PROJECT: TRENCHLESS TECHNOLOGIES AND WORK PRACTICES REVIEW FOR SASKATCHEWAN MUNICIPALITIES

PREPARED FOR: COMMUNITIES OF TOMORROW
TRENCHLESS TECHNOLOGIES
AND WORK PRACTICES REVIEW
FOR SASKATCHEWAN
MUNICIPALITIES

Prepared For:
Communities of Tomorrow
Regina, SK

Prepared By:
PINTER & Associates Ltd.

03 June 2013
File:12-1426

Distribution:
Communities of Tomorrow 2 copies
PINTER & Associates Ltd. 1 copy
PINTER & Associates Ltd. original

PINTER & Associates Ltd.

Ibrahim El-Baroudy, Ph.D.
Hydrogeologist

Lawrence Pinter, P.Eng.
President

© PINTER & Associates Ltd.
EXECUTIVE SUMMARY

Saskatchewan is one of the most rapidly growing provinces in Canada, showing unprecedented economic growth. This growth requires a corresponding response to the expected pressures on the province’s infrastructure in many urban and rural areas, to achieve sustainable communities.

A direct relationship exists between strong and sustainable communities and their infrastructures, in particular, underground assets dealing with water, wastewater, communications and energy (natural gas, electricity). Modern methods for installing and replacing utility piping no longer involve digging up mass amounts of earth and no longer need to cause extensive surface disruption. Trenchless technologies, equipment and standards are in place to ensure that these piping infrastructure systems can be quickly and without disruption, installed or replaced.

PINTER & Associates Ltd. (PINTER) was commissioned by Communities of Tomorrow to complete a review and evaluation study of modern trenchless technologies and work practices for use as practical guidelines for Saskatchewan municipalities. A thorough literature review of current underground asset management techniques and methods were undertaken, and a comprehensive report relating to trenchless pipe replacement, relining and installation is presented in this document.

The scope of this project involved reviewing current and emerging technologies and processes in trenchless pipe installation and rehabilitation for applications in water, sewer and gas lines. Recommendations and evaluations in this report are based on Saskatchewan municipalities as the intended target environments.

The report lists, in detail, a variety of the methods available in the municipal infrastructure market related to new pipe installation and pipe rehabilitation.
The methods introduced in this report vary from relatively simple to intensive technology processes, which in turn, suit different infrastructure installation and rehabilitation projects/applications. Trenchless technologies are usually divided into three main categories; pipe replacement methods, pipe renovation methods and new pipe installation methods.

Selection of the most appropriate technology depends on many interrelated factors. Many different decision support tools are available in the market. They differ in the number of technologies considered and the amount of updated information. Therefore, PINTER presented a simple selection tool developed for Saskatchewan municipalities to enable straightforward and easy to use selection method. The tool is designed to enable the user to incorporate additional technologies, in addition to the ones listed in the tool, and to update the corresponding information according to the local conditions.

In general, trenchless technologies outweigh traditional open-cut methods in high density urban areas, where access, traffic control and the cost of reinstatement of surfaces become more expensive, which adds up to the per metre of pipe price. The contribution of social costs relative to the project construction cost is estimated to range from 44% to 78% of the construction costs in the traditional open-cut method, whereas social costs for trenchless technologies ranges from 3% to 11% of construction costs. Those savings are added to the construction costs savings which amount to 20% - 40% of the total cost in cases using trenchless technologies, especially in heavily populated urban areas.

Trenchless technologies use innovative methods, materials, and equipment that require minimum surface excavation to renew and construct aging underground infrastructure. The cost of trenchless rehabilitation in many places around the world is decreasing as the market becomes more mature and development of technology plays a positive effect in reducing the unit rates. Meanwhile, open-cut methods are becoming more expensive as the indirect costs of fuels, spoil waste disposal and environmental and social impacts increase.
A proper comparison of trenchless technologies vs. open cut method should be based on a generic and comprehensive social cost protocol that can be used by different municipalities to identify and quantify social costs.
## TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>I</td>
</tr>
<tr>
<td>TABLE OF CONTENTS</td>
<td>IV</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>VII</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>IX</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td></td>
</tr>
<tr>
<td>1.1. Background</td>
<td>1</td>
</tr>
<tr>
<td>1.2. Report Organization</td>
<td>2</td>
</tr>
<tr>
<td>2. PIPE REPLACEMENT METHODS</td>
<td>4</td>
</tr>
<tr>
<td>2.1. Pipe Bursting/Splitting</td>
<td>4</td>
</tr>
<tr>
<td>2.1.1. Pipe Bursting - General</td>
<td>4</td>
</tr>
<tr>
<td>2.1.1.1. Pipe Splitting</td>
<td>7</td>
</tr>
<tr>
<td>2.1.2. Pipe Bursting Methods</td>
<td>7</td>
</tr>
<tr>
<td>2.1.2.1. Pneumatic Pipe Bursting</td>
<td>7</td>
</tr>
<tr>
<td>2.1.2.2. Hydraulic Expansion</td>
<td>8</td>
</tr>
<tr>
<td>2.1.2.3. Static Bursting</td>
<td>10</td>
</tr>
<tr>
<td>2.2. Pipe Implosion and Crushing</td>
<td>11</td>
</tr>
<tr>
<td>2.3. Pipe Eating/Reaming</td>
<td>11</td>
</tr>
<tr>
<td>2.4. Pipe Ejection/Extraction</td>
<td>13</td>
</tr>
<tr>
<td>2.5. Controlled Line and Grade (CLG) System</td>
<td>14</td>
</tr>
<tr>
<td>3. PIPE RENOVATION METHODS</td>
<td>16</td>
</tr>
<tr>
<td>3.1. Structural Methods</td>
<td>16</td>
</tr>
<tr>
<td>3.1.1. Slip lining</td>
<td>16</td>
</tr>
<tr>
<td>3.1.2. Cured-in-Place Piping</td>
<td>18</td>
</tr>
<tr>
<td>3.1.3. Spiral Wound Plastic Liners</td>
<td>20</td>
</tr>
<tr>
<td>3.1.4. Woven Hose Lining Epoxy Bonded</td>
<td>22</td>
</tr>
<tr>
<td>3.1.5. Close-Fit Slip lining</td>
<td>22</td>
</tr>
<tr>
<td>3.2. Non-Structural Methods</td>
<td>22</td>
</tr>
<tr>
<td>3.2.1. Shotcrete &amp; Cement Mortar Lining</td>
<td>22</td>
</tr>
<tr>
<td>3.2.2. Epoxy/Polyurethane Lining</td>
<td>23</td>
</tr>
<tr>
<td>4. NEW PIPE INSTALLATION METHODS</td>
<td>25</td>
</tr>
</tbody>
</table>
4.1. Horizontal Directional Drilling/Directional Boring 25
4.2. Pipe Ramming 28
4.3. Auger Boring (Case Boring/Jack & Bore) 31
4.4. Slurry Horizontal Rotary Boring 34
4.5. Water Jetting 34
4.6. Tunneling  Error! Bookmark not defined.
   4.6.1. Conventional Tunneling 35
   4.6.2. New Austrian Tunneling 35
   4.6.3. Road Header Method 35
4.7. Pipe Jacking/Micro-Tunneling 35
   4.7.1. Micro-Tunneling 35
   4.7.2. Pipe Jacking 37
4.8. Pilot Tubing Micro-Tunneling/Guided Boring 38

5. DESIGN & CONSTRUCTION CONSIDERATIONS 39
   5.1. Geotechnical Considerations 39
      5.1.1. Surface and Soil Conditions 43
      5.1.2. Groundwater Conditions 45
   5.2. Host Pipe 45
      5.2.1. Material 45
      5.2.2. Current and Required Sizing 47
      5.2.3. Depth and Profile 47
   5.3. Replacement Pipe 48
   5.4. Protective Sleeves 49
   5.5. Site Accessibility 50
   5.6. Other Utilities and Design Factors 50
   5.7. Service Connections 51
      5.7.1. The Service Connector Project 52
      5.7.2. Robotics and Service Connections 52
   5.8. Equipment Installation and Replacement Pipe Preparation 53
      5.9. Installation/Rehabilitation Operation 53
      5.10. Reconnection of Services and Sealing 54
      5.11. Manhole Preparation 55
   5.12. Testing of New Replacement Pipe 55
   5.13. General Comparison 55
6. ECONOMIC AND ENVIRONMENTAL CRITERIA 59
   6.1. Cost-Effectiveness Analysis of Trenchless Technologies 59
   6.2. Cost Categorization 60
       6.2.1. Direct and Indirect Costs 61
       6.2.2. Social Costs 63
   6.3. Cost-Effectiveness Comparisons 65
       6.3.1. Pipe Bursting Versus Open-cut Trenches 65
       6.3.2. Other Trenchless Pipe Replacement Costs 69
       6.3.3. Examples of Trenchless Technology Cost-Effectiveness 69
       6.3.4. Direct Cost Estimation 70

7. DECISION SUPPORT FOR TECHNOLOGY SELECTION 72
   7.1. Decision Support Systems 72
   7.2. TAG and TAG-R 73
   7.3. Generic Models 74
   7.4. Water and Wastewater Guidelines and Models 74
   7.5. A Guideline for Selecting Rehabilitation and/or Replacement Technology 80

8. TRENCHLESS TECHNOLOGY APPLICATION IN SASKATCHEWAN AND THE WORLD 86
   8.1. Introduction 86
   8.2. Trenchless Technology in Saskatchewan 87
   8.3. Gaps/Opportunities for Potential Future Research & Development of Trenchless Processes in Saskatchewan Applications 91

9. CONCLUDING REMARKS AND RECOMMENDATIONS 93

10. REFERENCES 96

APPENDIX A: PINTER QUESTIONNAIRE
APPENDIX B: INTERFACE SCREENS
APPENDIX C: TRENCHLESS CONTRACTS SEARCH
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Pipe Bursting (Construction Updates, 2012)</td>
<td>4</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Pipe Splitting (ISST, 2013)</td>
<td>7</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Pneumatic Pipe Bursting (Simicevic and Sterling, 2001)</td>
<td>8</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Hydraulic bursting head (Simicevic and Sterling, 2001)</td>
<td>9</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Hydraulic bursting body (UNITRACC, 2012)</td>
<td>9</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Rod Assembly Pulling the Replacement Pipe (ATT Technologies, 2011)</td>
<td>10</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Pipe Implosion/Crushing (Simicevic and Sterling, 2001)</td>
<td>11</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Crushed Bits of Pipe and Soil (Nodig-construction, 2013)</td>
<td>12</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Pipe Eating/Reaming (Simicevic and Sterling, 2001)</td>
<td>13</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Trenchless Pipe Ejection/Extraction (Simicevic and Sterling, 2001)</td>
<td>14</td>
</tr>
<tr>
<td>Figure 11</td>
<td>“CLG” System (Simicevic and Sterling, 2001)</td>
<td>15</td>
</tr>
<tr>
<td>Figure 12</td>
<td>“CLG” System Injection Pit (Trenchless Solutions, 2013)</td>
<td>15</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Pipe Slip lining (ISST, 2013)</td>
<td>16</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Grouted and Ung grated Annular Spaces (Zhao, 2003)</td>
<td>17</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Cured-in-Place Pipe (Trenchless Pipelining, 2013)</td>
<td>18</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Polyester felt tube (Trenchless Australia, 2012)</td>
<td>19</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Cured-in-Place Piping, (ISST, 2013)</td>
<td>19</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Cured-in-Place Piping (So Cal Plumbing Services, 2010)</td>
<td>20</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Spiral Wound Plastic Lining-Large Size (Interflow, 2013)</td>
<td>21</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Spiral Wound Plastic Lining- Small Size (Interflow, 2013)</td>
<td>21</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Spraying Hose inside the Lined Pipe (Trenchless Pipelining, 2013)</td>
<td>23</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Horizontal Directional Drilling/Directional Boring (ISST, 2013)</td>
<td>25</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Operator Applying Torque and Thrust to Change Directions (ASTEC Underground, 2013)</td>
<td>27</td>
</tr>
<tr>
<td>Figure 24</td>
<td>Pipe Ramming/Jacking, (Simicevic and Sterling, 2001)</td>
<td>29</td>
</tr>
<tr>
<td>Figure 25</td>
<td>Driving Ramming Tool (Oregon State University, 2013)</td>
<td>30</td>
</tr>
<tr>
<td>Figure 26</td>
<td>Auger Boring Machine (Trenchless World, 2013)</td>
<td>32</td>
</tr>
<tr>
<td>Figure 27</td>
<td>Cutter Head and Auger Drill and Remove the Spoil Material (Trenchless Technology, 2011)</td>
<td>33</td>
</tr>
<tr>
<td>Figure 28</td>
<td>Installing Pipes by Micro-Tunneling (Abraham et al., 2007)</td>
<td>34</td>
</tr>
<tr>
<td>Figure 29</td>
<td>Installing Pipes by Micro-Tunneling (ASTT, 2010)</td>
<td>36</td>
</tr>
<tr>
<td>Figure 30</td>
<td>Deep Installation using Pipe Jacking and Micro-Tunneling (Services First Limited, 2010)</td>
<td>38</td>
</tr>
<tr>
<td>Figure 31</td>
<td>Suggested Interactive Approach for Trenchless Projects (Richardson et al., 2003)</td>
<td>39</td>
</tr>
<tr>
<td>Figure 32</td>
<td>The Displaced Ground and Movement of the Soil (Simicevic and Sterling, 2001)</td>
<td>44</td>
</tr>
<tr>
<td>Figure 33</td>
<td>Underground Infrastructure Categorized Costs (Apeldoorn, 2012)</td>
<td>61</td>
</tr>
<tr>
<td>Figure 34</td>
<td>Schematic Representation of the Relation between Project Cost (Using Open-Cut Method) and the Excavation Depth, (Apeldoorn, 2012)</td>
<td>63</td>
</tr>
<tr>
<td>Figure 35</td>
<td>Relative Contribution of the Different Categories of Social Costs and Direct Costs for Case Studies, (Apeldoorn, 2012)</td>
<td>65</td>
</tr>
</tbody>
</table>
Figure 36. Bid cost for Pipe Bursting Technologies for Size-to-size Pipe Replacement Based on 1999 Prices (Simicevic and Sterling, 2001) .......................................................... 66
Figure 37. Bid cost for Pipe Bursting Technologies for Upsizing Pipe Replacement Based on 1999 Prices (Simicevic and Sterling, 2001) ........................................................................................................... 67
Figure 38. Pipe Replacement Cost Using the Pipe Bursting Technologies and the Traditional Open-cut Method, Based on a UK Study (Pool et al, 1985) .................................................................................. 68
Figure 39. Rehabilitation and/or Replacing a Water Main Flow Diagram (FCM and NRC, 2003) ....................................................................................................................................................... 76
Figure 40. Rehabilitation and/or Replacing a Storm and Wastewater Systems Flow Diagram (FCM and NRC, 2003) .................................................................................................................................................. 77
Figure 41. AWWA M28 Manual, Flow and Leakage Problems (AWWA, 2001) ......................... 79
Figure 42. Guideline for Selecting Rehabilitation and/or Installation Trenchless Technology for Municipal Infrastructure ........................................................................................................... 83
Figure 43. Ranking Criteria for the Selected Technologies ..................................................... 84
Figure 44. World Urban and Rural Population, 1950-2030 (the World Urbanization Prospects, 2006) ............................................................................................................................................. 86
LIST OF TABLES

Table 1. Summary of Main Features of Typical HDD methods (Abraham et al., 2007) .......... 26
Table 2. General Comparison of Selected Trenchless Technologies (Salem et al., 2008) ........... 57
Table 3. Summary of Cost (in US Dollars) Comparisons of Replacement Methods per Linear Meter Unit Installed (Apeldorn, 2012) .............................................................................................................. 62
Table 4. Social Costs Category and Implications for Payments and Responsibility, (Rahman et al., 2005) ....................................................................................................................................... 64
Table 5. Wastewater systems Guidelines and Models................................................................. 81
1. INTRODUCTION

Communities of Tomorrow commissioned PINTER & Associates Ltd. (PINTER) to complete a review and evaluation study of modern trenchless technologies and work practices. This document is for use as a practical guide for Saskatchewan municipalities. A thorough literature review of current underground asset management techniques and methods was carried out by PINTER & Associates Ltd. The review included current and emerging technologies and processes in trenchless pipe installation and rehabilitation for applications in water, sewer and gas lines. Recommendations and evaluations in this report were based on Saskatchewan municipalities as the intended target environments.

1.1. Background

Over the last five years, Saskatchewan has become one of the nation’s leading growing provinces, showing unprecedented economic growth. In response to emerging pressures, the Province's Planning for Growth (PFG) initiative is seeking to help develop Saskatchewan's urban and rural areas into viable, sustainable communities.

One of the most important aspects of strengthening a community is ensuring strong reliable infrastructure systems, in particular, underground assets dealing with water, waste and natural gas. Modern methods for installing and replacing utility piping no longer involves excavating mass amounts of earth and no longer causes extensive surface disruption to the community. Trenchless technologies, equipment and standards are in place to ensure that these piping systems can be quickly installed or replaced without major disruption local businesses or residents.

In the past, open-trenching surface excavation was the only method used for new pipeline installation and for pipe replacement. However, over the last 25 years it became clear that little was known about existing pipelines or utility infrastructures that have been previously installed. Research was quickly undertaken to find ways to gather information on existing pipes and ducts often too small to be entered manually by service workers. The need and adoption for trenchless technologies quickly emerged to meet the specific needs of different countries around the world. For
example, Micro-tunnelling evolved in Japan out of a demand for more sewer systems in the country’s larger cities. In the United Kingdom, where the infrastructure for many of the cities was built during the time of the Industrial Revolution, trenchless technologies were used to replace and fix aging sewers, water pipes and cast iron gas mains. In North America, another trenchless technology called Horizontal Direction Drilling (HDD) was developed to extend a number of oil wells vertically and then horizontally from a single well pad. The technology was adapted from oil wells to the widespread purpose of constructing long pipelines for the oil industry. By 1986, Japanese, American, and European engineers banded together to officially categorize all of these techniques under the umbrella of trenchless technology.

1.2. Report Organization
The first three chapters, Chapters 2, 3 and 4, present the literature review. The different trenchless technologies available in the local market and internationally are presented and discussed. Chapter 2 focuses on different pipe replacement methods (such as Pipe Bursting, Splitting, Pipe Eating...etc.). Chapter 3 presents pipe renovation methods classified into structural and non-structural methods. Chapter 4 presents methods used for new pipe installations. Each chapter explains, briefly, the basic set up of each method followed by discussion on its pros and cons. Figures and photographs are used to provide better insights into the method specific tools and machines.

Design and construction considerations of the different trenchless technologies are provided in Chapter 5, to assist the comparison between the different technologies. The Chapter opens by explaining the recommended steps to carry out a successful trenchless construction project. Through this demonstration different design aspects are discussed in details. The Chapter ends with a summarized comparison of selected trenchless technologies, which provides the reader with a holistic view of the main advantages and limitations of trenchless technology in general.

Chapter 6 focuses on the economic and environmental criteria involved in selecting the appropriate trenchless technologies. Details of cost categorization are presented to provide insights into direct and indirect costs associated with infrastructure projects. These costs directly affect the overall cost of similar projects and consequently the selection of a specific technology.
The presentations in Chapters 5 and 6 provide the preparation for the different decision support tools presented in Chapter 7, for proper technology selection. The Chapter starts by presenting the available decision support tools and their characteristics. The Chapter ends with presenting a simple selection tool developed by PINTER for Saskatchewan municipalities to enable a straightforward and easy to use selection method. The tool is developed using a simple EXCEL® spreadsheet with selection dropdown lists and calculation formulas. It is designed to enable the user to incorporate additional technologies, in addition to the ones listed in the tool, and to update the corresponding information according to the local conditions.

Chapter 8 provides the reader with a view of the trenchless technology market internationally and nationally. It shows the potentials of the trenchless technology market in the world and on the national level. The outcome of the PINTER questionnaire, developed to obtain information on the local market, and the direct contact survey is presented at the end of this Chapter. This provides a frame of reference for a discussion of Trenchless Technology use in Saskatchewan. Based on this information, Chapter 8 presents the gaps and opportunities for potential research and development of trenchless process in Saskatchewan application. The concluding remarks are presented in Chapter 9 followed by the list of references used in the report development.

**References:** there are a number of excellent references in the public forum that provide detail information on Trenchless Technologies. The text has been used directly with the due referencing.
2. PIPE REPLACEMENT METHODS

There are five general techniques for \textit{insitu} pipe replacement. These include; pipe bursting, pipe implosion or crushing, pipe eating or reaming, pipe ejection and extraction and controlled line and grade system. There are two main Pipe Bursting methods; the pneumatic or hydraulic expansion and the static pull. Each system requires a different bursting head and support equipment. Below each classification is described in detail.

2.1. Pipe Bursting/Splitting

Pipe Bursting and Splitting are well-established methods for trenchless replacement of worn out and undersized gas, water and sewer pipe. An existing pipe is replaced size-for-size or up-sized with a new pipe using the existing alignment (In-Line Replacement (Suleiman, 2010)). The technique is the most cost effective when there are few lateral connections, when the old pipe is structurally deteriorated, and when additional capacity (larger diameter pipe) is needed.

2.1.1. Pipe Bursting - General

Pipe bursting, which can be either pneumatic, hydraulic expansion or static pull, fractures a pipe and displaces the fragments outwards while a new pipe is drawn in to replace the old pipe, Figure 1.

![Figure 1: Pipe Bursting (Construction Updates, 2012)](image.png)

Typical pipe bursting involves the insertion of a conically shaped tool (bursting head) into the old pipe. The head fractures the old pipe and forces its fragments into the surrounding soil. At the same time, a new pipe is pulled or pushed in behind the
bursting head. The base of the bursting head is larger than the inside diameter of the old pipe (50 mm to 100 mm (2 inches to 4 inches) larger than the old pipe (ISST, 2013)) to cause the fracturing and slightly larger than the outside diameter of the new pipe, to reduce friction on the new pipe and to provide space for manoeuvring the pipe. The rear of the bursting head is connected to the new pipe, while its front end is connected to a cable or pulling rod. The bursting head and the new pipe are launched from the insertion pit, and the cable or pulling rod is pulled from the reception pit. The cable/rod pull through the annulus of the existing pipe together with the shape of the bursting head keep the head following the existing pipe. Specially designed heads can help reduce the effects of existing sags or misalignment on the new pipeline.

The size of pipe, currently being replaced by pipe bursting, typically ranges from 50 mm (2 inches) to 900 mm (36 inches). The diameter of pipe being burst, though, is increasing. Pipes up to 1200 mm (48 inches) diameter have, reportedly, been replaced (Brahler, 2012). Theoretically, there is no limit in the size of pipe that can be burst. Limitations, however, include cost effectiveness compared to conventional pipe replacement, local ground conditions (potential ground movement and vibration), and the ability to provide sufficient energy to break the existing pipe while simultaneously pulling in a new pipe.

Pipe Bursting is typically carried out in 90 m to 120 m (300 feet to 400 feet) lengths, which corresponds to a typical distance between sewer manholes. However, much longer pipe lengths have been replaced. The longer the pipe run the greater the skin friction on the new replacement pipe being pulled or pushed and the greater the force required to complete the installation.

Pipe suitable for Pipe Bursting are typically made of brittle materials, such as vitrified clay, cast iron, plain concrete, asbestos, or some plastics. Reinforced Concrete Pipe (RCP) can also be successfully replaced if it is not heavily reinforced or if it is substantially deteriorated. Ductile iron and steel pipes are not suitable for pipe bursting, and can only be replaced with pipe splitting. Pipe bursting does have limitations.

Difficulty can arise in expansive soils, close proximity of other service lines, point repairs that reinforce the existing pipe with ductile material, or a collapsed pipe at
a certain point along the pipeline, etc. Pipe Bursting operations create outward ground displacements adjacent to the pipe alignment. The ground displacements tend to be localized and to dissipate rapidly away from the point of bursting. At shallow depths or in soft soils bursting operations can cause ground heave or settlement above or at some distance from the pipe alignment. The most critical conditions for ground displacement are when: the pipe to be burst is shallow and ground displacements are primarily directed upward, significant upsizing percentages for large diameter pipes are used, and deteriorated existing utilities are present within 2-3 diameters of the pipe being replaced.

The most favourable ground conditions for Pipe Bursting are soils that can be moderately compacted (reducing the lateral extent of outward ground movements), in which the expanded hole behind the bursting head does not cave in before the replacement pipe is installed (lowering the drag and the tensile stresses in the pipe during installation). Less favourable ground conditions involve densely compacted soils and backfills, soils below the water table and dilatant soils. Each of these soil conditions tends to increase the force required for the bursting operation and to increase the zone of influence of the ground movements, i.e. heave (Timberlake and Berry, 2012). Special soils such as highly expansive soils or collapsible soils will also cause problems.

For most soil conditions, it is simply necessary to provide the required power to affect the burst, displace the soil and pull the replacement pipe in over the length of the burst. It is important to consider the potential effect of the ground displacements and vibrations on adjacent utilities and structures. Longer bursts can be accomplished more easily in favourable ground conditions. When the soil provides a high friction drag on the pipe and the length of run is long enough to generate high tensile forces on the replacement pipe, bentonite or polymer lubrication muds may be injected into the annular space behind the bursting head to help keep the hole open and to reduce the frictional drag on the replacement pipe.

High Density Polyethylene (HDPE) and Medium Density Polyethylene (MDPE) pipes are the most common replacement pipe materials. Other types of replacement pipe include cast iron pipe, vitrified clay pipe, and reinforced concrete pipe.
2.1.1.1. **Pipe Splitting**

Using essentially the same process as Pipe Bursting, Pipe Splitting involves cutting and splitting the pipe in order to pull the replacement through. This technique is generally used when the host pipe material is not brittle; materials such as, but not limited to, steel and ductile iron. The splitter head cuts the pipe along a line on the bottom and pushes it open for the new pipe to slide through, Figure 2.

![Pipe Splitting](image)

**Figure 2. Pipe Splitting (ISST, 2013)**

The head is pulled through using a steel rod assembly or wire assembly and consists, generally, of the following three parts: a pair of cutting wheels, or slitter wheels, which initiate the first cut; a "sail blade" which follows cutting behind the wheels; and a cone-shaped expander, with an off-centered alignment to help push the pipe open to make room for the incoming one.

This method of trenchless pipe replacement is generally quick and smooth, allowing a perfect space for the new pipe to slide in after the split. The old pipe is forced upwards from the new pipe alignment, and becomes a protective barrier around the top half of the new pipe.

2.1.2. **Pipe Bursting Methods**

2.1.2.1. **Pneumatic Pipe Bursting**

Pneumatic Pipe Bursting is the most frequently used type of Pipe Bursting to date. It is used on the majority of pipe bursting projects worldwide. The Pneumatic Pipe Bursting head is a cone-shaped soil displacement hammer. It is driven by compressed air and operated at a rate of 180 blows/minute to 580 blows/minute. The percussive action of the bursting head is similar to hammering a nail into a wall, where each
impact pushes the nail a small distance farther into the wall. In a like manner, the bursting head creates a small fracture with every stroke, and thus continuously cracks and breaks the old pipe, Figure 3.

![Figure 3. Pneumatic Pipe Bursting (Simicevic and Sterling, 2001)](image)

The percussive action of the bursting head is combined with the tension from the winch cable, which is inserted through the old pipe and attached to the front of the bursting head. It keeps the bursting head pressed against the existing pipe wall, and pulls the new pipe behind the head. The air pressure required for percussion is supplied from the air compressor through a hose, which is inserted through the new pipe and connected to the rear of the bursting tool. The air compressor and the winch are kept at constant pressure and tension values respectively. The bursting process continues with little operator intervention until the bursting head comes to the reception pit.

Typical Pneumatic Pipe Bursting may create quite a noticeable ground vibration on the surface above the bursting operation. Still it is very unlikely to damage the existing nearby surface or underground structures, unless it is carried out at very close proximity to them. The bursting head should not pass closer than 0.75 m (2.5 feet) from buried pipes and 2.50 m (8 feet) from sensitive surface structures. If distances are less than these, special measures should be taken to protect the existing structures, e.g. excavate the crossing point to relieve stress on the existing pipe.

2.1.2.2. **Hydraulic Expansion**

In the Hydraulic Expansion system, the bursting process advances from the insertion pit to the reception (pulling) pit in sequences, which are repeated until the full length of the existing pipe is replaced. In each sequence, one segment of the pipe (which matches the length of the bursting head) is burst in two steps: first the bursting head is pulled into the old pipe for the length of the segment then the head is expanded (using...
hydraulic pressure) laterally to break the pipe, Figure 3, Error! Reference source not found..

![Figure 4. Hydraulic bursting head (Simicevic and Sterling, 2001)](image)

The bursting head is pulled forward with a winch cable, which is inserted through the old pipe from the reception pit, and attached to the front of the bursting head. The rear of the bursting head is connected to the replacement pipe and hydraulic supply lines are inserted through the replacement pipe. The bursting head consists of four or more interlocking segments, which are hinged at the ends and at the middle. An axially mounted hydraulic piston drives the lateral expansion and contraction of the head, Figure 5.

![Figure 5. Hydraulic bursting body (UNITRACC, 2012)](image)

Another form of the Hydraulic Pipe Bursting is the Hydraulic Rod Bursting. This method uses a hydraulically powered rod pushing unit which initially pushes rods through the old pipe from one access point to the other. The guide rod at the front end of the rod chain during insertion is then replaced with the bursting head (either a
bladed head for brittle pipes or a cutting head for splitting non-brittle pipe) (ISST, 2005).

2.1.2.3. **Static Bursting**

In the static pull system, the force for breaking the existing pipe comes only from pulling the bursting head forward. The head is pulled by either a pulling rod assembly (Trenchless Replacement system (TRS) system) or a winch cable, which is inserted through the existing pipe and attached to the front of the bursting head. The tensile force applied to the bursting head is significant. The cone-shaped bursting head transfers this horizontal pulling force into a radial force, which breaks the old pipe and provides a space for the new pipe (ASTT, 2009a).

If a rod assembly is used for pulling, the bursting process is done in consecutive sequences, rather than continuously. Prior to bursting, the segmented rods are inserted into the old pipe from the reception pit. The rods are only a few feet long, and during insertion they are threaded together to reach the bursting head at the insertion pit. There, they are attached to the front end of the bursting head, and the new pipe is connected to its rear end. In each sequence during the bursting, the hydraulic unit in the reception pit pulls the rods for the length of individual rods, and the rods are removed from the rest of rod assembly as they reach the reception pit. If a winch cable is used instead of rods, the pulling process can be continuous. Typically, a rod assembly can apply or transmit a much larger force to the bursting head than a cable system, Figure 6.

![Figure 6. Rod Assembly Pulling the Replacement Pipe (ATT Technologies, 2011)](image-url)
2.2. **Pipe Implosion and Crushing**

The Implosion System is similar to a bursting one in which it crushes the pipe while pulling through the replacement. In this two step process the old pipe is crushed inwards in the first step. In the second step the old pipe fragments are pushed outward by the bursting tool. The replacement pipe is dragged in behind the bursting head. This method is useful for replacing defective utility pipe, (ASTT, 2009a).

The pipe implosion tool (sometimes called the bursting tool) consists of two parts: a crushing head. The cylindrically shaped crushing head is slightly larger than the existing pipe and has steel blades extending in a radial shape from the center. The head fractures the old pipe and pushes the pipe fragments inwards into the old pipe space. The second part is the steel cone which follows forcing the crushed pipe fragments and soil outwards and pulls in the new replacement pipe, **Figure 7**.

![Figure 7. Pipe Implosion/Crushing (Simicevic and Sterling, 2001)](image)

A rod assembly can be used just as in a static pull system to pull the crushing head through the pipe. The implosion method cannot be used to replace metallic or thermoplastic pipes and has the drawbacks of any typical pipe bursting technology, especially ground surface heaving (Montero et al., 2004).

2.3. **Pipe Eating/Reaming**

The Pipe Eating system is designed to tunnel through the existing pipe and ground, crushing the pipe, whilst simultaneously inserting the new pipe into the bored out space. This method differs from a bursting operation. The crushed fragments of pipe mixed with soil are vacuumed out, as slurry, through the new pipe and out of the space. This method is remotely controlled. The cutting head may be laser guided to a different alignment, "eating" segments of the old pipe as well as the soil, **Figure 8**.
A Pipe Eating system is comprised of two sections. The forward end is the cutting head, with cutting teeth and rollers that break up the pipe and soil and cut the “tunnel” to the diameter of the new replacement pipe. The pipe material is further stressed by the cone shape of the cutting head, which also helps to reduce wear on the teeth.

The second section is the shield section which holds the cutting head and protects the hydraulic motor powering the head. A thrust frame in the drive pit provides the pushing force via the replacement pipe to the shield and “eating” head sections. One of the main advantages of the pipe eating technology is that the old pipe material is totally removed and the new pipe is accurately installed (ASTT, 2009a).

**Pipe Reaming**

A Pipe Reaming operation is similar to the pipe eating technique in that it involves crushing the old pipe and mixing the pipe fragments and soil into a slurry, which is then pumped back to the surface for disposal. This option is often more suitable in
harder, more compacted soils and rock. With pipe reaming, a drill rig pulls the cutting/reaming head through the existing pipe, crushing it into pieces while pulling the new pipe into place. The reamer teeth pulverize the pipe in a cutting and flow process, rather than compacting and splitting the pipe. Drilling fluid is used to decrease friction, to hold the hole/tunnel open and to suspend pipe fragments and soil particles. The pipe and soil fragments and waste material flow with the drilling fluids to a reception pit where this slurry is pumped out with a vacuum mud collection truck, Figure 9.

![Figure 9. Pipe Eating/Reaming (Simicevic and Sterling, 2001)](image)

2.4. **Pipe Ejection/Extraction**

Pipe Ejection and Pipe Extraction are pipe replacement systems, in which the unbroken existing pipe is removed from the ground in whole segments, while the new pipe is simultaneously installed. The old pipe is broken into pieces only when it has been completely removed from the ground. These techniques are applicable only for pipes with sufficient remaining strength, integrity and thrust capacity to withstand the push or pull forces. Brittle and deteriorated pipes will not withstand the frictional forces from either pulling or pushing, and will simply crumple during the removal process. This method is generally used on shorter replacement sections to avoid high frictional resistance.

In pipe ejection, the replacement pipe pushes out the old pipe. The old pipe must have sufficient thrust capacity (ASTT, 2009b) to withstand the pushing forces develop by friction with the soil and the push of the new pipe. A jacking frame is placed into the insertion pit. The new pipe is placed against the old pipe through the
jacking frame. As the new pipe is jacked horizontally, the old pipe is pushed toward a reception pit or manhole. At the reception pit, the existing pipe is broken into pieces as it emerges. The pieces are removed and disposed. The jacking frame and the insertion pit are sized to fit the length of short, individual, new pipe segments, Figure 10.

![Figure 10. Trenchless Pipe Ejection/Extraction (Simicevic and Sterling, 2001)](image)

In Pipe Extraction, the replacement pipe is pulled rather than pushed to replace the old pipe. As with all *insitu* pipe replacements there are two pits or access points. An extraction machine is placed into one pit, and the replacement pipe is fed from the other pit. A pulling device (a pulling rod assembly) is inserted through the existing pipe, and attached to the extraction machine on one end. A tool assembly connected to the replacement pipe is attached at the other end. The tool assembly consists of a centraling device, pull plates, and a cylindrical expander or plug. The expander can be slightly larger than the existing pipe to reduce soil friction or it can be large enough to allow for upsizing to the desired pipe diameter.

### 2.5. Controlled Line and Grade (CLG) System

Controlled Line and Grade (CLG) System is a pipe replacement method with the ability to correct sags, humps or misalignments in existing pipelines. The system was brought on the trenchless market in the late 1990’s. A steel rod string, a series of short, steel rods coupled together, is inserted through the existing pipe, for the entire length of the replacement section. After the rod string is precisely aligned to the desired line and grade between the insertion and reception pit it is anchored in tension (pre-tensioned). Then a light cement slurry is pumped in to fill the old pipeline and any open voids around it. Once the cement slurry is cured (between 4 hours to
24 hours), a bursting head and a replacement pipe are attached to one end of the rod string. The rod is then pulled out towing the new pipe behind it. A bentonite may be used for lubrication to reduce the friction against the new pile and thereby reducing the pulling force required, Figure 11.

![Figure 11 “CLG” System (Simicevic and Sterling, 2001)](image)

As the bursting advances through the cured slurry, the bursting head encounters equal resistance from the cement/existing pipe/ground envelope at all points around its face and circumference, Figure 12. Because of that, the bursting head is not as likely to be deviated from its path and is less affected by sags, misalignments and undulations in the old sewer pipeline. The cured light cement provides the support and a shield against shards from the old burst pipe, rocks and harmful objects in the pipe zone.

![Figure 12. “CLG” System Injection Pit (Trenchless Solutions, 2013)](image)
3. PIPE RENOVATION METHODS

Pipe renovation is the rehabilitation of existing pipe \textit{insitu} without replacement. This method can be used for deteriorating pipe or leaking pipe.

3.1. Structural Methods

3.1.1. Slip lining

Slip lining is perhaps the oldest of all trenchless techniques. It involves the insertion of a new pipe into an existing pipe. Under the right conditions, slip lining is also the simplest trenchless technique. A new pipe with an outside diameter smaller than the inside diameter of the host pipe is either pulled or pushed into the host pipe. The ideal host pipes for slip lining are straight with no deformities, that is pipes with no or modest bends, no severe protrusions into the pipe, and only modest offset joints. Slip lining may be continuous or segmental.

Polyethylene (HDPE and PE) and Polyvinyl Chloride (PVC) pipes are most commonly used for continuous slip lining circular, non-human entry pipes. The new pipe is laid out above ground and pulled through an excavated pit into the host pipe, Figure 13. The new pipe is then winched through the host pipe to an exit pit or manhole. In situations where space, to layout the pipe above ground, is limited sections of the new PE or PVC pipe can be butt-fused during the installation process (Thornton et al., 2005).

![Pipe Slip lining](image.png)

\textbf{Figure 13.} Pipe Slip lining (ISST, 2013)
After the new pipe has been installed, the annular space between the new and host pipe is grouted. Grout may serve only to restrain the new pipe and transfer load from the existing pipe as shown in Figure 14. The grout may cause the new and host pipe to act as a composite, increasing the pipe’s ring stiffness and its resistance to external hydrostatic loads. The proper selection and application of grout is often the most difficult part of a slip lining job. Grouts that serve only as a filler to restrain the new pipe are relatively low strength grouts with low viscosities. Structural grouts that serve to link liner to the host pipe have higher compressive strengths than grout used only to restrain the liner (Zhao, 2003).

![Figure 14. Grouted and Ungrouted Annular Spaces (Zhao, 2003)](image)

Forces on the liner during grouting may be greater than what the liner will encounter during normal service. Excessive grouting pressure could damage or collapse the liner. In addition, floatation forces on the liner need to be taken into account when grouting and means taken to avoid floatation especially in large pipes, such as filling the pipe with water and grouting in stages.

Segmental slip lining is typically used to insert Glass Reinforced Plastic (GRP) pipes into circular and non-circular pipes. The size of the host pipe can range from small non-man entry to larger man entry pipes. Segmental liners may be pushed into the host pipe by hydraulic power or winched into place. Concrete and steel pipe with
higher compressive strength and stiffness may also be installed as slip liners and present fewer engineering challenges than plastic pipes during grouting.

### 3.1.2. Cured-in-Place Piping

Cured-in-place piping (CIPP) is perhaps the most reliable method of pipe rehabilitation and has been widely used in Europe and America for the past 30 years. This process involves inserting a new polyester pipe into the deteriorated host pipe and curing it in place, Figure 15. It can be used on pipe ranging from 100 mm to 2 700 mm (ISST, 2013). There are a wide variety of pipe applications that include, but are not limited to, sanitary sewers, storm drains and pressure pipelines for water, wastewater and gas. The host pipe generally needs to have retained a circular shape. Oval and rectangular pipe shapes can be lined with CIPP as well if the shapes are known in advance.

![Figure 15. Cured-in-Place Pipe (Trenchless Pipelining, 2013)](image)

Before the lining process can begin, the pipe interior must be prepared. Lateral connections must be removed and any substantial damages must undergo local repairs. The inside of the pipe must then be thoroughly cleaned out to remove all debris, deposits and rust (for iron pipe) pieces from corrosion.

A polyester felt tube is fabricated to fit the host pipe. It is then inverted (turned inside out) and pulled inside the host (old) pipe. The liners are impregnated with a polymer resin, which when cured will form a close fitting liner pipe within the host pipe. The liner may be designed with sufficient thickness when cured to sustain the loads imposed by external groundwater and internal service pressure, and by soil and traffic acting on the pipe, Figure 16.
The liner is thoroughly saturated with polyester, vinyl ester epoxy or silicate resin using vacuum, gravity or other applied pressure, Figure 17. The resin includes a chemical catalyst or hardener to facilitate curing. The outermost layer of the liner tube is coated with a polymer film to protect the liner during handling and installation. The impregnated liner may be chilled for transportation to maintain stability until installed.

The CIPP, in its inverted state, is inserted in the pipe and is unrolled and advanced into the pipe using air pressure or water pressure. This allows a tight fit against the
existing pipe. Once the design length has been achieved the resin is activated using hot water or steam. The resin hardens to form a pipe within a pipe. Figure 18 shows the pipe inside condition before and after the cured-in-place lining.

Figure 18. Cured-in-Place Piping (So Cal Plumbing Services, 2010)

The major advantage of using CIPP is that it is a no-dig trenchless solution and can be installed through existing access points like manholes. The liners may be installed using the inversion method (above), or using a winch system down a manhole and then inflated using water or air pressure, to squeeze against the existing pipe.

CIPP is not a suitable option when either one of the following is true; the existing host pipe is severely deteriorated and/or has lost any reasonable oval shape, the existing pipe has sections that have collapsed compromising shape, pipe capacity needs increasing, chemical usage of the pipe will corrode the inner liner, and/or the pipe effluent temperatures will be abnormally high.

3.1.3. **Spiral Wound Plastic Liners**

Spiral wound liners can be used to rehabilitate gravity pipeline applications such as storm sewers, sanitary sewers, conduits, culverts and process pipes. The configuration of spiral wound liners often allows installation of the liner under live flow. That is the installation can occur during normal operation of the existing or host pipe.

Prior to the installation of the liner the host pipe needs to be prepared. These steps include but may not be limited to repairing groundwater infiltration, removal of obstacles and renovation of blemishes (offset joints, fittings and localized flattening). The liner is installed in-situ in the host pipe through a manhole or insertion.
Manufactured strips of PVC, steel reinforced PVC or HDPE (profile) located on spools above ground are fed to a winding machine. The winding machine rotates causing the edges of the profile strips to interlock forming a water-tight liner. The rotational action advances the liner through the host pipe, Figure 19 and Figure 20. In smaller diameter pipes, the liner can be expanded by the winding machine to form a tight fit with the host pipe. Alternatively, a fixed diameter, field-fabricated liner can be installed, and the annular space between the host pipe and liner grouted.

Figure 19. Spiral Wound Plastic Lining-Large Size (Interflow, 2013)

Figure 20. Spiral Wound Plastic Lining- Small Size (Interflow, 2013)
The winding machine can remain stationary at the inserting pit in line with the host pipe, or for larger diameter circular or non-circular applications, the machine can travel along the host pipe. The traveling machine installs the spiral wound liner in contact with the host pipe forming a close-fit liner that generally conforms to the profile of the host pipe. The liner may be installed with a fixed dimension and the annular space between the spiral wound liner and host pipe grouted.

Laterals are located by measurement and reinstated after lining. Grouting of the annular space is generally preferred to lock the liner in place, effectively transferring external loads from the existing pipe onto the liner and to mobilize the support of the existing pipe to achieve the full potential of the liner to carry external loads.

Spiral wound pipe liner is typically PVC or HDPE which provide good flow characteristics and hydraulic efficiency.

3.1.4. Woven Hose Lining Epoxy Bonded
This method uses flat fibre reinforced polyethylene hoses from 150 mm to 500 mm, where it can sustain internal pressure up to 40 bars, (ISST, 2013). The woven hose is inserted at the inlet of the rehabilitated pipe and pulled using a winch at the outlet. Inflation takes place after securing the liner to the host pipe until it contacts its wall for bonding.

3.1.5. Close-Fit Slip lining
Close-fit slip lining is a rehabilitation method that is suitable for thermoplastic pipes. For this method the hosting pipe needs to be relatively straight and have a circular shape. To install the liner is deformed through diameter reduction or shape change. After insertion is complete the full liner diameter is restored by applying steam or water under pressure.

3.2. Non-Structural Methods
3.2.1. Shotcrete & Cement Mortar Lining
The shotcrete lining process involves pneumatically spraying concrete or mortar onto the inside of the old/host pipe. The wet liner on the inside of the pipe will cure, harden and seal the pipe. This technique is popular in relining of culverts and has become an all-inclusive term for both wet and dry concrete spraying processes.
For smaller diameter pipe applications, cement mortar lining is used to protect pipe interiors from corrosion. Other benefits include structural support to the pipe and sealing against leakage. The pipes must first be cleaned thoroughly with high pressure washers, then, in small diameter (no man-entry) pressure pipes, a thin layer of cement mortar is sprayed on using a rotating-head spray machine Figure 21.

![Spraying Hose inside the Lined Pipe](image)

**Figure 21. Spraying Hose inside the Lined Pipe (Trenchless Pipelining, 2013)**

The mortar is either fed through hoses from the surface, or in larger pipe applications, the mortar mix is often fed from a down-hole hopper. The speed that the spray machine is pulled through the host pipe determines the thickness of the coating. The spray application is followed by towelling, which is typically carried out by either rotating a spatula fitted to the spray machine or by a tubular shield sized to the internal diameter of the coating, which is pulled through the pipe behind the spray machine.

Cement mortar is often the cheapest method of pipe relining and is an easy instalment to protect against corrosion and structural damage. However, it is thick and slow to apply and cure, and could easily block utility connections in an existing pipe.

### 3.2.2. Epoxy/Polyurethane Lining

Both epoxy and polyurethane lining provide corrosion protection and enhanced flow characteristics in small diameter metallic host pipes and leak protection in large pipe
diameters. Like the cement mortar lining, the host pipe has to be cleaned and dry prior both coating application. Fast curing time, relative to the cement mortar, is the main advantage of the Epoxy and Polyurethane liners, 16 hours and 2 hours, respectively (ISST, 2013).
4. NEW PIPE INSTALLATION METHODS

4.1. Horizontal Directional Drilling/Directional Boring

Horizontal Directional Drilling (HDD) is one of the most widely used continuous trenchless technologies. It is used for the installation of everything from service connections to residential and commercial/institutional buildings, to pipes and cables under roadways and rivers. HDD is used for installing pressure pipes and conduits, where precise grades are not required and are applicable for diameters up to 1200 mm. The drive length of HDD outperforms any other trenchless technology; a 477 m bore distance was achieved under a harbour canal in Germany, (ASTT, 2009b)

The main components of HDD are: a directional drill rig of a size suitable for the job; drill rods linked together to form a drill string to advance the drill bit and for pulling back reamers and products (pipe); a transmitter/receiver for positioning of the location of the drill and product; a tank for mixing and holding drilling fluid; and a pump for circulating the drilling fluid. This is in addition to drilling bits, reamers, swivels and pulling heads, Figure 22.

The HDD industry is divided into three major sectors – large-diameter HDD (maxi-HDD), medium-diameter HDD (midi-HDD), and small-diameter HDD (mini-HDD, also called guided boring) – according to their typical application areas. There is no significant difference in the operational mechanisms between these systems.
However, the different application ranges require corresponding modification to the system configuration and capacities, mode of spoil removal, and directional control methods to achieve optimal cost-efficiency. Table 1 is adopted from Abraham et al. (2007), which compares typical maxi-, midi-, and mini-HDD systems.

Table 1. Summary of Main Features of Typical HDD methods (Abraham et al., 2007)

<table>
<thead>
<tr>
<th>Type</th>
<th>Diameter (mm)</th>
<th>Depth (m)</th>
<th>Drive Length (m)</th>
<th>Typical Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxi-HDD</td>
<td>600-1200</td>
<td>≤61</td>
<td>≤1800</td>
<td>Rivers and Highways Crossings</td>
</tr>
<tr>
<td>Midi-HDD</td>
<td>300-600</td>
<td>≤23</td>
<td>≤270</td>
<td>Rivers and Roadways Crossings</td>
</tr>
<tr>
<td>Mini-HDD</td>
<td>50-300</td>
<td>≤4.5</td>
<td>≤180</td>
<td>Telecommunication and Power Cables and Gas lines</td>
</tr>
</tbody>
</table>

Environmental impacts of drilling fluid must be considered in relatively large jobs. Impacts are minimized through recycling drilling fluid using a combination of screens, centrifugal pumps, and hydro cyclones to remove the cuttings from the fluid.

An HDD project has a launch site where the rig is set-up and positioned to drill a pilot bore (usually 75 mm to 150 mm in diameter) along a planned path to an exit pit. At the exit pit the product pipe, reamer or product pipe reamer is attached and pulled back through the bore hole. Small potholes may be required if the risk of damage to existing utilities is relatively high. Potholes help to relieve pressure on the utilities caused by ground movement (ASTT, 2009b) and compaction caused by the boring. The rig is secured by means of on-board power-rotating augers (anchors) and positioned at a distance behind the entry point to allow the drill to enter the ground at design angle and the planned location.

The entry angle of the drill string is typically 8 degrees to 16 degrees. A pit for capturing drilling fluids (returns) is excavated at the entry point and at the planned exit point. The drill string, comprised of a series of drill rods, is advanced by a combination of rotational and thrust forces supplied by the rig. The string is initially advanced using both rotational torque and thrust. Once the drill string has sufficient
down-hole stability the operator changes the direction of the drill string to advance along the predetermined, design alignment. There are many types of bits designed to navigate through different types of soil, from clays and sands to rock, Figure 23.

![Operator Applying Torque and Thrust to Change Directions](image)

**Figure 23. Operator Applying Torque and Thrust to Change Directions**  
(ASTE Underground, 2013)

Most drill bits have a slant-face, the orientation of which determines the direction that the bit will advance. To move in a straight line, the rig operator both rotates and pushes the drill string. To change direction, the operator, stops rotating the drill string and pushes the string. The path will change toward the direction in which the bit’s slant-face is pointing. On-board controls allow the operator to monitor the orientation of the bit and the change in general direction of the bore.

A walk-over tracking system (beacon and/or walk-over) is used to help guide and monitor the location of the bore. The system is comprised of a transmitter and receiver. The transmitter or sounder is located in a housing unit near the front of the drill string. The transmitter emits a continuous magnetic signal, which is picked up by a portable hand-held receiver used by the Tracking Hand (operator’s assistant). Data transmitted to the receiver allows the Tracking Hand to determine position, depth and clock-face position of the drill bit from the ground surface. This
information allows the operator to track location along the planned bore and to make changes as needed.

Drilling fluids, pumped down through the hollow drill rods and holes in the drill bit, are key to keeping the transmitter electronics cool, stabilizing the hole, and extracting returns from the bore hole. The drilling fluids are mixed to address the solid conditions that are anticipated along the planned path. During installation returns can be tested to confirm that the correct water-additive mixture is being used.

Once the pilot bore reaches the exit area, the reaming and installation of the product pipe (the product) phase begins, Figure 22. The hole is reamed in one or more passes to the required diameter. When the bore is large enough to accept the product - about 1.5 times the size of the product - the product is attached to the drill string, at the exit point, using a pulling head and swivel and pulled back to the rig. Like drill bits, reamers are designed to operate best in certain types of soil. The larger the product, the greater the number of passes of the reamer required to open up a hole to accept the product.

For smaller installations, returns (cuttings or tailings) are removed via vacuum trucks for disposal. Cuttings are often removed and drilling fluids recycled, in larger product installations, using a combination of centrifugal pumps, tanks with baffles, shaker screens, and de-sanding and de-silting hydro-cyclones. The residual material is removed for disposal.

The major challenge that faces HDD is a change in the soil profile. These changes can result in difficulty in controlling the drill rod direction, drilling fluid loss in soil voids and inability to advance to the exit point. Certain soil types such as dense clay tills, gravels, soils containing cobbles and boulders and highly compacted gravel and sand layers (ASTT, 2009b) can be challenging.

4.2. **Pipe Ramming**

Pipe ramming, also known as pipe jacking, is a trenchless method of installation for new pipes over, typically, short, shallow distances. This common method has been widely used for installation under railway lines and roadways because it causes little ground movement in comparison to other methods. Much like other related methods, pipe ramming is non-steerable and is applicable for installing small diameter steel or
other hard, rigid casings for sewer, water, gas, electrical, telecommunications, etc. applications.

The pipe ramming process uses pneumatic equipment to percussively hammer the pipe through the ground. Most often, the pipe is hammered into the side of an embankment to pass under the obstacle. The pipe is open-ended to allow the soil to move into the pipe rather than compacting it outside the pipe, thus, reducing surface heave and allowing this method to be used at shallow surfaces, Figure 24.

Compared to other trenchless methods such as auguring and directional drilling, pipe ramming can save both total installation time and costs under favorable conditions. Installation time can often be nearly 40% shorter than in auguring because the required width and depth of pits are smaller. The actual installation is faster (12 m to 18 m (40 feet to 60 feet) sections can be rammed in half an hour while auger boring the same distance requires half a day). Directional drilling is generally better suited for long bores; however, pipe ramming is often superior for installations in the 1.5 m to 18 m (5 feet to 60 feet) range (Simicevic and Sterling, 2001).

In the pipe ramming operation, a ramming tool is attached to the rear of a steel pipe to drive the pipe into the ground with repeated percussive blows, Figure 25. The method typically requires excavation of two pits. Before ramming, both the pipe and the ramming tool are placed into the insertion pit and lined up in the desired direction. Alternatively, the ramming can be launched without an insertion pit, if the ram is designed to start on the side of a slope.
Depending on the length of the new pipe to be inserted, the ramming can be done at one time. The pipe can become too heavy from the soil accumulation within the annulus of the pipe (this will depend on the material or soil density and compactness, pipe diameter and length of the installation). Shorter ram lengths can be carried out to allow the soil to be periodically cleared. Once the ramming is complete, and the pipe has reached the exit pit, the soil accumulation must be cleaned out. This material, known as “spoil”, can be removed with compressed air or can be augured out in the case of larger diameter pipes. The removal of spoil can often be trickier than the ramming itself if large cobbles and boulders are present in the spoil. If these conditions exist the may be a need for more frequent clearing throughout the ramming process.

In open-end ramming, either a prefabricated soil-cutting shoe is attached to the front of the pipe leading edge or a special band is welded around the outside or inside edge of the pipe. Both options reinforce the pipe edge and slightly overcut the hole in the soil, thus reducing internal and external friction between the pipe and soil.

When special bands are used, their design can be adjusted to the soil conditions to optimize the system’s performance. In most soil types, the bands are two rings (one
inside and the other outside the pipe) attached around the entire pipe circumference. In soft clays, however, the bottom 150 mm to 250 mm (6 inches to 10 inches) around the pipe invert may be left out to prevent pipe ebbing during the installation. The rings are usually 75 mm to 100 mm (3 inches to 4 inches) wide and attached directly to the pipe end. In stiff clays they may be wider, between 250 mm to 350 mm (10 inches and 14 inches), and attached at some distance, about 300 mm to 450 mm (12 inches to 18 inches), from the pipe end within the pipe (Simicevic and Sterling, 2001).

This design allows the rings to enlarge the hole in the ground after the pipe leading edge has already cut into the ground to reduce soil friction. In gravels and cobbles, the bands can be beveled to help rocks enter into the pipe, as well as to help in splitting or fracturing the rocks. In cementitious soils, which are the toughest soils for pipe ramming, rings with a beveled edge should be used and combined with auger or drilling teeth welded around the pipe.

4.3. Auger Boring (Case Boring/Jack & Bore)

Auger boring, also known as the “Jack and Bore” method, is a trenchless method for installing a new pipeline for sewer, water, gas or carrier purposes. This method is similar to the pipe ramming method in that it is common and particularly useful for short length pipe installations under railway, roadway or other similar type obstacles, where soil settlement is a concern (ISST, 2013). Auger boring works best in softer soil like clay but can be applied to many ground conditions with proper planning and design.

The auger boring process employs an auger boring machine to rotate a series of connected continuous flight augers (auger chain) positioned within a casing pipe and fitted to a cutter head at the front of the casing, Figure 26. The rotating cutter head, which is slightly larger in diameter than the casing pipe, excavates the soil in front of the casing. The soil is transported back to the machine via the helical auger chain. At the original entry point the soil is removed by hand or machine. The auger boring machine advances along a track, which is aligned to drive the casing pipe on the designed installation line.
Once the machine reaches the end of the track arrangement, the auger chain is disconnected from the machine and the machine is moved back to the original starting point on the track where a new casing segment is welded to the existing casing pipe, and a new auger length (chain) is connected to the machine and to the existing chain/cutter head. The excavation and thrust process is repeated until the planned bore is completed.

![Auger Boring Machine (Trenchless World, 2013)](image)

While it is possible to use the auger equipment to bore the hole and auger out the spoil material, leaving an uncased space for pipe insertion, this leaves an unsupported opening. It is more common practice to simultaneously ‘jack’ the new pipe casing into the hole while the cutter head and auger drill and remove the spoil material. This synchronized action derives the name “Jack & Bore” and has become one of the most widely used methods for pipe installations under railways and roadways.

Auger boring can be used to install casing pipe ranging from 100 mm (4 inches) to at least 1,500 mm (60 inches) in diameter, with the most common diameters ranging from 200 mm (8 inches) to 900 mm (36 inches). When the diameter of pipe to be installed is less than 200 mm (8 inches), other trenchless technologies are more appropriate and economical, especially, where the line and grade are not very critical. For larger diameters where the line and grade are more critical, pipe jacking and micro-tunneling can be the better alternatives which provide greater accuracy and cost effectiveness.

Auger boring was initially developed to cross under a two-lane roadway with an average length of 12 m (40 feet) and a maximum length of 21 m (70 feet). However,
typical project lengths range from 30 m (100 feet) to 91.5 m (300 feet), with the demand for longer installations increasing. The longest continuous track-type auger boring project is 270 m (886 feet), Figure 27.

There are two types of auger boring machines; Track mount and the Cradle type auger mount. The track type auger boring operation depends on a boring machine mounted on tracks or rails. It moves back and forth on the tracks while providing jacking and rotating forces to the augers and casings. Track type uses typical equipment such as boring machine, casings, cutting head, and augers, as shown in Figure 28. Casing lubrication system, steering system, locating system, and casing leading-edge band can also be used in the track boring operations (Iseley et al., 2004).

The cradle type auger boring machine is suitable for projects that provide adequate room. The bore pit size depends on the bore diameter and the length of the bore. This machine type is commonly used on petroleum pipeline projects where large rights-of-way are essential. The main advantage of the method is that all work is performed at the ground level rather than in the pit. The bore pit is deepened beyond the casing pipe invert to allow space for the collection of spoil and water as the bore hole is excavated. Another advantage of the cradle boring is that it does not require any
thrust structures; however, a jacking lug must be securely installed at the bore entrance embankment (Abraham et al., 2007).

![Boring Machine on the Track](image)

**Figure 28. Installing Pipes by Micro-Tunneling (Abraham et al., 2007)**

### 4.4. Slurry Horizontal Rotary Boring

It is a technique which creates a horizontal bore hole from a drive shaft to a reception shaft using a rotary drill bit and drill tubing. The drilling fluid (slurry, bentonite, water or air pressure) is used to facilitate the drilling process by keeping the drilling bit clean through spoil removal. At the beginning an unsupported hole is produced and the pipe installed afterwards, (Iseley and Gokhale, 1997).

### 4.5. Water Jetting

The excavation method relies on a high speed jet of water to liquefy soil and aid in spoil removal. A special nozzle is attached to the end of a solid rod and extended forward into the bore hole. It is a simple method and does not require sophisticated equipment; however, it does not provide good control over bore hole size. There is the potential of significant over cuts. The other main disadvantages are large quantities of water required to carry out excavation and consequently large amounts of spoil removal which may cause surface ground settlement (U.S. Army Corps of Engineers, 1999).
4.6. Tunneling

Tunneling, in general, is one of the most widely used trenchless techniques. It has been used to construct lines 2 and 3 of the Athens Metro in Greece, El-Azhar road tunnel in Cairo and the Euro Tunnel in UK (Mohammed et al., 2010).

4.6.1. Conventional Tunneling

Tunneling process involves removing soil from a front cutting face and installing a liner to provide a continuous support structure. Like any tunneling process it needs an entry and exit pits. The typical tunneling process involves four main steps, (1) soil excavation, (2) spoil removal, (3) segmental pipe installation, and (4) alignment control (ODOT, 2011). Soil excavation can be carried out by any excavation method, including hand mining, open-face mechanical excavation, or any tunnel boring machines. The available space dictates the appropriate spoil removal (such as slurry systems, vacuum extraction systems, belt and chain conveyors, etc.).

4.6.2. New Austrian Tunneling

This method has been developed basically in Salzburg, Austria, where it has been used to overcome problems of tunneling through the Alpine Mountain. The main objective of this method is to provide stable and economic tunnel support systems. It uses flexible primary lining constructed with shotcrete, wire mesh, rock bolts and lattice girder. In case of weaker rock mass, pipe roofing is used to provide support through crown support which in turn leads to less over-break as well as ensure safety during the excavation, (Karakuş and Fowell, 2004).

4.6.3. Road Header Method

This is a tunneling method used for sedimentary rock formations using a road header and controlled blasting (if required). The road header is either a wheel or track mounted cutting equipment and consists of a boom with spherical ball with a manoeuvrable cutting teeth at the end (Military Engineering Services, 2010).

4.7. Pipe Jacking/Micro-Tunneling

4.7.1. Micro-Tunneling

Micro tunneling is a process that uses a remotely controlled Micro-tunnel Boring Machine (MTBM) combined with the pipe jacking technique to directly install
product pipelines underground in a single pass as illustrated in Figure 29. The term micro-tunneling applies to remotely controlled, steerable, controlled excavation tunneling methods for pipelines of 3 400 mm diameter or less and usually for lengths up to 460 m (Najafi and Gokhale 2004). The spoil is removed from the cutting head within the new pipeline which is advanced by pipe jacking. This process avoids the need to have long stretches of open trench for pipe laying. Thus this method reduces extreme disruption to the community during construction. Spoil may be removed by auger, slurry conversion or vacuum extraction (ASTT, 2010).

Micro-tunneling machines are controlled from the surface, with location and operation of the machine being continuously monitored, usually by means of a laser guidance system. Typical micro-tunnel boring and support equipment consist of an MTBM matched to the expected subsurface conditions and the pipe diameter to be installed, a hydraulic jacking system to pipe jack the pipeline, a closed loop slurry system to remove the excavated tunnel spoil, a slurry cleaning system to remove the spoil from the slurry water, a lubrication system to lubricate the exterior of the pipeline during installation, a guidance system to provide installation accuracy, an electrical supply and distribution system to power all of the above equipment. Micro-tunneling works well in most ground conditions such as coarse sand, clay, mixed soil, and rock.
The high accuracy required when installing gravity sewers, combined with work where minimum disruption is required, makes micro-tunneling ideal for such work. The technology has developed where machines are now readily available to drive 100 m (330 feet) or more for sizes from 100 mm (4 inches) in diameter up to 1.50 m (5 feet). Accuracy, even below the water table, is typically ± 20 mm (± 3/4 inch) over these distances.

### 4.7.2. Pipe Jacking

Pipe jacking utilizes hydraulic jacks to force the installed pipe forward through the soil. Spoil is transferred through a screw drive shaft to the open end of the pipe at the entry pit, similar to spoil removal in the micro-tunneling method. Pipe segments are installed using the jack rams after the installation of each segment. Pipe jacking uses different excavation methods and can be categorized into five methods; Open Hand Shield, Cutter Boom Shield, Earth Pressure Balance, Backacter Shield, and Tunnel Boring Machine (TBM) (ASTT, 2009b).

Both Pipe Jacking and Micro-Tunneling are used for installations that require high accuracy in pipe alignment, deviation of less than 20 mm (3/4 inch) over a 100 m (330 feet) length. The jacked pipes should endure the encountered drive forces, i.e. the strength of the pipe should be high and it should be stiff. Pipe Jacking and Micro-Tunneling enable the installation of deep pipes without significant increase in cost, compared to other trenchless technologies, Figure 30.
4.8. **Pilot Tubing Micro-Tunneling/Guided Boring**

Pilot Tubing is a guided installation of a hollow tube on a precise line and grade. Guidance is carried out using a theodolite, camera, monitor screen and an illuminated LED target (ISST, 2013). It is usually used for small diameter service pipes; however modifications were carried out to allow larger diameters by enlargement of the pilot tube before installing the new pipe. Similar to any Micro-Tunneling method, it requires both entry and exit pits.

First, the installation of the pilot tube is carried out between the jacking and reception shafts using the guidance control setup. Then, a reaming head coupled with auger casings are jacked along the path created by the pilot tube. The turning action of the auger transports the spoil back to the jacking shaft where it is removed at the entry pit. The pilot tubes are advanced by the auger casings into the exit shaft and removed. The installed pipe, which is slightly smaller than the auger casing pipe, is jacked into the enlarged bore hole advancing the auger-casings into the reception shaft where they are removed. The pipe installation is complete when it reaches the reception shaft replacing the previously installed auger casings.
5. DESIGN & CONSTRUCTION CONSIDERATIONS

5.1. Geotechnical Considerations

A successful trenchless construction project requires thorough knowledge of the subsurface conditions (Allouche et al., 2001). Therefore, trenchless projects require gathering sufficient subsurface information to select appropriate construction methods and to prepare for likely obstacles. Geotechnical investigations to gather subsurface information for trenchless projects typically have three general phases. Figure 31 shows a proposed iterative approach of the three phases with possible inputs and outputs (Richardson et al., 2003). Those phases which are closely coordinated, progress from planning to investigation to reporting.

<table>
<thead>
<tr>
<th>Input</th>
<th>Design Phase</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project requirements/preliminary project information; desk study; case history search; existing geotechnical reports/boring logs search/review</td>
<td>PRELIMINARY</td>
<td>preliminary tunnel profile and alignment; anticipated ground conditions; lessons learned (projects in similar geological environments); generalized soil/rock properties; generalized groundwater elevation data; geotechnical investigation planning document preparation</td>
</tr>
<tr>
<td>Preliminary geotechnical investigation/borings; preliminary laboratory testing (soil/rock interface)</td>
<td>PLANNING</td>
<td>preliminary geological section; preliminary material properties (soil/rock); preliminary design parameters; preliminary tunnel profile and alignment adjustment</td>
</tr>
<tr>
<td>additional borings (as required); additional laboratory testing; owners review/comment/risk management</td>
<td>FINAL</td>
<td>final tunnel profile and alignment; preliminary material properties (soil/rock); final design parameters; geological/construction risk evaluation; geotechnical baseline report</td>
</tr>
</tbody>
</table>

Figure 31. Suggested Interactive Approach for Trenchless Projects (Richardson et al., 2003)

The planning stage of a trenchless construction project requires developing a preliminary ground surface survey. While each trenchless project has unique, site-specific requirements, Najafi (2005) suggests that a survey should be conducted for at
least 15 m (50 feet) on either side of the bore path and suggests that the pre-design surface survey should include the following elements:

- Work area requirements;
- Existing grade elevation data;
- Surface features, such as roadways, sidewalks, and utility poles;
- Boring or test pit locations;
- Waterways and wetlands;
- Visible subsurface utility landmarks, such as manholes or valve boxes; and
- Structures adjacent to the bore path.

The preliminary design stage includes subsurface investigations as the next step after the surface survey. The important subsurface information is the presence of existing utilities or other manmade obstructions, methods of placement, and the geotechnical conditions along the proposed trenchless construction alignment (Najafi, 2005). Simple and low-risk installations can often utilize an abbreviated, geotechnical investigation program.

The first step of the subsurface investigations usually involves obtaining information about existing utilities along the bore path. Usually, local municipalities and utility companies should be contacted to obtain the required information. Clients are also required to provide such information, as much as possible. Methods of confirming subsurface utility locations include surface-applied pipe locators, ground-penetrating radar, vacuum excavation equipment, and seismic survey. The second step of the subsurface investigation for a trenchless construction project is the geotechnical drilling program. The geotechnical subsurface investigation gives more precise information on subsurface conditions on the site. Najafi (2005) specifies that the steps for subsurface investigation should include the following:

- Determine the nature of soil at the site and its stratification;
- Obtain disturbed and undisturbed soil samples for visual identification and laboratory tests;
- Determine the depth and nature of bedrock if encountered;
- Perform in situ field tests;
- Observe surface drainage conditions from and into the site;
• Assess any special construction problems with respect to the nearby existing structures; and
• Determine groundwater levels, sources of recharge, and drainage conditions.

Various methods have been used to conduct subsurface investigations. Najafi (2005) lists the following as main methods of geotechnical surveys:

• **Ground-penetrating radar.** Effective in gravels and sands.
• **Acoustic (sonar).** Useful for determining rock depth, interfaces between soft and hard deposits, and buried objects.
• **Geophysical methods.** Variations in the speed of sound waves or in the electrical resistivity of various soils are useful indicators of the water table depth and of the bedrock.
• **Test pits or trenches.** This method is only suitable for shallow depths but allows visual observation over a larger area than is possible with samples from borings.
• **Hand augers.** Only suitable for shallow depths; only disturbed or mixed soil samples can be obtained with this method.
• **Boring test holes and sampling with drill rigs.** This method is the principal method for detailed soil investigations. Sampling intervals and techniques should be set to accurately describe the subsurface material characteristics, accounting for site specific conditions. Typically, split-spoon samples will be taken in soft soil at depth intervals of 5 feet in accordance with ASTM D 1586 (Najafi, 2005).

A limitation of conventional geotechnical investigations that drill vertical boreholes is that only a non-contiguous picture of underground conditions is developed. Drilling the large number of vertical boreholes that would be necessary to provide a complete picture of subsurface conditions for horizontal alignments is often not technically or economically feasible. An additional limitation of conventional vertical site characterization techniques is that they often cannot reach underneath structures, roadways, pipeline right-of-ways, or environmentally sensitive areas (O’Reilly and Stovin, 1996). These are the very areas in which the horizontal boring is to take place.
In response to these limitations, emerging horizontal site characterization techniques now provide a new alternative to the traditional vertical site investigation methods. These techniques include a family of soil samples, contact sensing probes, and borehole geophysical tools capable of providing horizontally continuous geotechnical information. These devices are usually advanced into the ground using Horizontal Directional Drilling (HDD) technology.

Allouche et al. (2001), states that a site characterization project that involves horizontal boring is economical, even for medium-scale micro-tunneling and tunneling projects. The increasing economic feasibility of this method is directly related to the improvements made in the HDD industry.

The preliminary investigation continues with a program of laboratory testing on the recovered soil samples. Najafi (2005) recommends that the following soil information should be determined from the laboratory testing:

- Standard classification of soils;
- Gradation curves on granular soils;
- Standard penetration test values where applicable (generally unconsolidated ground);
- Particle size distribution, including presence of cobbles and boulders;
- Shear strength;
- Atterberg limits (liquid, plastic, and shrinkage limits);
- Moisture content;
- Height and movement of water table;
- Permeability;
- Cored samples of rock with lithologic description, rock quality designation, and percent recovery;
- Unconfined compressive strength for representative rock samples (frequency of testing should be proportionate to the degree of variation encountered in the rock core samples) and Mohs hardness for rock samples. Where rock is encountered, it should be cored in accordance with ASTM D 2113 to the maximum depth of the boring;
- Presence of contaminated soils (hydrocarbons, etc.).
In the final stage of the geotechnical investigation, a Geotechnical Baseline Report (GBR) should be prepared. The GBR establishes a contractual statement of the geotechnical conditions anticipated to be encountered during underground or subsurface construction (Najafi, 2005). Richardson et al. (2003) states that a newer approach is to take design information out of the project data and GBR and include it in a separate design report that is excluded from the contract because the design recommendations are sometimes used by the contractor in a way not intended by the engineer.

However, in practice, detailed subsurface investigations are often not conducted because of the difficulty of quantifying the benefits of a given investment level in site characterization, which can sometimes lead to insufficient funding and inadequate subsurface information (Allouche et al., 2001).

5.1.1. Surface and Soil Conditions

The effect of different trenchless methods on the surrounding soil is a topic that is still being studied. Perhaps the most important consideration needed when replacing or installing subsurface piping is ground displacement and movement. It should be remembered that certain Trenchless Technologies have minimum ground disturbance such as CIPP and slip lining.

In general, when installing a pipe or upsizing one during a replacement operation, soil will be displaced to make room for the new pipe/casing. The displaced earth will have to move in the least resisted direction, which most of the time, is up towards the surface (IPBA, 2012). While there are a number of factors like density and soil makeup that will affect the extent and direction of the displacement, there is almost always ground movement whether the operation is a pipe burst, split, ream, drill, bore or jack. Displacements during a burst tend to be much greater than say during pipe ramming, but will diminish over time following the operation. They are generally somewhat localized and dissipate rapidly with distance from the source.

Ground displacements usually depend on the degree of upsizing, the type and compaction level of the existing soil around the pipe, and the depth of the operation. In a relatively homogenous soil, at shallow depths the displacements will likely be
directed upwards towards the surface, at increased depths, they will be more uniformly distributed.

The displaced ground and movement of the soil will end up being expressed as either surface heave, or surface settlement. Depending on how densely or loosely packed the material is, the surface will either heave up directly above the pipe, or the ground to either side will settle downwards Figure 32. Additionally, different types of pipe have different sensitivities to movement. For instance, asbestos-cement pipes are particularly sensitive, while HDPE pipes are not. Therefore, it is important for the designer to understand and predict ground displacements when considering safe distances to existing underground structures and overlying pavement.

During trenchless construction that uses a jacking force to advance the pipe and cutter head, surface subsidence mainly occurs due to a lack of driving force. Excessive driving force, however, can cause surface heaving if soil is being excavated faster than it can be removed. Additionally, the overburden pressure due to the depth of the pipe is important for determining the proper driving force that will
not lead to surface deformations (Shou and Chang, 2006). Pipe lining methods are considered to have little to no effect on the existing soil.

5.1.2. **Groundwater Conditions**

Simicevic and Sterling (2001) stated that Pipe Bursting below the groundwater table increases the difficulty of bursting operations. Bursting in saturated soil can cause the water pressure to rise around the bursting head, unless the soil (sandy soil) has a high enough permeability to allow the water pressure to dissipate quickly. The rise in water pressure causes the effective stress in the soil to drop and may cause the soil to behave more like a viscous fluid. When the fluidized soil displaces the surrounding soil, the ground movements tend to be more extensive and nearby services may displace more easily. During pipe bursting, insertion and receiving pits are preferably kept dry (Simicevic and Sterling, 2001). If the groundwater is removed to a large degree, consolidation/densification of the soil surrounding the existing pipe can result, significantly increasing the required bursting forces.

5.2. **Host Pipe**

5.2.1. **Material**

In practice, nearly any existing pipe material can be utilized with the slip lining process. Most brittle pipe materials make good candidates for pipe bursting, implosion/crushing, eating/reaming. Ductile pipes may be scored and then slit as in the pipe splitting operations described above. Pipe made of non-ductile abrasive material but with ductile reinforcing, are the most difficult to replace using most pipe replacement techniques. Common types of pipe and their bursting characteristics are indicated below (Simicevic and Sterling, 2001):

- Clay pipes are good candidates for bursting. They are brittle and fracture easily. Newer clay pipes may have PVC joints. Such plastic fittings may hinder the bursting operation slightly and may need special application tools but do not represent a real concern. The fragments of clay pipe may be sharp and there is some level of concern about the gouging or scoring of the replacement pipe and eventual point loading on the replacement pipe. Sacrificial external sleeve pipes are often used to ensure protection for plastic replacement pipes for high pressure pipe applications. There is much less concern for gravity sewer pipe applications.
• Plain concrete pipes are good candidates for bursting. They are relatively brittle and tend to fracture easily in tension especially when in a deteriorated condition. Thick plain concrete or reinforced encasements or repairs to the pipe may cause difficulty in bursting. The history of pipe maintenance and repair should be considered in planning.

• Reinforced concrete pipes present difficulty unless the concrete and reinforcing steel is deteriorated. They may be burst with powerful enough equipment but careful evaluation may be needed if the pipes are more than lightly reinforced and are not significantly deteriorated.

• Cast iron pipes are good candidates for bursting. The pipes are relatively brittle even when in good condition. The fragments of cast iron pipe may be sharp and there is concern about the gouging or scoring of the replacement pipe and eventual point loading on the replacement pipe. Sacrificial sleeve pipes are often used to ensure protection for plastic replacement pipes for high-pressure pipe applications. Special application tools and protection of the winch cable, when used, may need to be considered. Ductile repair clamps, service saddles and fittings can cause problems for the bursting operation and hardened cutter blades may be incorporated to cut through such clamps.

• Steel and ductile iron pipes are not good candidates for pipe bursting. They are strong and ductile. In smaller diameters, they may be replaced using pipe splitting techniques.

• PVC and other plastic pipes may be replaced using an appropriate combination of bursting and splitting techniques according to the strength and ductility of the pipe.

• Asbestos cement pipes are generally good candidates for bursting. Care should be taken to determine the class of the existing pipe. Thicker, higher tensile strength pipes (such as AC water main) tend to “ball up,” increasing required bursting forces. Modifications to standard bursting heads should include cutter blades to split the pipe. Gas mains from 75 mm (3 inch) to 450 mm (18 inch) diameter can be relined using this method. Virtually any type of durable liner material can be used, although
polyethylene is the most common. Worker safety and environmental impacts must be considered when working with and disposing of Asbestos Cement pipe.

For pipe splitting, the host pipe material should not be brittle (materials such as, but not limited to, steel and ductile iron).

Ejection/extraction techniques are applicable only for pipes with sufficient remaining thrust capacity to withstand the push or pull forces. Brittle and deteriorated pipes will not stand the frictional forces from pulling or pushing, and will simply crumple or fragment in place when removal is attempted. In these cases shorter replacement sections are used to avoid high frictional resistance.

5.2.2. Current and Required Sizing

Basically, there is no strict size requirement for the host pipe for slip lining and pipe lining methods. The technique has been used to restore pipe as small as 25 mm (1 inch), and there are no apparent maximum pipe diameters reported in the literature.

For other replacement methods such as pipe bursting, implosion/crushing, splitting, eating/reaming, and ejection/extraction, a small diameter pipe may be harder to burst than a larger size pipe, because the walls are thicker in relation to the size of tool. It is considered that an 200 mm (8 inch) pipe is easier to burst than a 100 mm (4 inch) pipe (Simicevic and Sterling, 2001). The host pipe diameter and the required upsize of the new pipe determine machine selection. To date, upsizing by up to 30% of the original pipe diameter is common, and greater upsizing has been successfully completed in many projects. Projects with a high upsizing percentage must be carefully examined in terms of required forces and ground displacements particularly for larger diameter pipe; that is diameters larger than 450 mm (18 inches).

5.2.3. Depth and Profile

For pipe replacement methods, the depth of the host pipe affects the expansion of surrounding soil as mentioned in the above section. This is in addition to water-table considerations, which vary with soil depth, soil type and regional geology. Insertion and reception pits grow larger and more complex as the depth increases. The existing
profile of the bursting run can also affect the planning and execution of the pipe bursting operation, especially changes in grade or bends. For example sometimes, a sag can be found in an existing sewer line. To work properly the sag in the sewer line needs to be eliminated. The replacement pipe needs to be installed with an acceptable grade and without the sag. The sag can be eliminated by local excavation and bringing the bottom of the pipe trench to a uniform grade in line with the existing pipe invert.

5.3. **Replacement Pipe**

Although, in theory, any material can be used for the new pipe in a slip lining method, in practice, Polyurethane (HDPE and PE) and Polyvinyl Chloride (PVC) are the most common choices and seem to work the best. Not only is this material well established in the potable water and gas industries, it is also abrasion resistant and sufficiently flexible to negotiate minor bends during installation. It can be butt-fused into a very long continuous length prior to being winched into the host pipe. These materials provide good flow characteristics and hydraulic efficiencies.

Slip lining pipes are most commonly polyethylene, but may be of any material that can be inserted into the host pipe. Annular grouting may be necessary after the insertion of the liner, so that the structure of the existing pipe provides some restraint and increases ring stiffness. The liner must be sized to the minimum dimensions of the host pipe, unless tapers are incorporated.

HDPE and MDPE are the most common new pipe materials used in bursting operations (Simicevic and Sterling, 2001). The main advantages of PE pipe are its continuity, flexibility, and versatility. The continuity is obtained by hot fusing long segments together in the field prior to insertion. The continuity during the installation reduces the likelihood of needing to interrupt the bursting process. The flexibility allows bending of the pipe for angled insertion in the field. In addition, PE is a versatile material that meets all the other requirements for gas, water, and wastewater lines. The relatively high thermal expansion coefficient is a disadvantage of PE pipes; although this is not generally a concern once the pipe has stabilized (cooled) *insitu* (Simicevic and Sterling, 2001).
Other types of replacement pipe used in Pipe Bursting include cast iron pipe, vitrified clay pipe, and reinforced concrete pipe (Simicevic and Sterling, 2001). It is reported that if the type of pipe requires installation in segments rather than a continuous length and if, as is normally the case, the pipe joint will not withstand significant tensile force, the bursting head and pipe installation technique needs to be modified. Typically, sectional rods are passed from the bursting head through the replacement pipe and these rods are used to clamp the replacement pipe in compression and to allow the replacement pipe string to be pulled from the rear of the pipe string rather than from the front. Installation is slowed because the bursting operation needs to be halted while the pipe sections are added and the pulling arrangement reconnected.

It is preferable that all pipe joints are designed for trenchless installations, i.e. to have a nominally flush exterior profile.

5.4. **Protective Sleeves**

Simicevic and Sterling (2011) reported that in water main replacement, an internal protective sleeve may be used to protect the interior of the water main from contamination from dirt, oil, exhaust gas, etc. caused by equipment and hoses that must be installed in the replacement pipe for the bursting operation to function. The static pull method does not require hoses or equipment in the replacement pipe if a continuous replacement pipe is used and hence, for this condition, does not require an internal protective sleeve or pipe for potable water applications. The exception to this condition is when a lubrication hose needs to be threaded through the continuous pipe.

In pressure pipe applications using plastic pipe, an external protective sleeve pipe may be used to prevent damaging stress concentrations and lowered failure pressures from occurring due to potential gouges caused by the pipe fragments in the ground. In this case, the external sleeve pipe is installed during the bursting operation and the product pipe can be installed later in a separate operation. When an external protective sleeve pipe is used, the size of the bursting head must be increased to accommodate the carrier pipe thickness and the annular space required for the product pipe to be inserted. This increased diameter increases power requirements for the bursting and also increased the extent of ground movements surrounding the bursting.
head. Alternately, the replacement pipe can be designed with sacrificial thickness to allow for the possibility of scoring.

5.5. Site Accessibility
The location of insertion and access pits should be such that their number is minimized and the length of bursting maximized consistent with the equipment available for the burst and the expected stress on the replacement pipe. In sewer replacement jobs, the burst length is usually from manhole to manhole. An intermediate manhole can be used with proper preparation. Longer than normal bursts may need larger tools and lubrication mud to reduce friction. The sizes of the existing pipe and the upsizing percentage have an effect on the safe or workable length of bursting.

Reusing and rehabilitation of existing manholes may prove to be prohibitive considering cost and production for relatively large up sizes (greater than 2-3 sizes). In these cases, it will be more cost-effective to replace each manhole. Simicevic and Sterling (2011), also recommended that clauses in contracts should clearly define a pit as “all excavation required per manhole location.” A contractor may be required to excavate in two directions in the case of an insertion pit, and thus expect to be paid for two pits at one manhole location.

5.6. Other Utilities and Design Factors
While not common in all jurisdictions, occasionally pipe bursting takes place through horizontal or vertical curves (Simicevic and Sterling, 2011). Although many long bursts through relatively short radius curves have been successful using both static (rod) and pneumatic systems, careful consideration of methodology is required. It is prudent to plan for the space and excavation requirements of a pit at the midpoint of a run, such as at the apex of a curve. The repair history of the line(s) to be burst should be noted carefully from utility records or video inspection.

Previous repairs may involve heavy repair clamps that can halt a bursting operation. Sometimes, repair clamps can be successfully burst using a cutting blade in combination with the bursting head unless the cutting blade happens to line up with the bolts of the repair clamps. Thick root masses are also considered obstacles
because roots wrapped tightly around the old pipe can absorb a lot of shock without breaking and hence make the pipe harder to break.

Obstructions in the pipe such as heavy solids build up, dropped joint, protruding service tap or collapsed pipe, may prevent the pipe bursting operation completely. If the obstruction cannot be removed from the pipeline by conventional cleaning equipment, it may be necessary to excavate and carry out point repairs prior to bursting. Otherwise, the bursting process may slow or stop. The risk and potential consequences should be considered before starting the job to determine whether to deal with the problem if it should arise or whether to take preventative action. Generally, provisional items in the contract for all potential eventualities will help confirm the final costs.

Zlokovitz and Juran (2005) reported that in practice, existing pipe within two pipe diameters of a burst pipe (especially if the pipe is to be upsized), would be locally excavated to provide stress relief to the existing pipe. The worst cases are when adjacent utilities are unknown and remain undiscovered prior to the replacement operation.

5.7. **Service Connections**

The reconnection of laterals and branches in conjunction with slip lining of gravity pipelines usually needs excavation. It may be possible to cut an opening in the liner prior to grouting, and to insert an inflatable bag into the lateral to seal between the branch and the liner and prevent grout from entering either. However, the complexity of this operation is justified only if external access is very difficult or impossible. This procedure can be used only in larger pipes. In most cases excavation must take place, and the branch must be disconnected, before grouting is carried out. Special couplings are available to reconnect the new junction to the existing branch.

Service connections (sewer, gas and water) to the pipeline being burst can create problems during bursting regardless of whether they are excavated prior to bursting or not (Simicevic and Sterling, 2001). The services are usually excavated prior to bursting to provide temporary bypass service and to protect the services during the bursting operation. If the connections are not excavated prior to bursting, they can easily be damaged and the damage to the service lateral may happen at some distance
from the connection. It can be in a location where the damage would not be detected during the connection process. However, it is reported by Simicevic and Sterling (2001) that if the connections are excavated prior to bursting, a hump in the profile of the replacement pipe at this location is often created. The hump is caused by the reduced resistance to upward movement of the replacement pipe at this point. This problem could be reduced by excavating beneath the pipe, as well as above the pipe, at the connection.

For pipe reaming or eating processes, there is less adverse impact on service connections. During bursting, the riser can be monitored and after bursting, the connection to the main can be excavated and reconnected.

5.7.1. The Service Connector Project

After three years of consultations, designs, and field-testing, the Saskatchewan Research Council (SRC) has produced a final design for a trench cage and winch system specifically designed to pull out residential water service connections and pull in new ones. The Phase 2 design is really based around a standard trench shoring cage, with the addition of a hydraulic winch, pulleys and cabling to allow the extraction operation. This version can be built for an estimated $35,000, which municipal contacts have told us makes it affordable because it can be used as an everyday shoring cage system when not pulling water lines.

5.7.2. Robotics and Service Connections

For the past two years SRC has also been working with CT on designing a prototype robotic system to execute service connection replacements. This year they created a laboratory scale prototype and successfully tested under lab conditions. The system is a platform that engages robotic arms and wrenches to hold both sides of a line, remove and install a new corporation or curb stop. In theory it would be able to complete a replacement in a fairly small bore excavation (3 to 4 feet wide), with no need for a man to go down in the hole.

Obviously, this is still conceptual technology. But the SRC will now be looking for funding to build a full scale prototype, and to test it under real-world conditions. The City of Regina is providing support and assistance to SRC in the continuation of this
work. Further information can be obtained from either Damian Rohraff at the SRC or Bob Youlyashiev at the City of Regina.

5.8. Equipment Installation and Replacement Pipe Preparation

Simicevic and Sterling (2001), illustrated that when the winch and pulling cables are used to pull the bursting tool through the pipe, the winch is placed into a reception pit and the cable pulled through the pipe and attached to the front of the bursting unit in an insertion pit. The winch helps to ensure the directional stability in keeping the unit on the line of the existing pipe.

The winch must supply sufficient cable in one continuous length so that the pull can be continuous between winching points. The winch, cable and cable drum must be provided with safety cage and supports so that it may be operated safely without injury to persons or property. Tremendous forces are generated in these operations. When rigid pulling rods are used instead, they are threaded from the reception pit through the existing pipe until the pipe reaches the insertion pit. The rods are then attached to the bursting head; therefore, there is less danger from snapping or breaking equipment.

5.9. Installation/Rehabilitation Operation

The bursting of the old pipe can be performed as a continuous action if the replacement pipe is continuous and the winch with continuous cable is used. When rigid rods are used as a pulling unit the bursting operation temporarily halts, for each rod sections to be unthreaded and removed from the reception pit. In addition, when the pipe is installed in segments, the preparation of each successive pipe segment also interrupts the operation, as it includes the following steps (Simicevic and Sterling, 2001):

- Changing the machine from pull to push;
- Removing the pulling plate from the previous joint installed;
- Setting the new pipe section and mating it to the previous pipe section;
- Lubricating the coupling with approved materials if required;
- Setting the O-rings or gaskets;
- Pushing the two pipes together;
• Pushing rods back through the new section of the pipe;
• Setting the pulling plate to attach the rods to apply the pulling force;
• Changing the machine back to pull mode; and
• The process continues until the bursting head is pulled completely back into the reception pit, ending the replacement.

5.10. Reconnection of Services and Sealing

The reconnection of laterals and branches in conjunction with slip lining of gravity pipelines usually necessitates excavation. It may be possible to cut an opening in the liner prior to grouting, and to insert an inflatable bag into the lateral to seal between the branch and the liner and prevent grout from entering either. However, the complexity of this operation is justified only if external access is very difficult or impossible. This procedure can be used only in larger pipes. In most cases excavation must take place, and the branch must be disconnected, before grouting is carried out. Electro-fusion is commonly used to fit branches to PE liners, in the same way as for new installations. Special couplings are available to reconnect the new junction to the existing branch.

After the bursting replacement is completed, the installed pipe is left for the manufacturer’s recommended time. Normally this is not less than four hours. Reconnection of service lines, sealing of the annular space in the manhole wall or backfilling of the insertion pit (Simicevic and Sterling, 2001) is carried out after this waiting period. This period allows for pipe shrinkage due to cooling and pipe relaxation due to the tensile stresses induced in the pipe during installation.

Following the relaxation period, the annular space in the manhole wall may be sealed. Sealing is extended a minimum of 200 mm (8 inches) into a manhole wall in such a manner as to form a smooth, watertight joint. Ensuring a proper bond between the PVC or PE replacement pipe and the poured manhole wall joint is critical. Service connections can be reconnected to the new pipe with specially designed fittings by various methods. The saddles, made of a material compatible with that of the pipe, are connected to the pipe to create a leak-free joint. Different types of fused saddles (electro-fusion saddles, conventional fusion saddles) are installed in accordance with manufacturer’s recommended procedures. Connection of new service laterals to the pipe also can be accomplished by compression-fit service connections.
Installation procedures and equipment are to follow manufacturer’s installation instructions and recommendations. After testing and inspection to ensure that the service meets all the required specifications of the service line, the pipeline returns to service. In case of groundwater, the replacement pipe may float at the point of excavation and require careful attention prior to service reconnection.

5.11. Manhole Preparation
For sewer pipe trenchless replacement or lining projects, all confined space entry safety procedures apply as appropriate. Simicevic and Sterling (2001), reported that entry and exit holes from manholes must be enlarged to accept the new pipe as required. The sewer manhole invert may need modification to allow tool passage. In cases of large upsize or when dealing with large diameter pipe, and where surface conditions allow, complete replacement of manholes may be the simplest and least expensive option. This can be beneficial in that a completely new system is the result.

5.12. Testing of New Replacement Pipe
After the installation, a few tests of the replacement pipe are normally performed in a pipe bursting job. The first test is carried out before the pipe has been sealed in place at the manholes, and before any service reconnections have been performed (low-pressure air test) (Simicevic and Sterling, 2001). The purpose of this test is to check the integrity of joints that have been made, and to verify that the replacement pipe has not been damaged during installation.

The second test is the service lateral connections test, performed after all service laterals have been completed for a particular section (smoke test). This test is to verify the integrity of reconnections at points where they join the replacement pipe and existing service lines. Additional acceptance testing following the applicable test procedures is performed if required. A video camera inspection and digital record is a common requirement.

5.13. General Comparison
The following is a general comparison of selected trenchless technologies showing the different aspects of these technologies. The comparison is based on Salem et al. (2008) assessment of trenchless use in culverts and drainage structures. The
information in Table 2 together with collected information from other sources is the basis for the Guideline developed in this report which is detailed in Chapter 7.
Table 2. General Comparison of Selected Trenchless Technologies (Salem et al., 2008)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Diameter Range mm</th>
<th>Maximum Installation m (feet)</th>
<th>Grouting or Resin</th>
<th>Liner Material</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
</table>
| Segmental Slip lining          | 600 - 450 (24 - 17) | 60 - 600 (200 - 2000)        | Grouting - Requires a thin, coarse mortar | Polyethylene, Polypropylene PVC, Glass reinforced pipe | ▪ Expensive specialized equipment is not needed  
▪ It is a simple technique  
▪ It can be used for both structural and nonstructural purposes  
▪ Existing flow does not restrict the process | ▪ Host diameter is typically reduced by ~10%, however, due to the liner pipes good flow characteristics; the hydraulic capacity is frequently improved  
▪ Grouting is required  
▪ Segmental installations, cannot typically push through angle points greater than 1-3 degrees (depends on diameter and clearance) |
| Continuous Slip lining         | 300-1600 (12 - 63) | 60-600 (200 - 2000)          | Grouting - Requires a thin, coarse mortar | Polyethylene, Polypropylene, PVC | ▪ Same as segmental slip lining | ▪ Same segmental slip lining |
| Cured In Place Pipe (CIPP) - inverted with air | 300-2700 (12 - 108) | 800 (3000)                  | Resin - polyester and vinyl ester | Polyester felt material, fiberglass reinforced or similar | ▪ Lining without joints  
▪ Grouting is not necessary  
▪ Smooth interior surface enabling an increase in flow capacity  
▪ Lining noncircular shapes is possible  
▪ Lining can be accomplished even in the presence of bends  
▪ Design life of 50 year – 100 years  
▪ Corrosion resistant  
▪ Relatively quick installation  
▪ A structural solution  
▪ Small cross-section reduction with increased flow capacity | ▪ The tube is custom made for each project  
▪ Existing flow must be diverted  
▪ Successful installation depends highly on the curing process  
▪ It can be expensive  
▪ Must divert any pipe flow |
| Cured In Place Pipe (CIPP) - winched at place | 300-2600 (12 – 100) | 460 (1500)                  | Grouting - varies (Cementitious Grout) | Polyester felt material, fiberglass reinforced or similar | ▪ Same as continuous slip lining | ▪ Same as continuous slip lining |
| Spiral Wound Pipe              | 300-3000 (12 – 120) | Unlimited                   | Grouting - sometimes required (Cementitious Grout) | PE, PVC, PP, PVDF | ▪ Large bends can be accommodated  
▪ Pipes are not stored on the job site  
▪ Mobilization costs are low | ▪ Skilled personnel are needed  
▪ Annuar space should be grouted  
▪ Dependency on a special winding machine  
▪ Reduction of sectional area, however an improvement in the roughness coefficient will compensate for this size reduction in most cases |
| Close-Fit Pipe (two types)     | 300-600 (12 – 24)  | 300 (1000)                  | N/A                | HDPE, MDPE                            | ▪ The new pipe is produced at a controlled environment  
▪ Minimal reduction in the existing pipe area  
▪ Mechanically folded pipes can accommodate 45 degree bends  
▪ Few or no joints  
▪ No grouting is required | ▪ The diameter and installation range is limited  
▪ A large working space is needed  
▪ Usually the flow needs to be bypassed  
▪ Existing culvert must be longitudinally uniform (diameter changes or discontinuous culverts may prohibit this method) (FHWA 2005)  
▪ Relatively complex method requiring special machinery (FHWA, 2005) |
| Mechanically folded liners     | 300-800 (12 – 30)  | 460 (1500)                  | N/A                | HDPE, PVC                            | ▪ The new pipe is produced at a controlled environment (factory)  
▪ Therefore quality is higher and installation is fast  
▪ The cross sectional reduction is minimal, thus minimal or no reduction in flow capacity  
▪ It can provide a design life of a new pipe  
▪ Few or no joints | ▪ Diameter range is limited  
▪ Bypassing the existing flow is required in many cases  
▪ Large working space may be required for some type of installations  
▪ Liner lengths are limited by pull-in forces or coil lengths (FHWA, 2005) |
| Reduced diameter pipes         |                    |                             |                    |                                      | ▪ Only worker entry pipes can be renewed by this method  
▪ Grouting must be applied to the annular space  
▪ Reductions in the cross sectional area may be significant |
| Thermoformed Pipe              | 1000 and larger (42 and larger) | N/A                        | Cementitious or polymer | PVC | ▪ Panel lining can be used in any shape of pipe  
▪ Chemical and abrasive resistant liners can be installed  
▪ It can be installed under restricted flow conditions  
▪ Change in pipe diameter can be negotiated with prefabricated transition | ▪ Only worker entry pipes can be renewed by this method  
▪ Grouting must be applied to the annular space  
▪ Reductions in the cross sectional area may be significant |
Table 2. General Comparison of Selected Trenchless Technologies (Salem et al., 2008)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Diameter Range mm (in)</th>
<th>Maximum Installation m (feet)</th>
<th>Grouting or Resin</th>
<th>Liner Material</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Formed-in-Place Pipe</strong></td>
<td>200-3050 (8 – 120)</td>
<td>&lt;180 (600&quot;)</td>
<td>N/A</td>
<td>Cementitious polymer mortar</td>
<td>- Can be used in any shape (circular, oval, vertically sided, symmetrical, or non-Sym.)</td>
<td>- Significant reduction in cross-sectional area of the culvert is possible</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+120 (400&quot;)</td>
<td></td>
<td>HDPE</td>
<td>- Can serve for both corrosion control and structural purposes and for long-drive length where access is limited</td>
<td>- Access shafts or great clean out process may be required</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+60 (200&quot;)</td>
<td></td>
<td></td>
<td>- Nonstandard shapes up to 12 ft in diameter are possible</td>
<td>- The annular space must be grouted</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- There might be an improved hydraulic capacity by providing a lower coefficient of friction</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Abrasive resistant and chemical resistant, excellent in corrosive environments</td>
<td></td>
</tr>
<tr>
<td><strong>In-Line Replacement</strong></td>
<td>200 - 1220 (8 - 48)</td>
<td>90 - 120 (300 - 400)</td>
<td>N/A</td>
<td>PE, PVC, Ductile Iron, Vitrified Clay</td>
<td>- Can be used for upsizing</td>
<td>- Bypassing of flow is usually required</td>
</tr>
<tr>
<td>(e.g. pipe bursting/splitting and pipe removal technologies)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- A wide range of existing pipe types and diameters are possible to replace</td>
<td>- Ground movements, vibrations, and possibility of damaging nearby utilities and existing structures must be evaluated for specific conditions of each project</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- The new pipe will follow the alignment of the existing culvert</td>
<td>- There is a risk of disturbing the pavement surface above the existing culvert</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- In pipe bursting, the existing culvert is left underground eliminating the need for its disposal</td>
<td></td>
</tr>
<tr>
<td><strong>Underground Coatings and Linings</strong></td>
<td>200 - 4500 (8 - 177)</td>
<td>425 (1400)</td>
<td>N/A</td>
<td>New material - cement-mortar or polymers</td>
<td>- Variations in cross section can be readily accommodated</td>
<td>- Relatively slow installation for cement-mortar lining</td>
</tr>
<tr>
<td></td>
<td>(8 - 177)</td>
<td></td>
<td></td>
<td></td>
<td>- Quick installation, thus higher production in polymers</td>
<td>- Requires safe conditions for worker entry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Polymers do not wear for longer life</td>
<td>- High-level operator skill is required</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- No pH effect for polymer coatings</td>
<td>- Water pH sensitive for cement-mortar lining</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Protects against corrosion</td>
<td>- Control of infiltration is required to prevent procure lining disbondment or collapse</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Some reinforcement can be used</td>
<td>- Slightly higher cost when using polymers</td>
</tr>
</tbody>
</table>
Renewal of aging underground infrastructure and installation of new ones are major challenges that municipalities in Canada and Saskatchewan face every day. Open-cut excavation methods (trenching) are the most widely used methods for traditional replacement or renewal of underground utilities. Contactors tend to use these methods in built-up areas and in projects with difficult soil and groundwater conditions. However, these methods are usually associated with long service disruption time and increasing costs due to the human labour involved and excavation and backfill costs.

Trenchless technologies use innovative methods, materials, and equipment that require minimum surface excavation to renew and construct aging underground infrastructure. They provide a tempting alternative to the traditional open-cut methods due to the minimal surface disturbance. However the direct costs are higher and there are several limitations based on the specific-site conditions.

Infrastructure projects are often motivated by economic criteria as they involve huge investments. The costs and benefits of different renewal and/or installation technologies can be expressed in monetary units. The criteria have been either to maximize the present value of the net benefits (total benefits less the costs) or minimize the costs of providing the service. To achieve the former involves cost/benefit analyses and to achieve the latter involves cost-effectiveness analyses.

The costs associated with any underground infrastructure renewal includes, but is not limited to, installation time, machinery, labour, and service disruption time, which all can be expressed in monetary units to facilitate the comparison of different technologies against traditional open-cut methods.

### 6.1. Cost-Effectiveness Analysis of Trenchless Technologies

Open-cut methods are well documented, and most municipalities have good design and construction specifications to complete these types of projects. The benefits of the open-cut method include:
• Longer expected life for the installed infrastructure than obtainable through most trenchless methods. This is due to the installation of all new appurtenances with the installation of new infrastructure;
• Better line alignment of the sewer and water mains;
• Easier lateral connections replacement and/or connection to meet current standards;
• Easier upsizing and/or grade change to meet current and future needs; and
• Concurrent to other infrastructure rehabilitation and/or replacement.

The drawbacks of the open-cut method include, but are not limited to:
• Substantial side costs (excavation, backfilling, etc.);
• Longer construction time and service disruption time (which can be easily estimated in monetary values) than with most trenchless technologies;
• Higher safety concerns due to traffic issues on road rights-of-way, the number of excavations required, and the large equipment needed to perform the work;
• Increased disturbances to other surface and buried infrastructure; and
• Higher social, third party commercial (business impacts) and environmental costs.

Literature on the feasibility of trenchless technologies usually focuses on a specific technology against the traditional open-cut method. A general comparison, which incorporates different technologies, is either not up to date or limited to a number of technologies. This is associated with the ever changing costs of the involved technologies and new materials introduced to the market.

6.2. Cost Categorization
Apeldoorn (2012) provided a more detailed anatomy of the costs associated with trenchless technologies, which paves the way for better cost-effectiveness analysis. He divides the costs into four main categories, namely;
(i) direct,
(ii) indirect,
(iii) social quantifiable, and
(iv) social non-quantifiable.
Each category is sub-categorized to allow further breakdown of the associated costs. Figure 33 shows a schematic diagram of the cost breakdown with examples for each sub-category.

6.2.1. Direct and Indirect Costs

Direct and Indirect costs are usually referred to as the “Project Costs” or “Construction Costs”, because they can be easily estimated, with a relative minor uncertainty, using standard estimation methods. However, the number of limiting factors affecting the direct and indirect costs may result in misleading estimates for both trenchless technology and/or the traditional open-cut method.

Apeldoorn (2012), presents a summary of cost comparisons of replacement methods, per linear foot installed, published by the Public Works Technical Bulletin, U.S Army Corps of Engineers in 1999, which compares these values to the cost of open-cut and trenchless technology rehabilitation methods, utilizing 1991 USEPA (United States Environmental Protection Agency) values, Table 3.
### Table 3. Summary of Cost (in US Dollars) Comparisons of Replacement Methods per Linear Meter Unit Installed (Apeldoorn, 2012).

<table>
<thead>
<tr>
<th>Pipe Size (mm)</th>
<th>Open-cut (US$/LM*)</th>
<th>Trenchless (US$/LM)</th>
<th>Trenchless Average (US$/LM)</th>
<th>Cost Savings Trenchless Cost vs Open-cut cost (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>275</td>
<td>50-175</td>
<td>292</td>
<td>106.3</td>
</tr>
<tr>
<td>500</td>
<td>400</td>
<td>200-500</td>
<td>345</td>
<td>86.0</td>
</tr>
<tr>
<td>1 200</td>
<td>800</td>
<td>500-1000</td>
<td>675</td>
<td>84.5</td>
</tr>
<tr>
<td>1 800</td>
<td>1,500</td>
<td>850-1600</td>
<td>1,240</td>
<td>82.6</td>
</tr>
<tr>
<td>2 500</td>
<td>3,000</td>
<td>1500-3000</td>
<td>2,545</td>
<td>84.8</td>
</tr>
</tbody>
</table>

* LM = lineal meter

The table supports the conclusion that trenchless technologies, in general, provide cost effective options for underground infrastructure replacement and/or installation. Direct and indirect costs fall by approximately 20% in cases of adopting the suitable trenchless technology, considering all site-specific limitations, for infrastructure replacement and/or installation over the traditional open-cut method.

The Louisiana Technical Institute (LATECH) produced a comparison of different trenchless technologies based on actual bid data, (successful & unsuccessful) on U.S. municipal pipelines. The data uses estimates to infer that in 2003, trenchless technologies provided significant savings over traditional open-cut methods, of up to 75%, particularly in the smaller pipe diameter ranges (Apeldoorn, 2012).

Apeldoorn (2012), presented a conceptual schematic diagram showing effects of the project location and excavation depth on the cost of the traditional open-cut method. As presented in Figure 34, trenchless technologies outweighs traditional open-cut method in high density urban areas, where access, traffic control and the cost of reinstatement of surfaces become more expensive, adding to the per metre/foot of pipe price. The same direct positive relation exists between cost and excavation depth; that is, the deeper the excavation the higher the per unit cost of installation.
6.2.2. Social Costs

Direct and indirect costs are easy to estimate, but if other limiting factors (such as soil type and pipe material...etc) and/or other costs interfere, the costs associated with the trenchless technology may exceed that of the traditional open-cut method, especially in low traffic density areas and shallow depth conditions.

Rahman et al. (2005) showed that the open-cut method is capable of causing major disruption to commerce and the general public. As a result, identification and quantification of the costs associated with service disruption and inconveniences are the key to provide a proper comparison between different trenchless technologies and traditional open-cut construction methods. These social costs may include, but are not limited to:

- Disruption to traffic and to business activities;
- Damage to existing paved surfaces;
- Adverse environmental impacts; and
- Disruption to normal life patterns of the people living, working and shopping around the construction zone.

Quantification, or in other words, the estimation of the equivalent monetary values of these disruptions is crucial to the incorporation these costs into the overall evaluation of the proposed method of installation and/or renewal of the underground infrastructure. These social costs are paid for by the community at large, and not realized as a direct project cost that is included in the tendered contract price (Apeldoorn, 2012).
Scattered literature is available regarding the estimate of the social impact costs for open-cut projects, which are estimated to range from 6% to 78% of the direct and indirect costs of the project. Pucker et al. (2006), estimate social impact costs for trenchless technologies to be in the range of 3%.

Rahman et al. (2005), presented a different way of sub-categorizing social costs based on their time duration, accuracy of estimate and bearer of the cost. As shown in Table 4, the sub-categorization provides better insight into the social costs and the entity bearing these costs to be included into the infrastructure project evaluation. In general, trenchless technologies can reduce indirect and social costs and consequently reduce the total Life Cycle Cost (LCC) of an infrastructure project. Najafi and Kim (2004), investigated cost-effectiveness for trenchless technology and open-cut methods over the life cycle of buried pipes, qualitatively.

Table 4. Social Costs Category and Implications for Payments and Responsibility, (Rahman et al., 2005)

<table>
<thead>
<tr>
<th>Social Cost Category</th>
<th>Time Duration</th>
<th>Accuracy</th>
<th>Bearer of cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Immediate</td>
<td>Accurate - can be accounted for using general accepted accounting principles</td>
<td>Municipal, provincial, national organization. Some costs may be passed on to contractor.</td>
</tr>
<tr>
<td>II</td>
<td>Short-term</td>
<td>Estimate - cost is based on estimate of cost to project</td>
<td>Municipal, provincial, national organization, contractor, tax payer</td>
</tr>
<tr>
<td>III</td>
<td>Long-term</td>
<td>Guestimate - minimal confidence in accuracy of cost, or the cost is uncertain.</td>
<td>Tax payer, insurance company, society</td>
</tr>
</tbody>
</table>

The limited information on the Canadian market and the available literature on cost analysis studies hinder the evaluation of social costs on the national level. However, evaluation of social costs in trenchless projects can benefit from the studies at the relatively similar US market.

The contribution of social costs relative to the project construction cost was estimated for 14 construction projects (10 open-cut and 4 trenchless methods) by McKim (1997). The social costs from traditional open-cut method ranged from 44% to 492% of the construction costs, whereas social costs for trenchless technologies ranged from
0% to 11% of construction costs. These numbers support the conclusion of Pucker et al. (2006) that the average social cost, as a percent of construction costs, ranges up to approximately 78% for the traditional open-cut method to only 3% for trenchless technologies.

Figure 35 is adopted from Apeldoorn (2012), which represents 3 case studies of estimated cost comparisons for trenchless construction and open-cut installation methods, including social costs (Pucker et al. 2006). This figure provides a further break down to the contribution of social costs to the overall cost of the project. It should be noted that Case Study 3 was carried out in a Greenfield subdivision, while Case Studies 1 & 2 took place in high-density urban areas in the United States of America. Therefore, the social cost ratio to the construction cost, in Case 3, is relatively smaller than the social cost ratios in Cases 1 & 2.

![Figure 35. Relative Contribution of the Different Categories of Social Costs and Direct Costs for Case Studies, (Apeldoorn, 2012)](image)

6.3. Cost-Effectiveness Comparisons

6.3.1. Pipe Bursting Versus Open-cut Trenches

The Trenchless Technology Center (TTC) Technical Report (Simicevic and Sterling, 2001) was the first available attempt to carry out a comprehensive quantitative comparison, focusing on the “Pipe Bursting” technology costs. The comparison was based on a cost-related questionnaire sent to different contractors and municipal agencies in the USA. The results of the questionnaire establishes a rough price range for actual bids on pipe bursting projects, which includes all costs associated with the different pipe bursting, without breaking down those costs to provide more
comprehensive comparison and the contribution of different cost categories. The survey focused on size-to-size pipe replacement and upsizing pipe replacement, based on 1999 prices as shown in Figure 36 and Figure 37. Current US prices can be extrapolated based on the prevailing inflation rates from 1999 to the 2012, which amount to 40% more than the 1999 prices.

Both graphs show that the unit bid cost increases steadily with the increase of the pipe size for all technologies, which is reasonable due to the increase in time, labour and energy associated with larger pipe diameters. The rate of increase in the size-to-size pipe replacement exhibits sharp inclination indicating the exponential increase in all costs. Using the 2012 prices, the average unit bid price ranges from approximately 179 USD/LM (linear meter) for 160 mm (6 inch pipe) to 538 USD/LM for 450 mm (18 inch) pipe (approximately a 3 times cost increase due to a corresponding increase in the pipe size). This range changes from 761 USD/LM for 600 mm (24 inches pipe) to 1792 USD/LM for 1200 mm (48 inches) pipe.

![Figure 36. Bid cost for Pipe Bursting Technologies for Size-to-size Pipe Replacement Based on 1999 Prices (Simicevic and Sterling, 2001)]
Similar behaviour occurs in the upsizing graphs (both small upsizing and large upsizing), where the steady increase in the unit cost exhibits significant change for large pipe sizes. The key focus presented in the graphs is that due to the limitations of different trenchless technologies with respect to site-specific conditions, it is not possible to provide unit prices for all pipe sizes for all trenchless technologies.

Simicevic and Sterling (2001) provided a case study to compare pipe bursting and traditional open-cut methods. The main cost prohibiting factor in using the traditional open-cut method is the depth of the trench, especially in unstable soil, as the cost of the excavation exponentially increases with the increase in the trench depth, which is evident in sewer replacement projects. The Simicevic and Sterling report (2001) shows an example of the cost comparison of pipe renewal with open-cut vs. pipe bursting introduced by Poole et al. (1985).
Pipe bursting prices in 2003 were published by the US Department of Agriculture for replacing Service Forest culverts. The prices range from $4486-$896/LM for 450 mm (18 inch) pipe to $3808/LM for 1200 mm (48 inch) pipe, adjusted to 2012 prices. Although the low end of the price corresponds to the previous numbers, the high end of the price range is much higher than the bid costs from the 1999 prices, which could be contributed to other indirect costs for remote places.

Figure 38 shows that, in general, the existence of other limiting factors such as problematic soil, heavy traffic and limited road service disruption provides pipe bursting technology (and any other trenchless technology) with an advantage over the traditional open-cut method for all trench depths. Trench depth becomes an economic limiting factor for using trenchless technology for depths less than 3 m, provided that all other limiting factors are not of high priority.

Hashemi (2008) carried out a cost comparison of pipe bursting as a typical example of trenchless technology and the traditional open-cut method. The TTC database and a pre-set questionnaire were used to provide the necessary data (up to 2007) for carrying out the cost comparison. A case study was provided to support the findings of Hashemi’s conclusions. The case study was based on data for replacing the sewer pipeline in the City of Troy, Michigan. The results of the research indicated that pipe
bursting (as a widely used trenchless technology) in many cases would be more cost-effective than the traditional open-cut method.

The research focused on two cost aspects, namely pipe size and lengths, without shedding any light on the effect on other factors such as soil and groundwater conditions, pipe alignment, energy, side effect remediation, etc. However, he used the TTC data and the survey results to statistically test his hypothesis that “the average price of pipe bursting technology”, and generally any trenchless technology, “is less than the open-cut method”.

The case study indicated that the replacement of the sewer pipeline in the City of Troy will cost $2.3 US/LM per mm of the pipe diameter ($18 US/Lf per inch of the pipe diameter), using the traditional open-cut method. The cost becomes $1.4 US/LM per mm of pipe diameter ($11 US/Lf per inch of the pipe diameter) in the case of using Pipe Bursting technology, thus, pipe bursting costs 40% less than the traditional open-cut method.

6.3.2. Other Trenchless Pipe Replacement Costs

The Forest Service of the US Department of Agriculture published, in September 2005, a summary of trenchless technology focusing on the use for forest service culverts. Slippining was applied to culverts up to 1600 mm in diameter for continuous pipe and up to 400 mm for segmental pipe. The cost varied from $175/LM for 450 mm (18 inch) diameter pipe to $1,700/LM for 1 500 mm (60 inch) diameter pipe.

Spiral wound pipe lining was applied to the forest service culverts of pipe size range 200 mm to 3 000 mm diameter. The price ranged from $350/LM for 450 mm diameter pipe to $2,500/LM for large pipe diameters. CIPP was also applied to pipe diameters up to 2 700 mm (108 inches) for $350/LM for 450 mm diameter pipe to $2,700/LM for larger pipe diameter. Horizontal Auger boring price ranged from $650/LM for 450 mm diameter pipe to $3,300/LM for 1500 mm diameter pipe. Pipe jacking ranged from $350/LM -3,000/LM for 900 mm diameter pipe.

6.3.3. Examples of Trenchless Technology Cost-Effectiveness

Current practices of many municipalities in North America favour trenchless technologies due to their apparent cost-effectiveness. For example, the City of
Windsor, Ontario, in June 2012 completed installation of 1,150 m of 900 mm diameter High-Density Polyethylene (HDPE) pipe along the busy Ojibway Parkway in the City’s industrial west end, a route which is also a major commuting thoroughfare to Windsor’s southern suburbs.

Using trenchless technology (pipe bursting) provided an advantage in that the City had to close just one southbound road lane, keeping all the utilities in place. Estimates of using Open-cut method indicated that the total project cost would be 20% to 40% higher than the current project cost of $3,795,000. A similar pipe bursting project was carried out in the City of Tallahassee, Florida, in 2008 to carry out HDPE pipe replacement. The total reported savings for the three kilometre project was estimated to be about $250,000.

Mohamed et al. (2008) presented a case study to examine the cost-effectiveness of trenchless technology (pipe bursting) compared to the open-cut method for replacing sewer pipes in the City of Troy, Michigan. The cost for sewer pipeline replacement in Troy using the open-cut method was estimated to amount to approximately $408 million. The estimated cost using the trenchless pipe-bursting technology was about $304 million.

The Pipe Bursting technology resulted in savings of 25.5% of the total project cost. Mohamed et al. (2008), calculated the unit price in each method based on the pipe size and length. It was determined that the Open-cut method costs would be about $250/LM per 100 mm of diameter. Trenchless pipe-bursting method costs were estimated to be $200/LM per 100 mm. Therefore trenchless technology appeared to be is less expensive than the open-cut method by about $50/LM per 100 of diameter. It should be noted that these savings do not include other indirect and social costs which will further add to the total savings achieved through trenchless technology.

6.3.4. Direct Cost Estimation
The factors affecting different trenchless technologies represent a difficulty in unifying their cost estimation. However, a few generic formulas were developed to estimate the cost of specific trenchless technology for various pipe materials. Zhao (2003) presented a formula that estimates the direct cost for water main rehabilitation,
excluding social costs. The formula was based on the published cost data of slip lining projects in North America for water main rehabilitation using HDPE pipes:

\[ C = 1.18 \cdot D^{1.053} \cdot L^{0.944} \]

Where:

C is the direct cost (Canadian $).

D is the diameter of the liner pipe (mm).

L is the total rehabilitation length (m).

Trenchless technologies provide significantly cheaper and more socially acceptable alternatives to traditional open-cut methods. The cost of trenchless rehabilitation in many places in the world is decreasing as the market becomes more mature and development of new technology produces a positive effect in reducing unit rates. Meanwhile, open-cut methods are becoming more expensive as the indirect costs of fuel, disposal of waste, environmental and social impacts increase.

Social costs can be in the range of up to 78% of the construction costs on certain projects. The problem lies in quantification of those costs based on widely accepted generalized methods. Therefore, social costs are sometimes identified and estimated using existing practices.

A proper comparison of trenchless technologies vs. open cut method should be based on a generic and comprehensive social cost protocol that can be used by different municipalities to identify and quantify social costs. Failure to account for the different indirect and social costs of an infrastructure project in the LCC of a project may result in poor decisions.
7. DECISION SUPPORT FOR TECHNOLOGY SELECTION

Selection of the most appropriate trenchless technology has been the focus of many publications. Several guidelines are available, most of which focus on specific application, i.e. water distribution system, sewer mains, etc. These guidelines provide guidance in selecting technologies for rehabilitating or replacing sections of different utilities. They are generic in nature and usually touch on the main issues associated with the selection of the appropriate trenchless technology.

Application of different trenchless technologies faces the usual reluctance of the decision maker to new technology. Decision makers in different municipalities usually require a solid proof before the introduction of any new technology into their communities. High initial costs, lack of published performance data on similar projects and local availability of the technology add to the doubts about the utility of trenchless technology in replacement and rehabilitation of aging infrastructure.

7.1. Decision Support Systems

Decision support systems, developed to address the problem of existing wastewater collection and water distribution systems renewal, involve the evaluation of many criteria and the associated parameters. Careful evaluation of different criteria provides means for the selection of optimal approach for rehabilitating or replacing those systems efficiently and cost-effectively. Methodical approaches, used in developing these decision support systems provide better insights into the selection process and allow the proper assessment of the feasibility of the selected renewal method.

EPA (2011) presented 8 (eight) case studies to show different selection processes in the United States. EPA (2011) points out the problem of limited number of commercial and/or public decision support models, which hinders the development of a nationally accepted systematic decision support model. In the review, only 20 models were developed during the last 17 years. EPA (2011) reviewed the 7 (seven) most complete models. The assessment of the complete model is based on the following capabilities:
• Processing condition assessment data;
• Screening multiple technologies based on various technical parameters;
• Performing cost analysis; and
• Ranking applicable technologies.

The following is a summary of the review carried out by EPA (2011) on the different decision support models. The models are classified into three main categories; (1) General models, (2) Wastewater models, and (3) Water models. General models, as can be inferred from the name, can be applied for selecting rehabilitation technologies for both sewer and water infrastructure, with a special focus on the Trenchless Assessment Guide (TAG) and the Trenchless Assessment Guide for Rehabilitation (TAG-R).

7.2. TAG and TAG-R

TAG provides a selection of construction methods for new installations or off-line replacement of sewer pipes, while TAG-R is used for rehabilitation selection. TAG contains technical data for more than 25 technologies while TAG-R contains more than 80 methods (Matthews et al., 2005; Matthews, 2010). Both versions were combined into a web-based application on the Trenchless Technology Center at the Louisiana Tech University (http://www.tagronline.com/index.asp), where it contains 20 trenchless technologies and 2 open cut methods for new pipe installation, 6 inline replacement methods, 34 trenchless rehabilitation methods, and 18 restoration and/or replacement methods of manholes.

Like any decision-making approach, TAG starts with problem identification (predefined in TAG-R), whether it is a structural or capacity problem. Specifics of the project, under consideration, are then inputted together with soil conditions. The most important component in TAG is the risk analysis component, which ranks different applicable technologies based on six risk parameters used to produce a final ranking based on risk scores (EPA, 2011). These risks are listed below:

- Length ratio (percentage of maximum database value);
- Diameter ratio (percentage of maximum database value);
- Depth ratio (percentage of maximum database value);
- SET Index (availability of specifications, owner’s experience and track record);
- Environmental Impact (ground settlement and heave; erosion; removal of trees and flora; creation of temporary hazards and the potential for the migration of drilling fluids to the surface); and
- Site accessibility (Qualitative measure).

EPA (2011) identified the two main gaps in TAG/TAG-R models, namely the lack of:

- Cost related details, which affects the utility of the model to municipalities where funding issues are usually paramount; and
- Specific defect or defect codes.

However, review of different risk parameters indicate that environmental impacts are based on qualitative measures and do not include other aspects of environmental concerns such as carbon dioxide emissions. This concern has a direct effect on technologies’ costs and the potential adverse impacts.

7.3. Generic Models
EPA (2011) reviewed 5 generic decision support models; TAG (2006), TAG-R (2008), Matthew (2010), Maniar (2010), and Hastak and Gokhale (2005). In general, these generic models have similar architecture, starting with problem identification and determination of its causes, then incorporating pipe characteristics and project specific requirements.

These models are designed to be applicable to different infrastructure utilities; water, sewer, and road infrastructure. EPA (2011) states that only the Matthews (2010) model has the four basic components required to satisfy the EPA criteria for any generic decision support model; an extensive database of the available technology; technical evaluation of the project conditions and characteristics; a cost analysis module; and a final method ranking. EPA (2011) indicates that none of the models has the ability to process different project conditions (except pipe condition to some degree).

7.4. Water and Wastewater Guidelines and Models
Several guidelines have been developed, during the last three decades, specifically for either water or wastewater applications, without the need to adapt, as in generic models. Guidelines presented by the Federation of Canadian Municipalities and
National Research Council (2003) presented two guidelines for rehabilitation and/or replacing; water mains, and wastewater systems, Figure 39 and Figure 40. Both guidelines start by identifying the nature of the infrastructure problem and allow the separation between structural related and non-structural related problems. This separation narrows the number of the applicable trenchless technologies.

The generic nature of these guidelines makes them applicable to similar linear infrastructure utilities such as gas/oil and power utilities. However, the final short list of the selected trenchless technologies, developed using these guidelines, does not provide a means to rank those technologies or insights into pros and cons of each technology. Attaching numeric values to quantify pros and cons of each technology provides a comprehensive tool for the selection process; i.e. a decision tree like process.

A list of the several guidelines developed specifically for wastewater applications, without the need for adaptation or modification, were presented by EPA (2011) as in the case of using generic models. These models are listed below:

- **Wastewater Systems**
  - German Society for Trenchless Technology (GSTT) basic guide for pipe construction and rehabilitation;
  - Existing Sewer Evaluation and Rehabilitation Manual (Water Environment Federation (WEF), 2009);
  - Sewer Rehabilitation Manual (SRM), Sewerage Risk Management Web (UK Water Research Center, 2010);
  - National Guide to Sustainable Infrastructure or InfraGuide, National Research Council Canada (NRCC, 2007);
  - Duggan and Doherty (1995);
  - Bielecki and Stein (1997);
  - McKim (1997) hierarchy-based model;
  - Abraham et al. (1998) rehabilitation of large combined sewers;
  - Shahab-Eldeen and Moselhi (2001) rehabilitation of concrete and clay sewer pipes;
  - Diab and Morand (2001; 2003) mutli-criteria analysis based selection model;
Figure 39. Rehabilitation and/or Replacing a Water Main Flow Diagram (FCM and NRC, 2003)
Figure 40. Rehabilitation and/or Replacing a Storm and Wastewater Systems Flow Diagram (FCM and NRC, 2003)
• Trenchless Technologies and Work Practices Review for Saskatchewan Municipalities, Communities of Tomorrow, SK

- Plenker (2002);
- Bairaktaris et al. (2007) closed-circuit television (CCTV) data based and neural network classifiers;
- Schroeder et al. (2008) extracting sewer defects from a Geographic Information System (GIS) database;
- Computer Aided Rehabilitation of Sewer Networks (CARE-S) multi-criteria methodologies to provide decision support (Bauer et al., 2005); and
- Halfawy et al. (2008), a prototype GIS-Based model, with modifications suggested by Plenker (2002).

- Water Systems
  - KANEW and PARMS (Burn et al., 2003), long-term rehabilitation and/or replacement strategies;
  - M-PRAWDS, Kleiner et al. (2001) Identification of optimal rehabilitation strategy;
  - Comprehensive Decision Support System (CDSS), Deb et al. (2002), selection of appropriate renewal methods for water distribution mains less than 600 mm (24 in);
  - Computer Aided Rehabilitation of Water Networks (CARE-S) multi-criteria methodologies to provide decision support (Bauer et al., 2005);
  - Ammar et al. (2010) selection and ranking methods;
  - The American Water Works Association (AWWA) M28 (2001), Manual flow charts for selecting rehabilitation techniques for resolving water system problems, Figure 41;
Figure 41. AWWA M28 Manual, Flow and Leakage Problems (AWWA, 2001)

- **Pipe has Poor Flow/Pressure and/or Excessive Leakage**
  - **Pipe HAS Structural Problems**
    - Go to Figure 2-3
  - **Pipe DOES NOT HAVE Structural Problems**
    - Renovated pipe would give INADEQUATE Hydraulic Performance
      - Many connections? Easy excavation/restoration? Low social disruption?
        - Yes to any R(C)
        - No to all R(C), R(PB)
      - Pipe HAS Excessive Leakage
        - Many connections? Easy excavation/restoration? Low social disruption?
          - No to all Joint Seals (D>16") R(C), R(PB), R(SL), L(4), L(2/3)
          - Yes to any R(C), Joint Seals (D>16")
    - Renovated pipe would give ADEQUATE Hydraulic Performance
      - Aggressive/Soft Water?
        - No to all Cement Lining Epoxy Lining
        - Yes to any Epoxy Lining

**Legend:**
- R(C)–Replacement (Conventional or Boring/Directional Drilling)
- R(PB)–Replacement (Pipe Bursting)
- R(SL)–Replacement (Sliplining)
- L(2/3)–Lining (Semi-Structural–Class II/III)
- L(4)–Lining (Structural–Class IV)
- Joint Seals (D>16")–Joint Seals for Diameters Larger than 16"
The common drawback of all the previously mentioned models and guidelines is the applicability to the North American market due to lack of applicable technologies and the associated costs in the national market. Some of these models, such as Halfawy et al. (2008), have the capability to be adopted for the North American markets. Other models can be used as precursors to nationally adopted guidelines and models, where some of these models are web-based and can be easily manipulated to accommodate the national market. The following table is adopted from USEPA (2011), which summarises the review results of the listed models.

7.5. A Guideline for Selecting Rehabilitation and/or Replacement Technology

The number of commercially available guidelines and selection procedures, for various infrastructure applications, demonstrate that it is not possible to create a generally acceptable yet simple tool. The nature of each application and specific considerations of each project require a flexible tool that can be used to both highly complicated problems and simple projects. Continuously developing trenchless technologies and spatially changing cost and environmental aspects add to the problem of the feasibility and possibility of developing such a tool. However, different guidelines and procedures share basic elements such as problem identification (to certain level of details), matching available technologies to the specific problem and providing the decision maker with easy to use ranking criteria for the selected technologies.

Availability of skilled human and technical resources in Canada in the field of trenchless technology, especially in the Prairie Provinces, limits the utility of the wide variety of the available trenchless technologies. This is in addition to the limited information on the cons and pros of nationally available technologies. An easy to use generic guide selection tool was developed to bridge this gap. The tool is easily adoptable by any municipality and can be improved by the user to cope up with site or community specific requirements and limitations.
<table>
<thead>
<tr>
<th>Model/guideline</th>
<th>Defect Data</th>
<th>Extensive Database</th>
<th>Technical Evaluation</th>
<th>Cost Analysis</th>
<th>Ranking Method</th>
<th>North America Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wastewater Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duggan and Doherty (1995)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bielecki and Stein (1997)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>McKim (1997)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Abraham et al. (1998)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Shahab-Eldeen and Moselhi (2001)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Diab and Morand (2001)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Plenker (2002)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Baur et al. (2003)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bairaktaris et al. (2007)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Schroeder et al. (2008)</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Halfawy et al. (2008)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CARE-S</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Water Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KANEW and PARMS (Burn et al., 2003)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>M-PRAWDS</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>CDSS Deb et al. (2002)</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>CARE-W</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Ammar et al. (2010)</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>AWWA M28 Manual Flow charts, (2001)</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
The following is a presentation of a simplified generic guideline (Figure 42), developed by PINTER, to accommodate both water distribution and wastewater systems. The main objective of the developed guideline is to provide municipalities in Saskatchewan with a user friendly guideline. The guideline is developed using a simple EXCEL® spreadsheet with selection dropdown lists and calculation formulas. The user can incorporate additional technologies, in addition to the ones listed in the guideline, and update the corresponding information according to the local conditions.

The flowchart in Figure 42 shows the process used to determine the technologies available for a specific situation. The flowchart begins by identifying the municipal system under consideration (namely drinking water and wastewater), which corresponds to a set of specific problems. Municipal system identification dictates the type of the problem(s) that initiated the need to rehabilitate and/or replace. The second step addresses potential system problem(s), where the answers to the different problems and its size narrow the list of the suitable solutions.

The available options focus on two possible alternatives: replacement/structural rehabilitation, or non-structural and semi-structural rehabilitation, which corresponds to the classification of the AWWA Manual of Water Supply Practices (M28) Rehabilitation of Water Mains, second edition (2001). Each technology can meet specific needs based on the structural integrity of the section under consideration requiring remedial action.

The selected technologies, based on the information supplied by the user, is ranked based on five main criteria; maximum pipe length and size, maximum drive length, site accessibility and pipe material, as shown in Figure 42. The selection of the criteria is optional and can be easily modified by the user through adding additional criteria to the method database spreadsheet. Ranking is carried out based on a single criteria or multi-criteria basis. The multi-criteria ranking is carried out using a simple score ranking method, which can be modified according to the user’s preference.

A digital copy of the excel sheet of the guideline is attached to this report.
Figure 42. Guideline for Selecting Rehabilitation and/or Installation Trenchless Technology for Municipal Infrastructure
Figure 43. Ranking Criteria for the Selected Technologies.
The following are screen shots of spreadsheets of the guideline for two different cases; (1) water distribution system and (2) wastewater system. The method database spreadsheet is shown in Appendix B, where different properties corresponding to each trenchless technology are specified in different fields such as applications, technical aspects, site specific conditions...etc. Water distribution system and wastewater interface screens are shown in Appendix B.
8. TRENCHLESS TECHNOLOGY APPLICATION IN SASKATCHEWAN AND THE WORLD

8.1. Introduction

The use of different trenchless technologies in many infrastructure projects is rapidly increasing worldwide. This is supported by the continuously increasing urbanization in both developed and less developed countries, Figure 44. Aging infrastructure in the Western world, and in particular in Saskatchewan, will require the most cost effective processes available. The variety of trenchless technologies capable of handling different projects and site conditions offers an advantage in favour of those technologies over the traditional open cut methods.

![Figure 44. World Urban and Rural Population, 1950-2030 (the World Urbanization Prospects, 2006)](image)

A survey of the trenchless market in North America (Underground Construction, 2007) indicates that the percent of trenchless market ranges from 16.2% to 22.1% for the new construction of both water main and wastewater projects, respectively. The percent share for the rehabilitation projects ranges from 30.9% to 69.2%, wastewater and water main projects, respectively.

The following is a summary of different trenchless projects around the world from Ariaratnam, S.T., (2010). The Table 6 shows the wide aerial coverage of these
projects and with different types of infrastructures. The table shows the variety of projects in which different trenchless technologies are applied. These projects were capable of handling different soil conditions and managed to work in the most difficult terrain in heavily populated urban centers, especially in the less developed countries in South America, Asia and Africa. The feasibility of applying trenchless technology is clearly demonstrated in mega infrastructure projects where the budget is usually in the order of millions of US Dollars. Relatively small infrastructure projects are also considering low cost trenchless technologies due their indirect social and environmental costs.

8.2. Trenchless Technology in Saskatchewan

The Prairie Provinces vary in their acceptance and application of trenchless technologies. British Columbia and Alberta lead the western provinces in the number of projects utilizing trenchless technologies. Therefore, British Columbia region was approved as a separate chapter by the North American Society for Trenchless Technology (NASTT) in 2005 (NASTT, 2005). The number of relatively highly populated urban centres, difficult terrain, and intensive oil industry projects are the main reasons for the preference of trenchless technologies in infrastructure projects in those three provinces. Utilization of different trenchless technologies in infrastructure projects is limited in Manitoba and Saskatchewan. This limitation is a direct result of fewer heavily populated urban centers and professional contractors.

A questionnaire survey was drafted (Attached in Appendix A) to collect information on trenchless projects in Saskatchewan. The main objective of the questionnaire was to obtain information, from different parties (professionals, municipalities’ officials and contractors), on the type of trenchless technologies applied in the province and the factors affecting the applicability of different technologies. Only a limited number of replies were received. PINTER carried out a web search on the trenchless contracts in the province together with direct personal contact, which did not explicitly indicate the type of the preferred installation method.
<table>
<thead>
<tr>
<th>Region</th>
<th>Country, City, State/Province</th>
<th>Projects</th>
</tr>
</thead>
<tbody>
<tr>
<td>South America</td>
<td>Brazil, Sao Paulo &amp; Rio de Janeiro</td>
<td>Petrobas’ GASTAU project involves 97km of 28” diameter natural gas pipeline with numerous crossing utilizing auger boring. Water pipeline program in Campinas to rehabilitate 2.4km using trenchless methods including pipe bursting.</td>
</tr>
<tr>
<td></td>
<td>Colombia</td>
<td>Numerous project involving micro-tunneling, CIPP, and HDD in Bogota and Medellin.</td>
</tr>
<tr>
<td></td>
<td>Venezuela</td>
<td>Various oil &amp; gas pipelines and telecommunications using HDD</td>
</tr>
<tr>
<td>North America</td>
<td>USA, Honolulu, HI</td>
<td>Currently undergoing a $516USD Million wastewater improvement upgrade program.</td>
</tr>
<tr>
<td></td>
<td>USA, Portland, OR</td>
<td>6.7 m TBM of a 9.5km tunnel as part of a two decade $1.4USD Billion sewer overflow reduction.</td>
</tr>
<tr>
<td></td>
<td>USA, New Orleans, LA</td>
<td>$196USD Million over 5 years to address sewage leaks.</td>
</tr>
<tr>
<td></td>
<td>USA, San Francisco, CA</td>
<td>$4.3USD Billion SF Water System Improvement Program. Micro tunneling installation of 1,280m, 96” concrete cylinder pipe at $55.67USD Million.</td>
</tr>
<tr>
<td></td>
<td>Canada, Alberta, Canada</td>
<td>Installation of 900mm diameter twin sanitary sewer force mains 1,350m and 1,200m crossings of the Athabasca River by HDD.</td>
</tr>
<tr>
<td></td>
<td>Canada, Peace River, Alberta</td>
<td>River crossing installation of 1,100 m, 42” natural gas line using HDD intersect methods (1.1 M &amp; 160K lb rigs).</td>
</tr>
<tr>
<td></td>
<td>Canada, Hamilton, Ontario</td>
<td>Major inspection program for Western Sanitary Interceptor (WSI) using GPR, Sonar, CCTV. Over 1.5km of 1.525mm diameter pipe.</td>
</tr>
<tr>
<td>Asia</td>
<td>Malaysia</td>
<td>Major sewer infrastructure projects using Microtunneling.</td>
</tr>
<tr>
<td></td>
<td>Sri Lanka</td>
<td>Three TBM’s used on a 44.6 km raw water tunnel.</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>Delhi and Jaipur sewerage upgrade programs and Oil pipeline projects using HDD.</td>
</tr>
<tr>
<td></td>
<td>China</td>
<td>Major oil and gas project including 2.6 km West-East gas pipeline crossing of the Chang Jiang River using HDD. $23.3USD Billion West-East gas pipeline project involving the installation of 8.704 km using HDD. Major tunneling projects in Wuhan, Shanghai, Guangzhou, and Chengdu.</td>
</tr>
<tr>
<td></td>
<td>Singapore</td>
<td>50 miles of CIPP rehab valued at $18.5USD Million as part of a major $295USD Million sewer rehab program (2009-14).</td>
</tr>
<tr>
<td></td>
<td>Bahrain</td>
<td>National Master Plan for Sanitary Engineering involves the installation of over 20km of new trunk sewer using micro-tunneling over the next 20 years.</td>
</tr>
<tr>
<td>Australia</td>
<td>Sydney, Australia</td>
<td>Wastewater project at Sydney Harbour using HDD.</td>
</tr>
<tr>
<td></td>
<td>Western Australia</td>
<td>$10.9USD Million relining of mining pipelines.</td>
</tr>
<tr>
<td></td>
<td>Auckland, New Zealand</td>
<td>HDD and CIPP projects are currently underway.</td>
</tr>
<tr>
<td>Europe</td>
<td>Russia</td>
<td>Major gas pipeline construction using HDD including 108 crossing on the Kasimovskoye UGS-Voskresensk CS trunk-line.</td>
</tr>
<tr>
<td></td>
<td>Amsterdam, Holland</td>
<td>Slip lining and pipe jacking program at Schipol Airport to repair cracks in sewer pipes under runways.</td>
</tr>
<tr>
<td></td>
<td>Czech Republic</td>
<td>Pipe jacking of 56m or 1,200mm Hobas pipe and parallel DN1 400mm steel pipe for water.</td>
</tr>
<tr>
<td></td>
<td>Aarhus, Denmark</td>
<td>CIPP of 400m sewer pipe with a cross-section of 2 m²</td>
</tr>
<tr>
<td></td>
<td>Dalum, Denmark</td>
<td>Pipe jacking 750m of 2.5 and 1.6m pipe to reduce overflow of combined sewer system.</td>
</tr>
<tr>
<td>Africa</td>
<td>Durban, South Africa</td>
<td>$205USD Million Asbestos Cement Pipe Replacement Project involving 1,750km of water pipe replacement using pipe cracking.</td>
</tr>
<tr>
<td></td>
<td>Johannesburg, South Africa</td>
<td>$1.7USD Million project involving the installation of multi-duct pipe (electrical, gas, fibre optic, hot/chilled water) using HDD.</td>
</tr>
<tr>
<td></td>
<td>Cairo, Egypt</td>
<td>Various trenchless projects using Microtunneling and HDD, especially the Greater Cairo Underground tunnels under the Nile and Al-Azhar Tunnel.</td>
</tr>
</tbody>
</table>

* Not all of these projects are in 2010.
The application of trenchless technologies is still limited; whether in number of the projects or the type of technologies applied to different infrastructure projects. The few replies and direct contact conversation revealed the following facts:

- CIPP has been the standard trenchless technology utilized by the City of Saskatoon due to its cost effectiveness compared to other technologies – both open and trenchless.
- Decision making for using trenchless technologies is influenced by external factors. For example:
  - The existing roadway and/or crossing condition. If the existing roadway and/or crossing are in poor condition and require complete replacement, the evaluation of implementing a trenchless technology will involve more than simply comparing open cut installation to trenchless technologies, or trenchless technologies against one another.
    - The project would then be compared as a whole, i.e. cost effectiveness of carrying out an open cut replacement and/or refurbishment and install a new road in a single project, or implementing a trenchless technology then replace the roadway; and
    - It is often more desirable to install a new pipe and replace the existing roadway than to perform both jobs separately.
  - The availability of professional contractors. For example, the City of Saskatoon occasionally utilizes shotcrete technology for refurbishment of manholes. However, there is only one contractor in the City of Saskatoon capable of performing such work, therefore, the City is exploring additional technologies to force a more competitive market.
- The following technologies are used in many infrastructure projects in the City:
  - Cured-in-Place Pipe (CIPP) rehabilitation technology is the standard for the City of Saskatoon in:
    - Sanitary sewer – 100% CIPP;
    - Water Mains – CIPP is becoming increasingly common since 2010;
    - Largest used by City – 400 mm;
    - More common for small diameter (major)
    - Slip lined before (only previous over-sized pipe)
    - For pressure pipes (not gravity) – commented on the 400 mm
- Approximately 100 sewer lines per year
- Approximately 10-13 water lines per year
- Approximately 200 connections per year
- Every 3-5 years, interceptor larger diameter projects (main lines)
  - Pipe bursting technology has been used for connection replacements for specific locations but is being replaced by CIPP due to limited local contractors.
  - Shotcrete is used for manhole refurbishment, where approximately 50 manholes are refurbished every other year. Utilization is limited to single contractor where the City is exploring other technologies for a more competitive market.
- Current and On-going Projects:
  - Current 200 mm to 300 mm (8 inch to 12 inch) diameter pipes – locally, approximately $3.5 million Canadian in 2013 (approx. 3 km of pipe); $4 million Canadian for water main 150 mm to 300 mm (6 inch-12 inch) diameter pipes;
  - Standard contracts:
    - Pipe bursting line connections – approx. 200 per year
    - Primary line replacement 1 every 1-2 years
  - Larger projects, such as current McOrmond road directional drilling, are “1-of” projects – not common. The capacity of the previous pipe designed for 30 years was exceeded after 5 years due to city expansion

A survey was carried out for this report on sample projects in both Regina and Saskatoon for the period from 2007 to 2012. This survey was based on the Request for Proposals (RFP) which clearly states the type of the project, i.e. trenchless or open cut. Most trenchless projects were implemented in wastewater infrastructure (Sewer mains, trunks and storm drains).

For example in Regina many projects were carried out using trenchless technologies for sewer main rehabilitation for diameter range from 150 mm to 900 mm (6 inches to 36 inches) and for lengths ranging from 1 m to 22 m. CIPP was the most common rehabilitation method used, which supports the outcome of the personal contact results summarized above. In Saskatoon storm outfall rehabilitation is carried out for diameters up to 1 500 mm (60 inches). The most recent large trenchless project in Saskatoon is the McOrmand Drive project, where two sanitary trunks of 1 200 mm to
2 400 mm (48 inches to 90 inches) for a length of 1 500 mm will be installed using the Tunnel Boring Machines (TBMs).

Obtaining representative information regarding implementation of trenchless technologies was not possible due to the lack of information resources and clear statement, in many RFP’s, of the type of technology applied in the project. Verbal information with the few municipal officials revealed that there is no systematic approach regarding the feasibility of different technologies. Limited number of professional contractors in the province restricts the applicability of other technologies and consequently limiting rational feasibility evaluation. A copy of the Request for Proposal (RFP) is attached in Appendix C.

8.3. **Gaps/Opportunities for Potential Future Research & Development of Trenchless Processes in Saskatchewan Applications**

Saskatoon is the largest municipality in Saskatchewan and the fastest growing city in Canada with an estimated GDP growth rate in 2013 of approximately 3.7% (Statistic Canada). Both Regina and Saskatoon attracted a record number of newcomers in 2012 according to Mario Lefebvre, director of the Centre for Municipal Studies (the Epoch times, 2013). Current and expected growths of the Prairie Provinces, especially in Saskatchewan, present a challenge to the development of major urban centers. Trenchless technologies present prominent cost and time effective methods, relative to the traditional open cut method. However, implementing trenchless technologies is faced with a number of challenges such as lack of experienced and professional contractors. This limitation affects the exploration of new technologies.

Creating a competitive market for new professional contractors is the key to enhance major urban centers infrastructure development and management. Municipal officials and decision makers, involved in infrastructure development and management should follow a methodological selection procedure based on up to date information of the different options available in the market. Economical aspect is the limiting factor in many infrastructure projects. Therefore, the selection procedure of the suitable technology should include different costs associated with each technology.

Information gaps can be bridged through research, which will provide the decision maker with the best selection procedure(s). Research can answer different concerns of municipal officials through (a) well based evaluation approach(es). The following is an example list of some information gaps:
• Economic aspects of Trenchless Technologies:
  o Installation speed corresponding to different Trenchless Technologies is a crucial factor in determining their effectiveness. This speed is a direct function of the specific site conditions. Therefore, it is useful to develop generic guidelines to estimate different technologies’ installation speed to guide selection process;
  o Different trenchless technologies require specific labour skills and training, and intensity which directly affect the utility and feasibility of the technologies to specific projects. The selection process should consider the availability and the cost of such skilled labour involvement in the specific project; and
  o Accurate cost estimate should include different costs associated with the specific technology. Initial and operational costs can significantly affect the overall cost of the project, which can affect the selection decision. Therefore, it is important to have a good estimate of the projected initial and operational costs to be included into the technology overall cost estimate;
  o There is no information of local contractors who have the required experience to carry out trenchless projects (available to the municipalities’ officials and decision makers).

• Technical aspects of Trenchless Technologies:
  o Long-term performance of the installed pipe;
  o Maintenance requirements of the installed infrastructure system;
  o Technical problems and the associated mitigation measures to overcome these problems, such as (sagging, misalignment, etc).
Currently, Saskatchewan is one of the most rapidly growing provinces in Canada, showing unprecedented economic growth. This growth requires a corresponding response to the expected pressures on the province’s infrastructure in many urban and rural areas to achieve sustainable communities. Significant financial resources required for infrastructure projects have been one of the main limiting factors in coping with communities’ needs for growth.

A direct relation exists between strong and sustainable communities and their infrastructure, in particular, underground assets dealing with water, wastewater and gas/energy. Modern methods for installing and replacing utility piping no longer involve digging up mass amounts of earth and no longer cause extensive surface disruption to the community or business activities. Trenchless technologies, equipment and standards are in place to ensure that these piping infrastructure systems can be quickly and without disruption, installed or replaced.

Traditional open-cut method (trenching) is still the most widely used method in new pipeline installation and pipe replacement in Saskatchewan. The need for and adoption of trenchless technologies has quickly emerged to meet the specific needs of different countries around the world. This process was more evident in heavily populated urban areas where service disruptions caused major traffic diversions. Surface disruptions, a main fallback of the traditional open-cut method, have damaging effects on the communities’ economy and well-being. Saskatchewan can take advantage of the lessons learned from elsewhere in the world.

A wide variety of trenchless technologies are available to address the different needs of infrastructure rehabilitation and/or installations. This variety responds well to the specific technical and economic aspects of every infrastructure project. Although trenchless technologies use innovative methods, materials, and equipment that require minimum surface excavation to renew and construct aging underground infrastructure, they involve expensive technology and skilled personnel which affects the availability and total cost of the project. Trenchless technologies provide a cost effective alternative to the traditional open-cut method, considering relatively higher initial costs and several limitations based on the specific-site conditions.
Economic evaluation of different trenchless technologies usually focuses on a specific technology against the traditional open-cut method. A general comparison, which incorporates different technologies, is either not up to date or limited to a small number of technologies. This may be related to the quickly and ever changing costs of the involved technologies and new materials introduced to the market. It should be noted that the focus of those comparisons, that are available, is on construction costs, or direct costs, without paying attention to the associated indirect and social and environmental costs. Estimation of the equivalent monetary values of these indirect costs is crucial to the overall evaluation of the proposed technology (compared to the open-cut method) of installation and/or renewal of underground infrastructure.

The contribution of social costs relative to the project construction cost is estimated to range from 44% to 78% of the construction costs in the traditional open-cut method, whereas social costs for trenchless technologies range from 3% to 11% of construction costs. Those savings are added to the construction costs savings which amount to 20% to 40% of the total cost in cases using trenchless technologies, especially in heavily populated urban areas. In general, trenchless technologies outweigh traditional open-cut methods in high density urban areas, where access, traffic control and the cost of reinstatement of surfaces become more expensive, which all add to the per foot of pipe price.

Generally, intensive use of trenchless technologies in Canada is limited to heavily populated urban centers in Ontario, Quebec and British Columbia and in resources exploration centers in Alberta. Less populated provinces, especially Manitoba and Saskatchewan, rely mainly on traditional open cut method and relatively limited dependence on different trenchless technologies. Lack of professional contractors and the limited number of available trenchless technology alternatives limit the implementation of these technologies in different infrastructure projects.

Municipal officials and decision makers in large municipalities in Saskatchewan, i.e. Saskatoon and Regina, do not have enough local information on the cost/benefit of available trenchless technologies. National and provincial research facilities can bridge the information gap by providing different municipalities with insights into the capabilities of different technologies. They can also provide the decision makers with a methodological guideline for the selection of the most appropriate installation and/or rehabilitation technology and/or method.
Scattered literature is available on this issue but with a focus on non-local, specific applications. This report is a simple contribution towards that goal of providing decision makers with a comprehensive review of potential options for sustainable infrastructure.
10. REFERENCES


Australian Society for Trenchless Technology (ASTT) (2009b), Guidelines for Horizontal Directional Drilling, Pipe Bursting, Microtunnelling and Pipe Jacking, Document # CPJP8029-GUI-C-001, September.

Bairaktaris, D., V. Delis, C. Emmanouilidis, S. Frondistou-Yannas, K. Gratsias, V. Kallidromitis and N.


International Pipe Bursting Association (IPBA) (2012) Guideline for Pipe Bursting, Owing Mills, MD.


Federation of Canadian Municipalities (FCM) and National Research Council (NRC) (2003), Selection of Technologies for Sewer Rehabilitation and Replacement: A Best
Practice by the National Guide to Sustainable Municipal Infrastructure, Issue No 1.0, March.


Hashemi, S. B. (2008), Construction Cost of Underground Infrastructure Renewal: a Comparison of Traditional Open-Cut and Pipe Bursting Technology, Master of Science Dissertation, the University of Texas at Arlington, USA.


Military Engineering Services (2010) Trenchless Instructions: Trenchless Technology, Engineering-In-Chief’s Branch, Intergraded HQ of MOD (ARMY), New Delhi, India.


**Websites for Photos**


Construction Updates (2012) [http://constructionduniya.blogspot.ca/2012/06/pipe-bursting.html](http://constructionduniya.blogspot.ca/2012/06/pipe-bursting.html)


Oregon State University (2013) [http://web.engr.oregonstate.edu/~armin/H_PipeRamming.php](http://web.engr.oregonstate.edu/~armin/H_PipeRamming.php)
Services first Limited (2013) http://servicesfirstltd.co.uk/drainage/diversions/sewer-diversion/


Trenchless Pipe Lining (2013) http://www.craftsmanpipelining.com/how-it-works/

Trenchless solutions http://www.trenchlesssolutions.co.uk/


UNITRACC http://www.unitacc.com/