SELECTION OF TECHNOLOGIES FOR SEWER REHABILITATION AND REPLACEMENT

A BEST PRACTICE BY THE NATIONAL GUIDE TO SUSTAINABLE MUNICIPAL INFRASTRUCTURE

National Guide
to Sustainable
Municipal
Infrastructure

Guide national pour
des infrastructures
municipales
durables

Canada

NRC · CNRC

Federation
of Canadian
Municipalities

Fédération
canadienne des
municipalités

Selection of Technologies for Sewer Rehabilitation and Replacement
Issue No. 1.0
Date: March 2003

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FOREWORD

In spite of recent increases in public infrastructure investments, municipal infrastructure is decaying faster than it is being renewed. Factors, such as low funding, population growth, tighter health and environmental requirements, poor quality control leading to inferior installation, inadequate inspection and maintenance, and lack of consistency and uniformity in design, construction, and operation practices have impacted on municipal infrastructure. At the same time, an increased burden on infrastructure due to significant growth in some sectors tends to quicken the ageing process while increasing the social and monetary cost of service disruptions due to maintenance, repairs, or replacement.

With the intention of facing these challenges and opportunities, the Federation of Canadian Municipalities (FCM) and the National Research Council (NRC) have joined forces to deliver the *National Guide to Sustainable Municipal Infrastructure: Innovations and Best Practices*. The Guide project, funded by the Infrastructure Canada program, NRC, and through in-kind contributions from public and private municipal infrastructure stakeholders, aims to provide a decision-making and investment planning tool as well as a compendium of technical best practices. It provides a road map to the best available knowledge and solutions for addressing infrastructure issues. It is also a focal point for the Canadian network of practitioners, researchers, and municipal governments focused on infrastructure operations and maintenance.

The *National Guide to Sustainable Municipal Infrastructure* offers the opportunity to consolidate the vast body of existing knowledge and shape it into best practices that can be used by decision makers and technical personnel in the public and private sectors. It provides instruments to help municipalities identify needs, evaluate solutions, and plan long-term, sustainable strategies for improved infrastructure performance at the best available cost with the least environmental impact. The five initial target areas of the Guide are potable water systems (production and distribution), storm and wastewater systems (collection, treatment, disposal), municipal roads and sidewalks, environmental protocols, and decision making and investment planning.

Part A of the *National Guide to Sustainable Municipal Infrastructure* focuses on decision-making and investment planning issues related to municipal infrastructure and therefore is qualitatively distinct from Part B. Among the most significant of its distinctions is the group of practitioners for which it is intended. Part A, or the decision making and investment planning component of the Guide, is intended to support the practices and efforts of elected officials and senior administrative and management staff in municipalities throughout Canada.

It is expected that the Guide will expand and evolve over time. To focus on the most urgent knowledge needs of infrastructure planners and practitioners, the committees solicited and received recommendations, comments, and suggestions from various stakeholder groups, which shaped the enclosed document. Although the best practices are adapted, wherever possible, to reflect varying municipal needs, they remain guidelines based on the collective judgements of peer experts. Discretion must be exercised in applying these guidelines to account for specific local conditions (e.g., geographic location, municipality size, climatic conditions).

For additional information or to provide comments and feedback, please visit the Guide at <www.infraguide.gc.ca> or contact the Guide team at infraguide@nrc.ca.

ACKNOWLEDGEMENTS

The dedication of individuals who volunteered their time and expertise in the interest of the *National Guide to Sustainable Municipal Infrastructure* is acknowledged and much appreciated.

This best practice was developed by stakeholders from Canadian municipalities and specialists from across Canada, based on information from a scan of municipal practices and an extensive literature review. The following members of the National Guide’s Storm and Wastewater Technical Committee provided guidance and direction in the development of this best practice. They were assisted by the Guide Directorate staff and by Delcan Corporation.

John Hodgson, Chair	City of Edmonton, Alberta
André Aubin	Ville de Montréal, Quebec
Richard Bonin	Ville de Québec, Quebec
David Calam	City of Regina, Saskatchewan
Kulvinder Dhillon	Province of Nova Scotia, Halifax, Nova Scotia
Tom Field	Delcan Corporation, Vancouver, British Columbia
Wayne Green	City of Toronto, Ontario
Sam Morra	Ontario Sewer and Watermain Construction Association, Mississauga, Ontario
Peter Seto	National Water Research Institute, Environment Canada, Burlington, Ontario
Timothy Toole	Town of Midland, Midland, Ontario
Bilgin Buberoglu	Technical Advisor, NRC

In addition, the Storm and Wastewater Technical Committee would like to thank the following individuals for their participation in working groups and peer review:

Erez Allouche	University of Western Ontario, London, Ontario
Ken Chua	City of Edmonton, Alberta
Pierre Desjardins	Les produits NC Ltée, Laval, Quebec
Kulvinder Dhillon	Province of Nova Scotia, Halifax, Nova Scotia
Sam Morra	Ontario Sewer and Watermain Construction Association, Mississauga, Ontario
Steven Murphy	CBCL Limited, Halifax, Nova Scotia
William Sims	City of Nanaimo, British Columbia
Bruce Tait	City of Moncton, New Brunswick
Paul Smeltzer	Ontario Concrete Pipe Association, Burlington, Ontario
Darryl Bonhower	Key Surveys Enginnering, Moncton, New Brunswick

This and other best practices could not have been developed without the leadership and guidance of the Project Steering Committee and the Technical Steering Committee of the *National Guide to Sustainable Municipal Infrastructure,* whose memberships are as follows:

Project Steering Committee:

Mike Badham, Chair	City Councillor, Regina, Saskatchewan
Stuart Briese	Portage la Prairie, Manitoba
Bill Crowther	City of Toronto, Ontario
Jim D’Orazio	Greater Toronto Sewer and Watermain Contractors Association, Ontario
Derm Flynn	Mayor, Appleton, Newfoundland
David General	Cambridge Bay, Nunavut
Ralph Haas	University of Waterloo, Ontario
Barb Harris	Whitehorse, Yukon
Robert Hilton	Office of Infrastructure, Ottawa, Ontario
Dwayne Kalynchuk	City of St. Albert, Alberta
Joan Lougheed	City Councillor, Burlington, Ontario Stakeholder Liaison Representative
René Morency	Régie des installations olympiques Montréal, Quebec
Saeed Mirza	McGill University, Montréal, Quebec
Lee Nauss	City Councillor, Lunenburg, Nova Scotia
Ric Robertshaw	Region of Halton, Ontario
Dave Rudberg	City of Vancouver, British Columbia
Van Simonson	City of Saskatoon, Saskatchewan
Basile Stewart	Mayor, Summerside, Prince Edward Island
Serge Thériault	Department of Environment and Local Government, New Brunswick
Alec Waters	Alberta Transportation, Edmonton, Alberta
Wally Wells	Dillon Consulting Ltd., Toronto, Ontario

Technical Steering Committee:

Don Brynildsen	City of Vancouver, British Columbia
Al Cepas	City of Edmonton, Alberta
Andrew Cowan	City of Winnipeg, Manitoba
Tim Dennis	City of Toronto, Ontario
Kulvinder Dhillon	Province of Nova Scotia, Halifax, Nova Scotia
Wayne Green	City of Toronto, Ontario
John Hodgson	City of Edmonton, Alberta
Bob Lorimer	Lorimer & Associates, Whitehorse, Yukon
Betty Matthews-Malone	City of Hamilton, Ontario
Umendra Mital	City of Surrey, British Columbia
Anne-Marie Parent	City Councillor, City of Montréal, Quebec
Piero Salvo	WSA Trenchless Consultants Inc., Ottawa, Ontario
Mike Sheflin	Former CAO, Regional Municipality of Ottawa–Carleton, Ontario
Konrad Siu	City of Edmonton, Alberta
Carl Yates	Halifax Regional Water Commission, Nova Scotia

EXECUTIVE SUMMARY

The operations, maintenance, and management of storm and wastewater systems can be complex. With much of the sewer infrastructure buried, it is difficult to prioritize maintenance, repair and replacement activities while continuously operating a reliable system that meets the needs of the customers and the community. The requirement to rehabilitate or replace existing sewers to meet the community's needs is an ongoing activity across Canada. To meet this need, this best practice was developed to focus on the selection of available technologies for the replacement or rehabilitation of storm, combined, and sanitary sewers. Municipalities are provided with a method of selecting the appropriate sewer rehabilitation or replacement technology based on their social, economic, and environmental factors, and on current best practices in the industry.

A municipality should provide sufficient financial resources to carry out both reactive (emergency repair and replacement) and proactive (planned rehabilitation) programs. Understanding the overall operations of the storm and sanitary collection systems is critical in this regard, and a municipality should have as much background information on its infrastructure as possible to help prioritize decisions. Activities related to sound operations and systems management include the following.

- Make certain the appropriate level of operations and maintenance activities are taking place.

- Collect, store, and analyze all data gathered on the sewer infrastructure condition (structural, service, hydraulic) to allow managers to make knowledgeable operations, maintenance, and/or rehabilitation/replacement decisions.

- Understand the type and condition of the soils and bedding adjacent to the sewers, as well as any other buried or surface infrastructure that could have an impact on the system.

- Consider all community concerns including financial constraints, life cycle costing, social issues, local environmental issues, and coordination of other surface and buried infrastructure work.

These activities provide managers with the ability to make decisions on whether remedial action is required on a section of the sewer system.

This best practice assumes that the municipality has already determined that a section of sewer requires remedial action. That determination should have been based on a prioritization scheme in the best overall interests of the community.

Once that determination is made, the following items should be considered before selecting the appropriate rehabilitation/replacement technology:

- construction issues including safety, operability, neighbourhood disruption, cost, and efficiency;
- the size of the contract, as smaller contracts may preclude some technological alternatives due to the cost of mobilizing specialized equipment and personnel;
- risk impacts and mitigation options related to the project, focusing on environmental and constructability issues, and anything that may adversely affect the project’s objectives;
- local availability of the various technologies, as some technologies are not yet available in certain geographic areas of Canada;
- the depth of the sewer, which may limit the technologies available to rehabilitate/replace that sewer;
- the density of lateral connections, which can substantially increase the overall cost of construction of some of the newer technologies, if excavations are required to reconnect the sewer laterals; and
- roadway conditions (traffic volumes, surface conditions, and remedial requirements), which may encourage or discourage the open cut method.

After considering all these issues, this best practice provides a flow diagram that a municipality can follow to determine the technologies available for the rehabilitation/replacement of sewers, based on the specific situation. This flow diagram identifies the problems, addresses the possible causes of the problems, provides two options (full replacement/structural rehabilitation, or non-structural or semi-structural rehabilitation), and identifies all the possible technologies to remedy the situation. The following technologies are discussed, including the benefits and drawbacks for each:

- open cut construction (i.e., new sewer by trenching);
- sliplining;
- diameter reduction sliplining;
- fold and form sliplining;
- cured-in-place pipe (CIPP);

- pipe bursting;
- horizontal drilling;
- internal joint seals;
- panel and section insert linings;
- chemical grouting;
- full tunnelling and micro-tunnelling;
- auger boring; and
- pipe eating.

By following all the steps in this best practice to select an appropriate sewer replacement or rehabilitation technology, a municipality can feel confident that it has considered all economic, social, environmental, and local issues in its decision process, all of which were in the best interests of the community.

1. GENERAL

1.1 INTRODUCTION

This best practice was initiated following a scan completed for the National Guide on Prioritizing and Choosing Technologies for Construction and Rehabilitation of Storm and Wastewater Linear Systems. The executive summary of this scan, referred to as Scan SWW-1, can be viewed on the National Guide's Web site <www.infraguide.gc.ca>. Based on the collected data, it was recommended that a best practice be developed on how to select appropriate technologies for the rehabilitation or replacement of sections of a storm and wastewater collection system requiring remedial action.

1.2 SCOPE AND FRAMEWORK

The objective of this best practice is to provide municipalities with a method of selecting the best technologies available to rehabilitate or replace sections of their storm, combined, and wastewater collection systems based on current practices and on local issues and conditions. The intent is to use standard terms that are recognized nationally and internationally, allowing municipalities to communicate among themselves in terms that have previously been defined. By selecting appropriate technologies for the rehabilitation or replacement of sections of their storm and wastewater collection systems, municipalities can then make capital improvements, and operations and maintenance decisions in the best interests of the communities they serve.

Two leading organizations represent municipalities, storm and wastewater utilities, consultants, contractors, individuals, and other organizations in the pursuit of best practice with regards to sewer rehabilitation and replacement. For those municipalities involved in research and in developing strategies for the rehabilitation and replacement of sewers, it is recommended that they refer to the Water Environment Federation (WEF) and the North American Society for Trenchless Technologies (NASTT). This, in turn, will allow their knowledge and expertise to be disseminated by these organizations for the betterment of municipalities everywhere. These organizations can be monitored or contacted via their Web sites <www.wef.org> and <www.nastt.org>. It should also be noted that there are many other organizations involved in infrastructure rehabilitation, including the CERIU in Quebec <www.ceriu.qc.ca>, the American Water Works Association (AWWA) and The American Society of Civil Engineers (ASCE). There is also a growing amount of research being conducted at the universities in efforts to advance systems and asset management technologies. All organizations have a role to play in the pursuit of continuous improvement initiatives for sewer replacement and rehabilitation.

1.3 GLOSSARY

A glossary of terms used in this best practice follows. Most of these definitions have been provided courtesy of NASTT and can be found at http://www.nastt.org/glossary/j.html along with many other trenchless technology terms.

Auger machine — Machine used to drill earth horizontally by means of a cutting head and auger or other functionally similar device. The machine may be either cradle or track type.

Boring — Dislodging or displacing spoil by a rotating auger or drill string to produce a hole called a bore. An earth-drilling process used for installing conduits or pipelines.

Boring pit — Excavation in the earth of specified length and width for placing the machine on line and grade.

Butt fusion — Method of joining polyethylene pipe where two pipe ends are heated and rapidly brought together under pressure to form a homogeneous bond.

CCTV (closed-circuit television) — Inspection method using a closed-circuit television camera system with appropriate transport and lighting mechanisms to view the interior surface of sewer pipes and structures.

Electrofusion — Joining method for polyethylene materials using electrical energy.

Epoxy — Resin formed by the reaction of biphenols and epichlorohydrin.

Fold and form sliplining — Method of pipeline rehabilitation in which a liner is folded to reduce its size before insertion and reversion to its original shape by the application of pressure and/or heat.

Frac-out — Drilling reference to indicate the process used to widen or open the pores of a substance, altering or breaking its formation.

Grouting — Filling of the annular space between the host pipe and the carrier pipe. Grouting materials may be cementitious, chemical, or other mixtures.

Impervious — Impenetrable, completely resisting entrance of liquids.

In situ — Describes work on site; in the original place. For example, in situ concrete would differentiate cast-in-place concrete from precast concrete.

Internal corrosion — Corrosion that occurs inside a pipe because of the physical, chemical, or biological interactions between the pipe and the water or wastewater that flows in the pipe.

Joint sealing — Method in which an inflatable packer is inserted into a pipeline to span a leaking joint. Resin or grout is injected until the joint is sealed, and the packer is then removed.

Rerounding — Preparatory process which involves the insertion of an expansion device into a distorted pipe to return it to a circular cross section. This is usually carried out prior to the insertion of a permanent liner or supporting band.

Spot repair — Repair work on a pipe to an extent less than the run between two access points.

Spray lining — Technique for applying a lining of cement mortar or resin by rotating a spray head, which is winched through the existing pipeline.

Swageing — Reduction in diameter of a polyethylene pipe by passing it through one or more dies. The die may be heated if necessary.

Trenchless technology — Techniques for utility line installation, replacement, rehabilitation, renovation, repair, inspection, location, and leak detection, with minimum excavation from the ground surface.

2. RATIONALE

Cities have developed a vast network of roads, bridges, airports, and buried infrastructure to support the growth of urban population and businesses. Much of this infrastructure, which has an estimated asset value of $1.6 trillion, is reaching the end of its useful service life. A recent initiative by the Canadian Society of Civil Engineers, the Canadian Council of Professional Engineers, and the Canadian Public Works Association, in collaboration with the National Research Council, estimated that, on average, the country’s civil infrastructure system has used over 79 percent of its service life. The inefficiencies in these systems are causing Canadian cities to be less competitive (CSCE, 2002). Storm and sanitary systems account for a large part of this infrastructure picture.

The operations, maintenance, and management of a storm and wastewater system can be complex. With much of the sewer infrastructure buried, it is difficult to prioritize maintenance activities while continuously operating a reliable system that meets the needs of the customers and the community. Storm and wastewater collection systems can account for up to 80 percent of the expenses of an overall storm and wastewater system and, as such, should be operated, maintained, and managed as efficiently as possible while providing a reliable service with minimal environmental impacts.

A scan was undertaken by the National Guide to Sustainable Municipal Infrastructure during the winter of 2001–02 to examine rehabilitation and replacement practices across Canada. The findings indicated that many municipalities would benefit from a best practice on selecting appropriate technologies for the rehabilitation or replacement of sections of a storm or wastewater collection system. This information would give municipalities the opportunity to make better decisions with respect to capital investment priorities, operational and maintenance activities, sewer system security/reliability issues, and customer service levels.

It should be noted that this best practice assumes a municipality has already determined that remedial action on a section of the sewer system is required. As such, the municipality now has to determine the best method to rehabilitate or replace the section of storm or wastewater sewer and the associated appurtenances.

2.1 UNDERSTANDING STORM AND WASTEWATER COLLECTION SYSTEMS

The ultimate goal of any municipality is to provide its customers with reliable storm and wastewater systems that meet all flow conveyance capacity and structural requirements, and promote good environmental stewardship. Storm and wastewater collection systems are two components of the overall system that provide these services. Older municipalities or neighbourhoods may have both these functions provided by a single combined sewer system. Other critical infrastructure components include wastewater treatment facilities (wastewater plants, lagoons, etc.), storm detention ponds, wastewater storage facilities, and pumping stations. The operation of sewer systems, associated maintenance activities (planned and emergency), and the level of service all affect customers. This best practice focuses on the linear storm, wastewater, and combined collection systems, and the required rehabilitation or replacement of a section of sewer.

2.2 OPERATIONS, MAINTENANCE PRACTICES, AND COSTS

Appropriate levels of operations and maintenance activities can extend the life of the infrastructure and reduce or delay the need to rehabilitate or replace sewers. Such activities include mechanical and chemical root removal, flushing, and inspection. It is important to note however, that notwithstanding the importance of good operation and maintenance practices, system operators must be aware of recurring and/or increasing operation and maintenance costs. This may trigger the need for a more permanent system improvement by way of a rehabilitation or replacement initiative.

Major operational activities affecting sewers require data handling (e.g., collection, storage, and management) and operations of system appurtenances (e.g., pumping stations, storage tunnels, overflows, and general maintenance activities). These data can be useful when developing the rehabilitation program and the technologies used (e.g., high maintenance levels, flooding history, etc.).

2.2.1 DATA HANDLING

The collection, storage, and management of operational and maintenance data can provide substantial insight into the issues that affect storm and wastewater collection systems. Another National Guide’s best practice, Best Practices for Utility-Based Data, provides guidance on the determination of the type of operational data to collect, the best method for collecting the data, and the appropriate means to manage this information. That best practice also provides guidance on how to get consistent sets of data for comparison. Of particular importance is the fact that operational and maintenance activities can mitigate the deterioration of hydraulic capacity or structural integrity of sewer infrastructure. Good operational procedures and appropriate levels of maintenance activities can minimize sewer deterioration and reduce or delay the need to rehabilitate or replace sections of the sewer system (i.e., extending the life of the sewers). Appropriate operations and maintenance activities can also provide improved hydraulic capacity. Data related to the operations and maintenance activities that have an indirect impact on the hydraulic capacity or deterioration of sewers include:

- sewer cleaning (length of sewer cleaned, inspected);

- valves/gates maintenance (at storage facilities, overflow chambers, etc.);
- inflow/infiltration detection programs;
- infrastructure data (sewer pipe lengths, diameters, materials, ages, shapes, conditions, locations, slopes, depths);
- valve/gate data (force mains, etc.);
- financial data for operation, maintenance, and rehabilitation costs; and
- waste type (storm, sanitary, combined).

2.3 SUBSURFACE INVESTIGATION

For any type of buried infrastructure work, an understanding of the type and condition of the soil, and any possible infrastructure conflicts, is of critical importance. Depending on soil and ground water conditions, the options for rehabilitating, replacing, or repairing a sewer section may be limited. As such, a geotechnical investigation is normally undertaken to confirm soil conditions and any possible infrastructure conflicts before designing options to rehabilitate or replace a section of sewer system. It is advisable to have staff or organizations specialized in this field of work undertake any geotechnical investigations.

2.4 FINANCIAL ISSUES

Financial issues will always play a role in determining sewer rehabilitation or replacement. In addition to providing financial resources to repair failed sewers (reactive), the municipality should invest money to inspect and carry out rehabilitation of pipe to preserve their physical integrity (proactive). As such, a structured approach is suggested, including a prioritization process to determine which section of sewer should be rehabilitated or replaced first, based on the overall best value to the community. Best value to the community takes into account many aspects, including life cycle costing, disruption, local economic issues, business issues, and environmental concerns. In many cases, a prioritization and scheduling model may be required to allow for different technology and financial options that take budget availability and resource constraints into consideration.

2.5 COMMUNITY ISSUES

Many community concerns come into play when determining which section of sewer to rehabilitate or replace and how to do it. These include community growth, environmental issues, urban/rural development issues, health and safety, other infrastructure coordination issues (primarily water mains and roads), and criticality of sewer service (i.e., industrial discharges, possible environmental impacts).

3. SELECTION OF APPROPRIATE TECHNOLOGIES

3.1 GENERAL ISSUES TO CONSIDER BEFORE SELECTING A REHABILITATION OR REPLACEMENT TECHNOLOGY

Sewer rehabilitation or replacement needs are often not known to a municipality as this infrastructure is underground. It takes a regular program of inspection, usually through closed-circuit television (CCTV), to maintain awareness of the physical condition of the sewers. Operational issues (e.g., sewer backup, basement flooding, overflows, and odour complaints) are often indicators of rehabilitation needs in the system. A municipality can choose a balance between reactive rehabilitation (responding to pipe collapses that cause backups and/or road surface failures) and proactive rehabilitation (investing in lower cost rehabilitation when internal inspection shows early signs of physical distress but the pipe has not yet failed). Choosing to preserve the physical condition of sewers ahead of time is cost-effective since reactive repairs are several times the cost of proactive rehabilitation. A municipality, as part of its review of sewer rehabilitation or replacement technologies should also consider factors not dealt with in this best practice, such as:

- the proprietary nature of certain technologies, which may affect contracting or long-term maintenance;
- up-to-date information on developments in the various technologies on the market;
- level of service, growth, and capacity needs;
- insight into local community issues that should be considered;
- the uncertain life expectancies for rehabilitation methods; and
- good quality assurance and quality control mechanisms to make certain the requirements of the contract have been met.

Municipalities may choose to engage a specialist to undertake this work, or develop their own expertise in-house.

Other critical items that should be considered before selecting an appropriate rehabilitation or replacement technology include the social impacts (need for peak hour or nighttime construction, costs of road shut down, time of year, dust and noise), size of the contract, local availability of the types of technologies, surface conditions, the density of sewer laterals, and the depth of the sewers and laterals being considered for remedial action.

3.1.1 CONSTRUCTION ISSUES

A review should be undertaken before starting a construction project, to verify construction issues in the best interests of safety, efficiency, operability, and cost. In other words, is the proposed construction possible? A review that includes the knowledge and experience of construction and traffic personnel is essential, particularly for trenchless construction. The extent of the review normally depends on the complexity of the project and must be specific to user and system needs.

While the nature of project and contractual arrangements may vary from one municipality to another, certain critical ingredients are present in each project. To ensure success of the construction review, the following steps may be taken.

- Clearly communicate senior management's commitment and generate a similar commitment from all the project participants.
- Encourage teamwork, creativity, new ideas, and new approaches.
- Assign one individual who possesses leadership, communication skills, and knowledge of the organization's operation to lead the review.
- Start the review as early as possible to make certain all ideas are incorporated into the design of the project.
- Emphasize total project integration, not optimization of individual parts.
- Establish a construction procedure for inclusion in project execution plans.
- Evaluate progress and the results.

The project manager should assemble a construction assessment team of personnel involved in the project (e.g., project manager, construction superintendent, design engineer, planner, estimator, operations, equipment or trade representative).

Maximum benefits occur when people with construction knowledge and experience become earnestly involved at the outset of a project. Effective and timely integration of construction and field operation inputs during planning and design will greatly reduce the chance of costly changes to the project thereafter.

3.1.2 SIZE OF CONTRACT

The size of the contract can preclude some technologies, as it may not be economical to have specialized equipment and personnel travel long distances for smaller contracts. Initial mobilization and demobilization for some specialty technologies can be expensive. With larger contracts, more options are available for various technologies. Coordination of similar types of construction activities with surrounding municipalities may be one way to make some technologies more economical.

3.1.3 RISK ASSESSMENT

An understanding of the project risks, including environmental issues and risks associated with the applicable construction techniques, is essential for the success of the project. Project risk is the chance of occurrences adversely affecting the project's objectives. It is characterized by the probability of events and what is at stake. An event and its outcome must be associated with a certain degree of uncertainty for it to be considered a risk. In practice, it is virtually impossible to avoid all risks.

The risk assessment process requires identification, quantification, evaluation/assessment, response development and control, and documentation. The assessment goals are to identify uncertainties and mitigate risks. Recognition of these risks and the establishment of appropriate risk management strategies make it possible for the project to proceed while assuming a reasonable level of risk. Techniques are available to mitigate different kinds of risks (Wideman, 1992).

3.1.4 LOCAL AVAILABILITY

Local availability is also a critical factor, as some regions across Canada may have very little local presence of some of the newer technologies. This should be considered early in the selection evaluation, allowing the municipality to narrow the options quickly.

3.1.5 DEPTH OF SEWER

The depth of a sewer plays a major role in determining the technologies available for rehabilitation or replacement. Trenchless technologies are frequently the least expensive for deeper sewers in an urban setting. The depth that begins to favour trenchless methods will vary depending on local and project conditions. This depth can range from four to eight metres. Factors to consider include soil type, the depth to the ground water table, possible utility conflicts, road surface conditions, and traffic volume. Factors that decrease the depth are poor soils, extensive road surface profiles, and high traffic volumes. Factors that favour increasing the depth include good soils, road surfaces needing improvement, and low traffic.

3.1.6 DENSITY OF LATERAL SERVICES

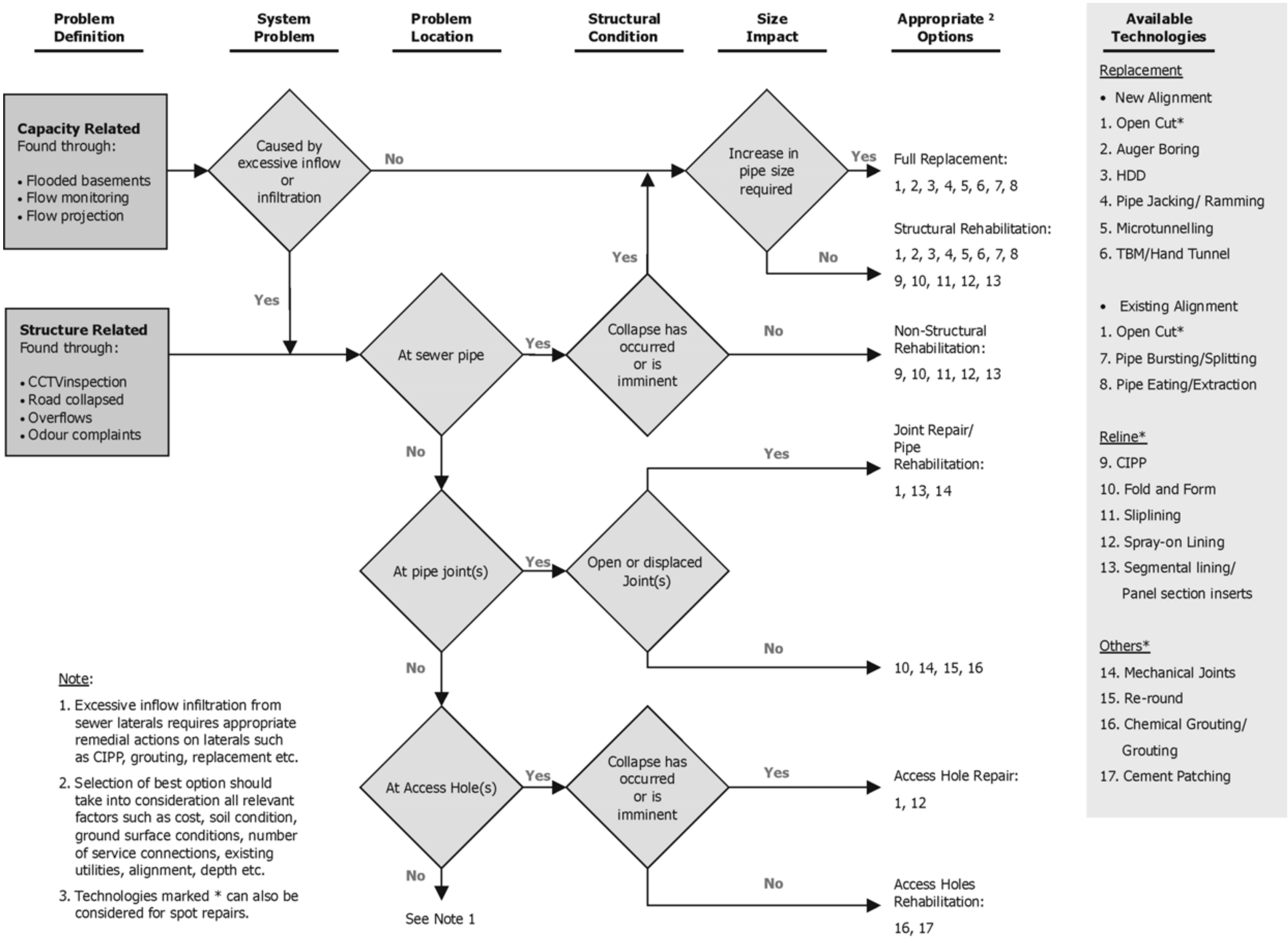
The number of storm and wastewater sewer laterals connected to the sewer requiring remedial action may play a large role in determining possible remediation technologies. This assumes that even when a trenchless technology is used to rehabilitate or replace a sewer, the sewer laterals will be replaced using excavation methods (i.e., not using a trenchless technology). As a rule, a higher number of sewer laterals per length of sewer being rehabilitated favours open cut replacement as the most economical solution. However, using a different rehabilitation or replacement technology at a higher construction cost than the open cut method may be in the best interests of the community. When other issues are considered, such as traffic concerns, impacts on commercial and industrial customers, environmental concerns, and safety issues, cost may be less of a factor. This is why it is essential for municipalities to have a good rehabilitation or replacement selection process.

3.1.7 SURFACE CONDITION AND OTHER FACTORS

The condition of the ground surface can affect the method of rehabilitation chosen. Many communities have no-cut policies for new pavements (prohibiting the use of open cut methods for several years after installation). This favours trenchless methods. High traffic volumes also favour trenchless methods. On the other hand, open areas, road surfaces in poor condition, capacity needs for the subject pipe and adjacent utilities needing rehabilitation tend to favour open cut methods and replacement. Proximity to other utilities' buried infrastructure must also be considered in selecting the method of rehabilitation.

3.2 SELECTION OF THE REHABILITATION OR REPLACEMENT TECHNOLOGY

The flow diagram in Figure 3–1 outlines the process a municipality should follow to determine the technologies available for the specific situation. The flow diagram first identifies the problem(s) that initiated the requirement to rehabilitate or replace a section of the sewer system. It then addresses the possible system problems, the possible causes of the system problems, two options available and the various rehabilitation or replacement technologies. The problem(s), system problems and causes have been discussed previously or are self-explanatory. The options available to a municipality focus on two possible alternatives: replacement/structural rehabilitation, or non-structural and semi-structural rehabilitation. Both trenchless and open cut methods find places as alternatives at points in the flow diagram.



Note:

1. Excessive inflow infiltration from sewer laterals requires appropriate remedial actions on laterals such as CIPP, grouting, replacement etc.
2. Selection of best option should take into consideration all relevant factors such as cost, soil condition, ground surface conditions, number of service connections, existing utilities, alignment, depth etc.
3. Technologies marked * can also be considered for spot repairs.

Figure 3–1: Selecting appropriate technologies for the rehabilitating or replacing storm and wastewater systems

Each technology can meet specific needs based on the structural integrity of the section of sewer requiring remedial action. These technologies are well addressed in various reports and manuals. The Water Environment Research Foundation Report “New Pipes for Old: A Study of Recent Advances in the Sewer Pipe Materials and Technology” (2000) and the AWWA Manual of Water Supply Practices M 28 “Rehabilitation of Water Mains,” Second Edition (2001), were the two primary literature resources used for describing these technologies. The resources of the NASTT were instrumental in drafting this report. The experiences and knowledge of the Best Practice Working Group also provided supporting information regarding these technologies.

3.2.1 OPEN CUT CONSTRUCTION

The installation of new or replacement sewers by trenching is frequently referred to as the open cut method. This technique is well documented, and most municipalities have good design and construction specifications to complete these types of projects. The installation of new pipe should be undertaken when the review of all potential technologies has been completed and the open cut method is ranked as the best alternative.

Benefits:

- A new sewer is installed, complete with all new appurtenances. This provides a longer expected life than obtainable through most trenchless methods.
- The alignment of the sewer can be set to meet the needs of the local area.
- Sewer connections can be replaced to meet current standards.
- The sewer sizing and/or grade can be changed to meet current and future hydraulic requirements.
- Other infrastructure can be rehabilitated or replaced at the same time, allowing for coordination of work and sharing of costs.
- Combined sewers can be separated.
- Storm sewer laterals currently connected to the sanitary system can be disconnected.

Drawbacks:

- The cost of the open cut method can be substantial compared to some newer technologies.
- Construction is usually longer than with most trenchless technologies due to the quantity of disturbance to other infrastructure and traffic, and the amount of reinstatement work required following the installation of the sewer.

- There are more 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.

- There can be disturbances to other surface and buried infrastructure.

- The social and economic costs of major open cut projects can be substantial during construction.

3.2.2 SLIPLINING

Sliplining is the insertion of flexible liners directly into the sewer. Either continuous or jointed discrete lengths of pipe are pulled or pushed through the existing pipe. Sliplining creates a new pipe inside the old sewer without a complete excavation. The sliplined pipe is then reconnected to the existing sewer at both ends.

PVC and HDPE (high density polyethylene) pipe is primarily used in sewer sliplining applications. With PVC pipes, joints are traditional push-on joints with a low profile bell. HDPE pipe are either butt fused (thermal process), or joined together by electrofusion in various possible lengths above ground, then inserted into the host sewer at entry pits.

Jointed discrete lengths of pipe can also be used for sliplining applications. These pipe lengths can be joined by collar or collarless methods, such as screw threads on the ends of the pipes, or snap-lock joints. This means shorter lengths of pipe can be inserted via the entry pit, and less working space is required at the surface of the job site.

Once the new sliplined pipe has been inserted into the host pipe, grouting is generally required to fill the void between the new and old pipes. Grouting is an important step in the sliplining process to maintain the structural stability of the new pipe.

A sliplined pipe substantially reduces the cross-sectional area of the pipe. However, the reduction in friction with the lined pipe compared to the previous, old unlined pipe can partially compensate for the reduced internal diameter. Hydraulic requirements must be considered carefully before selecting sliplining as a preferred alternative. In force mains, the loss of cross-sectional area could be offset with a higher operating pressure.

Mandrel testing of the existing pipe is required to ensure the host pipe can accommodate the sliplining. With the advances in CCTV digital imaging technology, owners may want to map the ovality of the pipe at the same time.

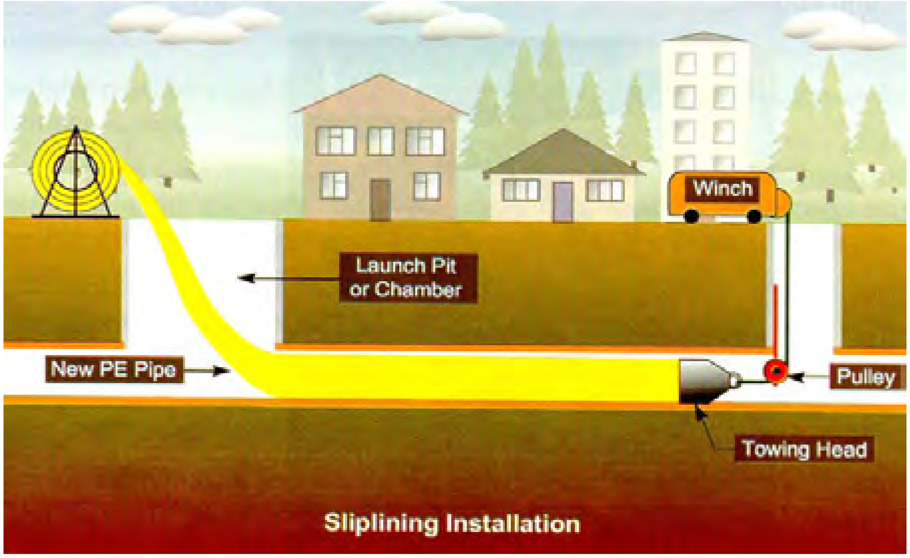


Figure 3–2: Continuous sliplining installation (small diameter)
(Courtesy of Hastak and Sanjiv)

Benefits:

- Sliplining can be applied to most types of pipe.
- It is rapid and causes little disturbance to other utilities.
- It is most successful with few connections.
- It usually provides an improved friction coefficient for improved hydraulic performance.
- Depending on flows, installations can be done in live lines without bypass pumping.

Drawbacks:

- The sliplined pipe is usually sized so its outside diameter is at least 10 percent smaller than the inside diameter to allow for smooth insertion. This reduction, in association with the wall thickness of the pipe, leads to the loss of cross-sectional capacity.
- Sliplining requires a long assembly/lay down area.
- When short pipe sections are used, there is an increased cost in the jointing techniques.
- Poorly controlled grouting to the annular space can lead to buckling of the liner pipe.

- Many excavations may be required if many service and branch reconnections are involved.

- Because the liners used for sliplining do not turn through elbows, the alignment of the unlined pipe must be considered before selecting this technique.

3.2.3 DIAMETER REDUCTION SLIPLINING

Close fit sliplining involves inserting a thermoplastic tube that has been temporarily deformed to allow sufficient clearance for insertion into the host pipe. The tube is subsequently returned to its original shape and diameter, providing a close fit in the host pipe. The outside diameter of the tube is the same or slightly larger than the inside diameter of the host pipe. The tube is passed through a set of dies (referred to as “swageing”) or through an array of compression rollers, to reduce the tube diameter to allow for insertion by winching. The tube then reverts to its original dimensions once the winch tension is released, and in most cases, with the help of internal pressure.

Benefits:

- Close fit diameter reduction sliplining can be applied to most types of pipe.

- It is rapid and causes little disturbance to other utilities.

- It is most successful when there are long runs with few connections.

- It usually provides an improved friction coefficient for improved hydraulic performance.

- There is minimal loss of pipe diameter and no grouting requirement when compared to the traditional sliplining technique.

- The liner can be selected to provide either full structural integrity or semi-structural integrity, depending on the condition of the host pipe.

Drawbacks:

- The energy required to reduce the pipe diameter increases dramatically with larger pipe sizes and greater wall thicknesses.

- The installation of the tube may get hung up during the installation of pipes that are deformed, have dimensional irregularities or displaced joints.

- Manufactured pipe for insertion usually requires special extrusion dies due to non-standard pipe diameters.

- The host pipe needs surveying, cleaning, and preparation.

- Sufficient site space is required to accommodate butt-fusion welding of pipes before the diameter reduction and during insertion.

- As with standard sliplining, the alignment of the host pipe must be considered before selecting the diameter reduction technique, as the winched pipe does not turn well through elbows.

3.2.4 FOLD AND FORM SLIPLINING

This technique is based on the liner being heated and folded at the manufacturer’s factory, and then transported to the installation site. The folded liner is then winched into the host pipe and re-rounded using a combination of heat and pressure and, at times, a device propelled through the liner. PE liners are preferred for pressure applications while PVC systems are mainly used for gravity sewers.

Folded PVC liner for sewer renovation, showing close fit after reversion

Figure 3–3: Fold and Form
(Courtesy of Hastak and Sanjiv)

Benefits:

- Fold and form sliplining can be applied to most types of pipe.

- It is rapid and causes little disturbance to other utilities.

- It is most successful with few connections.

- It usually provides an improved friction coefficient for improved hydraulic performance.

- There is minimal loss of pipe diameter and no grouting requirement when compared to traditional sliplining techniques.

- The liner can be selected to provide either full structural integrity or semi-structural stability depending on the condition of the host pipe.

- The cutting and reinstatement of service connections can be done remotely with robotic equipment reducing surface excavations.

- Some liners can be used in host pipes with bends up to 45°, with some internal wrinkling.

- The site-folded technique is less sensitive to the variations in diameter or pipe with dimensional irregularities, when compared to the diameter-reduction technique.

Drawbacks:

- The folding and re-rounding process of the liner may affect the long-term pressure capability of the liner.

- Sometimes, the reversion process may not be completed fully.

- The liner may move in relation to the host pipe due to stresses that may be developed in the liner (e.g., due to thermal expansion or contraction).

- The liner cannot be used in bends of more than 45°.

- The host pipe needs surveying, cleaning, and preparation.

- For full structural applications, the folding and re-rounding process of the installed liner must be carefully monitored to avoid long-term liner problems.

- Pre-grouting may be necessary in damaged areas or where there are voids.

3.2.5 CURED-IN-PLACE PIPE (CIPP)

CIPP is frequently referred to as in situ relining. A fabric tube is impregnated with a thermosetting or ambient-cured polyester or epoxy resin before being inserted into the host pipe. The resin is then cured to produce a rigid pipe within the host pipe. The combination of the fabric material, with or without fibres, and the resin can be designed to produce a new pipe that has full structural capabilities or semi-structural capabilities.

The fabric material to be used can be tailored in the factory to suit the diameter of the host pipe. Non-circular sections can also be lined if required. CIPP liners can also negotiate 90° bends within the host pipe.

There are three main groups of CIPP systems. These are available independently or in combination: felt-based, woven hose, and membrane systems. All three are usually installed by inversion, in which the liner is fed through the host pipe and turned inside out by water or air pressure. Some CIPP liners can also be installed by winching the liner through the host pipe and then inflating it.

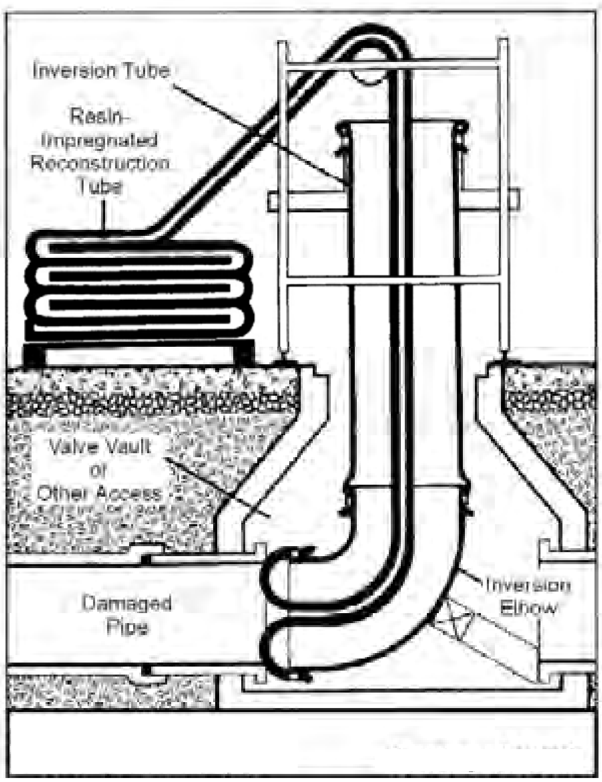


Figure 3–4: Felt tube fed into pipe (Courtesy of AWWA)

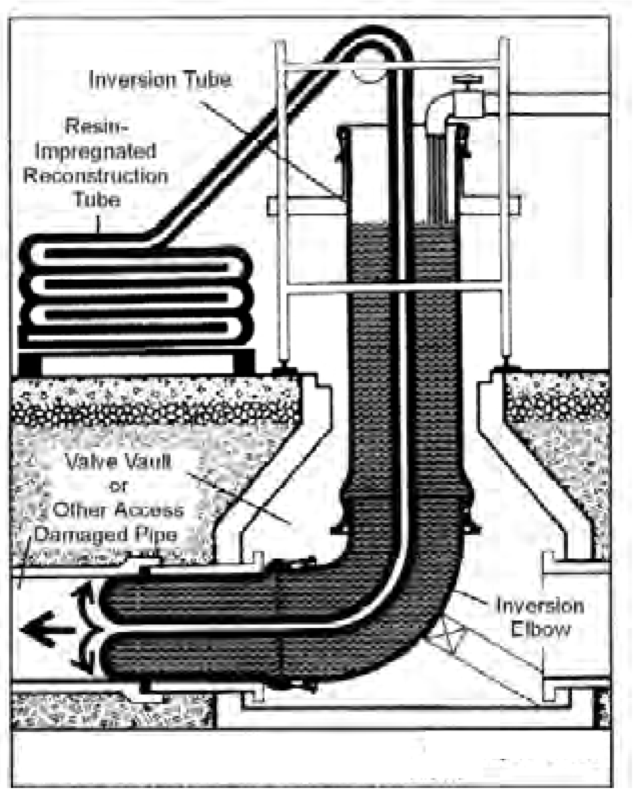


Figure 3–5: Filling the tube – feeding standpipe with cold water (Courtesy of AWWA)

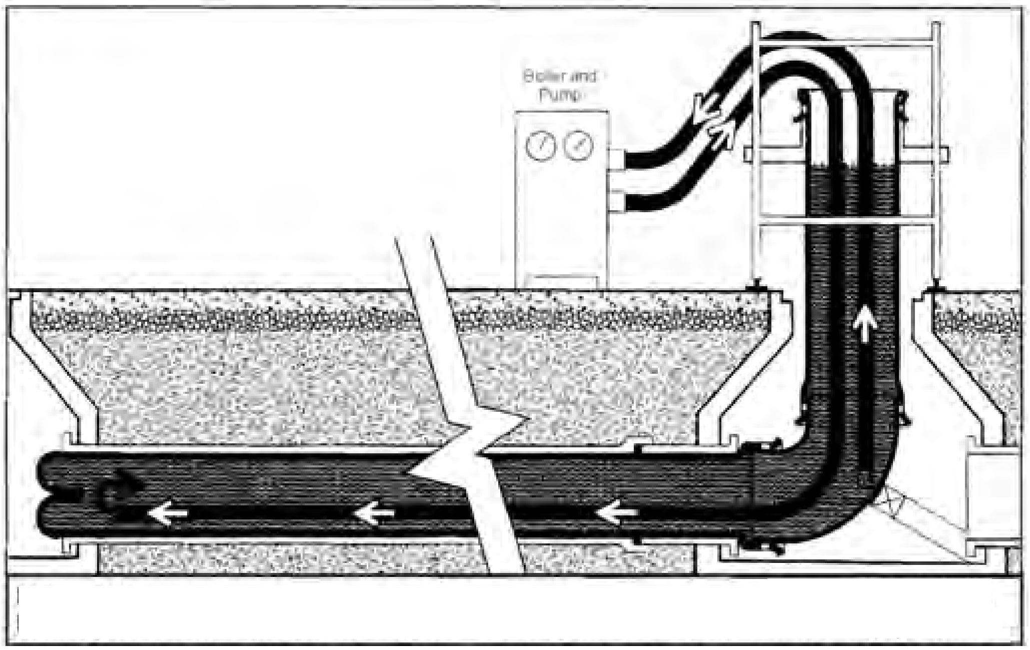


Figure 3–6: Heating water after the tube is in place, causing the resin to cure and harden against the pipe walls (Courtesy of AWWA)

Felt-Based Liner System: This liner is made of non-woven polyester felt, coated on one face with a layer of elastomer. The felt-based liner can include reinforced fibres to provide full or semi-structural integrity of the liner. The resin used in this application also plays a large role in the structural integrity of the new liner. The liner is normally impregnated with the resin at the factory then transported to the site for installation. The transportation to the site frequently occurs in a refrigerated truck to prevent premature setting of the resin. For larger diameter liners, the resin is sometimes applied on site.

Woven Hose System: These liners normally offer a semi-structural system within the host pipe. This system is used in force mains with internal corrosion and pinhole leakage, leakage due to faulty joints and localized external corrosion. The liner is very thin and the successful installation depends on the quality of the adhesive bond to the host pipe wall. As such, the quality of the cleaning done on the host pipe before insertion of the liner is of prime importance.

Membrane System: This liner system is inserted into the host pipe with an elastomeric membrane coated with resin. This membrane is very thin and was initially designed for low-pressure gas main rehabilitation applications (less than 70 kPa or 10 psi). This system is suitable for non-structural sewer rehabilitation applications and is primarily used to offer internal corrosion protection. It can bridge very small pinholes and joint gaps.

Benefits:

- Installation is relatively fast with minimal excavation required.
- Access to the sewer is normally gained from an existing access hole.
- It offers a choice of different resins to suit the application.
- The system can accommodate very long lengths as well as a variety of diameters and can negotiate bends.
- Service connections can be reinstated by robotic cutters, reducing excavation requirements.
- It fits in very tightly to the host pipe, and resists thermal expansions or contractions.
- An improved interior friction coefficient usually increases hydraulic capabilities.
- It can be used in structural, semi-structural, and non-structural applications.
- CIPP is widely available.

Drawbacks:

- The host pipe needs extensive surveying, cleaning, and preparation.

- Sizes smaller than 100 mm or larger than 600 mm have greater difficulty of installation.

- Partial buckling and/or ovality may occur during installation.

- For full structural applications, liner preparation and installation processes must be carefully monitored to avoid long-term liner problems.

- Pre-grouting may be necessary in damaged areas or where there are voids.

3.2.6 PIPE BURSTING

Pipe bursting is a trenchless technology that replaces a sewer by breaking and displacing the existing pipe and installing a replacement pipe in the void created. The system uses a pneumatic, hydraulic, or static bursting unit to split and break up the existing pipe, compressing the materials into the surrounding soil as it progresses. The new replacement pipe is simultaneously pulled or pushed with the bursting head to fill the void created.

It is possible to upsize to about 30 percent greater than the diameter of the existing pipe, but this depends on soil conditions, the proximity of other existing structures, and the depth of cover. The pulling force of the bursting unit must be maintained at a value less than the tensile strength of the replacement pipe to avoid overstressing the new pipe. The replacement pipe must be installed in one continuous length and, as such, butt-fused PE pipe is used in most cases.

Service connections and other appurtenances connected to the sewer to be rehabilitated must be excavated and exposed before starting the pipe bursting. As well, all pipes and underground structures within one metre of the sewer to be rehabilitated by bursting must be excavated and exposed to avoid damage due to the forces transmitted through the soil during the pipe-bursting process.

Benefits:

- Cleaning of the existing pipe is not necessary.

- A larger diameter pipe can be inserted. This, in conjunction with the improved interior friction coefficient, can substantially increase the hydraulic capabilities of the new sewer.

- It provides for full structural rehabilitation.

- It is most successful when there are long runs with few connections.

- Continuous pipe (HDPE) or discrete, joined pipe, such as PVC or DI can be used.

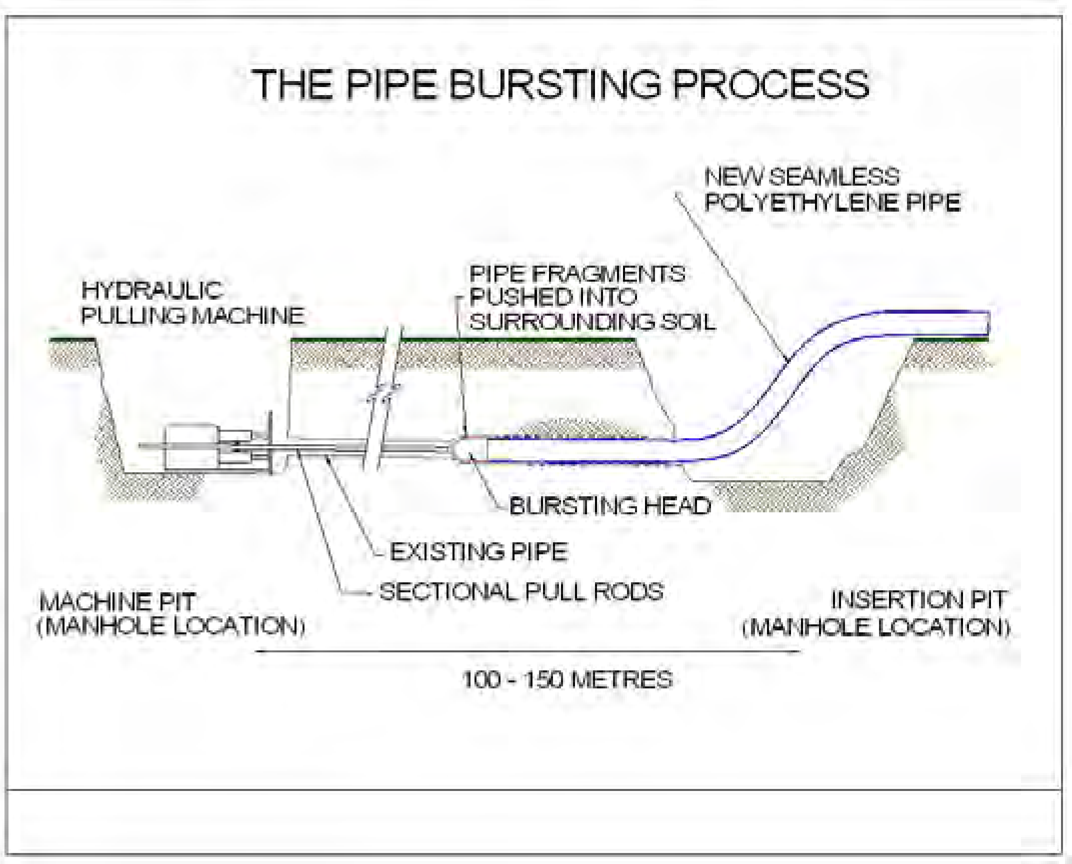


Figure 3–7: The pipe bursting process
(Courtesy of City of Nanaimo, British Columbia)

Drawbacks:

- Pit excavations are normally required to accommodate the replacement of pipe sections.
- All sewer appurtenances must be excavated before bursting, and reconnected to the new sewer afterward.
- All underground structures within one metre of the existing sewer to be rehabilitated must be excavated to avoid damage that may occur due to the force being transmitted, and the displacement of soil, by the bursting technique.
- Any rigid obstructions in the host pipe bedding will deflect the new pipe. This method is not recommended where grade is critical.
- Ground surface heaving can occur if the depth of cover is too little.

3.2.7 HORIZONTAL DRILLING

Horizontal drilling, frequently referred to as HDD (horizontal directional drilling), consists of several stages for installation. First, a pilot bore is made with a suitably sized drilling rig. The bore is steered to create an initial hole at the required line and grade. Successive reamers are then pulled back to enlarge the hole diameter to the desired size. During the last stage of the reaming, the service pipe is pulled back into the bore.

This method is primarily employed when an open cut excavation is completely unsuitable (e.g., at a railway crossing) and a new sewer alignment is desired. Most sewer force mains installed by this method are continuously welded PE pipe, although steel, ductile iron and PVC have also been used. Gravity sewer installations are also possible.

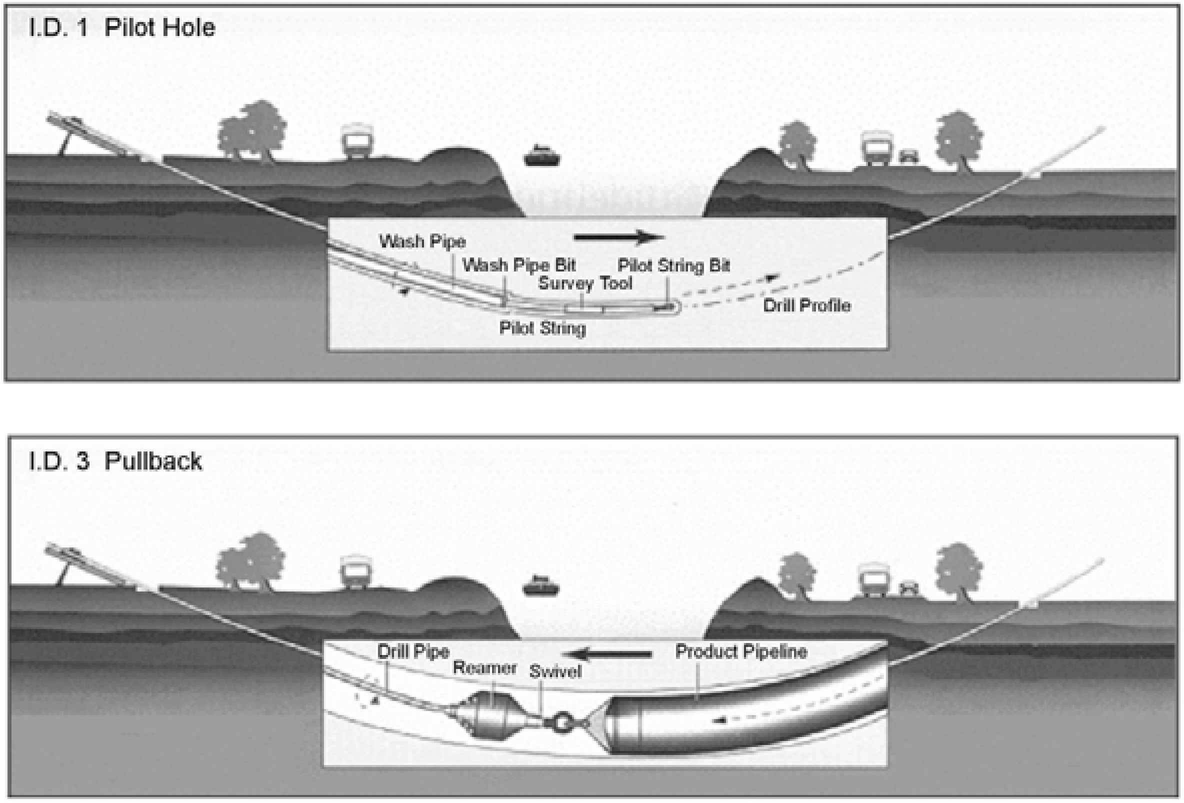


Figure 3–8: Horizontal drilling
(Courtesy of Hastak and Sanjiv)

Benefits:

- There is reduced disruption to surface operations, such as major thoroughfares, railway tracks, rivers, buildings, and trees.
- There is less disruption to buried infrastructure compared to the open cut method.

- It allows for a new sewer alignment.
- This method usually has lower restoration costs compared to the open cut method.

Drawbacks:

- Exact pipe alignment can be difficult to attain, although still fairly accurate.
- Cobble and gravel seams might cause difficulties during the pilot bore and pullback stages.
- On large installations, large quantities of drilling mud are used creating the potential risk of frac-out and costly slurry management actions (i.e., recycling, containment, and disposal).
- HDD requires consistent and good soil conditions (e.g., firm clay, boulderless cohesive tills) for good performance.

3.2.8 INTERNAL JOINT SEALS

Internal joint seals make the inside surfaces of leaking concrete pipe joints watertight. This technique is primarily used in pressure applications, such as force mains or water mains. The seal's flexibility ensures a bottle-tight seal around the entire pipe joint, while its low profile and graded edge allows water to flow without creating turbulence. Internal joint seals are made of EPDM (ethylene propylene diene monomer) synthetic rubber. This technique requires people to access the sewer to perform the work and, as such, pipe diameters of sufficiently large size are good candidates for this technology.

Internal preparation of the pipe is really critical for internal joint seals to perform to specifications. Complete pipe preparation is appropriate for the working environment of the workers. The pipe joints must be completely cleared of debris and dust. Complete preparation of the area on either side of the joint is also required to accommodate the lip of the seal.

Once the cleaning is completed, a Portland cement grout is used to fill the joint gap completely and made flush with the internal surface of the sewer. Next, the area must be cleaned with a dry brush and coated with a lubricant soap compatible with the type of seal being used. The lubricant soap is only an aid for installing the seal. The seal is then placed in position, spanning the gap. Stainless steel retaining bands are then installed in the grooves of each seal. A hydraulic expanding device is used to apply the correct pressure to the retaining bands, thereby keeping the seal in place.

Benefits:

- This technology is specific to pipe joint issues only.

- Minimal working space is required at the surface.
- It is a low-cost alternative.

Drawbacks:

- It can only be used in pipe sizes suitable for human access.
- It does not address other possible pipeline deficiencies.
- Bypass pumping is required.

3.2.9 PANEL AND SECTION INSERT LININGS

Panel or section insert liners are used only where person entry to the sewer is available. Various materials can be used, but GRP (glass reinforced plastic), GRC (glass reinforced concrete) and Ferro-cement are primarily designed for this type of application. When panels are used, they are designed to form a close fit, with fixed spacers, then grouted in place. The panels are relatively light and are designed to pass through access holes.

Larger diameter sewers can be lined with sections rather than panels. These would be carried into the pipe and joined in situ. The sections should also be grouted in place.

Benefits:

- These technologies can be applied for structural or non-structural purposes.
- The liner can be designed to match the original host pipe diameter, thereby minimizing the loss in capacity.
- The liner can be effectively laid to a required grade as individual pipes can be fixed within the host pipe by spacers.
- There is reduced infiltration.
- There is minimal disruption at the surface as access can take place from existing access holes (manholes).

Drawbacks:

- Bypass pumping is required.
- It is a labour-intensive technology.
- There is a loss of cross-sectional diameter in the existing pipe due to the installation of the panels or sections and the grouting space required.

3.2.10 CHEMICAL GROUTING

Chemical grouting is a technology primarily used for spot repairs to seal joints and non-structural cracks. Chemical grouting reduces or stops water infiltration and exfiltration. The chemical grout builds up an external, flexible, and impermeable mass in the soil surrounding the spot repair location.

Chemical grouting is used primarily for cracks in pipes, at leaky joints, and in access holes. One of the main benefits of grouting includes the fact that sections of sewer can remain in service during the rehabilitation process.

Benefits:

- It is a cost-effective method to stop water infiltration by filling voids and sealing fissures in fractured soil.
- It can prevent future structural damage.
- Chemical grouting is effective when used with other technologies.

Drawbacks:

- Its application is restricted due to potential harmful effects.
- There is the potential of ground water pollution (selection of grout type is a major consideration).
- It does not provide structural repair.

3.2.11 FULL TUNNELLING AND MICRO-TUNNELLING

Full tunnelling and micro-tunnelling are techniques normally used for very deep installations. Although primarily used for new installations, applications have been included for rerouting existing sewers. Experts in this field should be engaged for application of this technology.

Full tunnelling is a construction method of excavating an opening beneath the ground without continuous disturbance of the ground surface and of sufficient diameter to allow individuals to access and erect a ground support system at the location of the material excavation.

Micro-tunnelling is different than full tunnelling in that the process uses a remotely controlled boring machine combined with the pipe jacking technique to install pipelines directly.

Benefits:

- There is a high level of accuracy due to the laser-guided installation.
- Non-human entry reduces safety considerations (micro-tunnelling).

- There is continuous tunnel support. Micro-tunnelling is suitable in unstable ground conditions.

- The method is applicable in deep sewer installations.

Drawbacks:

- Tunnelling needs a minimum depth of cover.

- A tail tunnel is required for effective spoil removal (full tunnelling).

- It is expensive for short stretches.

- Extensive geotechnical information is required.

- The potential exists for ground settlement.

- High-level operator experience is needed.

3.2.12 AUGER BORING

Auger boring is the process of simultaneously jacking casing through the earth between two pre-sunk shafts while removing the spoil inside the encasement with a rotating flight auger. The casing supports the surrounding soil as spoil is systematically removed. As a general rule, auger boring has poor steering capabilities. There are two types of auger boring: track type and cradle type. The track type method consists of a track system, machine, casing pipe, cutting head, and augers. The boring operation is cyclic, as pipe segments and auger flights are added after a prescribed auger flight length is installed. Thrust is developed by hydraulic rams located at the rear of the boring machine. One end attaches to the end of the boring machine while the other attaches to lugs connected to the track system. No rotation is applied to the casing as it is jacked through the soil by hydraulic thrust rams located at the rear of the machine. Lubrication is used to reduce skin friction and to aid with soil cutting and transport. An additional common measure to reduce skin friction includes an over excavation in the order of 25 mm to 50 mm. Pipe diameters range from 200 mm to 1200 mm, and overall installation lengths are typically limited to 100 m.

In the cradle-type auger boring method, the boring machine and the complete casing auger system are held in suspension by construction equipment (i.e., side booms, excavators, or cranes) as the boring operation is executed. There is no requirement for any thrust structures; however, the entire casing length must be assembled outside the launching pit before beginning the boring operation, with the complete auger and cutting head unit placed inside the casing. The entire system is then lowered into position in the bore pit via cranes. Once the desired line and grade of the casing are established, the boring process is performed in a continuous manner until completed.

Benefits:

- The technology is well established and widely available.
- There is minimum surface disruption. Boring is suitable for road and railway crossings.
- The steel casing remains in the bore after the drilling operation is complete; it can be used as a conduit or as the host pipe.

Drawbacks:

- Steering capability is limited after installation is initiated.
- It cannot be used in loose sand and very soft clay/organic soils.

3.2.13 PIPE EATING

Pipe eating is a technique based on micro-tunnelling, in which a defective pipe is excavated together with the surrounding soil. The micro-tunnelling shield machine will usually need some crushing capability to perform effectively. The replacement pipes are connected to the back of the tunnelling shield. The defective pipe may initially be filled with grout to improve steering performance of the shield machine. The pipe fragments can be removed by either vacuum excavation or by slurry pumping.

Benefits:

- This method permits in-line replacement and upsizing of sewers with reduced potential for disturbing paved surfaces or adjacent utilities.
- No fragments from the old pipe are left in the ground.
- It enables sagging sewers to be realigned.
- Some systems allow the wastewater to be pumped through the shield during installation, thus eliminating the need for a bypass.
- Steering is possible within limits, and can follow the alignment of existing pipe.

Drawbacks:

- The method is not suitable for the replacement of metallic or thermoplastic pipes.
- It can be costly in comparison with pipe bursting.
- Working space is needed above ground for ancillary construction equipment.

Table 3–1: Limitations of technologies

Technology	**Diameter Range mm**	**Maximum Installation Range m**	**Rehabilitation Capability**			**Types of Material**
			Full Structural	**Semi-Structural**	**Non-Structural**	
Open cut	Any diameter	Unlimited	X			All
Sliplining						
- Continuous	100 to 1600	300	X			PE, PVC, PP, PE/EPDM
- Discrete sections	300 to 4000	1700	X			PE, PVC, PP, GRP
- Diameter reduction sliplining	100 to 1000	100	X	X	X	PE, PP
Fold and form sliplining	100 to 600	600	X	X	X	PE, PVC, FRP
Cure-in-place						
- Felt-based	100 to 2750	1000	X	X		Non-woven polyester fibre
						Woven polyester fibre
- Woven hose	100 to 2750	1000		X	X	Elastomeric membrane
- Membrane	100 to 2750	1000			X	
Pipe bursting	50 to 1200	150	X			PE, PVC, DI, VC
Horizontal drilling	100 to 1200	1500	X			PE, PVC, DI, steel
Internal joint seals	400 or larger	No limit	X			EPDM
Pipe eating	200 to 600	200	X			GRP, PVC, VC, concrete
Auger boring	100 to 1800	100	X			DI, steel
Panel and section linings	1200 or larger	No limit	X	X		GRP, GRC, Ferro-cement
Full tunnelling	900 or larger	No limit	X			Concrete
Micro-tunnelling	300 or larger	250	X			Concrete, DI, PE, PVC, steel
Chemical grouting	Person access required	No limit			X	Acrylates, urethane foam, urethane gel

Notes: PE = polyethylene; PVC = polyvinyl chloride; PP = polypropylene;
PE/EPDM = polyethylene/ethylene propylene diene monomer; DI = ductile iron;
GRP = glass reinforced plastic; GRC = glass reinforced concrete; VC = vitrified clay

3.3 TRENCHLESS TECHNOLOGIES SUPPORT INFORMATION

Most of the currently available rehabilitation or replacement methods are introduced in this best practice. When a storm or wastewater utility needs to initiate a rehabilitation or replacement project, the first step to take is the identification of all technology options suiting the needs. This has to be followed by an investigation of costs of each option for the specific case. The final decision should be taken after due consideration of the costs, benefits, and risks associated with each option.

Rehabilitation or replacement methods considered capable of addressing the problem at hand, based on the analysis provided by Figure 3–1, should then be subjected to a second technical evaluation based on the specific parameters of the project using the evaluation templates provided in Appendix A, which includes the following tables.

- **Tables A–1 to A–3:** Technical capabilities of trenchless construction methods for new installation (new alignment).

- **Table A–4:** Generic representation of the compatibility of various trenchless construction methods with different soil conditions.

- **Tables A–5 to A–8:** Technical capabilities of trenchless construction methods for in-line replacement.

These tables are derived from Allouche and Ariaratnam (2002) with permission from the authors.

They provide a simplified approach for evaluation of trenchless construction methods for new installations (new alignment) and in-line replacement in separate templates.

Also available as support information are decision support systems (DSS). One such example is AUTOCOP (AUTomatic Option evaluation for COnstruction Processes). To find out more about AUTOCOP, reading Hastak and Sanjiv (2002) is suggested.

4. APPLICATIONS AND LIMITATIONS

This best practice should be undertaken on an as required basis whenever a sewer has to be replaced or rehabilitated. Municipalities should provide financial support for ongoing inspection and proactive rehabilitation and replacement programs. It is recommended that municipalities stay current with sewer rehabilitation and replacement technologies through organizations, such as the WEF and the NASTT. This will increase the chances of operating, maintaining, replacing, or rehabilitating the sewer infrastructure in the most efficient, effective, and environmentally sound manner.

If a municipality applies the suggested approach of this best practice, it should expect to have the knowledge required to make sound decisions regarding the replacement or rehabilitation of a sewer system. This, in turn, provides benefits to the municipality with regards to customers and to the environment while still being financially responsible by adopting the best alternative that meets the needs of the community.

APPENDIX A: A SIMPLIFIED EVALUATION PROCEDURE FOR TRENCHLESS CONSTRUCTION METHODS (NEW ALIGNMENTS AND IN-LINE REPLACEMENT)

Attached are two guides outlining the thought processes for selecting appropriate trenchless technologies for new alignments and in-line rehabilitation or replacement. Considerable support material is provided for the technical activities. These procedures focus on the technological constraints (length, diameter, materials), soil suitability, and ground water table considerations. After potential trenchless technologies have been identified, they can be evaluated for cost effectiveness along with open cut methods as additional factors (e.g., road surface conditions, traffic volumes, rehabilitation needs in adjacent utilities, design life) influence the economic analysis. Following this process, the practitioner will need to conduct further assessment based on other economic, social, and environmental factors. To ensure the technical integrity of the project development, the practitioner must use appropriate expertise from the technical and construction industries, consult with stakeholders and be aware of local conditions.

EVALUATION TEMPLATE – IN-LINE REPLACEMENT TRENCHLESS CONSTRUCTION METHODS

Step 1: Identify the in-line replacement trenchless construction technologies for evaluation based on the results of the Figure 3–1 assessment.

Step 2: For each selected technology answer the following questions.

Construction Method	**Method No. 1**		**Method No. 2**		**Method No. 3**	
	Y	**N**	**Y**	**N**	**Y**	**N**
1. Is the maximum single drive length (MH to MH**) smaller than or equal** to the value given in Table A–5 column 2?						
2. Is the **new** pipe diameter **smaller than or equal** to the value given in Table A–5 column 3?						
3. Is the maximum single drive length (MH to MH**) greater than or equal** to the value given in Table A–6 column 2?						
4. Is the **existing** pipe diameter **greater than or equal** to the value given in Table A–6 column 3?						
5. Is the exiting pipe material considered acceptable according to Table A–7?						
6. Is the proposed pipe material considered acceptable according to Table A–8?						

If the answer to any of the above questions is NO, the method may not be suitable for the proposed project.

Step 3: For each selected technology answer the following questions.

Construction Method	**Method No. 1**		**Method No. 2**		**Method No. 3**	
	Y	**N**	**Y**	**N**	**Y**	**N**
1. Does the existing pipe suffer from excessive sagging or misalignments along its length?						
2. Does the pipe contain tees or bends 45° or larger?						
3. Does the pipe diameter need to be increased by a factor greater than 2?						

If the answer to any of the above questions is YES, the method may not be suitable for the proposed project.

Notes:

Some pipe bursting equipment cannot burst certain types of repair clamps and restrainers.

The ability to achieve direction changes decreases significantly with increases in pipe diameter.

EVALUATION TEMPLATE – NEW ALIGNMENT TRENCHLESS CONSTRUCTION METHODS

Background: The values used for comparison purposes are common operating parameters for the various technologies. Performance that is better than indicated in the tables might be achievable, but could be associated with higher risk and/or costs, or require specialized equipment and/or expertise.

Step 1: Identify the trenchless construction technologies for technical evaluation based on the results of the Figure 3–1 assessment.

Step 2: For each selected technology answer the following questions.

Construction Method	**Method No. 1**		**Method No. 2**		**Method No. 3**	
	Y	**N**	**Y**	**N**	**Y**	**N**
1. Is the maximum single drive length (MH to MH**) smaller than or equal** to the value given in Table A–1 Column 2?						
2. Is the pipe diameter **smaller than or equal** to the value given in Table A–1 Column 3?						
3. Is the maximum depth **smaller than or equal** to the value given in Table A–1 Column 4?						
4. Is the degree of alignment accuracy specified in Table A–1 Column 5 **satisfactory**?						
5. Is the degree of profile accuracy specified in Table A–1 Column 6 **satisfactory**?						

If the answer to any of the above questions is NO, the method may not be suitable for the pipe segment under consideration.

Step 3: For each selected technology answer the following questions.

Construction Method	**Method No. 1**		**Method No. 2**		**Method No. 3**	
	Y	**N**	**Y**	**N**	**Y**	**N**
1. Is the maximum single drive length (MH to MH**) greater than or equal** to the value given in Table A–2 Column 2?						
2. Is the pipe diameter **greater than or equal** to the value given in Table A–2 Column 3?						
3. Is the depth of cover **greater than or equal** to the value given in Table A–2 Column 4?						
4. Is the specified pipe material(s) considered acceptable according to Table A–3?						

If the answer to any of the above questions is NO, the method may not be suitable for the pipe segment under consideration.

Step 4: Based on the available geotechnical data (N = SPT blow count per ASTM 1452) please answer the following questions.

1. What is the expected **most dominant soil type** along the proposed alignment?

Cohesive Soils (Clay)			Cohesionless Soils (Sand/Silt)			Gravel	Cobble/ Bolders	Sandstone Bedrock	Bedrock
Soft (N<5)	Firm (5<N<15)	Stiff-hard (N>15)	Loose N<10	Medium 10<N<30	Dense N>30				

2. What is the expected **second most dominant soil type** along the proposed alignment?

Cohesive Soils (Clay)			Cohesionless Soils (Sand/Silt)			Gravel	Cobble/ Bolders	Sandstone Bedrock	Bedrock
Soft (N<5)	Firm (5<N<15)	Stiff-hard (N>15)	Loose N<10	Medium 10<N<30	Dense N>30				

If the most dominant soil type is considered NOT SUITABLE according to Table B–4, OR if the most dominant soil type is considered POSSIBLE and the second most dominant type is considered NOT SUITABLE, the method may not be suitable for the proposed project.

Step 5: Based on the available geotechnical and hydrogeological data, please answer the following questions.

1. Is the invert of the pipe at the lowest point along the proposed alignment at a depth of 3 m or more below the normal level of the ground water table during the expected time of construction?
   If the answer is YES, methods with classification C1 in Table A–4 could be deemed suitable for the project.

2. Is the invert of the pipe at the lowest point along the proposed alignment at a depth up to 3 m below the normal level of the ground water table during the expected time of construction?
   If the answer is YES, methods with classifications C1 OR C2 in Table A–4 could be deemed suitable for the project.

3. Is the invert of the pipe at the lowest point along the proposed alignment at a depth up to 1 m below the normal level of the ground water table during the expected time of construction?
   If the answer is YES, methods with classifications C1, C2 OR C3 in Table A–4 could be deemed suitable for the project.

NEW INSTALLATIONS

Table A–1: Technical Capabilities of Trenchless Construction Methods (maximum operating values)

Method (1)	Installation Length, (m) (2)	Product Diameter, (mm) (3)	Depth (m) (4)	Accuracy[1] (Alignment) (5)	Accuracy (Depth) (6)
Directional drilling (micro)	50	100	10	Medium	Medium
Directional drilling (mini)	100	150	15	Medium-high	Medium-high
Directional drilling (midi)	350	400	30	Medium-high	Medium-high
Directional drilling (maxi)	1500	1200	75	Medium-high	Medium-high
Rotary air drilling	1500	900	50	Medium-high	Medium-high
Water jutting	100	150	15	Low-medium	Low-medium
Dry boring	100	250	15	Medium-high	Medium-high
Auger boring (track type)	100	1200	30	Medium	Medium
Auger boring (cradle type)	150	1500	30	Low	Low
Slurry horizontal rotary boring	100	200	30	Medium	Medium
Micro-tunnelling (auger method)	120	1800	30	High	High
Micro-tunnelling (slurry method)	250	2700	30	High	High
Pipe jacking	300	1060	30	High	High
Utility tunnelling	Unlimited	3600	50	High	High
Non-steerable impact mole	30	75	Note [1]	Low	Low
Steerable Impact mole	50	75	Note [1]	Medium	Medium
Rod-pushing (non-rotational)	50	100	Note [1]	Low	Low
Rod-pushing (long-range)	125	200	4	Low-medium	Low-medium
Pipe ramming	60	1800	Note [1]	Low	Low

Note: [1] Depends on the safe/economic depth to which the shaft can be constructed.

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[1] Designation	Description
Low	No steering capabilities after leaving launching pit.
Low-medium	Limited steering capabilities after leaving launching pit.
Medium	Dedicated tracking and steering capabilities after leaving launching pit.
Medium-high	Capable of max. deviation of ±100 mm in terms of alignment and grade of pilot bore/product.
High	Capable of max. deviation of ±50 mm of alignment and grade of pilot bore/product.

Table A–2: Technical Capabilities of Trenchless Construction Methods (minimum operating values)

Method (1)	Installation Length, (m) (2)	Product Diameter, (mm) (3)	Recomended Minimum. Depth of Cover, (m) (4)
Directional drilling (micro)	5	25	0.6
Directional drilling (mini)	10	25	0.6-0.9
Directional drilling (midi)	50	50	0.9
Directional drilling (maxi)	100	100	2 m or cover/dia ≥ 4
Rotary air drilling	100	50	0.6-0.9
Water jutting	10	25	0.6-0.9
Dry boring	10	25	0.6-0.9
Auger boring (track type)	12	200	1.5 m or cover/dia ≥3
Auger boring (cradle type)	12	200	1.5 m or cover/dia ≥3
Slurry horizontal rotary boring	12	25	1 m or cover/dia ≥3
Micro-tunnelling (auger method)	25	250	1.5 m or cover/dia ≥3
Micro-tunnelling (slurry method)	25	250	1.5 m or cover/dia ≥3
Pipe jacking	25	1060	1.5 m or cover/dia ≥3
Utility tunnelling	10	1200	N/A
Non-steerable impact mole	12	25	1 m for 100 mm of tool dia.
Steerable impact mole	12	25	1 m for 100 mm of tool dia.
Rod-pushing (non-rotational)	50	25	1 m for 100 mm of tool dia.
Rod-pushing (long-range)	125	25	1 m for 100 mm of tool dia.
Pipe ramming	12	100	N/A

Table A–3: Pipe Material Compatibility

Method	HDPE	PVC	Steel	Clay	Concrete	Corrugated Metal	Fiber-glass
Directional drilling (micro)	1	1	1	0	0	0	0
Directional drilling (mini)	1	1	1	0	0	0	0
Directional drilling (midi)	1	1	1	0	0	0	0
Directional drilling (maxi)	1	0	1	0	0	0	0
Rotary air drilling	1	0	1	0	0	0	0
Water jutting	1	1	1	0	0	0	0
Dry boring	1	0	1	0	0	0	0
Auger boring (track type)	0	0	1	0	1	0	0
Auger boring (cradle type)	0	0	1	0	1	0	0
Slurry horizontal rotary boring	1	1	1	0	1	1	1
Micro-tunnelling (auger method)	0	1	1	1	1	0	1
Micro-tunnelling (slurry method)	0	1	1	1	1	0	1
Pipe jacking	0	0	1	0	1	0	1
Utility tunnelling	1	0	0	0	1	0	0
Non-steerable impact mole	1	1	1	1	0	0	0
Steerable impact mole	1	1	1	1	0	0	0
Rod-pushing (non-rotational)	1	0	1	0	0	0	0
Rod-pushing (long-range)	1	0	1	0	0	0	0
Pipe ramming	0	0	1	0	0	0	0

Notes: 0 = not suitable; 1 = suitable.

Table A–4: Compatibility with Various Soil Conditions

Soil Type (define using SPT blow count; N value as per ASTM 1452)	**Cohesive Soils (Clay)**			**Cohesionless Soils (Sand/Silt)**			**Gravel**	**Cobble† Boulder**	**Sandstone Bedrock**	**Bedrock (MPa)**	**High GWT Classification***
Technology	**N <5 Soft**	**5 <N <15 Firm**	**N >15 Stiff-Hard**	**N <10 Loose**	**10 <N <30 Medium**	**N >30 Dense**					
Horizontal guided drilling and boring methods											
HDD maxi/midi	✓	✓	✓	P	✓	✓	P	P	✓	<80	C1
HDD mini/micro	✓	✓	✓	P	✓	✓	✗	✗	✗	✗	C2
Pneumatic/rotary air drilling	✗	✗	✓	✗	✗	✗	✗	✗	✓	✓	C3
Water jetting	✓	✓	✓	✗	P	P	✗	✗	✗	✗	C2
Dry boring	✓	✓	✓	✗	P	✓	✗	✗	✓	✓	C2
Auger boring (track type)	P	✓	✓	✗	✓	✓	✓	<0.3D	✓	<80	C2
Auger boring (cradle type)	P	✓	✓	✗	✓	✓	✓	<0.3D	✓	<80	C2
Slurry horizontal rotary method	P	✓	✓	P	✓	✓	✓	<0.3D	✓	<80	C1
Pipe jacking methods											
Micro-tunnelling (auger system)	✓	✓	✓	✗	P	✓	✗	<0.3D	✓	<200	C2
Micro-tunnelling (slurry system)	✓	✓	✓	P	✓	✓	✓	<0.3D	✓	<200	C1
Pipe jacking (hand excavation)	✗	✓	✓	✗	✓	✓	P	<0.95 D	P	✗	C3
Tunnelling - TBM	P	✓	✓	P	✓	✓	✓	P	✓	✓	C1
Tunnelling - hand excavation	✗	✓	✓	P	✗	✓	✓	<0.95D	✗	✗	C3
Soil displacement methods											
Impact mole	✗	✓	✓	✗	✓	P	✗	✗	✗	✗	C2
Pipe ramming	✓	✓	✓	✓	P	P	✓	<0.9D	✗	✗	C2
Rod pushing	✓	✓	✓	✗	✓	✗	✗	✗	✗	✗	C2
In-line replacement											
Pipe bursting	✓	✓	✓	✓	P	✗	P	✗	✗	✗	C1
Pipe splitting	✓	✓	✓	✓	P	✗	P	✗	✗	✗	C1

Pipe eating	✓	✓	✓	P	✓	✓	✓	✓	✓	✗	C1
Pipe reaming	✓	✓	✓	P	✓	✓	✗	✗	✓	✗	C1
Pipe extraction and replacement	✓	✓	✓	P	✓	✓	P	✗	✓	✓	C1
Cut-and-cover methods											
Plow	✓	✓	P	✓	P	✗	✗	✗	P	✗	C3
Trenching	✓	✓	✓	✗	✓	✓	✗	✗	✓	✓	C3
Backhoe	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	C3
Dragline	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	C3

Notes: ✓ = suitable ; ✗= not suitable ; P = possible ; <0.3D = boulder diameter as a function of casing diameter †.

*Method classification for high water table conditions

C1: suitable or possibly suitable for construction at invert depth of 3 m or more under the ground water table.
C2: suitable or possibly suitable for construction at invert depth up to 3 m below the ground water table.
C3: suitable or possibly suitable for construction at invert depth up to 1 m below the ground water table.

IN-LINE REPLACEMENT

Table A–5: Method Capability Matrix – Maximum Operating Values

Method (1)	Installation Length, m (2)	New Pipe Dia., mm (3)
Pipe bursting	350	600
Pipe splitting	350	300
Pipe eating (micro-tunnelling)	225	1200
Pipe reaming (HDD)	200	600

Table A–6: Method Capability Matrix – Minimum Operating Values

Method (1)	Installation Length, m (2)	Existing Pipe Dia., mm (3)
Pipe bursting	10	50
Pipe splitting	10	50
Pipe eating (micro-tunnelling)	25	250
Pipe reaming (HDD)	15	150

Table A–7: Method capability matrix – Existing Pipe Material

Method	HDPE	PVC	Steel	Clay	Non-Reinforced Concrete	Reinforced Concrete	Cast Iron	Corrugated Metal
Pipe bursting	0	1	1	1	1	1	1	1
Pipe splitting	1	1	1	0	0	0	0	1
Pipe eating (micro-tunnelling)	1	1	0	1	1	1	1	1
Pipe reaming	0	1	0	1	1	0	1	0

Table A–8: Method capability matrix – New Pipe Material

Method	HDPE	PVC	Steel	Clay	Concrete	Corrugated Metal
Pipe bursting	0	1	1	1	1	0
Pipe splitting	1	1	1	0	0	1
Pipe eating (micro-tunnelling)	1	1	0	1	1	0
Pipe reaming (HDD)	1	1	0	0	0	0

Notes: 0 = not suitable; 1 = suitable.

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