification". *Automation in Construction.* 75, pp. 91-107.

[7] Aboriginal Affairs and Northern Development Canada (2014). "Emergency Response Plan for Wastewater Systems in First Nations Communities" *Government Services Canada*. [Online] Available:https://www.aadncaandc.gc.ca/eng/1398359749727/1398359828549

[8] Romanova et al., (2013). "Sewer Inspection and Comparison of Acoustic and CCTV Methods." *Proceedings of the Institution of Civil Engineers - Water Management*. 166(2), pp. 70-80.

[9] Van Riel et al. (2016). "Valuing Information for Sewer Replacement Decisions". *Water Science and Technology.* 74(4), pp. 796-804.