NORTH AMERICAN TRENCHLESS TECHNOLOGY SURVEY AND AN APPROACH TO EXPLORE THE I&I PROBLEMS IN SEWER LINES

by

Janga B. Thapa

Submitted in Partial Fulfillment of the Requirements

for the Degree of

Masters of Science

in the

Civil and Environmental Engineering

Program

YOUNGSTOWN STATE UNIVERSITY

August, 2017

North American Trenchless Technology Survey and an Approach to Explore the I&I Problems in Sewer Lines

Janga B. Thapa

I hereby release this thesis to the public. I understand that this thesis will be made available from the OhioLINK ETD Center and the Maag Library Circulation Desk for public access. I also authorize the University or other individuals to make copies of this thesis as needed for scholarly research.

Signature:

Janga B. Thapa, Student Date

Approvals:

Dr. Jai K. Jung, Thesis Advisor Date

Dr. AKM Anwarul Islam, Committee Member Date

Dr. Shakir Husain, Committee Member Date

Dr. Salvatore A. Sanders, Dean of Graduate Studies Date

ABSTRACT

The current technologies in practice, to construct/rehabilitate of underground infrastructures, are open cut method and trenchless technologies. In general, open cut is the traditional method. The method which does not need excavation is called trenchless. Trenchless technology is the fastest growing construction method in North America, especially for underground infrastructure. The open cut method is often associated with major disruptions to surface activities such as road closures, delays in traffic, loss of access to home and business, and construction noise. Underground infrastructures are considered to be an essential part of every city or municipality as they are used to fulfill daily and vital needs of people such as water, gas, oil, transportation, telecommunications, and information networks. However, these structures are getting old. On the other hand, many cities have underground infrastructure that are out dated. These out dated systems are of primary concern when understanding possible point sources of inflow and infiltration (I&I). This study explores how the technology is being used and what types of factors are involved with the relative technologies.

This study was divided into two sections. The first section includes a survey questionnaire from Canadian municipalities regarding the open cut and trenchless methods of construction/rehabilitation of underground infrastructures. While the second examines a specific example (Youngstown sewer line systems) to see what possible problems are occurring and to create a representative model that shows areas of interest with the highest susceptibility of I&I. Overall, the results from the first section indicated that trenchless methods are more beneficial method compared to open cut method. Especially in the replacement/rehabilitation of underground infrastructures in congested urban areas. Cured-in-Pipe-Place (CIPP) was found to be the most popular method to replace or rehabilitate the underground infrastructure. However, lack of budget, appropriate knowledge, skills, education, and special trainings are discovered to be the major factors hindering the use of trenchless technologies. The results disclosed that the trenchless technology is more effective in reducing environmental impact and urban congestions compared to open cut method. Moreover, the results showed the trenchless method is cost effective for installation of deep pipe network. Infiltration and inflow were reported as the major waste water network issues (rating- 3.9 out of 5) in the municipalities. Whereas annual number of water mains breaks (rating- 3.9 out of 5) and pipe structural integrity (rating- 3.8 out of 5) were proclaimed as major water mains network issues in the municipalities. Overall, the survey revealed that the trenchless method is cost effective and environmental friendly method in comparison to the open cut method. However, lack of information, engineering knowledge, skills, trained contractors, separate management group (government policy), and allocated budget are obstacles for the adoption of the trenchless technology.

The second section concluded with the various maps showing different piping conditions (considering some important factors contributing I&I problem) ranging from very good to very poor. Very poor conditions indicated on the map showed a high chance of occurring I&I problem in the specific area. Most of the pipelines were determined to be out dated (more than 100 years). The majority of the pipe lines from downtown and south side of the Youngstown were determined to be in very poor condition i.e. high susceptibility to I&I problem. The method used in this study reduces the scale of work by giving the map with indicating only the highest I&I problems which requires field testing.

Keywords: Trenchless Technology, Open Cut, CIPP, Underground Infrastructures, I&I

ACKNOWLEDGEMENTS

First and foremost, I would like to thank Dr. Jai K. Jung, my advisor, for his continuous guidance and encouragement throughout the development of this thesis work. I am indebted to the members of my advisory committee, Dr. Anwarul Islam, Department Chair, and Dr. Shakir Husain for their willingness to serve on my thesis committee and provide valuable suggestions and feedbacks. I must also thank Dr. Guang-Hwa Andy Chang from Department of Mathematics and Statistics for his valuable suggestions. His help to build the logic and to perform the statistical analysis using software, Statistical Software Package for Social Sciences (SPSS), was very important for this research. I would like to acknowledge Youngstown State University for providing the funding for this research work, a wonderful learning experience, and research environment.

I also extend my gratitude to Dr. Mark Knight, and Dr. Rizwan Younis from Centre for Advancement of Trenchless Technologies (CATT) for giving me an opportunity to work on the trenchless survey for North American municipalities. The analysis of the trenchless survey facilitated by CATT is one of the major objectives of my research work.

My sincere appreciation is extended to MS Consultants of Youngstown, who provided me the valuable data needed for this study. I would also like to thank Mr. Charles T. Shasho, Deputy Director of Public Works, City of Youngstown, who provided data for the research.

I am also thankful to Linda Adovasio for her support and assistance at YSU. A special thanks goes to Mr. Richard Yovichin for his contribution in the data collection process. I do not want to miss this opportunity to thank all the colleagues in my department, who have contributed immensely to my professional and personal life and encouraged me at various stages during the research works and thesis writing.

Finally, yet importantly, I am highly obliged especially to my father Chhatra Bahadur Thapa and my mother Dil Maya Thapa for helping and supporting me to succeed in my life. Their everlasting guidance and encouragement have helped me overcome tough situations and motivated me to be a better person.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ASCE	American Society of Civil Engineers
AWWA	American Water Works Association
CATT	Centre for Advancement of Trenchless Technologies
CIPP	Cured-In-Place-Pipe
EPDM	Ethylene Polypelene Diene Monomer
GIS	Geographic Information System
GRP	Glassfiber Reinforced Polyester
HDD	Horizontal Directional Drilling
HDPE	High Density Polyethylene
I&I	Infiltration and Inflow
PE	Polyethylene
PP	Polypropylene
PPP_S	Public Private Partnership
PVC	Poly Vinyl Chloride
PVDF	Poly Vinylidene Chloride
SIPP	Spray-On or Spray-In-Place-Pipe
SPSS	Statistical Package for the Social Sciences
US EPA	United States Environmental protection Agency
SCC	Social Cost Calculator
TTC	Trenchless Technology Centre
US EPA	United States Environmental Protection Agency
SSO_S	Sanitary Sewer Overflows

CSO_S	Combined Sewer Overflows
DTS	Distributed Temperature Sensing
CCTV	Closed Circuit Television
ANN	Artificial Neural Network
CMOM	Capacity Management Operations and Maintenance

Chapter 1 Introduction and Literature Reviews

1.1 General Overview

A pertinent part of every city or municipality is the underground infrastructure. Underground infrastructure is defined as the structures that are constructed below the ground surface to fulfill daily and vital needs of people such as water, gas, oil, transportation, telecommunications, and information network. Linkov et al. (2007) defined underground infrastructure as structures which are connected physically below ground surface-level for specific purpose/function. Network of underground infrastructures are planned in such a way that they are interconnected to each other, forming a network, to perform specific purpose. For example, city sewerage are connected to collectors and finally to a treatment plant. Underground infrastructures are also called critical infrastructures (CIs). Even if a small disruptions or destructions occurs in small portion of them can cause a large negative impact on health, safety, security or well-being of the society or proper functions of government or economy (Bialas et al. 2016). For example, small defects/cracks in the sewer lines leading to inflow and infiltration (I&I) in pipe network which can increase the cost of treatment plan. Excess I&I also contaminate the drinking water supply system causing serious health hazards. It is very important to mitigate any negative impact on such CIs to preserve the economic growth, social prosperity, and sustainable development of our human civilization (Bialas et al. 2016). For this, smooth functioning of such infrastructures is very important, which can be acquired through the concept of sustainable development. Development of the infrastructure meeting the present generation's needs without compromising the future generation's ability to meet their own need is called sustainable development (United

Nations General Assembly 1987). Nowadays, underground pipe network such as water mains, waste water, and storm water network are facing serious issues of cracking and leaking causing I&I and overflow in the systems due to their exceedance in service life. Tafuri et al. (2002) explained that a majority of the wastewater collection systems in use today were constructed in the early 1900s and these systems can be overwhelmed or burdened by I&I. These issues are causing the world to become aware of sustainability for resources, economic efficiency, and protection of environment (Popawala 2013). Therefore, future potential issues that cause negative impact on socio-economic status of communities are needed to be addressed during their development phases. The implementation of sustainable development, by reducing the possible negative impact on the environment, in present and future, is beneficial to communities. The concept of sustainable development can be achieved through the use of effective design and appropriate choice of materials along with advanced technologies.

The current technologies in practice are open cut method and trenchless technologies. In general, open cut is the traditional method of construction of the underground infrastructures. The method which does not need to excavate trench is called trenchless method of construction. Each technology has its pros and cons. Open cut method causes traffic disruption, noise and air pollution, while the trenchless method would be the better option to install or rehabilitate the underground pipe network. Recently, the United States Environmental Protection Agency (EPA) has placed a strong emphasis on reducing the overall pollution to the environment. It has been found that use of open cut method can increase emissions such as carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxide (NO_X), total organic compounds (TOC), and sulfur oxide (SO_X) by 80 percent or greater, when compared to the advanced trenchless technology (Ariaratnam et al. 2009). This study explores how the technology is being used and what types of factors are involved with the I&I problems.

The study was divided into two sections. The first section includes a survey questionnaire from Canadian municipalities regarding the open cut and trenchless methods of construction/rehabilitation. While the second examines a specific example to see what possible problem are occurring and to create a representative model that shows areas of interest with the highest susceptibility of I&I. In addition, a need to examine a specific example was shown to investigate the current issues plaguing a municipality with an outdated underground system. However, there are various factors affecting I&I regarding a specific pipe segment, this model only explains some important factors. Some of these factors include age, soil types, material types, and sewer classifications (group 1 and group 2). This qualitative model can be generalized and applied to other communities or municipalities.

The first section has addressed the cost effective method, such as trenchless, to construct or rehabilitate the underground infrastructures. Moreover, first section has explored the different methods which are cost effective and are used in order to develop the sustainable infrastructure (meeting the current and future demands with minimum negative impacts on environment). The result from first section indicated that the I&I problem is one of the critical issues in waste water network. Such problems reduce the capacity of the pipe network, increase the cost of treatment plants, and contaminate the drinking water causing serious health hazards to the public. Ultimately, the communities have to bear the cost due to all the negative effects of I&I. Moreover, due to the rapid growth in population and urbanization of the cities, it is necessary to construct new pipe network or rehabilitate the existing pipes, especially older and structurally deficit (having more chances of I&I), network in order to meet the current demand. Open cut methods have been proven to be very costly compared to trenchless methods. Therefore, the entire study has been able to address the cost effective construction/rehabilitation methods i.e. trenchless and issues related to the underground pipe network such as I&I in the older city like Youngstown.

1.2 Research Objectives

Understanding the utilization of trenchless technology or trenchless construction methods by Canadian municipalities and to explore the I&I problems in sewer lines are the main objectives of this research. The first section explores the status of trenchless technology and its future demands in Canadian municipalities. On the other hand, first section gives a picture of survey questionnaire which reflects the latest research, education, training, marketing and technical status of trenchless technology in Canada, the trends and the factors affecting/influencing trenchless technology in the future.

Inflow and Infiltration (I&I) is an unavoidable problem which affects all the underground infrastructures such as water mains, sewer lines, and storm water systems. The extraneous amount of water and intruded debris due to I&I can arrest the capacity of the pipelines. The seeping and leaking along with intrusion of roots and organics in to drinking water supply system, which is also known as water mains, can contaminate pure water. This becomes costly to the community causing serious health hazards. However, with a proper management, such problem can be minimized and controlled so that communities and families are protected from possible risks and hazards which could have possibly happened due to I&I problems. The quantification of I&I is very difficult and expensive due to the large network of sanitary pipes and expenses of water monitoring. Several methods such as flow monitoring, manhole and visual pipe inspections, dye tests, smoke tests, closed circuit television methods can be used to point out the I&I problems in the pipeline systems. Thus, qualitative approach is considered to be the cost effective method over quantitative method. The second section presents a qualitative approach to determine the areas of highest I&I using Geographic Information System (GIS). More specifically, section helps to find the areas with higher susceptibly to I&I. The areas based on the extent of I&I problems can be prioritized for the I&I field testing. This study has contributed to minimize the costs by depicting only those areas where field testing is needed. Ultimately, the costs which could have been used for I&I field testing in the areas where I&I is not severe, could be saved.

1.3 Literature Reviews

Trenchless technology is the fastest growing construction method in North America, especially for underground infrastructure. The trenchless technology includes advanced material and equipment for the installation of a new underground infrastructure and rehabilitation/replacement of existing infrastructure with minimal or no need of excavation. This technology is gaining popularity amongst municipal engineers in the construction field, as it is an alternative method to an open cut method (traditional method). The open cut method is often associated with major disruptions to surface activities such as road closures, delays in traffic, loss of access to home and business, and construction noise. Such disruptions have proven to be very costly especially in urban areas where high traffic and dense population often exist. On the other hand, the trenchless construction method, by its very nature, minimizes the surface disruption and ultimately its total cost is less than that for traditional methods.

For more than several decades, underground infrastructure including water, wastewater, oil and gas, telecommunication, and power line has taken the responsibility of transporting necessary natural resources and information. Such role is critical to maintain the normal operation of city. In addition, with the increasing demands of the underground infrastructure and deterioration of existing infrastructure, utilities and local municipalities are facing with the tremendous task of installation, inspection and rehabilitation of the infrastructure. Traditional of installation, inspection, repair and replacement of underground infrastructure is open cut methods. However, such operations have been proven to be very expensive, particularly in a swarming urban area (Ariaratnam. et. al 1999). For example, open cut methods can cause significant disruptions to traffic and adjacent commercial and industrial activities. Especially in a metropolitan area, the problem of traffic disruption, particularly those associated with traditional open cut method is a major concern. The user delay or customer delay cost due to open cut is significant for commercial district. Environmental impact is another growing concern for the city. To avoid such problems, it has been recommended that the use of the trenchless technology can be the most effective and economic alternative to the open cut method (McKim 1997; Tighe et al. 1999). Trenchless technology, a new and one of the fastest growing methods, is a type of construction method which includes different materials, and equipment to install a new, or rehabilitation of existing, buried utility systems with minimal or no need of excavation resulting less destruction on the surface activities (AWWA 2001).

Even though the trenchless technology is a cost effective methods of construction and rehabilitation in compare to the open cut methods, it is still the most underrated method of construction/rehabilitation in the world of underground infrastructures sustainability. This leads to a question that why the trenchless technology is still not often used or easily accepted method? One of the strong reasons is the lack of knowledge regarding the technology and the cost associated with the method. Trenchless technology is relatively new practice in the construction field which may need more research and education to utility owners and contractors.

In general, construction project consists of three types of costs, namely, direct costs, indirect costs and social costs. Costs for purchasing material, equipment and labor payment are categorized into direct cost. Air pollution, traffic delays, noise pollution, and business losses are the results of negative effect of open cut method and the cost associated with such effects are referred to as social costs. On the other hand, the equivalent monetary values associated with the negative effects of open cut method are commonly referred to as 'social costs' or 'external costs'. Social costs are thus defined as costs resulting from construction activities that are born by the community rather than by the contractual parties (Allouche et al. 2004). Social costs associated with open cut method are significantly higher than the social costs due to trenchless technologies (Islam et al. 2014). A study conducted by Islam and his colleague in 2014 showed that use of trenchless technologies can reduce the social costs by factor of 5 to 17. These costs have to be determined before the commencement of any project (during bidding) so that related agencies (bidding organization) can distinguish the difference between the advantages and disadvantages of using both open cut and trenchless method. The inclusion of the social costs in bid invitations and evaluations is very important because this could support the wider utilization of the trenchless construction method (Mathews et al. 2014). Quantification of social costs can help understating the effective use of trenchless technology. Islam et al. (2014) recommended a Social Cost Calculator (SCC) developed by Trenchless Technology Center (TTC) which quantifies the social costs for the trenchless projects.

Kramer et al. 2000) conducted a feasibility study regarding water leakage issues and pipe breaks in north of Dallas/ Fort Worth, Texas. This paper mentioned that municipalities were very concerned about the potential surface disruption that would occur with any replacement or rehabilitation project. Finally, feasibility study concluded that a trenchless technology could be successfully implemented at a lower cost compared to traditional open cut methods. Moreover, this paper mentioned that approximately 3,962 m (13000 ft.) of water mains in multiple phases were replaced using directional drilling.

With the introduction of the Cured-In-Place Pipe (CIPP) in the 1970's, the pipe relining market segment began to grow. It was found that CIPP had continued to grow in U.S market place after the introduction in 1976 because this method was more accepted and understood by the utility managers and consulting engineers (Rush et al. 2013).

Trenchless technology can be used for both new construction and rehabilitation of existing underground infrastructure. Various types of trenchless technologies for new construction of underground infrastructure include horizontal directional drilling, micro-tunneling, pipe jacking, and augur boring. Types of technologies, descriptions, and their applications have been shown in Table 1-1.

Table 1-1: Trenchless methods for new construction of underground infrastructures

Technology	Descriptions	Applications
Horizontal directional drilling (HDD)	Consists of two-stage process: i) A pilot hole is made by drilling a small diameter directional hole, ii) Back reamer and product are then pulled back through pilot hole. It does not required excavation.	Force mains, gravity sewers, utility conduits, geotechnical investigation, pipelines
Micro-tunneling	Remotely controlled system so that no person required in pipe. Consists of guided pipe jacking process that provides support to excavation face. Pipe is installed from drive shaft to reception shaft.	Gravity sewer installations. Can be applied to smaller diameter pipe (minimum diameter: 250 mm)
Pipe jacking	Unlike to micro-tunneling, person needs to be inside of the pipe to perform excavation and/or remove spoil. Pipe is jacked horizontally from drive shaft to reception shaft. Excavation performed either manually or mechanically.	Gravity sewers, force mains, diversion chambers. Only applies to large diameter (minimum size: 1060 mm=42 inch)
Augur boring	Pipe pushed from drive shaft to reception shaft, while rotating flight auger simultaneously removes spoil. This method does not apply pressure to cutting face.	Relatively short crossings (pipes and conduits). Applies for the pipes between 200 mm (8 in) to 1500 mm (60 in).
Pipe bursting	Conical shaped bursting head is used to burst or split the existing pipe. In the same time, new pipe of equal or greater diameter is pulled behind bursting head.	Mainly used in replacement of force mains and gravity sewers. The range of the diameter for this method is 75 mm (3 in) to 1060 mm (42 in).

(Source: Ariaratnam et al. 1999)

Micro tunneling uses remotely controlled systems to install the new underground pipelines. This method can be used to install the small diameter (250mm/10 in) gravity sewer lines. Table 1-2 presents the various trenchless methods which are used to rehabilitate the existing underground infrastructures. Pipe lining, pipe scanning and evaluation, and robotic spot repair are the trenchless methods which are used for rehabilitation of the existing underground infrastructures.

Table 1-2: Trenchless methods for rehabilitation of underground infrastructures

Technology	Descriptions	Applications
Lining of pipe	Either new pipe inside old pipe is installed or inside relining of the pipe is adopted to extend the useful life of pipe. Slip lining and spiral winding are used to insert new pipes while cured in pipe place (CIPP) method is for lining the pipes.	Applied for water, sewer and natural lines
Pipe scanning and evaluation	In this method, pipes are inspected to determine their conditions by using various methods such as sonar, seismic transmission, and radio electromagnetic and closed- circuit television. This is a non- destructive method.	Inspection of existing infrastructures
Robotic spot repair	Epoxy is injected inside the pipe walls by remotely controlled systems. This method helps to improve structural integrity of the pope as well as it controls the leak.	Sewer and water lines

(Source: Ariaratnam et al. 1999)

Unlike the slip lining, CIPP is used to rehabilitate the existing conditions of the pipes without installing the new pipelines. Various methods such as sonar, seismic transmission, and radio electromagnetic along with closed circuit television are used for scanning and evaluation of the existing underground pipelines. In robotic spot repair method, remotely controlled robot is used to inject the epoxy to seal the internal surface of the pipes. This method not only controls the leaking problem of the pipe but also helps to improve the structural strength of the existing pipes.

The Centre for Advancement of Trenchless Technologies (CATT) conducted the Canadian Municipal Infrastructure Survey in 2013/14 and 2014/15 fiscal year to obtain current snapshot of trenchless technologies used in water, wastewater, and storm water network for more than one hundred municipalities. The survey was designed to compare the utilization of both open cut and trenchless methods in construction, renovation and maintenance of their underground assets. The main purpose of this survey is identifying the current scenario, importance, and demands, along with different factors which play the vital role in selecting and using of both methods.

Hasegawa et al. (1999) developed a method for condition prediction of sewers using condition parameters such as pipe material, length, and diameter. This model estimated the degrees of necessity of repairs for existing sewer pipes based on four viewpoints: 1) decrease in flow capacity, 2) road collapse possibility, 3) sewer overflow and flooding as influenced by I&I, and 4) increase in treatment cost due to I&I. The degree of necessity for repair is evaluated at the pipe level. However, the procedure was complex, required a large amount of data and could lead to anomalous results (Fenner 2000). Ariaratnam et al. (2001) developed logistic models to evaluate condition of sewer lines. Their model was developed through historical data by logistic regression models, a special case of linear regression, based upon factors such as pipe age, diameter, material, waste type and depth. They illustrated their methodology in a case study involving the evaluation of the local sewer system of Edmonton in Alberta, Canada. The outcome of their model did not produce a prediction of condition rating but, by having used the historical inspection records, aimed to provide decision makers with a means of evaluating sewer sections for the planning of future scheduled inspection based on the deficiency probability.

Similarly, Kulandaivel (2004) developed an Artificial Neural Network (ANN) model for predicting the condition of sewer pipes based on the historic condition assessment data. The neural network model was trained and tested with acquired field data. The developed model was intended to aid in identifying the distressed segments of the overall sewer pipeline network using a set of known input values, which could then be directed toward assessing and prioritizing the maintenance measures needed to prevent accelerated future distress and eventual failure of sewer pipes.

May et al. (1998) studied the various factors affecting the operational condition of sewers and divided them broadly into hydraulic and non-hydraulic categories. They further sub-divided the mentioned categories as shown in Fig. 1-1.

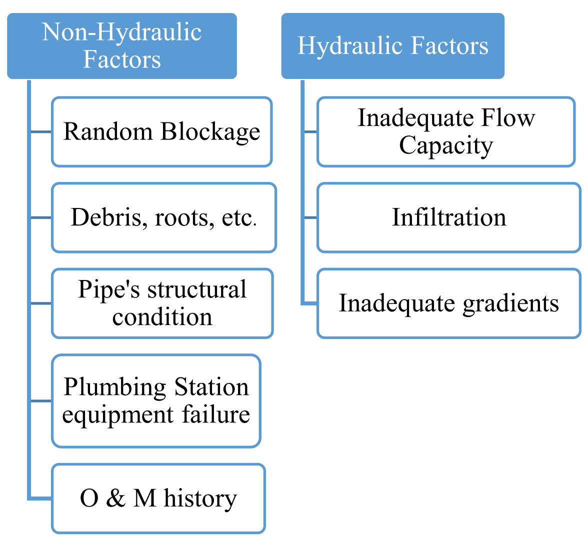


Figure 1-1: Major factors affecting sewer pipeline operational condition (After May et al. 1998)

Chughati and Zayed (2007) provided an empirical regression model to quantify the operational performance of sanitary sewers. Their goal was to relate various pipe properties including pipe age, diameter, length, and slope to determine the sections of a conveyance system that would have the highest rates of I&I. Chughati and Zayed (2007) created a model to empirically analyze collection system in Montreal, Canada. Their equation, shown in equation 1.1, had a linear regression fit value of 0.879. The operational performance provided by the model is related to the condition of the pipe; lower performance value indicates lower pipe condition and higher performance value indicates the pipe is in good condition.

$$(\text{Operational Performance})^{0.63} = 0.308 + \frac{0.507 \text{ x } \frac{\text{Age}}{\text{Diameter}^{n}} \text{ x Length}^{\text{Slope}}}{\text{Age}^{0.63}} \quad (1.1)$$

Where n = Manning's roughness coefficient, length = Length of the pipe section (m), Diameter = Pipe diameter (mm), and Age = Pipe Age (years), Slope = Slope (grade) of pipe segment in %

Boersma (2012) applied equation 1.1 to Milwaukee Metropolitan Sewerage District (MMSD) sewer system and obtained operational performance values for the MMSD. However, Boersma (2012) noted that the model did not include many important factors such as pipe material, quality of construction, and soil properties, and thus provide only rough estimate.

Brodsky et al. (2014) suggested A Capacity Management Operations and Maintenance (CMOM) program as long term solutions to I&I issues for the City of Waltham. The CMOM is a comprehensive program to evaluate the issues with respect to sewerage collection system. The CMOM stands for C- Capacity (addressing blockages, structural issues, I&I issues), M-Management (performance measures, standard operating procedures, training), O- Operation (operation of pump stations and programs), and M-Maintenance (preventive, predictive and corrective maintenance). The CMOM is identified as national best practice and is also recommended by United States Environmental Protection Agency (US EPA).

Apparently every sewer system has some infiltration and/or inflow. Generally, small amounts of I&I are expected and tolerated. However, high amount of I&I can cause several serious problems including public health hazards. Additionally, I&I can engulf the sewer, creating sewer backups and overflows, and ultimately increase sewer treatment cost. According to the city of Roseville, Minnesota, the sewer backups cause increase in cost of wastewater treatment plants about $300-$400 million annually (source: www.cityofroseville). Greaterohio.org published a paper in 2015 describing how the rating for the water and sewer systems is of poor quality. These rating were established by the American Society of Civil Engineers (ASCE). They estimated the cost to upgrade and modernize the current systems to be around $25 billion over the next 20 years. Many of the cities in USA have a lack of funding, which cause the issue to not be a priority. Another issue, causing these cites to not be of major concern, is that the population is declining in these cities/communities. Youngstown is not the exception for this case. The cost to address aging infrastructure and to solve the issues resulting from the aged infrastructure has to ultimately burden by the communities (Greater Ohio Policy Centre 2015). The over-haul of these systems is of major concern because they directly affect public health. A study conducted by Milwaukee metropolitan shows that it costs $500 per year to treat every gallon per minute of continual I&I. Brodsky et al. 2014 conducted a research on I&I evaluation for the city of Waltham, MA and revealed that I&I can reduce 60% of commercial tax base which is equivalent to more than $80 million in annual tax revenues. Ultimately, this cost has to be bear by residents of the community who pay the wastewater utility bill. In addition, ASCE report card 2017 revealed that many of the water mains were laid early to mid-20th century with life span of 75 to 100 years. This indicates that the service life of that pipe network is almost over now. Older pipes may have cracks and structural deficit causing leaking of water every day, every hours and every minute. Approximately, 6 billion gallons of treated water is lost due to leaking of pipes (ASCE 2017). Therefore, it is very necessary to capture the snapshot of I&I problem and to rehabilitate/reconstruct of pipe network to meet the current water supply demands.

Cities can be relatively new or old in comparison with age. Sewage network in some cities can be considered out dated, while others are relatively new. These out dated systems are a cause of concern when understanding the overall effect on a city. Many cities have underground infrastructure that are out dated. These out dated systems are of primary concern when understanding possible point sources of inflow and infiltration. In United States, most municipal sewer systems are aged at least of 60 years and that for communities are older than 100 years (USEPA 2015). Sewer conveyance systems are designed to carry expected flow called designed flow/capacity of the pipe network. However, excessive inflow and infiltration lessens the capacity and efficiency of waste water transport capacity. In general, infiltration occurs due to material and joint degradation/deterioration as well as when sewer lines are poorly designed and constructed. Inflow normally occurs when the rainfall enters the sewer system through direct connections such as roof leaders, yard drains, catch basins, sump pumps, manhole covers and frame seals or indirect connections with storm sewers. Even though the inflow and infiltration are different phenomenon, it is difficult to separate specific amounts of inflow and infiltration in the sewers so they are usually grouped together and referred to as I&I (Boersma 2012). Moreover, I&I can increase the cost of collection system and treatment facility plan by adding extra run time for pumps and pump station and costs for energy, maintenance, and repairs (West Virginia University 1999).

During the rainy season, the amount of I&I is increased to high amount which causes sanitary sewer overflows (SSOs) and basement backups. When SSOs spill into the roads and nearby streams, called hydraulic overloading, it harms the environment and poses the health hazard to the public (City of Superior n.d.). In addition, the excess volume not only arrests the capacity of sewer line but also deteriorates the sewer systems. Precise quantification of the I&I and identification of respective contributions of infiltration into sewer along with information of inappropriate connections of runoff water to sanitary sewers can help to control the SSO (Raynaud et al. 2008). However, quantification of I&I is a very tedious job due to large network of the pipeline. There are two types of approaches; i) quantitative and ii) qualitative to assess and localize the I&I problems. Quantitative method such as flow rate measurement, stable isotope method, and pollutant time series method are used to assess the amount of the I&I in pipe network while Smoke testing, Dye testing, Distributed Temperature Sensing (DTS) method, and Closed Circuit Television (CCTV) method are listed as qualitative method and are used to locate/detect the I&I problems in underground pipe network. This research is a qualitative approach which helps to find the I&I susceptible areas. Maps are then generated considering some important but not all influencing factors, contributing to I&I problem. The major influential factors used in this research were pipe age, soil types (hydrologic soil groups) around the pipes, sewer classifications (group 1 and group 2), and empirical operating coefficient.

The quantification of I&I is very difficult and expensive due to the large network of sanitary pipes and expenses of water monitoring. Several methods such as flow monitoring, manhole and visual pipe inspections, dye tests, smoke tests, closed circuit television methods can be used to point out the I&I problems in the pipeline systems. Cost and time are considered to be the main governing factors which have control over whether the project is effective, economy, and reliable or not. The methods mentioned above are costly and time consuming itself and need special knowledge and apparatus to perform the test. For example, manhole and pipeline inspection methods include equipment such as i) Manhole pick and shovel to open manholes, ii) Wrench to open bolted down manholes, iii) Camera and flash light mounted on a bar, iv) Hand held camera, v) traffic control equipment such as cones, signs, flags and flag person, etc., vi) Metal detector, and vii) Probing rods along with man power (HDR/Archer 2010). Sometimes, it may hinder the regular traffic flow which ultimately causes loss of regular business hours leading socio economic loss. Thus, a qualitative approach is considered to be one of the cost effective method over quantitative approach to find I&I susceptible area in the sewer conveyance system. The qualitative approach can reduce the amount of work load by giving a rough estimate of the I&I susceptible areas in the first step. Once the high susceptible areas are located, then field testing can be carried out only to those places where it is necessary. Thus, qualitative approach is considered to be one of the effective and economic methods.

Chapter 2 Methodology and Study Approach

2.1 Survey Methodology

A questionnaire was designed with 114 questions. Total of 126 municipalities from 13 provinces were participated in the survey across the Canada. Municipalities were categorized into three groups depending on their population size: small for less than 50,000, medium for 50,000 to 300,000, and large for more than 300,000, respectively. The pipe network was grouped in to three different categories by its usage: Water mains, Waste water, and Storm water. The whole section of survey questionnaire was divided in to three subsections. The first section is related to asset management and network financial condition. The second section includes construction methods, renovation and their benefits. In addition, this section has addressed the critical issues of all pipe networks. The last section deals with the general perception related to the trenchless technologies. It discusses the barriers to the use of trenchless technologies, and the importance of education to promote the use of trenchless technologies. A copy of survey questionnaire is attached in Appendix A. The data analysis was performed using SPSS, a software package used for statistical analysis. The Person correlation coefficient and chi square test was performed during the analysis to find the correlation between some variables in the survey. The results are discussed in the following sections.

2.2 I&I Study and Approach

Youngstown area was considered as the interest of study (Fig. 2-1). The analysis was performed using Geographic Information System (GIS). The GIS data file for the study included the sewer systems and the hydrologic soil classifications (A, B, C and D) of the city of Youngstown area. In general, hydrologic soils are classified based on their grain size distribution, run off potential and infiltration capacity. Group A through D are classified based up on their grain size distribution which can relate directly to infiltration rate and run off potential. For example, soils with gravel and coarse sand (group A) have high infiltration capacity (0.3 to 0.45 inch per hour) with low run off potential. The soil group D is composed of clays and has low infiltration capacity (0 to 0.05 inch per hour) with high run off potential. Similarly, soil group B has moderately coarse texture with slow infiltration rate (0.15 to 0.30 inch per hour) and group C has moderately fine to fine texture with slow infiltration rate (0.05 to 0.15 inch per hour). The group A, B, C and D has high (0.30 to 0.45 in/h), moderate (0.15 to 0.30 in/h), slow (0.05 to 0.15 in/h), and a very slow (0 to 0.05 in/h) rate of water transmission, respectively. The details descriptions of soils classification is given in the section 3.2.3.

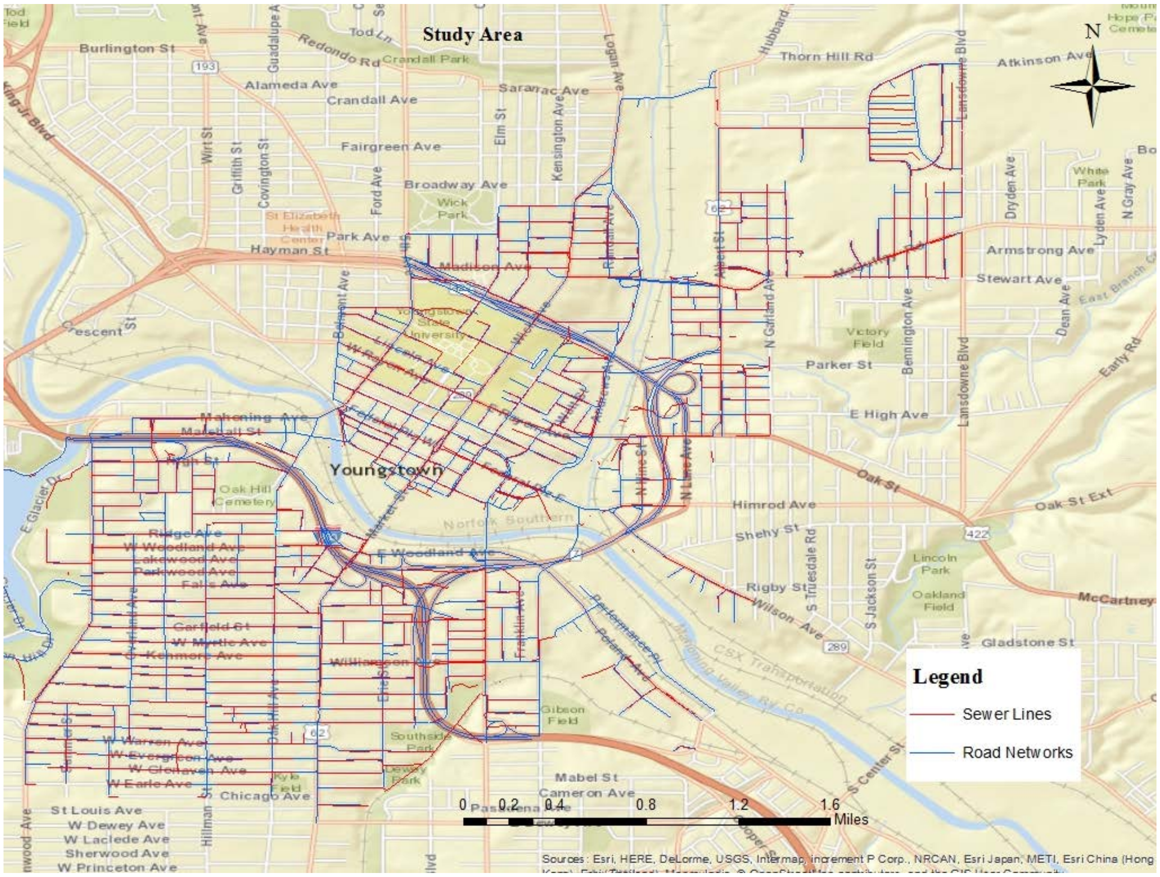


Figure 2-1: Study Area

Various mapping models were generated to identify the I&I susceptible areas considering the influential factors contributing to I&I problem. There were four parameters/factors in the model: pipe age, empirical operating coefficients, soil classifications, and sewer classifications. The first three factors were more likely to be responsible for the I&I in the sewer segments. The last factor, sewer classifications/groups, emphasized the effects of I&I. Sewer lines were divided into two categories: group 1 (6 inches to 18 inches) and main (more than 18 inches) lines. Pipe age for each segment of the pipe was calculated by subtracting their date of construction or rehabilitation from the current year, 2017. Empirical operating coefficients for each pipe segment were calculated using the equation 3.1. The different types of models were created by combining the effect of each parameter in equal or different weightage basis. For example, a model with an equal emphasis was created by giving 25% weightage for each parameter. Similarly, other maps were generated giving different weightage values for each parameter. The weighted value generated for each pipe segments indicates the vulnerability towards I&I of that particular pipe segment. Maps for each generated model were developed using GIS showing area of I&I susceptibility. As a result of this research, one can prioritize the segments that need I&I field testing for future research.

Chapter 3 Results

3.1 Survey Analysis Results

3.1.1 Survey Participants

Survey questionnaire was distributed to 13 provinces across Canada where 126 municipalities were participated in 2014/2015 survey whereas 124 municipalities were participated in 2013/2014 survey. In 2014/2015 survey, about 71 % of the respondents were participated from Ontario whereas more than 90% of the respondents took part in survey 2013/2014 from Ontario. As illustrated in Fig. 3-1, participants from Alberta, Manitoba, New Brunswick, and Nova Scotia has been increased in 2014/2015 survey and geographically well distributed when compare to the 2013/2014 survey. The geographic distribution for the survey 2013/14 is displayed in Fig. 3-2.

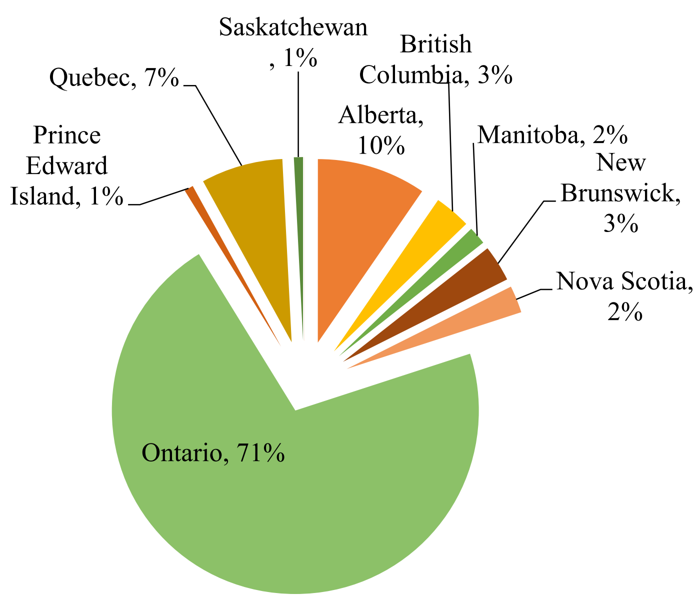


Figure 3-1: Survey participants in 2014/2015

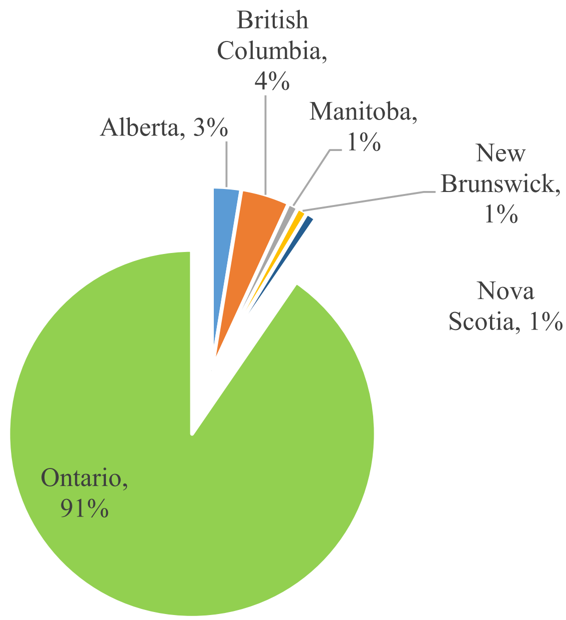


Figure 3-2: Survey participants in 2013/2014

The participated utilities were categorized into small, medium, and large following the criteria summarized in Table 3-1. 52% of the respondents from large, 30 % from medium and 18% from small municipalities were found to be participated in 2014/15 survey

Table 3-1: Municipalities size distribution

S. No.	Size	Population
1	Small	<50000
2	Medium	50000- 300000
3	Large	>300000

3.1.2 Asset Management and Financial Information

The survey was designed to disclose the municipalities' maturity level regarding familiarity and extent of using trenchless technology. Maturity level in the question refers to the current condition of the system in terms of its level of service, condition of assessment and operation, maintenance, and access to the funds to implement and monitor the asset management (AM) plan. Three different conditions such as i) No asset management, ii) Basic asset management, and iii) Advanced asset management were given in the questions to address the maturity level of utility/municipalities. No asset management represents the low maturity level while advanced asset management indicates the high maturity level. Similarly, other question was designed to find the status of the asset management of municipalities/utility i.e. whether it is a separate group or as a part of water/wastewater operations. The following is an example of question asked in the survey.

i. Is asset management a separate group in your municipality or is it part of water/wastewater operations?

    a. Separate group

    b. Water/waste water operations

Obviously, condition of asset management plays a vital role to have advanced utility/municipality system. The municipalities having an asset management department as a separate group have more access to the funds and have more authority to imply the new and innovated technology when compare to those having the asset management department as a joint group in the organization.

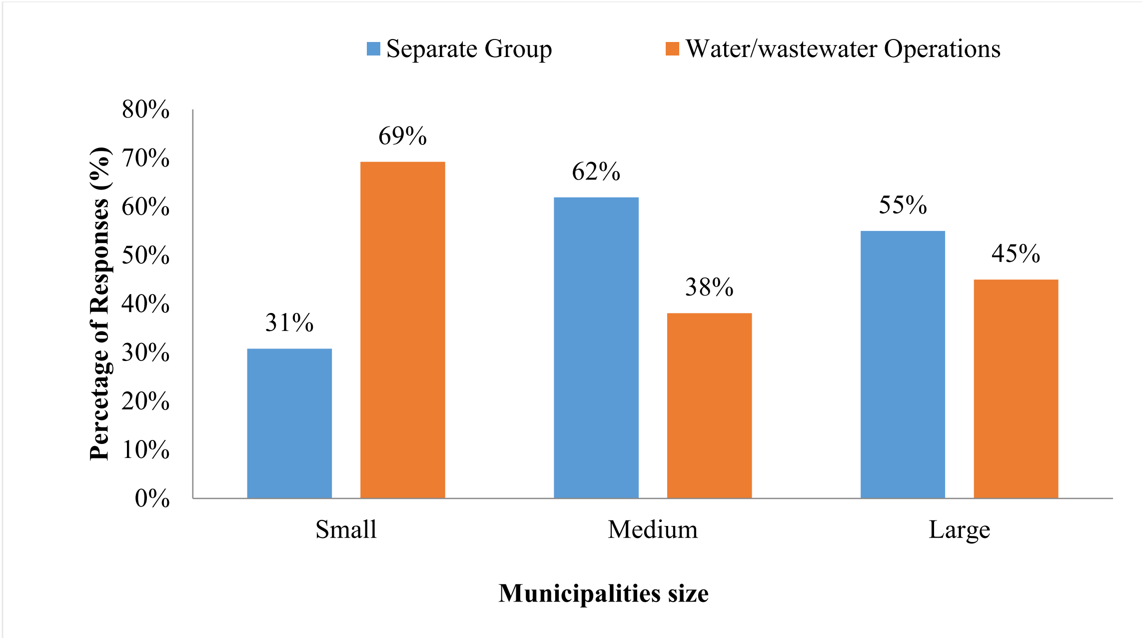


Figure 3-3: Asset management group

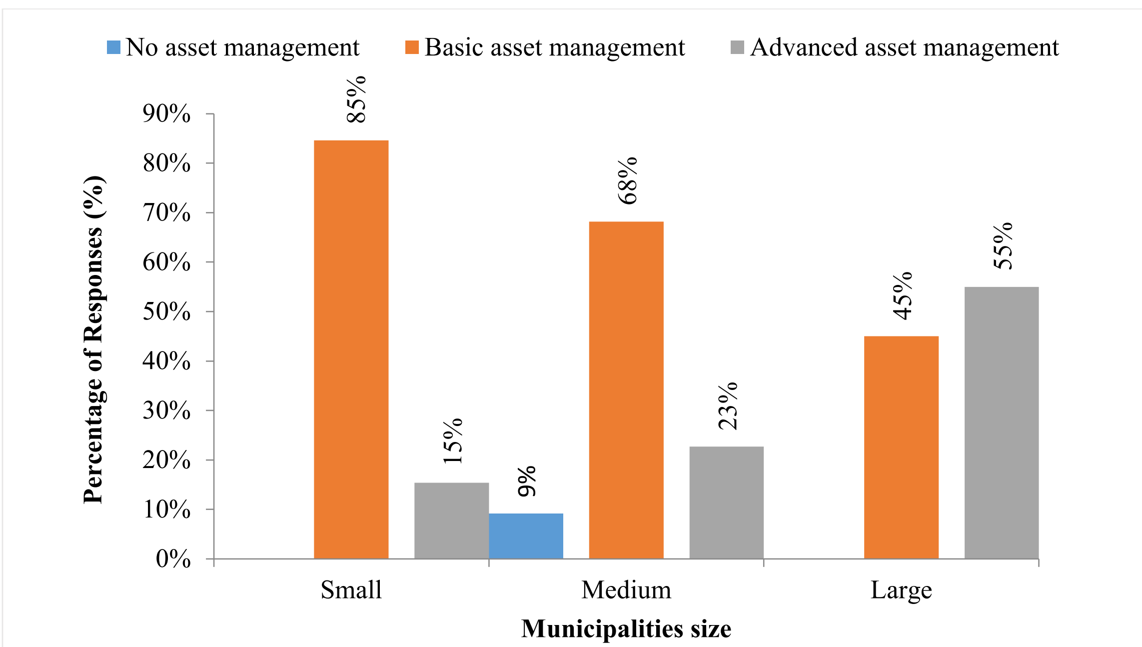


Figure 3-4: Maturity level

The results from the survey showed that 31% of the respondents from small municipalities have separate asset management group while 62% and 55 % of medium and large municipalities have separate asset management, respectively as shown in Fig. 3-3. 85 % of the respondents from small municipalities have only basic asset management group while only 15% of respondents have advanced asset management group as illustrated in Fig. 3-4. However, 55% of the respondents from large municipalities have indicated that they have advanced asset management group in their organization.

Statistical analysis (Chi-Square test) was performed between the asset management maturity level (AMLVL) and asset management group type for the municipalities (AMTYE). Chi-square test was performed to find the association between the two variables. The Chi-square statistic/test is considered to be a non-parametric, also known as distribution free, tool. This test is designed in order to analyze group differences when the dependent variable is measured at a nominal level (McHugh 2013). Chi-square provides substantial information compared to other non-parametric and some parametric statistics about how much each groups performed in the study. The initial hypothesis for this model was that there is an association between AMLVL and AMTYE. The results from the statistical analysis are summarized in Table 3-2 and Table 3-3.

Table 3-2: Contingency Table for AMLVL and AMTYE

AMTYE		AMLVL		Total
		Basic Asset Management	Advanced Asset Management	
Separate Group	Count	6	15	21
	Expected Count	9.7	11.3	21
Water/Wastewater Operations	Count	12	6	18
	Expected Count	8.3	9.7	18
Total	Count	18	21	39
	Expected Count	18	21	39

Table 3-3 gives the Chi-Square tests statistics and their corresponding p values. Pearson-chi-Square for the given value is 5.660 with p value 0.017. In such a situation, we can conclude that the obtained p value (0.017) is smaller than 0.05. Therefore, the association between the AMLVL variable and AMTYE variable is statistically significant. Moreover, Table 3-3 also provides Chi-Square statistics with continuity correction (4.231) along with Fisher's exact test results. As mentioned in Table 3-3, p values for continuity correction and Fisher's exact results are determined to be less than 0.05. Overall, these results with p values less than 0.05 indicated that correlation between the two categorical variables (AMLVL & AMTYE) is statistically significant. Additionally, in order to conclude the Chi-Square test results, some assumptions based on sample size should be considered. At least 80% percent the cells should have expected count 5 or more and no cell should have an expected count less than one (McHugh 2013). In this study, minimum expected count is 8.31 (greater than 5) is observed as shown in Table 3-3. Sample size in this analysis (39) is more than the number obtained by multiplying number of cells with 5 i.e. 20. Therefore, the results from Chi-Square with all p values less than 0.05 indicated the initial hypothesis can be accepted. Thus, it can be concluded that the maturity level is higher when there is advanced asset management group in the organization.

Table 3-3: Chi-Square Tests

	Value	df	Asym. Sig (2-sided)	Exact Sig. (2- Sided)	Exact Sig. (1-sided)
Pearson Chi-Square	5.660[a]	1	.017		
Continuity Correction[b]	4.231	1	0.040		
Likelihood Ratio	5.793	1	0.016		
Fisher's Exact Test				0.026	0.19
Linear-by-Linear Association	5.515	1	0.019		
N of Valid Cases	39				

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 8.31.

b. Computed only for a 2x2 Table

A comprehensive financial plan is a very important factor in any organization to achieve the financial and operational goals. Thus, financial and operational performance of an organization/company depends on how well the budget is allocated. In other words, a budget gives the overall snapshot of the company's strategic plan to accomplish its goals (Stratton 2016). It indicates that budget plays a very important role in which new technology will be implemented. For example, a municipality, lacking financial support, will not be able to use new technologies because of the initial costs associated with them. Moreover, the money allocated for capital works, maintenance, and for long term capital expenditure is necessary for the effective use of such technologies. Inspection, maintenance and replacement on regular basis can increase the project performance and its service life i.e. increases the sustainability of the project. The budget is of importance when creating an effective plan.

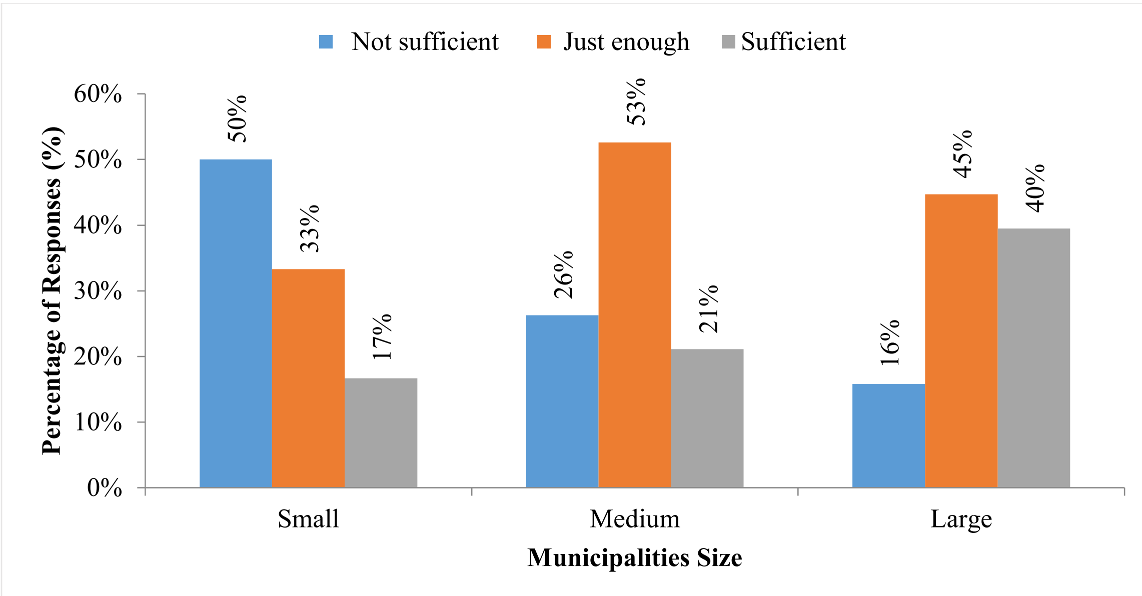


Figure 3-5: Budget allocation for capital works

The survey turned out that the small municipalities do not have sufficient fund for capital works in comparison to medium and large municipalities. As shown in Fig. 3-5, 50% of the respondents from the small municipalities indicated that they do not have sufficient funds. On the other hands, only 16% of the large municipalities do not have sufficient funds for capital works.

A question was designed to explore the state of the long term budget allocated for the capital expenditures in the municipalities. Municipalities were asked to mention their views on whether they have sufficient funds to meet capital expenditure or not for the next 5-10 years. Typical question which was asked in the survey is given below:

Does your municipality/utility have sufficient funds to meet capital expenditures for the next 5-10 years?

i) Do not have sufficient fund

ii) Have just enough fund

iii) Have sufficient fund

As shown in the Fig. 3-6, 28% from large municipalities have indicated that they have sufficient budget to meet the capital expenditures for the next 5-10 years. None of the small municipalities have sufficient budget for next 5-10 years to meet capital expenditures. The trend of the results have showed that budget proportional with the size of the municipalities i.e. larger the size of municipalities more budget for long term expenditures.

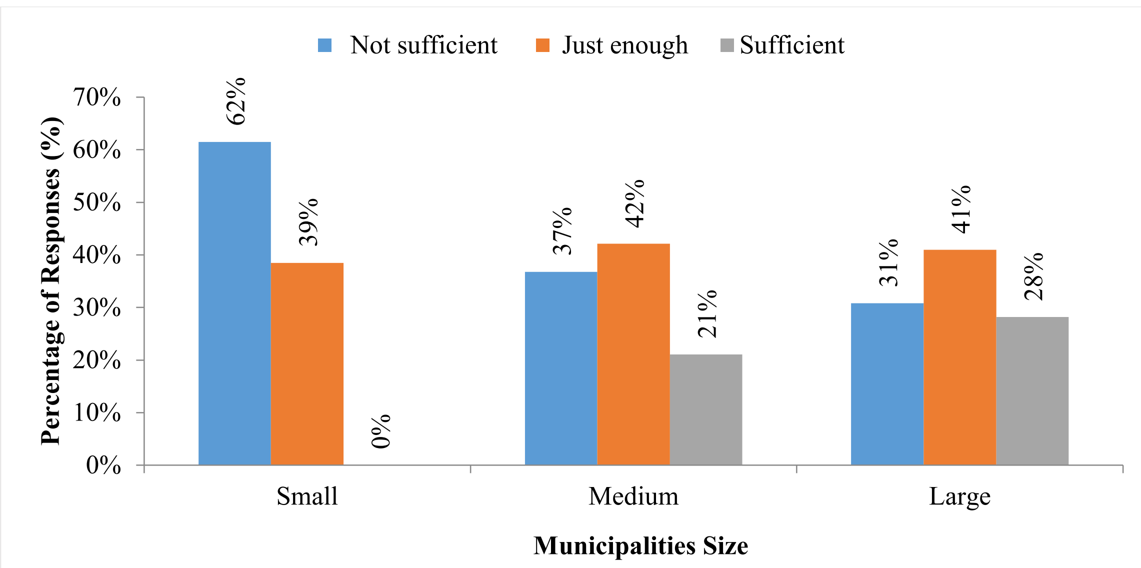


Figure 3-6: Long term budget

3.1.3 Removing the Water and Sewer Infrastructure Backlog

Water and sewer infrastructure backlog is a common issue in the pipe network. Various factors, which are linked with trenchless technology, need to be addressed to minimize the backlog effect in the pipe network.

A survey question was designed to find the importance of the different issues which need to be addressed to upgrade the technology and hence finally minimizing the backlog effect in the pipe network. The participants were asked to rate how important is to incorporate the government regulations, public education, professional education, access to long-term financing and government grants, increased water/sewer rates, creating storm water fees, and public private partnerships for minimizing the water and sewer infrastructure backlog effect in their municipality policies. The rating scale for each issue was provided from 5 (very critical) to 1(not critical).

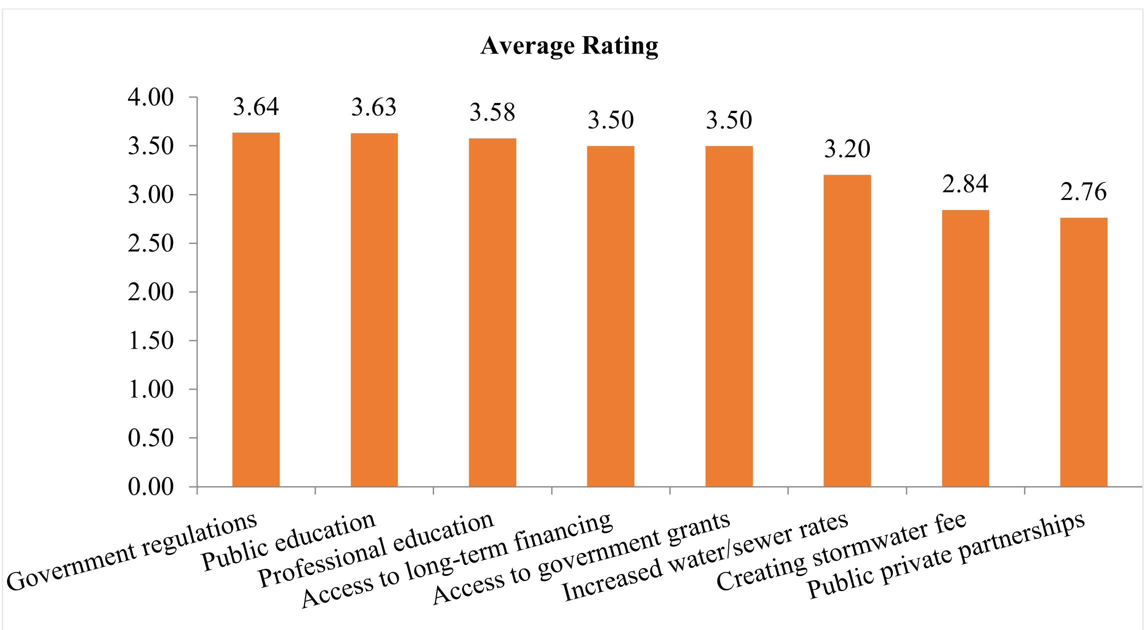


Figure 3-7: Average ratings for different factors to reduce backlog effect in pipe network

Fig. 3-7 shows the average rating for different factors from all the municipalities. Municipalities consider government regulations, public education and professional education (3.6 out of 5) as the highest rated factors that need to be incorporated to reduce the backlog effect in the pipe network. Similarly, public private partnerships policy was rated lowest (2.75 out of 5) among all the factors as shown in Fig. 3-7. This indicated that the lack of skills, appropriate knowledge and assets shared from each sector (public and private) can still be considered as the major factors hindering to deliver the quality service or facility to the general public. In addition, the results indicated that government regulations and policies along with the appropriate education systems, effective training and skills are very important to use the technology effectively.

3.1.4 Methods for Renovation and Replacement

Aging of the underground pipe lines in United States is one of the serious issues as most of the pipelines are more than 100 years old. Due to lack of pipe replacement and broken and leaky pipes, about 1.7 trillion gallons of water are wasted every year (Morrow 2016). This amount is estimated only for restoring the pipes i.e. without including the cost of constructing new infrastructure or repairing treatment plants (Buckley et al. 2016). In the United States, according to the research conducted by American Society of Civil Engineers (ASCE), it has been estimated approximately $US 1.3 trillion over the next five years to maintain current underground infrastructures systems (Mohammed et al. 2008). According to ASCE report card ‘D^+’ released in 2017, American Water Works Association (AWWA) has estimated the cost to maintain and expand water facilities to meet the increasing water demand over the next 25 years to be approximately $1 trillion. Moreover, approximately $271 billion is estimated for maintaining and expanding the waste water network to meet the future demand over next two decades due to population increase (ASCE 2017). Trenchless rehabilitation technologies offer solutions to restore functional use of pipeline systems and extend life expectancies of existing systems. Basically, the use of trenchless technology and its growth depends on two scenarios. First, how the communities are aware of the impact of infrastructure development on society, whereas second is the necessity for renewals/maintenance and rehabilitation of underground infrastructures. Age is one of the major factors among other various factor such as pipe material, type of soil around the pipe, empirical coefficient. Trenchless technology is recognized as an environmentally and socially acceptable method of construction, particularly in comparison with traditional open excavations.

In the survey questionnaire, a question (given below) was designed to rank the methods which are being used for renovations of water mains, waste water, and storm water pipe network in the municipalities.

Please rank the methods (1 being the primary method) that you see being used for water mains' renovation and construction in your municipality (Check N/A if not used at all)

- ☐ Open cut ☐ N/A
- ☐ Directional drilling ☐ N/A
- ☐ Cured in Place Pipe (CIPP) ☐ N/A
- ☐ Micro-tunneling ☐ N/A
- ☐ Slip-lining ☐ N/A
- ☐ Cement mortar lining ☐ N/A
- ☐ Spray-on or Spray-in Place Pipe (SIPP) lining ☐ N/A
- ☐ Other Methods ☐ N/A

The results for water mains, waste water and storm water network are described in the following section.

3.1.4.1 Water Mains

Even though the modern technology for renewal of water distribution infrastructure have developed fast over the last 20 years of period, the average rate (~1%) of system renewal is not adequate to keep pace with increasing needs of water utilities (Sterling et al. 2009). Many of the water pipes are laid in the early to mid-20th century with lifespan of 75 to 100 years (ASCE 2017). Based upon the ASCE report card 2017, the need to renovate or construct new water mains to meet the current demand is becoming a concern. However, due to rapid growth of the populations and urbanization of cities, it could be more costly to use traditional method to renovate and replace new underground infrastructures. Social costs are indirect costs associated with negative effects e.g., traffic delay, air pollution, noise pollution, safety, loss of business hours and etc. Therefore, trenchless method could be more effective method, especially, in urban area. According to the ASCE infrastructures report card (2017), approximately 240,000 water main breaks per year in the United States. According to the report, maintenance and expansion of service is crucial to meet the drinking water demand over the next 25 years. The estimated amount for the maintenance and service expansion is approximately 1 trillion dollars. The data mention above describes the need to improve or develop current and new technology. It can be concluded that such needs will help to offer new opportunities and technology such as trenchless to make more effective investments in water and wastewater system performance.

The municipalities were asked to rank (from 1–primary to 8–not applicable) their primary methods of renovation and replacement. As shown in Fig. 3-8, the results indicated that the 85% of the participants mentioned open cut method as their primary method of renovation and replacement of underground infrastructures. Similar results were observed in the survey 2013/14 which is shown in Fig. 3-9.

As we looked in the results about barrier to the use of the trenchless technology, municipalities mentioned lack of sufficient fund is their major barrier, and education as the second barrier. Obviously, direct cost to use the trenchless technology would be higher than the open cut method. However, social cost associated with the open cut method will be more burdens to the society and for overall economy of the. Indeed, trenchless method is environmental friendly and economic approach offering low surface disruption, minimum excavation and low cost of construction in comparison to open cut method. Thus, it can be concluded that trenchless has less negative environmental impact in comparison to the open cut method.

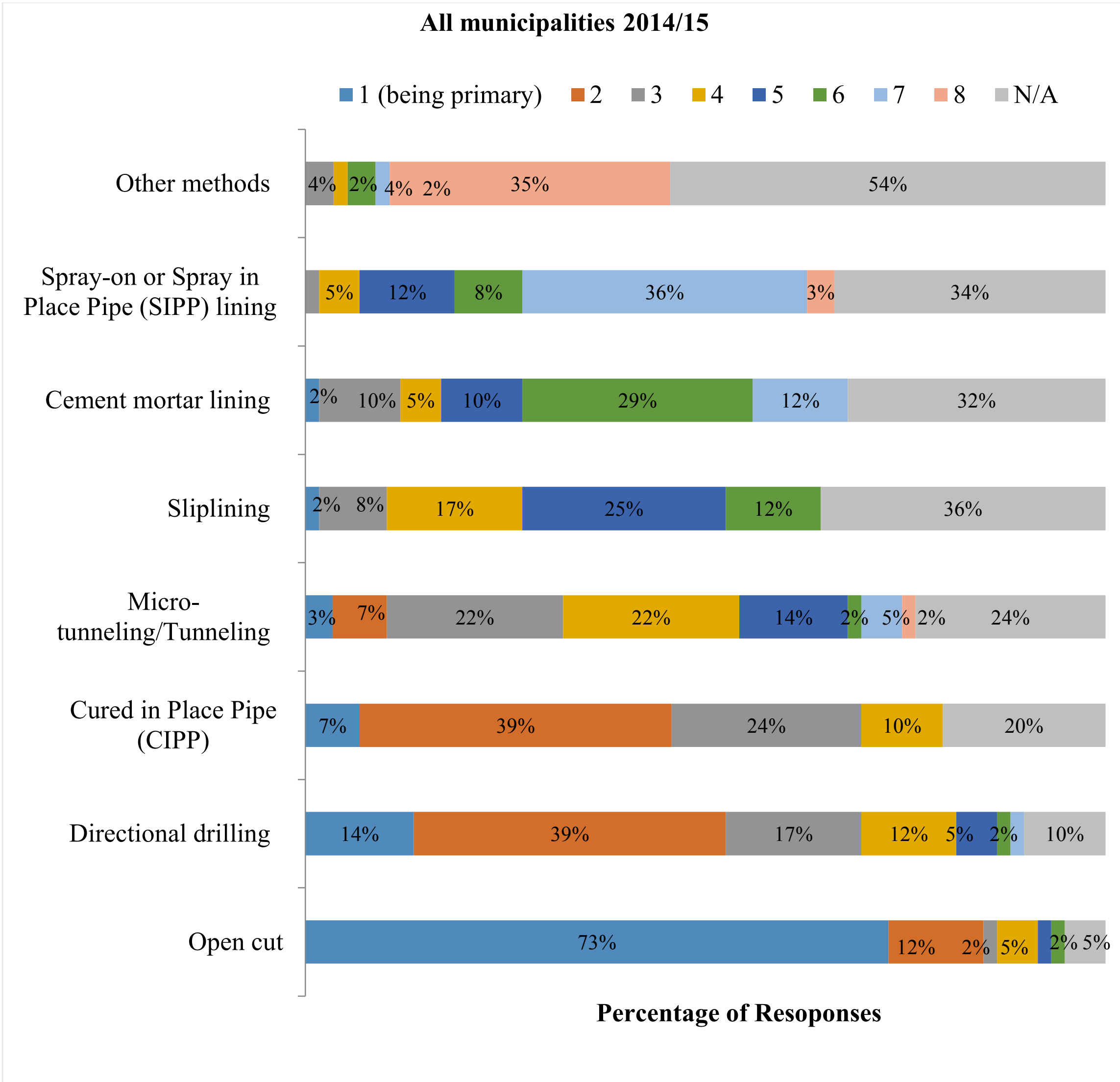


Figure 3-8: Water mains primary method of construction and renovation in 2014/15

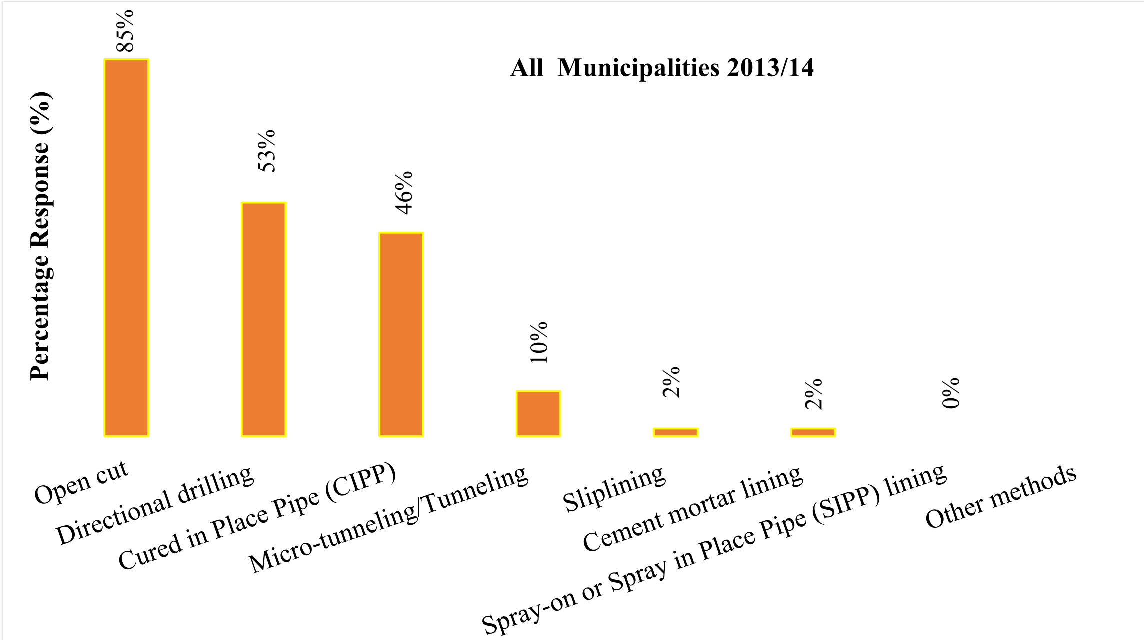


Figure 2-9: Water mains primary method of construction and renovation in 2013/14

3.1.4.2 Waste water

The results from the survey 2014/15and 2013/14 for the waste water pipe network are shown in Fig. 3-10 and 3-11, respectively. As illustrated in Fig. 3-10, 81% of municipalities ranked open cut method as their primary method of renovation and replacement for waste water network. Participants ranked directional drilling (52%) as their second popular method for renovation and replacement for the waste water pipe network.

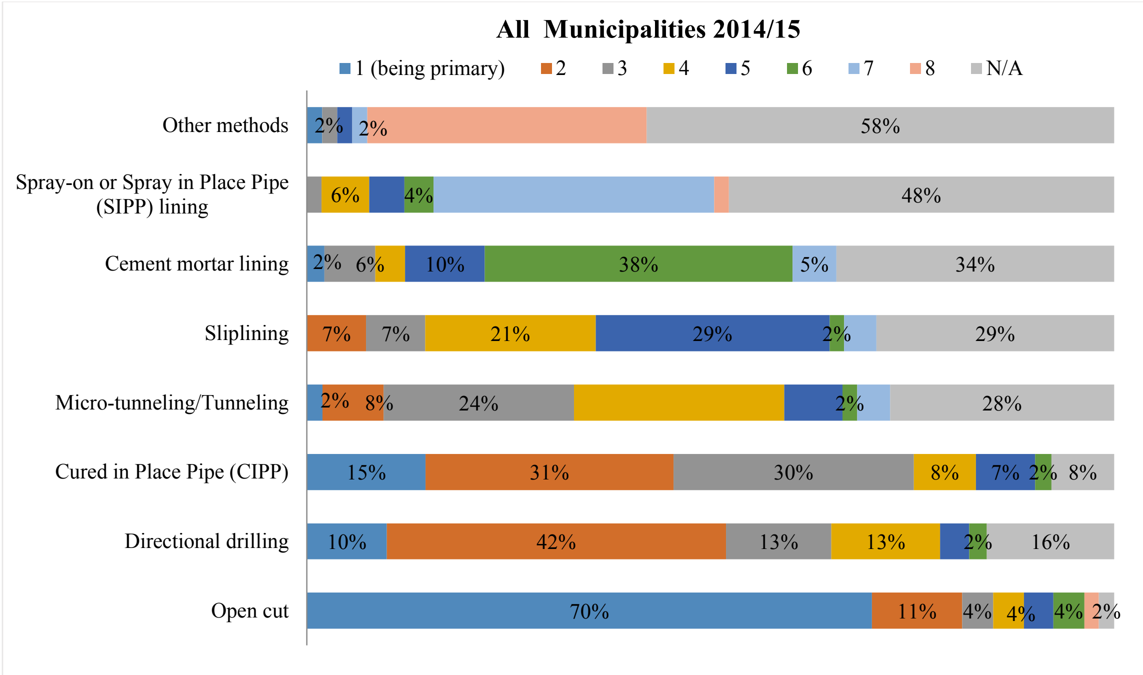


Figure 3-10: Waste water primary method of construction and renovation in 2014/15

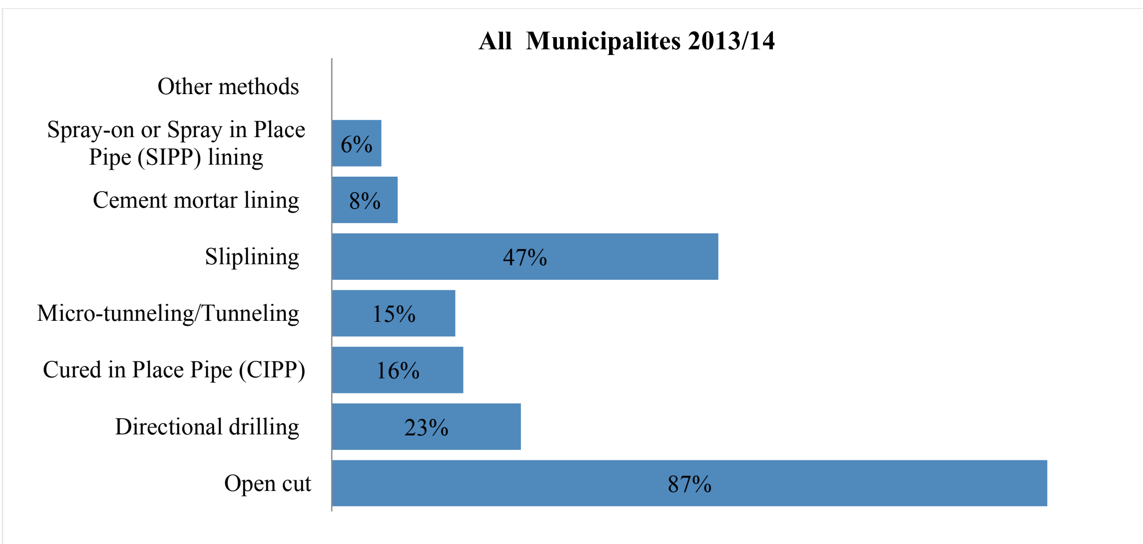


Figure 3-11: Waste water primary method of construction and renovation in 2013/14

3.1.4.3 Storm water

The results for storm water network from 2014/15 survey are shown in Fig. 3-12. The results revealed that 80% of the respondents mentioned open cut method as their primary method of renovation and replacement for their storm water pipe network. Similar results were observed in survey 2013/14. Horizontal Direction Drilling (HDD) and Cured in Place Pipe (CIPP) method was placed as second and third primary method for the renovation and replacement of storm water pipe network. Micro tunneling is the least utilized technology among the used trenchless method.

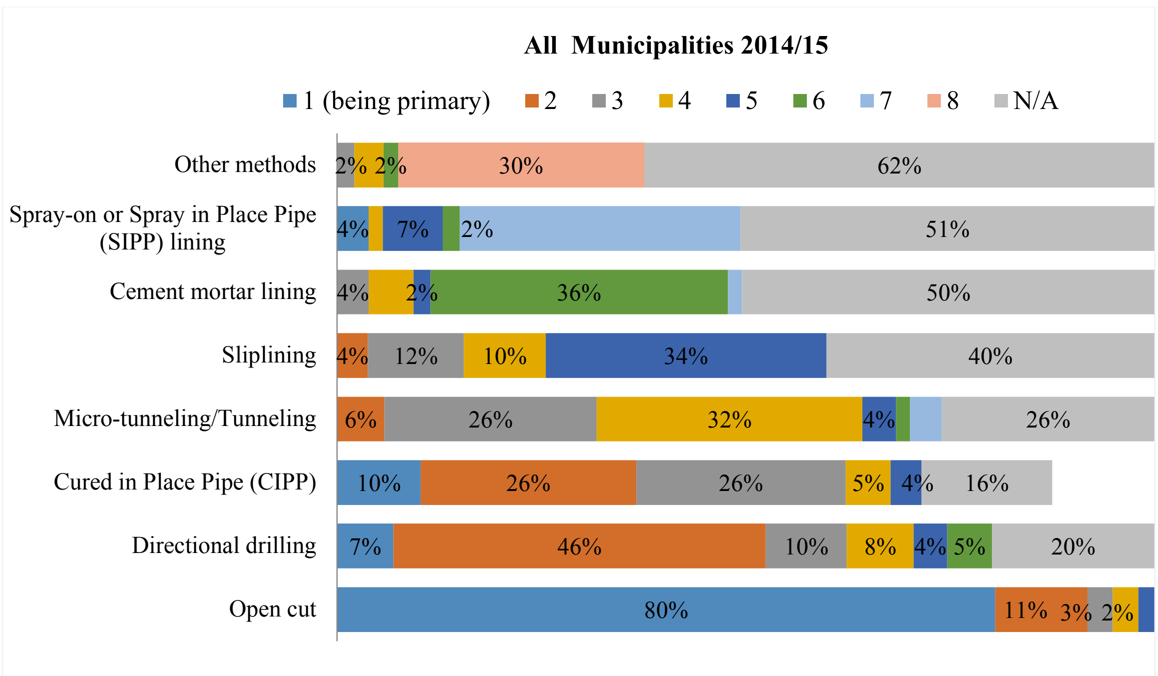


Figure 3-12: Storm water primary method of construction and renovation in 2014/15

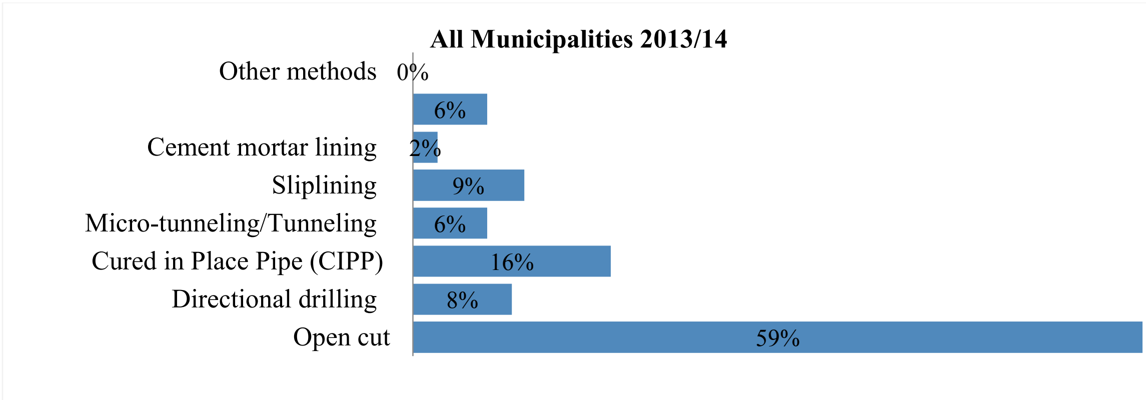


Figure 3-13: Storm water primary method of construction and renovation in 2013/14

The similar results were observed in previous research performed by Ariaratnam and his colleague in 1999. They stated that micro tunneling needs a special aptitude, skill or knowledge and there are very few contractors who have that knowledge. Micro tunneling system works with four main attributes: 1) remote control to operate micro tunneling boring machine, 2) guidance system to guide the boring machine, 3) pipe jacking system to install the pipelines, and 4) continuous pressure on the excavation face to balance groundwater and earth pressure (ASCE/CI 36-14). It indicated that micro tunneling requires a lot of knowledge and skills to use the technology effectively. Micro tunneling was the least favorable method in trenchless technology in 1999, and 2013/14 survey result, as shown in Fig 3-13, still showed the same result. The survey results imply that the situation (skill, contractor, appropriate training and knowledge, etc.) has not improved enough to promote the use of micro tunneling.

Overall, the use of trenchless technology is still overshadowed by the open cut method. It can be concluded that the budget, appropriate training, skills, and knowledge about the trenchless technology are the major hindrance to the use of trenchless technology. The capital cost for the trenchless technology is more than that for the open cut method (Najafi 2014). A sort of cost comparisons are shown in below Fig. 3-14. The labor cost and material cost for the trenchless technology is more than that for the open cut method. However, the social costs is significantly lower than cost of trenchless technology.

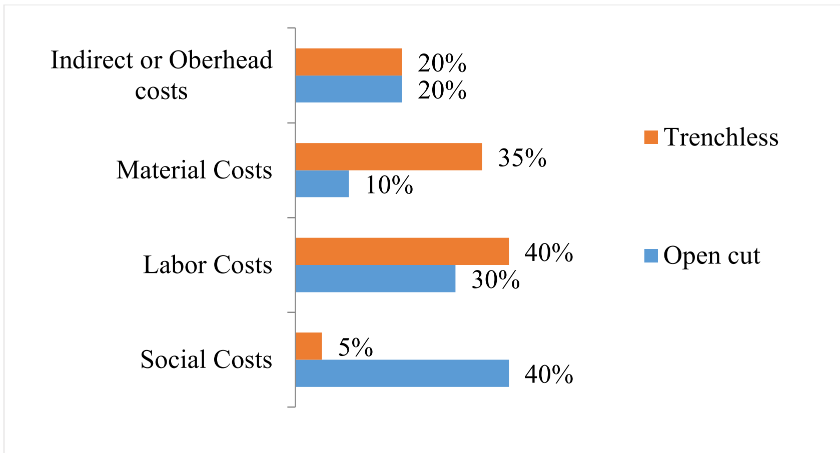


Figure 3-14: Cost comparison between the open- cut method and trenchless method. (After Najafi, 2004)

Mathews et al. (2015) conducted a study and showed that the social costs and criteria are of importance when establishing the social costs calculation analysis for the installation of underground utilities. Examples of social costs are re-routing traffic and noise pollution, which are separate from direct cost. By allowing bid invitations and evaluations from separate entities, new advanced and cost efficient construction technologies can be practiced. Some of these new methods include trenchless technology, which decrease environmental disturbance. Moreover, trenchless technology is beneficial to urban areas because it offers a sustainable design, which reduces the need for regular maintenance and construction. These social costs also affect industry. Finally, the study recommended that a reliable automated approach for estimating social costs on typical values is very necessary to encourage the use of trenchless method. Thus, it is clear that the use of trenchless method can be promoted by analyzing the details of social cost and putting those figures during the offer of bidding. The details of social cost may include the equivalent monetary values of the disruptions caused by open cut method. Due to lack of standard methods for estimation and evaluation, many of the engineers and project managers ignore the social costs during the planning and designing phase. Therefore, Matthews et al. (2015) presented eight different social cost categories and their mathematical calculation methods. Travel delay, loss of business revenue, loss of parking revenues, cost of dust control, noise pollution costs, vehicle operating costs, decreased road surface, and safety were the most important eight social costs parameter identified by Matthews and his team.

3.1.5 Benefit of the Trenchless Technology

3.1.5.1 Water Mains

Various trenchless technologies have their own advantages, limitations and disadvantages depending on their methods of applications. This section reveals the perceptions of the users/municipalities in benefit of the various trenchless technologies which are used for renovation or construction of the three different pipe networks. The questions given in Appendix A (Q. 27, 35, 43, 51, 59, 67) were asked in order to disclose the conditions of the trenchless technologies and their benefit.

Participants were asked to rank the benefit of the trenchless method that they have used. As shown in Fig. 3-15, Cured-in-Place Pipe (CIPP) has been ranked as first method to be beneficial to very beneficial method (52%) followed by Horizontal Directional Drilling (47%) and Micro Tunneling (31%) in water mains network. In 2013/14 Survey, 65% of the municipalities have indicated Horizontal Directional Drilling (HDD) as the most beneficial method followed by CIPP (44%) and Micro Tunneling (34%), as shown in Fig. 3-16.

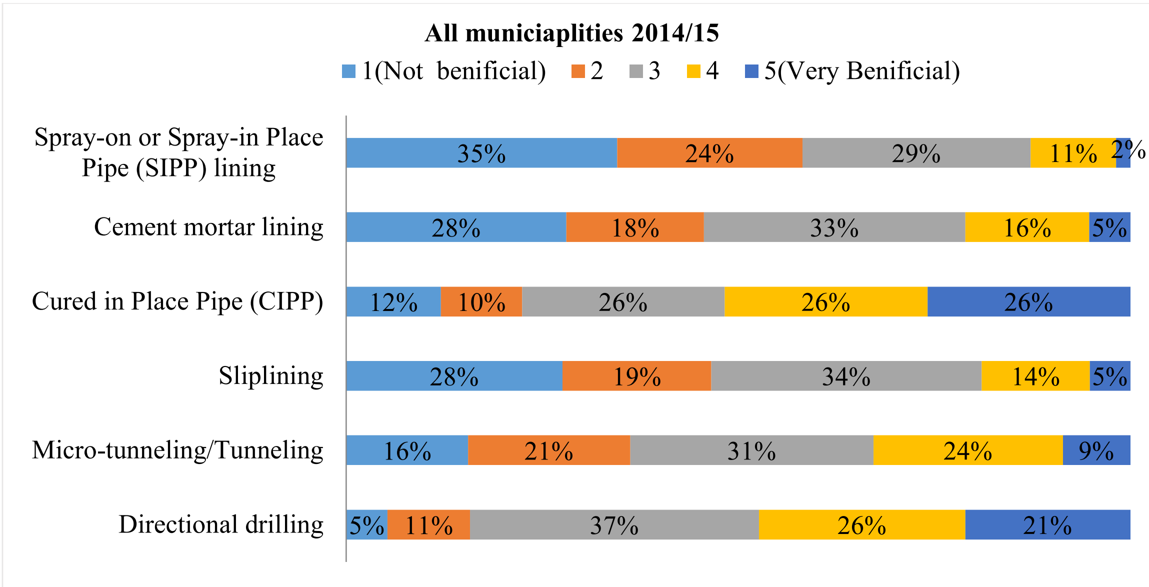


Figure 3-15: Rating of benefit of the trenchless method in 2014/15

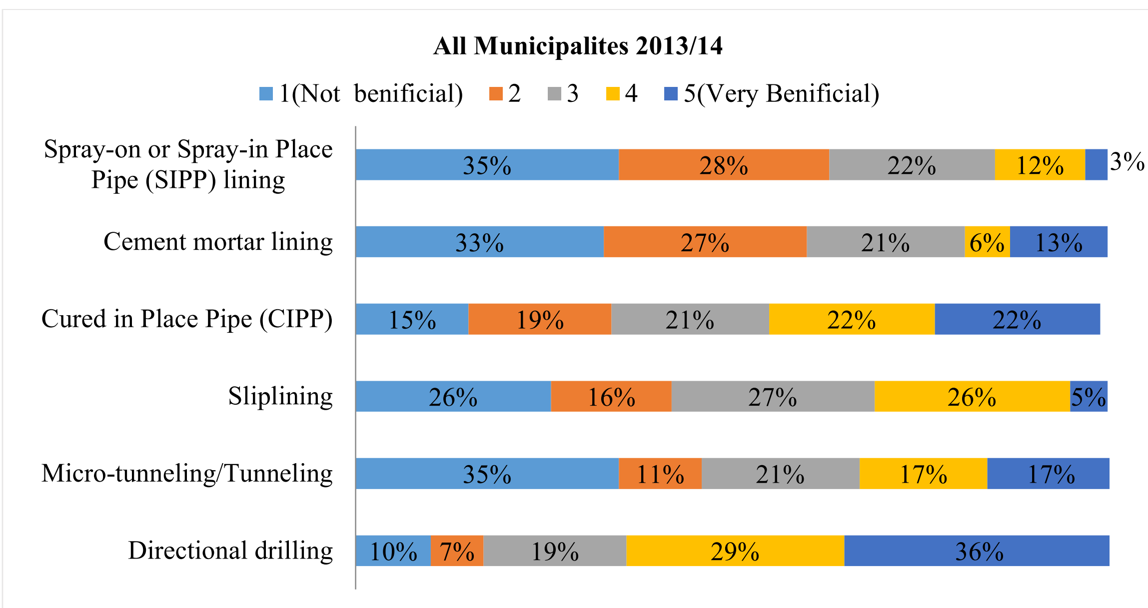


Figure 3-16: Rating of benefit of the trenchless method in 2013/14

CIPP method uses the remote controlled robot to repair the underlying pipe and does not require local excavation. According to the study conducted by Rush et al. (2013), CIPP reduces the carbon foot print by 85% or more than traditional open cut method and associated cost savings can be as much as 50%. His study implies that CIPP is considered as environmental friendly method when compare to the traditional method. Moreover, it is easy to apply this method even the pipe is significantly bent, and it increases the HAZEN Williams coefficient by greater than 120 which improve the flow capacity (Rush et al. 2013). Pipe relining guide (2013) has mentioned that the life of pipe can be increased by 50 years or more by using the CIPP method. It can be concluded that the gaining popularity of the CIPP is because of the reasons mentioned above.

3.1.5.2 Waste Water

The results from 2014/15 survey for the waste water network are shown below in Fig. 3-17. The results indicated that 68 % of municipalities think that CIPP method is beneficial to very beneficial. The CIPP method is the most popular method among the various trenchless methods. Likewise, as shown in Fig. 3-18, the municipalities ranked Directional drilling (42%) followed by Micro tunneling (33%), SIPP (30%), Cement mortar lining (27%), and Slip lining (19%) from beneficial to very beneficial method. The results from the survey 2013/14, shown in Fig. 3-18, are similar to the results from 2014/15. The CIPP method is also ranked as most popular method among other trenchless method. CIPP is the one of the trendy methods to repair and lining. Many utilities owners throughout the globe have used CIPP method and it is also recognized as one of the most grown trenchless technologies (Koo et al. 2011).

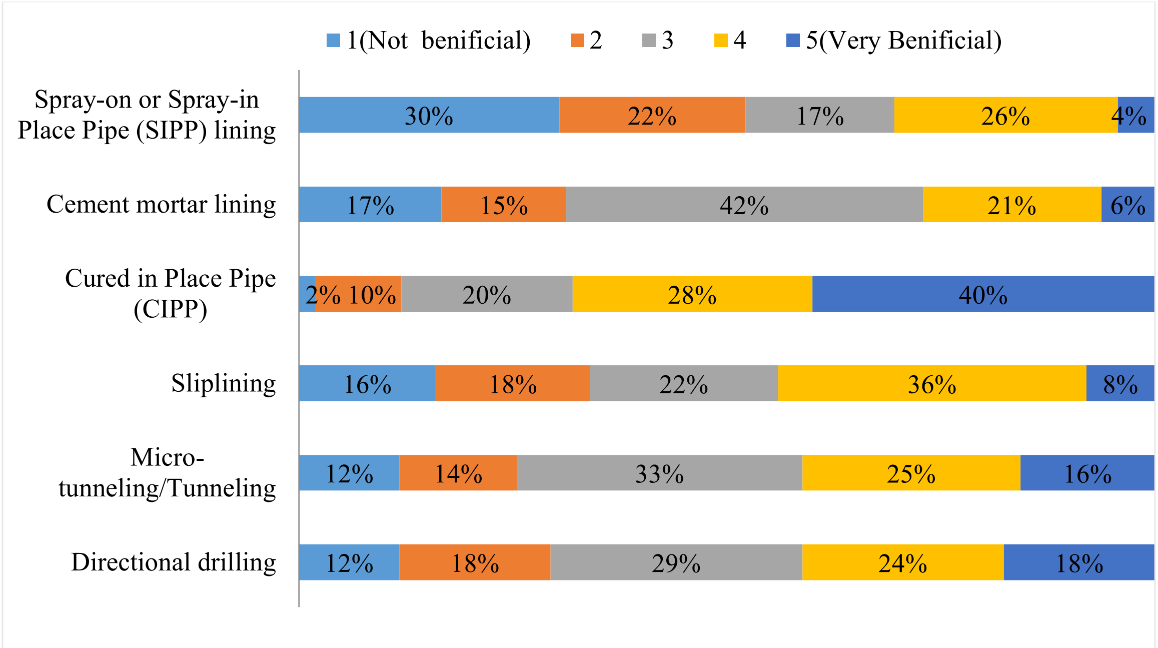


Figure 3-17: Waste water network, benefit of trenchless technology in 2014/15

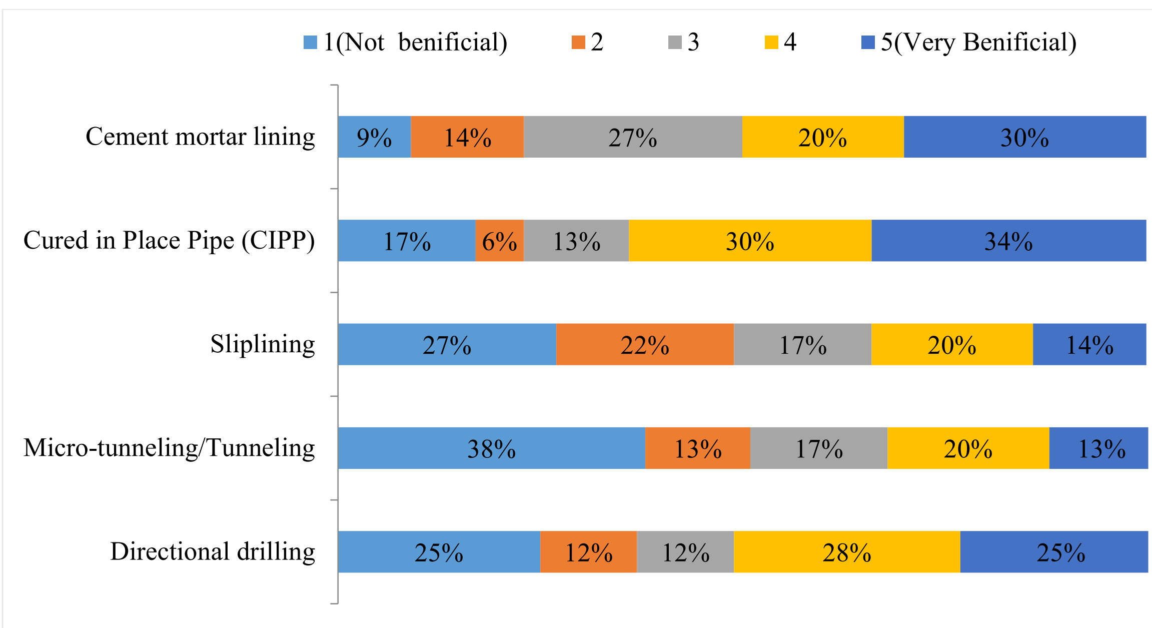


Figure 3-18: Waste water network, benefit of trenchless technology in 2013/14

From the above results, it can be noticed that the use of trenchless technology to rehabilitate or replace waste water network is still has not been increased. However, the results indicated that CIPP is the most popular method among trenchless methods.

3.1.5.3 Storm Water

In 2014/15 Survey, CIPP method was considered to be beneficial to very beneficial method of construction and renovation of storm water pipe network. As shown in the below Fig. 3-19, response count for CIPP (48%) was noticed to be the highest as compared to the other methods. Directional drilling was considered second most popular and beneficial method with count 40 % in response. Almost similar kind of results was observed from the results for survey 2013/14 which is illustrated in Fig. 3-20.

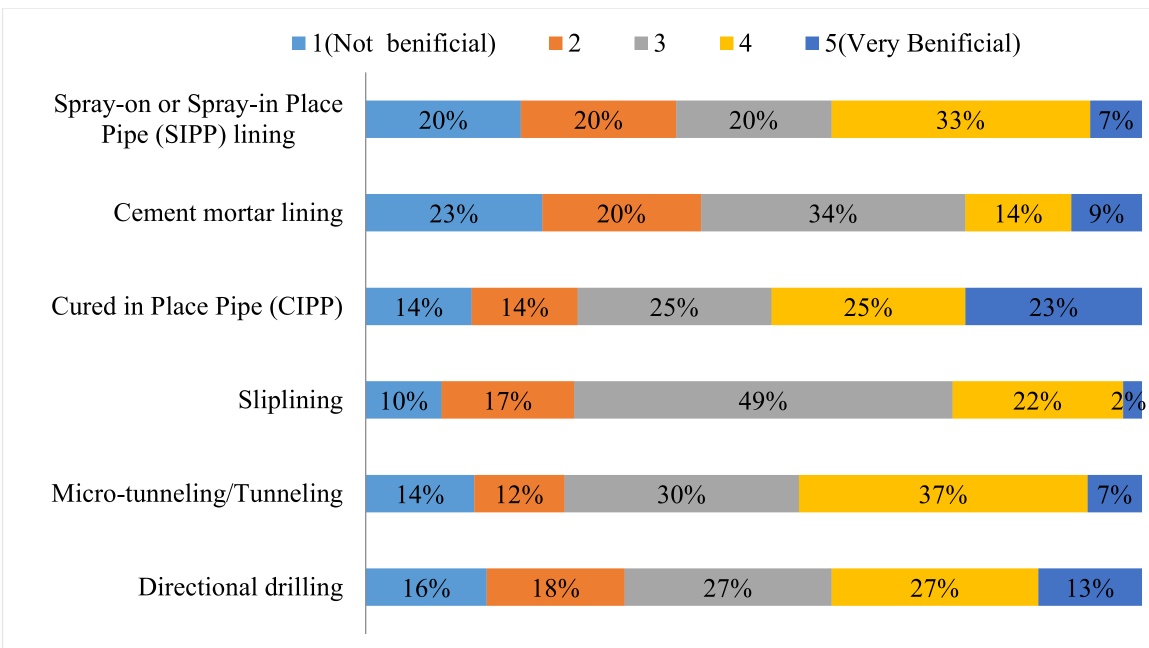


Figure 3-19: Storm water network, benefit of trenchless technology in 2014/15

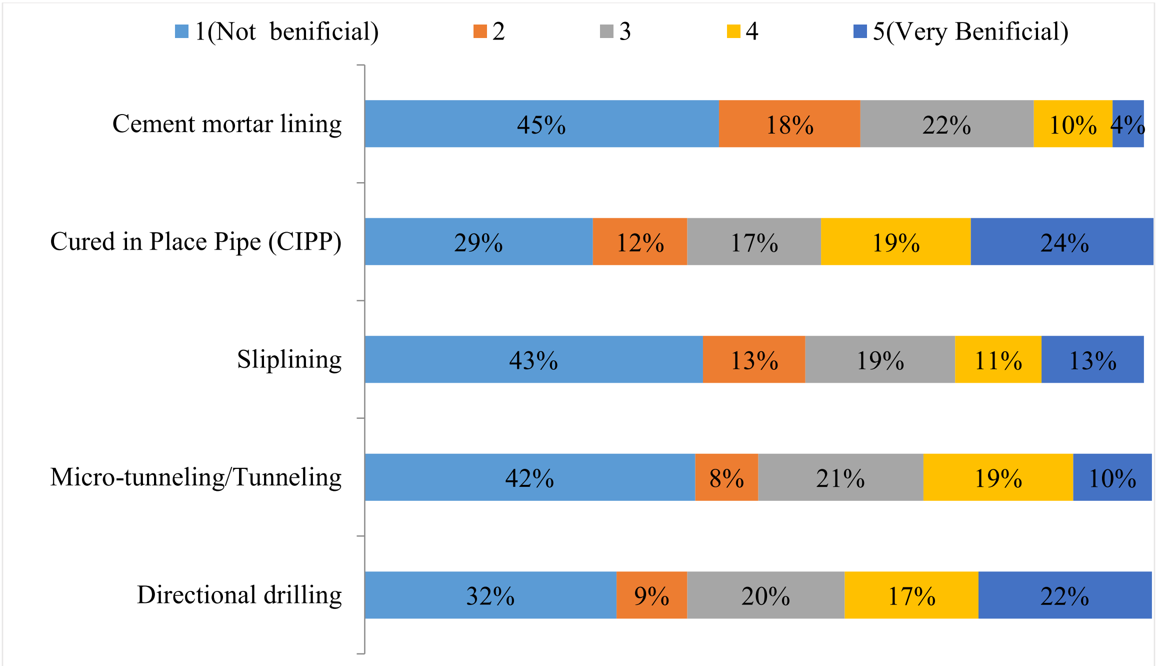


Figure 3-20: Storm water network, benefit of trenchless technology in 2013/14

3.1.6 Trenchless Technology and Effectiveness

Trenchless technology has been proven to be very effective method over open cut method in different scenarios/issues. For example, trenchless technology has less social cost (Najafi 2014); minimal surface disruption, less severe environmental effects (reduced carbon foot print); traffic delays and reduced site restoration (Mathew et al. 2012). Trenchless techniques are becoming popular in both developing and developed countries because they are considered to be the one of the most cost-effective methods to renovate water and sewage network in congested cities (Downey 2006). The questions were designed to rate the effectiveness of trenchless technology in terms of i) Cost effectiveness, ii) Depth of pipeline c) Reducing the urban congestion, and d) Environmental Impact. The rating was assigned from 1 (not effective) to 5 (very effective) as shown in Fig. 3-21. Respondents from all municipalities have reported that the trenchless technology, based upon the possible 4 choices, is effective or very effective (collectively) in terms of Environmental impact (67%), Depth of pipeline (64%), Reducing urban congestion (58%), and Cost effectiveness (51%).

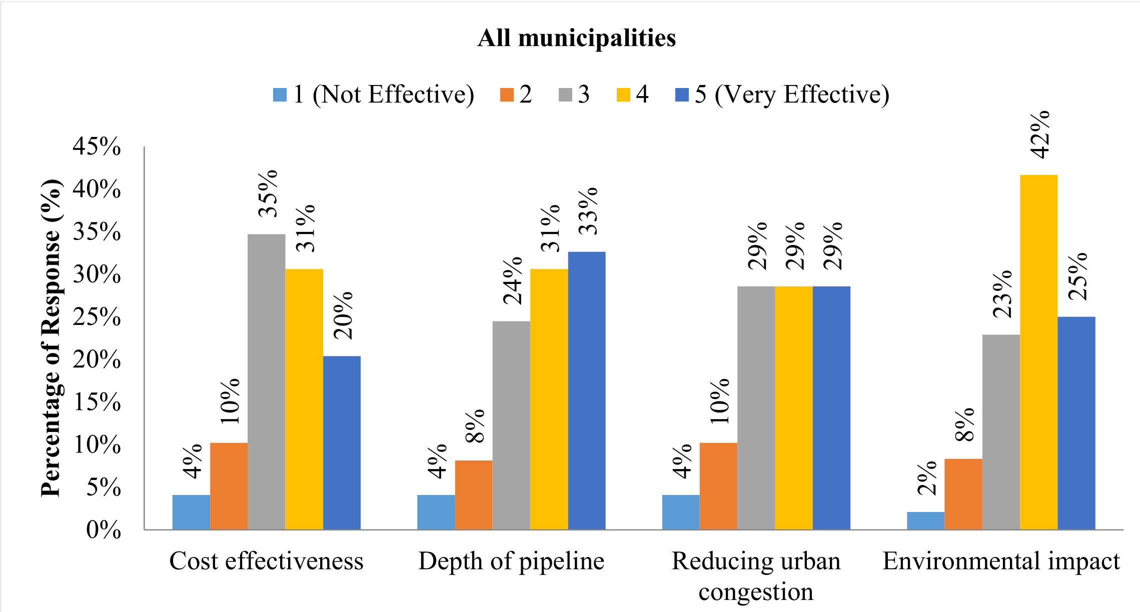


Figure 3-21: Effectiveness of the trenchless technology

Trenchless technology is found to be more effective in environmental impact issues. It is obvious that open cut method results in a significant amount of dust and air pollution. The heavy equipment makes loud noise which ultimately decreases the quality of life (Ballesteros et al. 2010; Gilchrist et al. 2003). Trenchless technology was ranked second with 61% responses in terms of depth of pipeline as illustrated in Fig. 3-21. The results also agree with the findings from the research conducted by Apeldoorn (2013). He stated that the cost of open cut increases with the depth of pipeline and its location. Cost comparison was performed in terms of depth of pipeline and its location. The conclusion of finding was that, the cost varies from lowest, moderate, and to highest for shallow pipe (residential), medium depth (low density urban area), and deep pipe (high density urban), respectively. He also mentioned that sometimes cost of construction using trenchless technology exceeds the open cut method, especially, in residential areas with shallow depth conditions.

The survey results have showed that the trenchless technologies have more benefits compared to open cut method. Even though the trenchless technology has becoming popular with advancement of technology, there still exists the lack of recognizing the costs associated with benefit of trenchless methods over open cut method by government agencies, design and consulting engineers and municipalities (Najafi et al. 2004). This indicates that there is still lack of appropriate education, skills and knowledge which can be used to promote the effective use of trenchless technology.

3.1.7 Necessity of Consultants' Involvement in Policy and Decision Making Process

The municipalities were asked to explore the importance of the consultant's participation in policies and decision making process with respect to the following issues:

i. Increased water/sewer rates
ii. Access to government grants
iii. Government regulations
iv. Public private partnerships
v. Access to long-term, financing

As shown in the Fig. 3-22, 84% of large and 71% of the medium municipalities think consultant's involvement to make policies to promote the use of public private partnerships ,also known as PPPs, could be very effective in the use of trenchless technology. It is believed that existence of PPPs have been recorded worldwide since

Roman Empire (Forrer et al. 2010). German et al. (2001), from University of Bamberg in their syllabus (updated version at 2015), stated that public private partnership policies are better in dealing with governance of complex socio-technical issues. The examples of such issues include development and operation of public utilities and services such as (green/sustainable) power plants, rail network and stations, hospitals, prisons, schools, water treatment facilities, and urban regeneration programs. Public private partnerships (PPPs) can be also be defined as involvement of three sectors in any project to accomplish some special goals such as to address the socio-technical issues. First sector involves public which is also known as local government body. The second stands for private which includes business and investor organizations. The last “P” stands for local public or people.

The access to long term financing was of importance to 57% of medium municipalities and only 12% of large municipalities believed this to the case. The small municipalities showed much higher interest in the access to government grants. However, with regards to all of the municipalities, they believe the governmental regulations were of equal importance. Less than 50% from all the municipalities showed their interest for consultants to be involved during policy and decision-making process to increase water/sewer rates.

Based up the nature of question (to divulge the necessity of the factors mentioned above) and the results explained above, it can be concluded that PPPs along with government regulations are very important for the effective use of trenchless technology. In summary, participation of consultants in policy and decision making process in regards to public private partnerships and access to government grants along with government regulations could help the use of trenchless technology in an effective way.

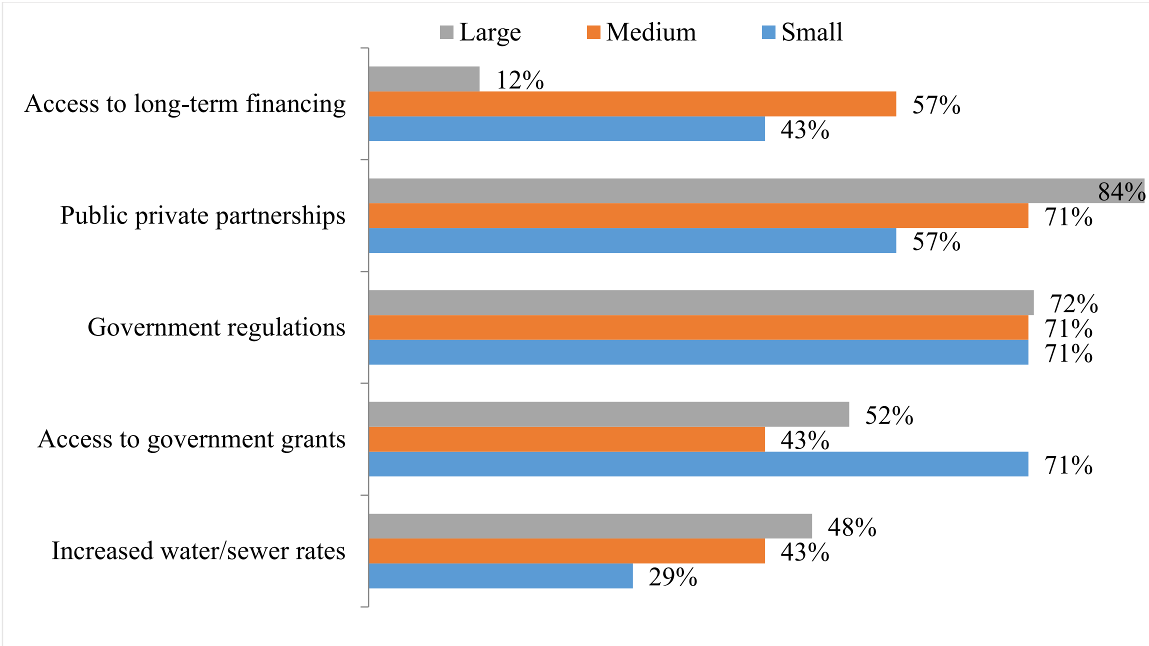


Figure 3-22: Consultants help with policy and decision making

3.1.8 Barriers to the Use of Trenchless Technologies

The survey question was designed to disclose about potential barrier influential factors. The major factors such as cost, lack of sufficient knowledge, consultants' lack of knowledge, and contractors' availability were asked to rank from 1 (very influential) to 4 (not much influential). 2013/14 CATT survey had concluded the cost and education were the major influential factors to the use of trenchless technology. Similar results were observed in the 2014/15 survey. Almost 80% of respondents believe that the cost and education are the major barriers to the use of trenchless technology. As mentioned in section 3.1.4, trenchless technology has more capital cost but less social cost. Moreover, trenchless technology is economic and environmental friendly method of construction and rehabilitation in comparison to open cut method. Lack of sufficient knowledge/ training, Consultants' lack of knowledge and Contractor's availability was ranked followed by the cost.

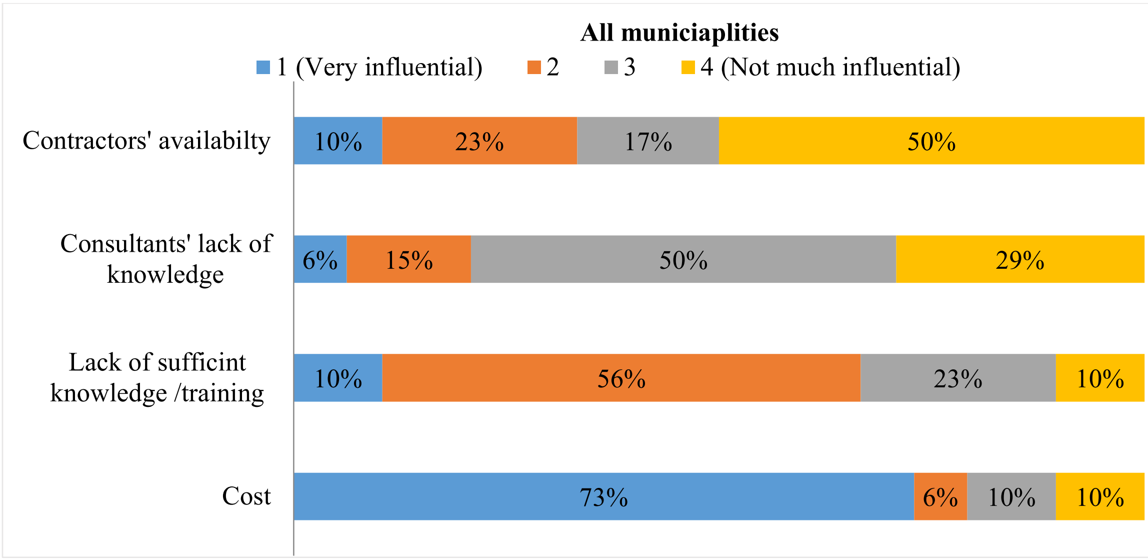


Figure 3-23: Barriers to the use of trenchless technology

The above results displayed in Fig. 3-23 can be correlated with the results obtained in the questions asked about the importance of offering extra training and education for the company's staff. As shown in Fig. 3-24, almost 90% of participants from all small municipalities indicated that offering education to the staff is very important. 67% of participants from the medium municipalities and 52% from the large municipalities have mentioned that staff training is essential to promote the use of the trenchless technology in an effective way. Only few participants (3%) form the large municipalities have stated that staff training is not important.

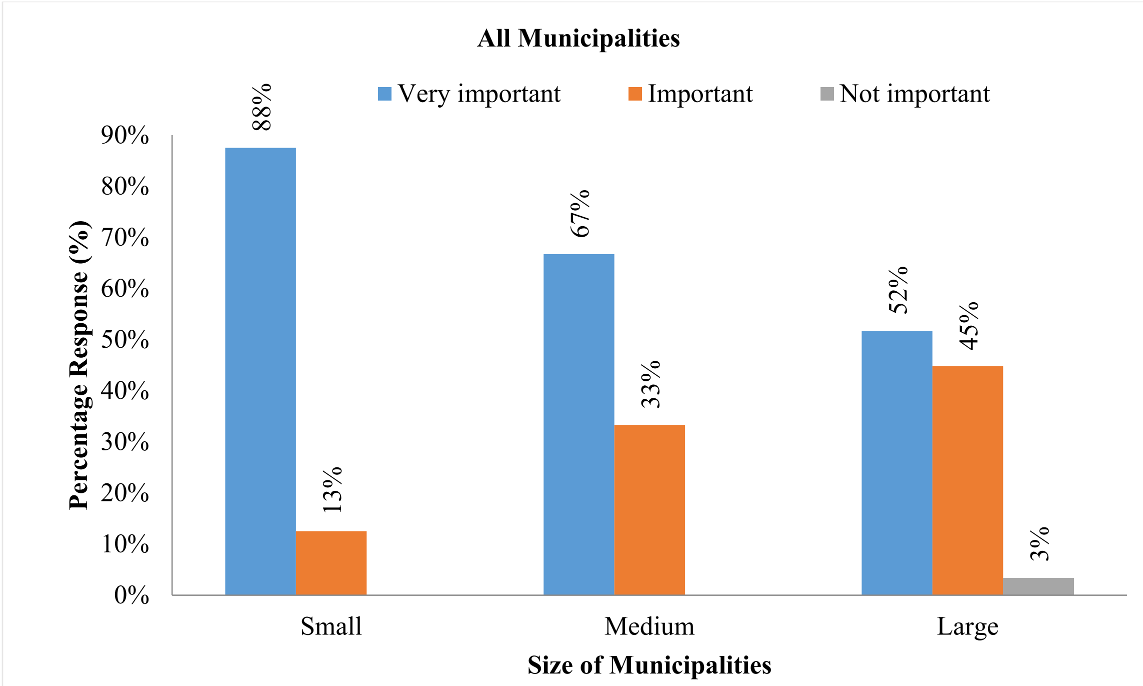


Figure 3-24: Importance of offering education

3.1.9 Critical Issues in Pipe Network

As shown in Fig. 3-25 below, inflow and infiltration were major/critical issues reported in waste water network with ratings 4.1 and 3.9 out of 5, respectively. Similarly, reducing the number of annual waterman breaks (3.9 out of 5) and pipe structural integrity (3.8 out of 5) was rated highest as critical issues in water main network as illustrated in Fig. 3-26.

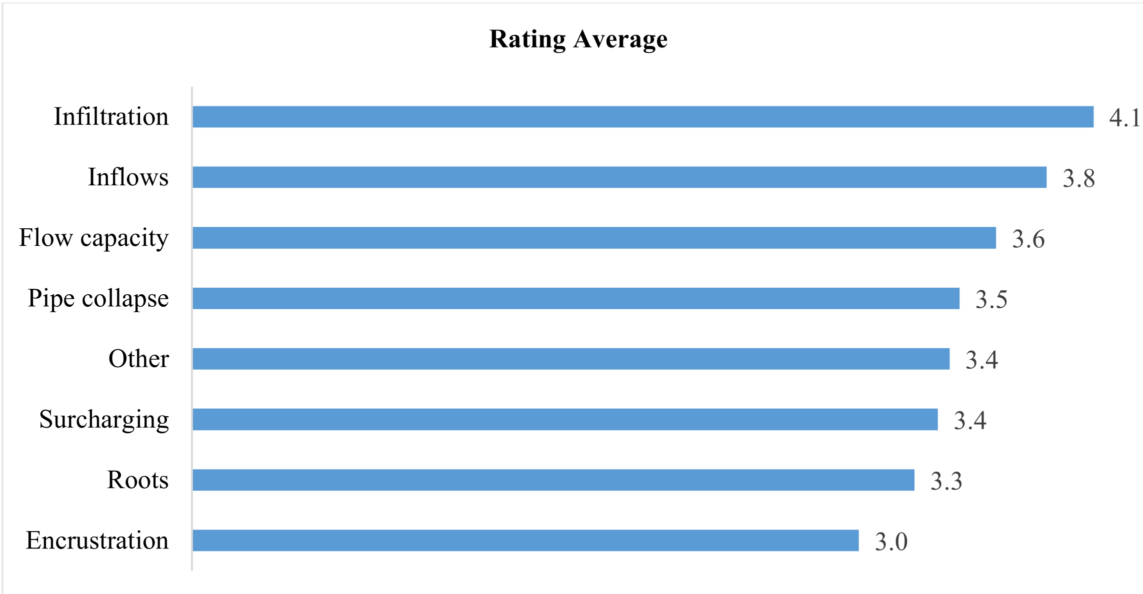


Figure 3-25: Waste water network issues ratings

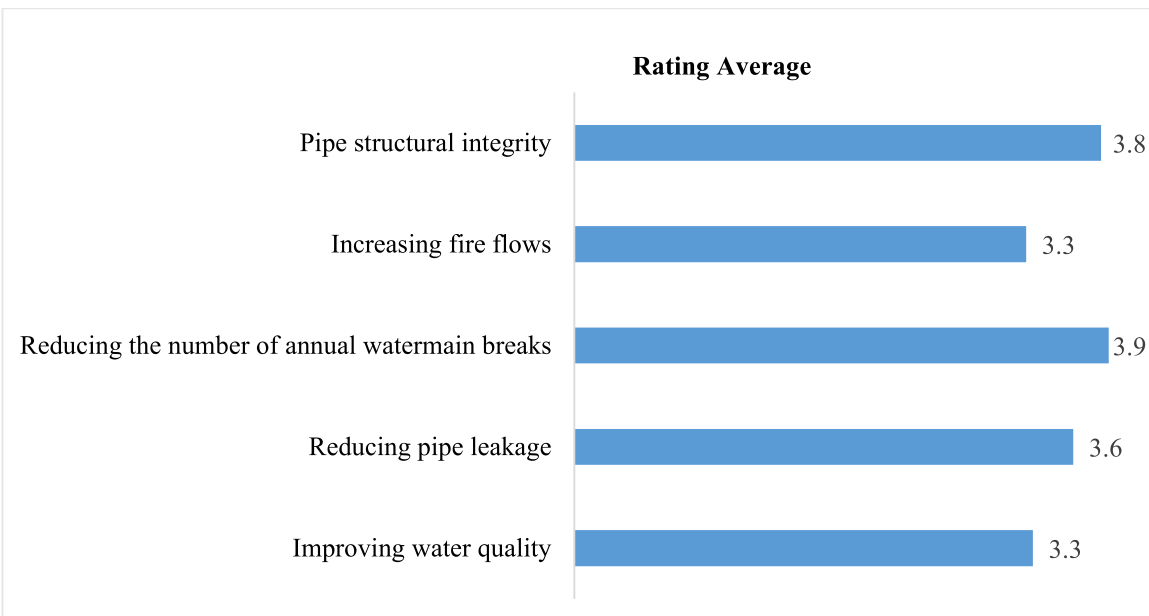


Figure 3-26: Water mains network issues ratings

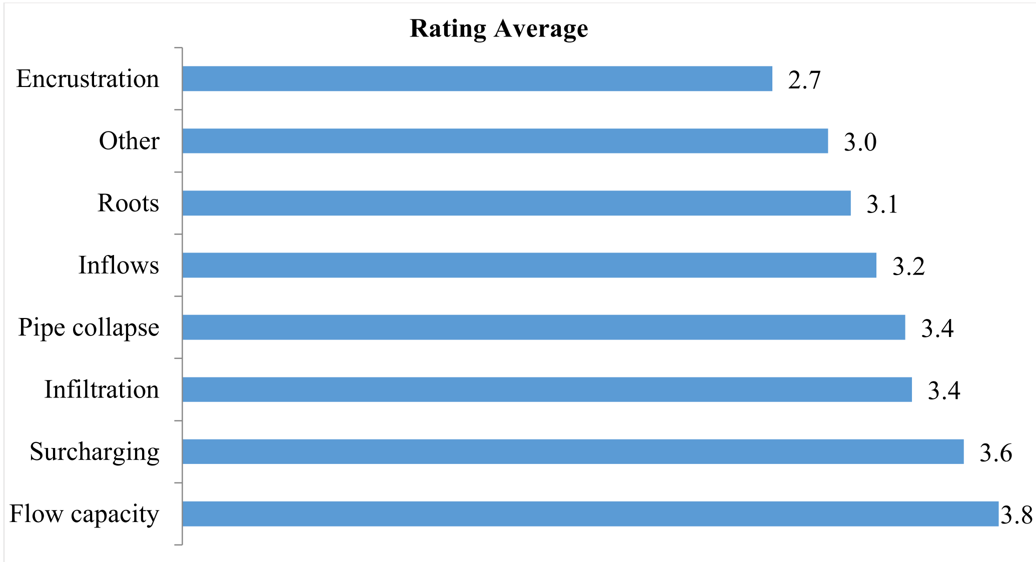


Figure 3-27: Storm water network issues ratings

As shown in Fig. 3-27, Flow capacity (3.8 out of 5), Surcharging (3.6 out of 5), Infiltration (3.4 out of 5), Pipe collapse (3.4 out of 5), Inflows (3.2 out of 5), Roots (3.1 out of 5) and Encrustation (2.7 out of 5) had been reported as the problems in the storm water network. Flow capacity was listed as very critical issues in storm water network.

3.1.10 Length of the Pipelines

Total length of the water mains network was categorized into four different group sizes: less than 300 km, 300-500 km, 500-800 km, and more than 800 km. The participants were asked to estimate the length of the pipe network in their municipalities. The results from the survey for three different pipe networks (water mains, waste water and storm water) are given below.

3.1.10.1 Water mains

As illustrated in Fig. 3-28, it reflects the statistical survey response for the total estimated length of each respective municipality. 67% of the small municipalities indicated the total length of the water main network were less than 300 km. On average, small municipalities had a length less than 300 km, and 300-500km for medium municipalities regarding water lines, while larger cities had a length greater than 800km. As shown in Fig. 3-28, similar results have been observed for medium and large size municipalities.

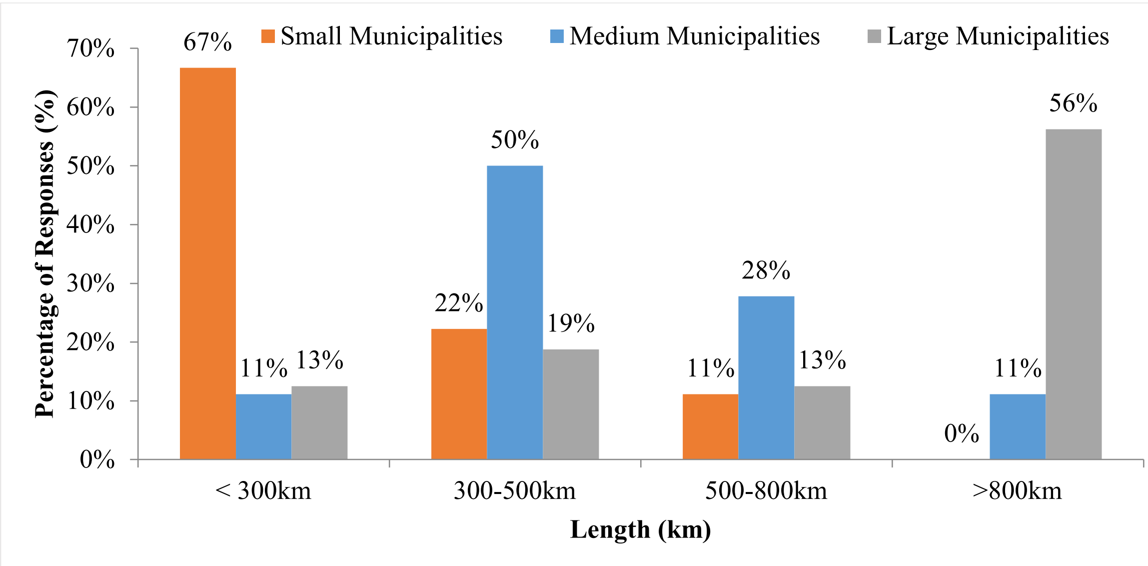


Figure 3-28: Estimated total length of water mains network

3.1.10.2 Waste Water

The distribution of an average length in different sized municipalities for waste water network is shown in Fig. 3-29. The results disclosed that 75% of the participants from small municipalities have mentioned the length of the waste water network to be less than 300 km while only 25% of the respondents indicated the length to be 300-500 km. According to the results described in Fig. 3-29, it can be extracted that the average estimated length of the waste water network for the medium municipalities fall between 300 and 500 km with 40% responses count. The length for the large municipalities fall in more than 800 km category as 53% of the response has been observed in this category.

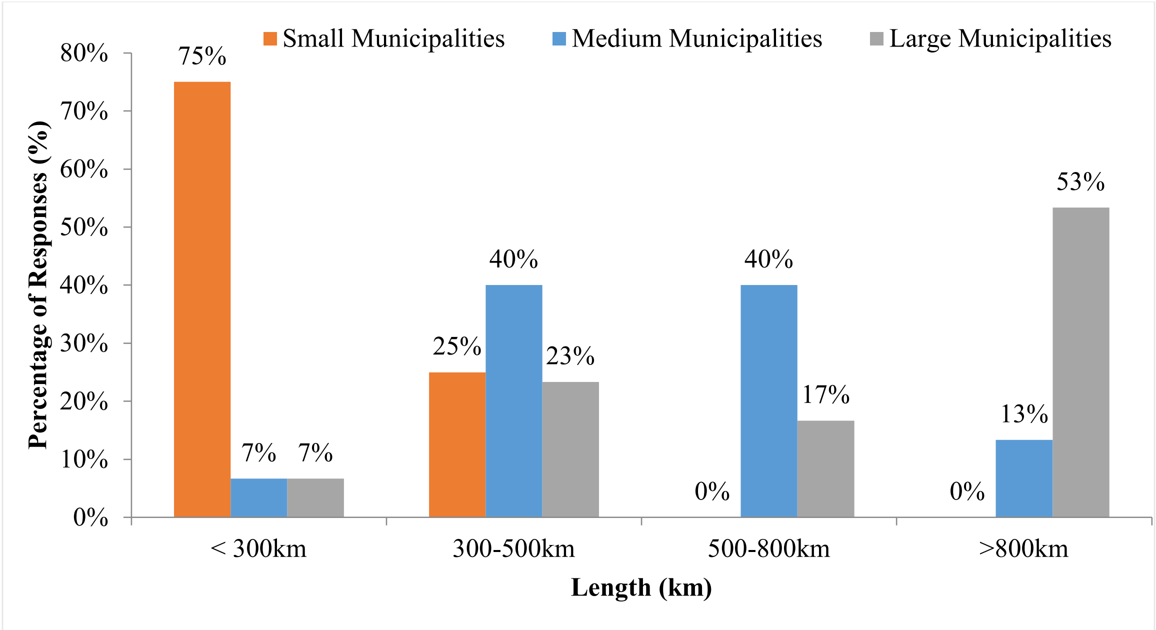


Figure 3-29: Estimated total length of waste water network

3.1.10.3 Storm Water

The results for the total estimated length of the storm water network is shown in Fig. 3-30. The results indicated that 88% of the respondents from the small municipalities have mentioned that their municipality's storm water network are less than 300 km in length and 12% showed a range between 300 and 500 km. The results indicated that the large and medium municipalities were the most diverse groups and their storm water network length comprised all four categories. In Fig. 3-30, medium municipalities were mostly comprised of a storm water network between 300 and 500 km with a response of 63%. The survey results revealed that 24% (<300 km), 16% (300-500 km), 24% (500-800 km), and 36 % (>800 km) based upon the response of large municipalities.

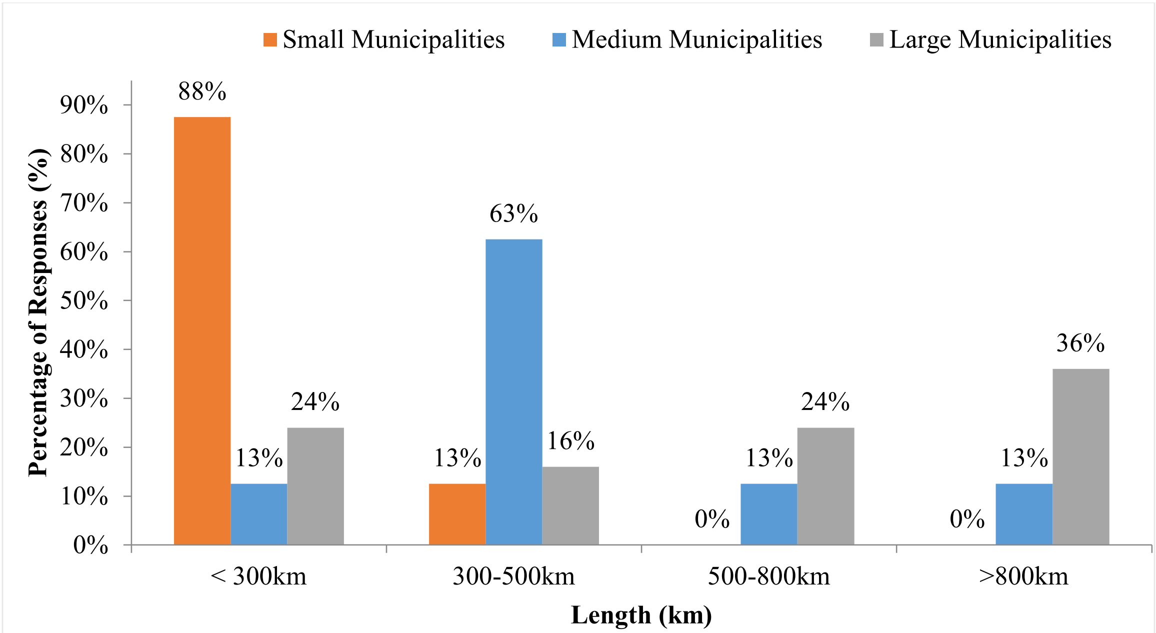


Figure 3-30: Estimated total length of storm water network

In general, there are two types of sewer systems, combined and separate sewer systems. Separate sewers include two different network composed of a sanitary and storm. As described above, the data collected from large municipalities didn't exhibit a trend. The data collected from these larger cities could be skewed. The questionnaire asked about the length of storm and wastewater network, but didn't take into account municipalities with combined sewers. City of Toronto described that a substantial number of Ontario's large cities have a combined sewer systems. To eliminate the possible biasness in the results, a set of question asking about both combined and separate system is suggested in the recommendation section.

3.1.11 Age of the Pipe Lines

In the United States and Canada, most of the underground infrastructures were installed during 1800s, between 1900 and 1945, and post 1945 (Folkman, 2012). This implies majority of underground pipes are now becoming more than 100 years old. The average useful life span of cast iron pipes installed around the late 1800's is about 120 years on average. The type of materials and manufacturing techniques used affects the life expectancy of a pipeline. Pipes installed in the 1920s have an average life of about 100 years, and pipes which were laid post World War II have an expectancy of about 75 years (AWWA 2001). As pipes age, they deteriorate and form cracks (weakens structural integrity of the pipe) allowing extraneous water to enter these pipe network (Boersma 2012). This indicates that it is necessary to rehabilitate and replace the pipe network which have exceeded their design life or are about to. To draw a picture of the average age of a pipeline in the municipalities and to assess the need of rehabilitation or replacement of those pipe networks, a question was asked to find the average age of these network. On average from both surveys, 6% of the respondents have reported their water mains are more than 70 years old. Similarly, 8% of participants mentioned their waste water network have been in use for more than 70 years. Most of the participants have reported their network is between 30 to 50 years old. Fig. 3-31 and 32 show the result from the survey.

Considering, the typical design life of a pipe is between 75 and 100 years (AWAA 2001) the majority of the pipelines need to be replaced or rehabilitated within 15 to 20 years. The use of trenchless technology for replacing or rehabilitation of the pipe network would help to save large amount of money which could have been used for open cut method. Therefore, the provision of appropriate education and training as well as government policy will be important to the effective use of the trenchless technology.

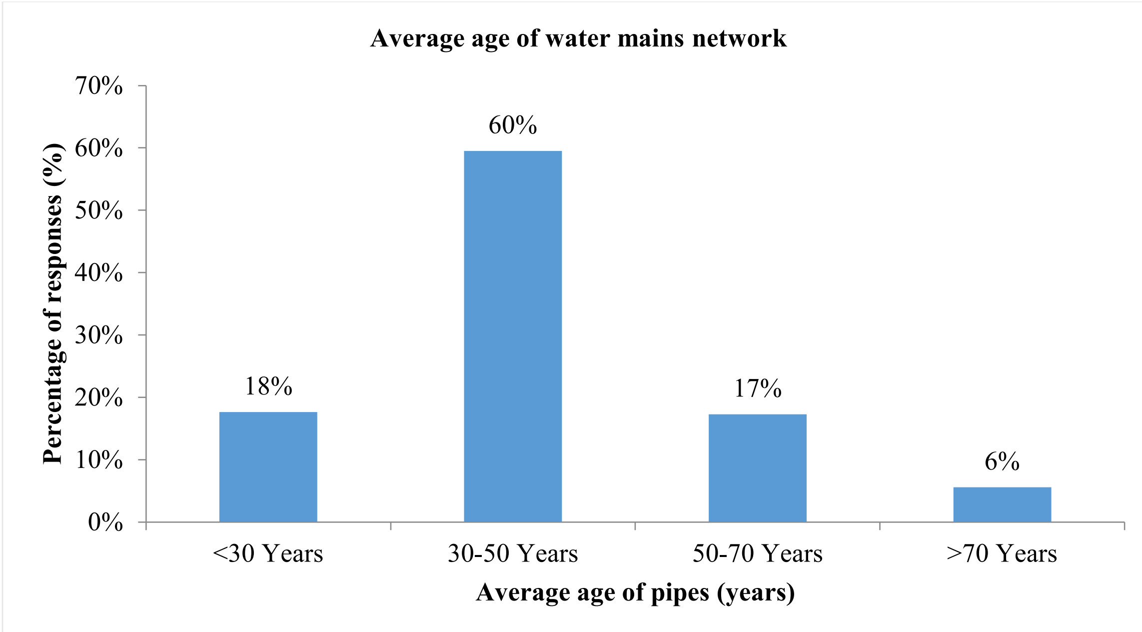


Figure 3-31: Average age of the water mains pipe network

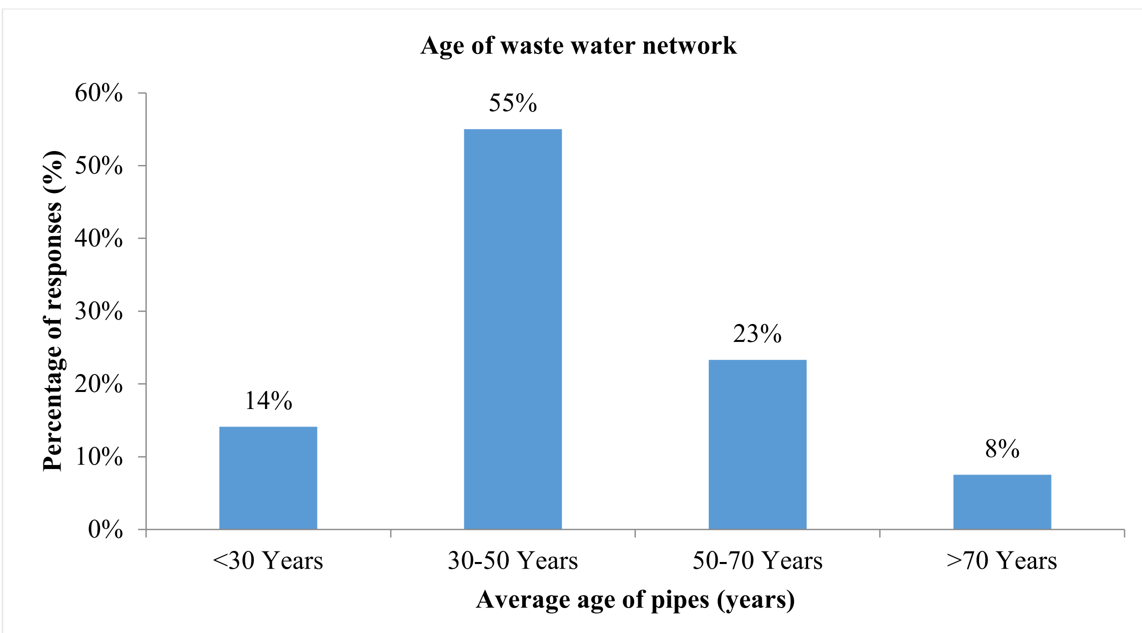


Figure 3-32: Average age of the waste water pipe network

In 2014/15 Survey, no such questions were asked to determine the relative age of their storm water network. Therefore, only two results for water mains and waste water network have been mentioned in this paper.

3.1.12 Renovation/Replacement Method: Trenchless vs. Open Cut

The survey designed a question, to establish, which municipalities use trenchless or open-cut method in the replacement/renovation of their water mains, waste water, and storm water. The participants from all municipalities were asked to describe the technology used and the length of piping replaced/renovated by this technology.

3.1.12.1 Water mains, Waste water, and Storm water

As described in Figs. 3-33, 3-34, and 3-34 for water mains, waste water, and storm water network, respectively, the findings show that trenchless technology was of significance importance when describing pipe length <0.5km, in all three types of piping. Open cut method was an important when describing piping >4.0 km. The greatest percentage difference between the two technologies was found for lengths <0.5km for all types of piping and pipes >4.0 km for only water mains and waste water.

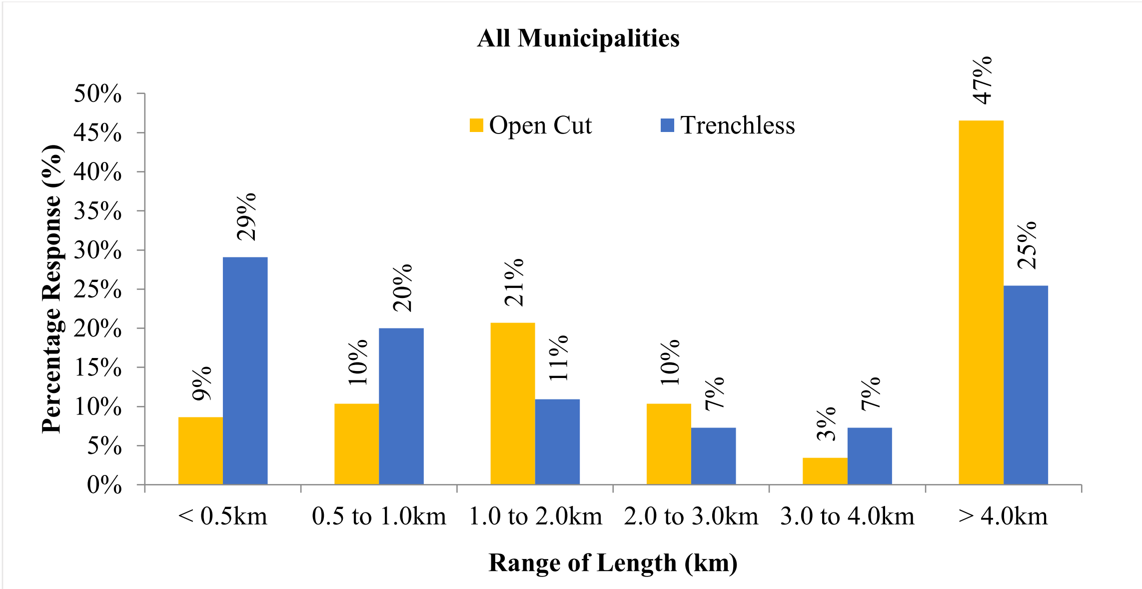


Figure 3-33: Water mains network

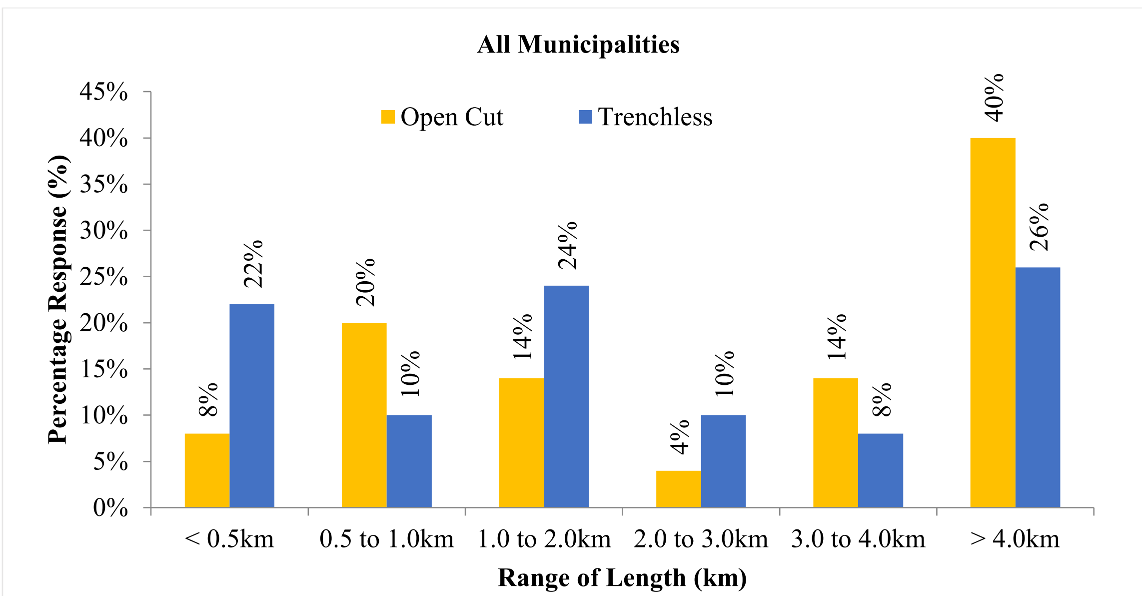


Figure 3-34: Waste water network

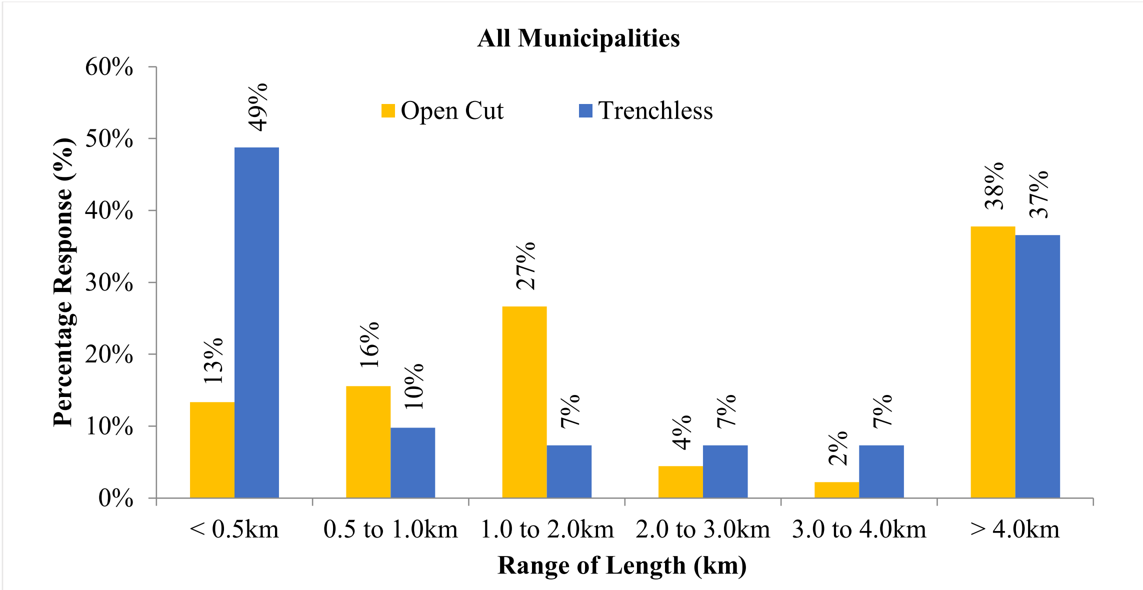


Figure 3-35: Storm water network

It has been observed that, all the municipalities mentioned trenchless technology as their popular method for renovation and replacement of pipe network with smaller length (<0.5km). As described in Table 3-4 the use of trenchless technology is restricted by several factors such as pipe diameter, maximum pipe length installation, and type of materials of pipe network (EPA 1999). It is possible that trenchless technology contributes mostly to pipe length less than 0.5 km due to this restriction; which governs the use of such technologies.

Table 3-4: Various sewer rehabilitation techniques showing range of length, diameter, and material

Method		Diameter Range (mm)	Maximum Installation(m)	Liner Material
In-Line Expansion	Pipe Bursting	100-600	230	PE, PP, PVC, GRP
Sliplining	Segmental	100-4000	300	PE, PP, PVC, GRP (-EP & -UP)
	Continuous	100-1600	300	PE, PP, PE/EPDM, PVC
	Spiral Wound	150-2700	300	PE, PVC, PP, PVDF
CIPP	Inverted-In-Place	100-2700	900	Thermoset, Resin/Fabric Composite
	Winched-In-Placed	100-1400	150	Thermoset, Resin/Fabric
	Spray-on-Linings	76-4500	150	Epoxy, Mortar
Internal Point Repair	Robotic repair	N/A	N/A	Epoxy Resins Cement Mortar

(Source: EPA 1999)

Where, EPDM = Ethylene Polypelene Diene Monomer GRP = Glassfiber Reinforced Polyester HDPE = High Density Polyethylene PE = Polyethylene PP = Polypropylene PVC = Poly Vinyl Chloride PVDF = Poly Vinylidene Chloride

3.1.13 Contractors' and Consultants' Performance at a Glance

Municipalities were asked to rate their satisfaction level in regards of consultants and contractors' performance in using trenchless technology. The questions were designed to compare the performance level of consultants and contractors on use of open cut method, trenchless method, project management, and innovation. Ratings from 1 (Not satisfied) to 5 (very satisfied) were provided in question. As shown in Table 3-5, contractor's performance (73%) in use of trenchless method is more satisfied than consultant's performance (45%).

Table 3-5: Contractor's and consultants' performance

	Contractors' Performance	Consultants' Performance
Open Cut	65 %	62%
Trenchless	73%	45%
Project Management	41%	52%
Innovation	38%	40%

Results from both survey years 2013/14 and 2014/15, in regards of consultant's performance, are mentioned in Fig. 3-36 and 3-37, respectively. The results have clearly indicated that the satisfaction rate has been increased from 10% in 2013/14 to 45% in 2014/15 as respondents reported the trenchless technology as very satisfied. Nevertheless, as mentioned in Fig. 3-38 and 3-39, responses in the contractor's satisfaction have not been increased.

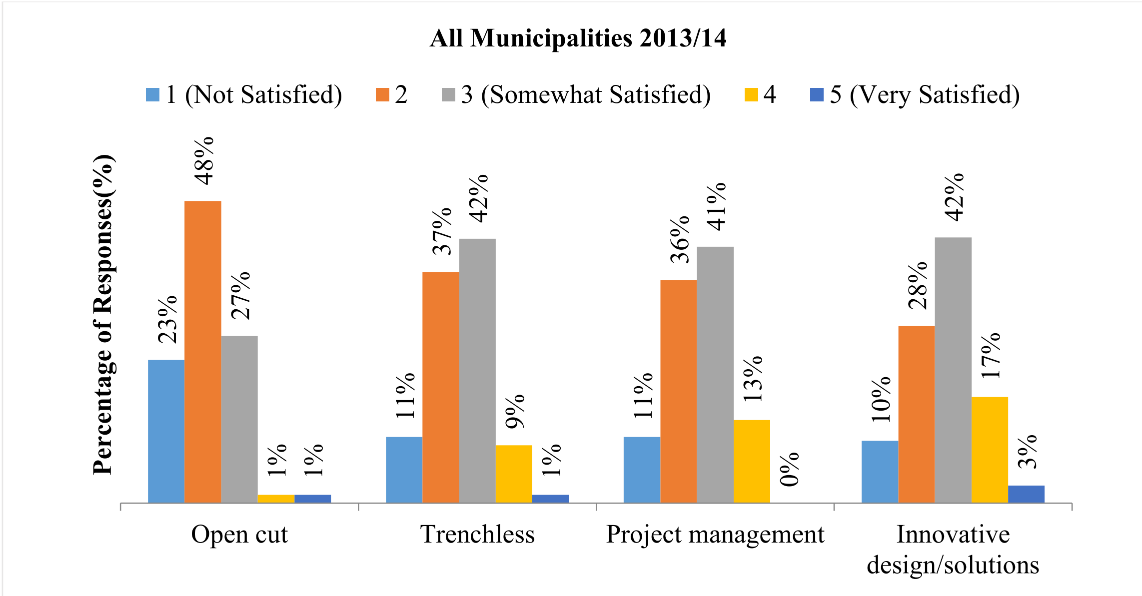


Figure 3-36: Consultants' performance in 2013/14

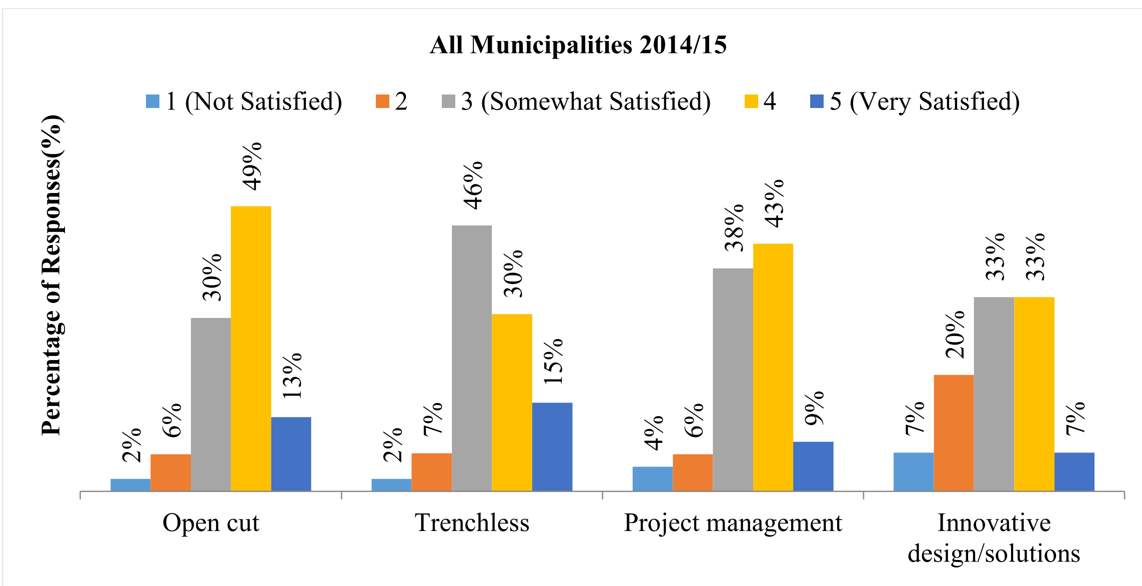


Figure 3-37: Consultants' performance in 2014/15

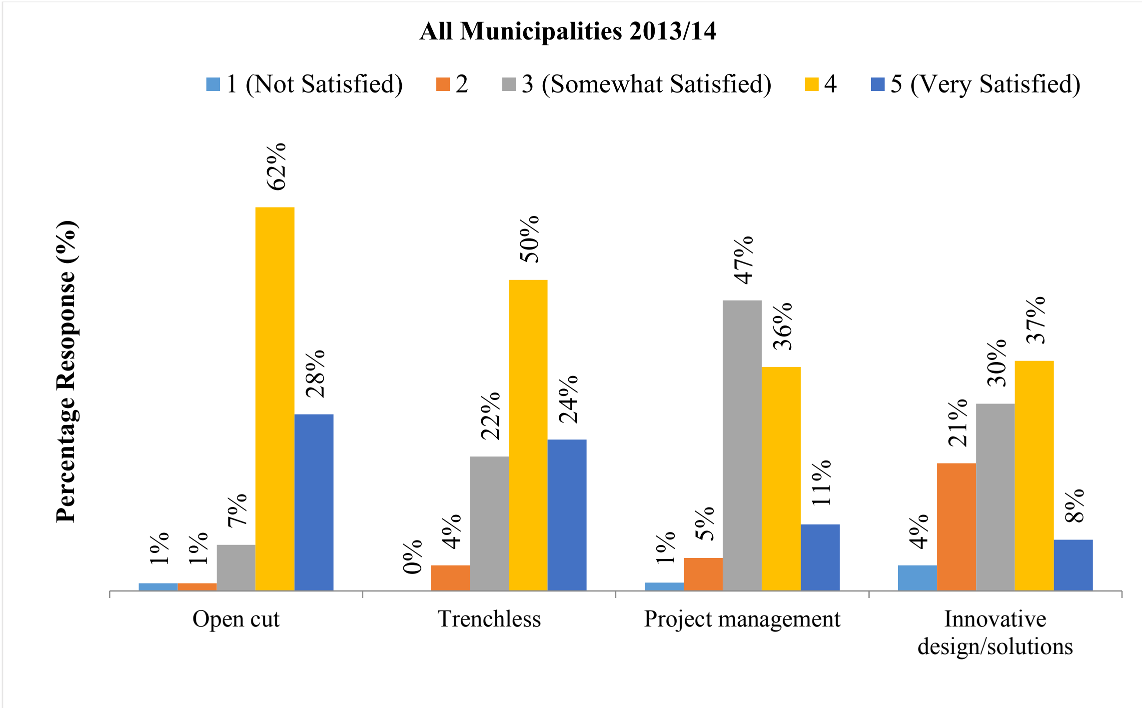


Figure 3-38: Contractors' performance in 2013/14

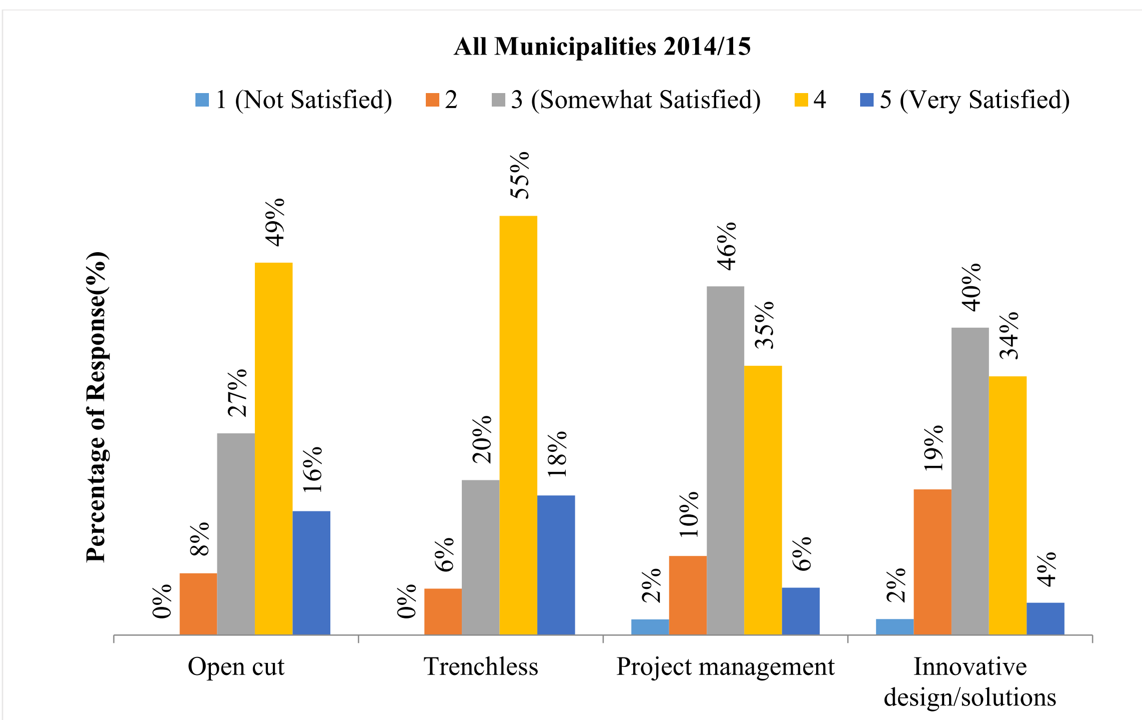


Figure 3-39: Contractors' performance in 2014/15

As shown in Fig. 3-36 and 3-37, consultant's satisfaction level in regards of project management and innovative design/solutions have been significantly increased from 13% to 53%, and 20% to 40%, respectively. However, the percentage response in contractors' performance in regards of project management and innovative design and solutions have not been increased.

3.2 I&I Study and Results

Various parameters have been used in the preparation of the model. Pipe age, the empirical operating coefficient, and soil classifications are the factors which increase the amount of I&I in the sewer lines. The other one, sewer classification, emphasizes the effect of I&I in the sewer lines on the basis of their sizes. Each parameter is discussed in more detail in the following subsections.

3.2.1 Pipe Age

In the United States and Canada, most of the underground infrastructures were installed during 1800s, between 1900 and 1945, and post 1945 (Folkman 2012). In other words, the pipes constructed in late 1800s are now becoming more than a 100 years old. The average useful life span of cast iron pipes installed around the late 1800's is about 120 years on average. The type of materials and manufacturing techniques used affects the life expectancy of a pipeline. Pipes installed in the 1920s have an average life of about 100 years, and pipes which were laid post World War II have an expectancy of about 75 years (AWWA 2001). As pipes age, they deteriorate and form cracks (weakens structural integrity of the pipe) allowing extraneous water to enter these pipe network (Boersma 2012). It is necessary to rehabilitate and replace the pipe network which have exceeded their design life or are about to.

Kerr Wood Leidal Assoc. (2011) developed an empirical relationship between age and I&I rate (Rainfall Dependent-RD) in the pipe network. The study was conducted in 54 independent sewer catchments with corresponding 100- year I&I rate during peak hour. The correlation coefficient value (R^2) from the study was evaluated to be 0.9 which indicates that the relationship between the pipe age and the I&I rate is consistent, accurate, and highly correlated. The derived equation 3.1 from the experimental study resembles that there is an exponential relationship between I&I rate and the sewer age.

$$\text{I\&I Rate}_{100} = 12355\ e^{(0.0325*(\text{sewer age}))} \quad (3.1)$$

Where, sewer age = age in years, I&I rate = Liter/hectare/day.

In this study, pipe age was given to each pipe segment manually because the pipe age was not already available in GIS file (.shp file). The files collected from City of Youngstown were in Tag Image File Format (.tif). A sample of a file is given in Appendix E.

The given .tif file consists of the information such as name of the street, date of construction, name of the contractor, name of the person involved in the installation of pipelines. In addition, the file also has the invert elevation and elevation of street. The date of construction was manually input in GIS file for each pipe segment using attribute table properties. Manual input is possible when attribute table is in editing mode. The current age of the pipe was evaluated using the equation 3.2.

$$\text{Pipe Age} = 2017 - \text{Date of Construction or Rehabilitation} \quad (3.2)$$

The statistical results are shown in Table 3-6 and are displayed in Fig. 3-40

Table 3-6: Pipe Age Statistics

Number of sections	1768
Youngest Age	67
Oldest Age	132
Average Age	112
Standard Deviation	12.3

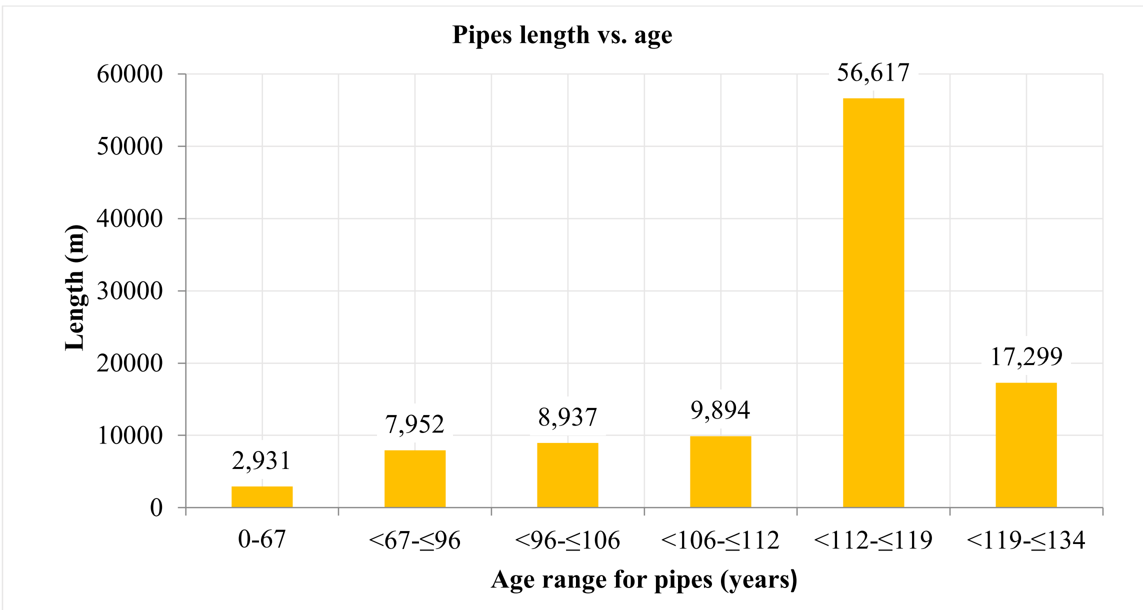


Figure 3-40: Length of pipes for different range of pipes age

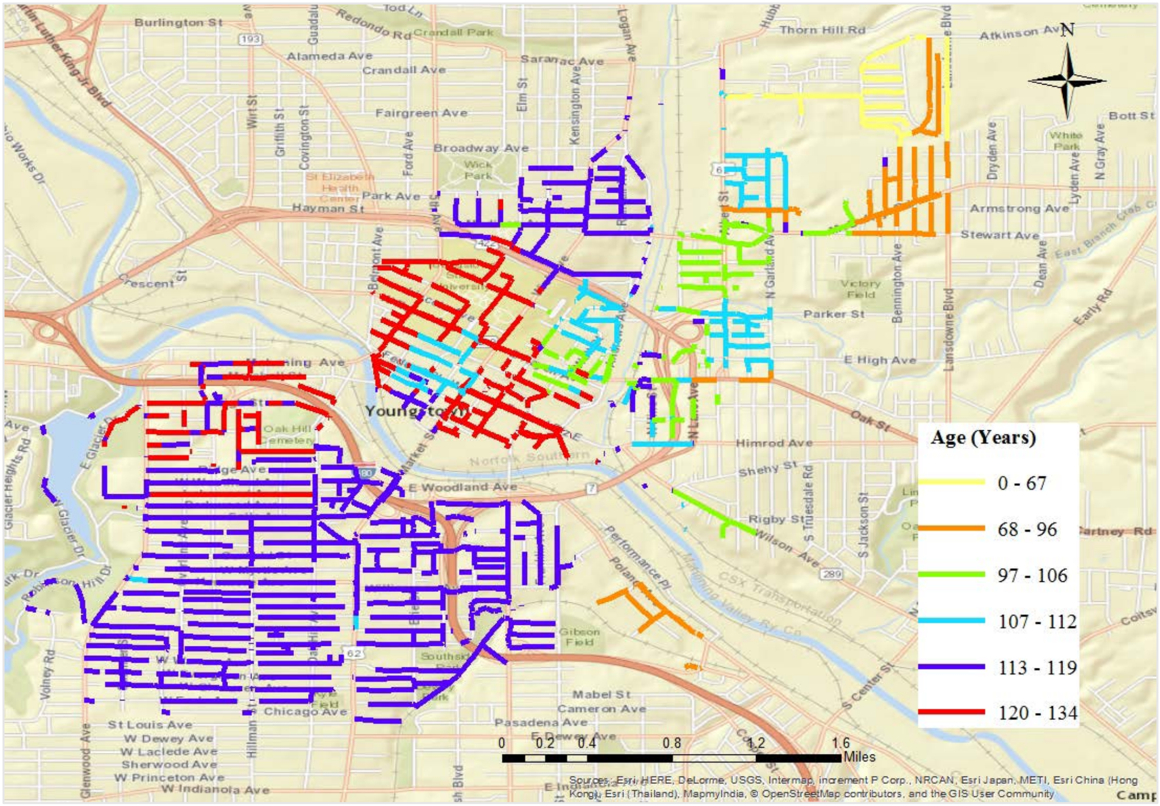


Figure 3-41: Age of the sewer lines

As shown in Fig. 3-41, the pipe age ranges from 70 years to 130 years. Most of the pipe segments are determined to be installed between 110 to 120 years. This indicates that majority of pipelines in Youngstown area are determined to be installed post world war II. In general, the pipes are older near downtown area and south side of Youngstown.

3.2.2 Empirical Operating Coefficient

Every day in communities across the United States, millions of gallons of human and industrial waste are conveyed through complex underground sewer systems. Eventually, the wastes are discharged into wastewater treatment plants. Later, the clean water from the treatment plant will be distributed to communities. This whole systems work every day throughout the years to fulfill the demand and supply of the water to the communities. Because of its nature, defect in that pipe network may harm directly to the healthy environment of our families in communities. Therefore, continuous assessment of such important underground assets is very important to contribute healthy water to the communities. However, continuous inspection and maintenance of those wastewater collection systems is one of the challenging tasks.

Proper monitoring of existing operational performance or hydraulic condition of sewer pipeline network helps for better understanding of current performance of sewer pipe line network (Chughtai et al. 2007). Proper monitoring will not only enhance the performance but also helps to obtain information about when and where the pipes is going to fail. In other words, proper maintenance or enough preparation can be done before the serious problem occurs. A study conducted by Chughtai and Zayed (2007) proposed an empirical regression model to quantify the operational performance of sanitary sewers. They use various pipe properties such as pipe age, diameter, length, and slope to evaluate the operational performance of the pipe sections. The developed model empirically analyzes Montreal's collection system. The equation 1.1 mentioned in previous section demonstrates the relationship of various pipe parameters used in the model. The regression fit value of the equation was 0.879. In general, the lower value from the equation indicates poor pipe condition and the higher value indicates healthy condition of the pipe network.

Variables for the Youngstown's sewers were entered into equation 1.1 to obtain operational values of the Youngstown and surrounding areas. Age for each pipe segment was taken from attribute table of GIS file. The pipe lengths from .shp file were converted into meter and used in the model. Other parameters, diameter and slope, were taken from Youngstown sewer shape file.

Manning's roughness coefficient (n) was assumed to be 0.011. According to sewerhistory.org, vitrified clay (with a salt glazing applied to both the pipe's interior and exterior surfaces, a "carry-over" process from Europe) was the major choice for the sewers by the 1800-1900s. Since the majority of pipe in Youngstown were laid between 1800 and 1900s, it can be speculated that the sewer lines in Youngstown are also made of vitrified clay. The Manning's roughness coefficient for vitrified clay, closed conduit, ranges from 0.011 to 0.017 (ODOT Hydraulics Manual 2014).

The calculated operating performance values are summarized in Fig. 3-42. The performance values evaluated using equation 1.1 reflects the current performance of the pipe conditions. The value ranges from 2 to 48. The higher the performance value, the better the condition of the pipe and vice versa. The majority of the performance values range between 6 and 8. The pipelines with various colors coding describing the operational performance value are displayed in the Fig. 3-43.

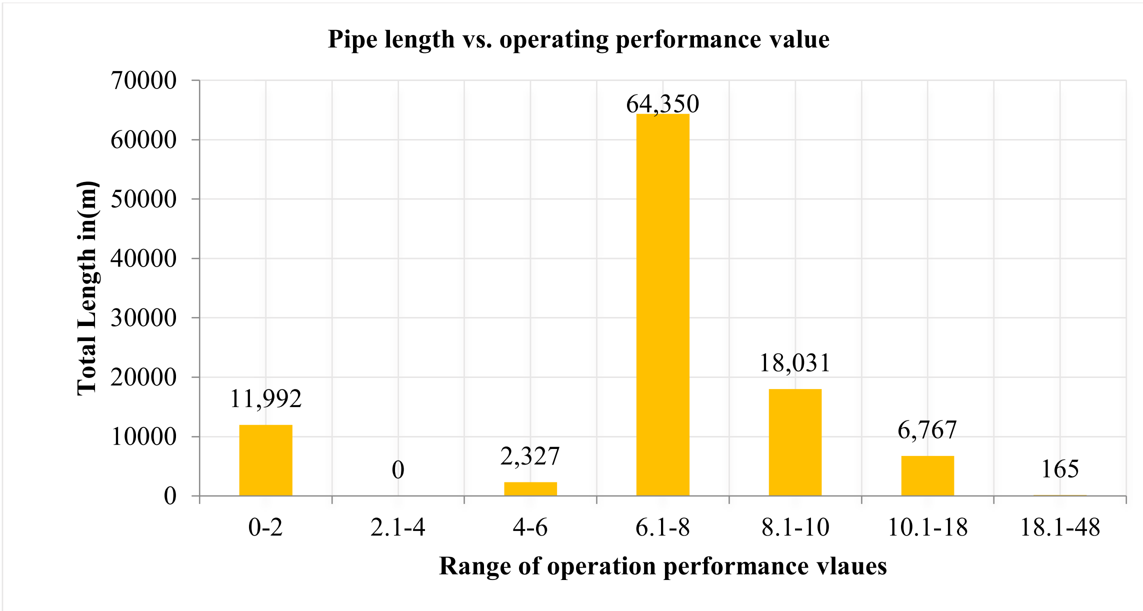


Figure 3-42: Range of operating performance values

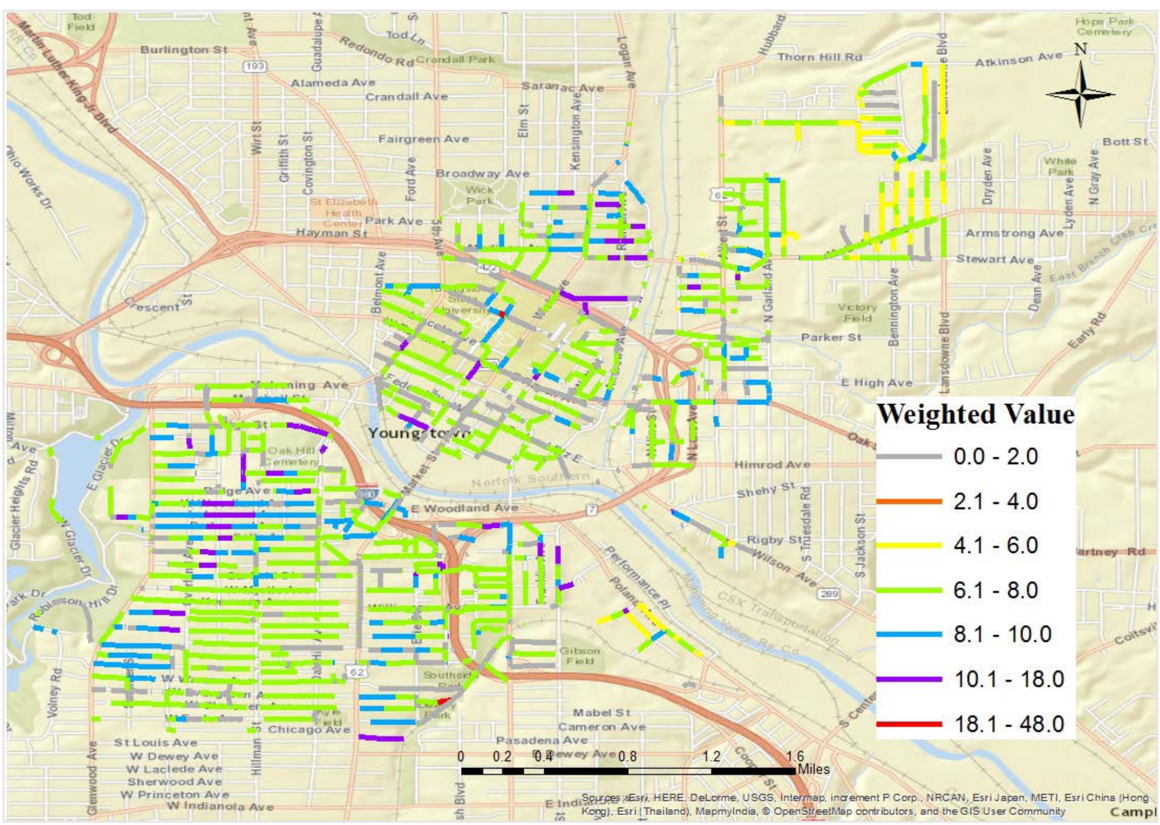


Figure 3-43: Operational performance value for the pipes

3.2.3 Soil Classifications

Soil is classified based on its texture for this model. Soil texture such as percentage of sand, silt and clay are the major inherent factor affecting infiltration. Infiltration rates are measured as how fast water enters the soil and are typically expressed in inches per hour. Slow movement of water (low infiltration rate) may lead to ponding of water in the soil and cause erosion from the surface runoff on sloping fields and less I&I will occur. The pipelines which are laid over or in the soil with high infiltration (low runoff) rates have more chances to have I&I problem.

Based on the National Engineering Handbook Part 630 Hydrology, United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS), the soils were categorized into four different groups – A, B, C, and D. This is the classification based on infiltration capacity of the soil, and also called hydrologic soil classification system (NRCS, USDA. *"Part 630 Hydrology National Engineering Handbooks*" 2009). The soil which falls under group A has highest infiltration capacity whereas soil group D has lowest infiltration capacity. As shown in Tables 3-7 and 8, depending on the depth of water impermeable layer, depth of high water table, and saturated hydraulic condcutivity of the soil, soils are categorized into four different hydrologuc groups. The following Tables 3-7 and 8 demonstrate the details of the soil classifications by NRCS used in this study.

Table 3-7: Matrix of hydrologic soil group assignment criteria for water impermeable layer exists at a depth 50 [20 inches] to 100 centimeters [40 inches]

Soil Property	Hydrologic Soil Group A	Hydrologic Soil Group B	Hydrologic Soil Group C	Hydrologic Soil Group D
Saturate Hydraulic Conductivity of the least trans-missive layer	>40.0 μm/s (>5.67 in/h)	≤40.0 to >10.0 μm/s (≤5.67 to >1.42 in/h)	≤10.0 to >1.0 μm/s (≤1.42 to >0.14 in/h)	≤1.0 μm/s (≤0.14 in/h)
Depth of water impermeable layer	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	50 to 100 cm [20 to 40 in]	<50 cm [<20 in]
Depth of high water table	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	60 to 100 cm [24 to 40 in]	<60 cm [<24 in]

Group A: Soils in this group normally have less than 10 percent clay and more than 90 percent sand or gravel. If the soil type is loamy sand, sandy loam, silt or silt loam with low bulk density or more than 35% rock fragments and are well aggregated, then they can be placed under this group. When the soil in this group undergo thorough wetting, they have low runoff potential. As shown in Table 3-8, when the location of the impermeable water table and depth of water table is more than 50 cm [20 inches] and 60 centimeters [24 inches] respectively, the hydraulic conductivity of the soils in this group exceed 40.0 μm/s (5.67 in/h). The hydraulic conductivity for the soils located deeper than 100 centimeters [40 inches] to a water impermeable layer exceeds 10 μm/s (1.42 in/h).

Table 3-8: Matrix of hydrologic soil group assignment criteria for water impermeable layer exists at a depth greater than 100 centimeters [40 inches]

Soil Property	Hydrologic Soil Group A	Hydrologic Soil Group B	Hydrologic Soil Group C	Hydrologic Soil Group D
Saturate Hydraulic Conductivity of the least trans-missive layer	>10µm/s (>1.42 in/h)	≤10.0 to >4.0 µm/s (≤1.42 to >57 in/h)	≤4.0 to>0.40 µm/s (≤0.57to>0.06 in/h)	≤0.40 µm/s (≤0.06 in/h)
Depth of water impermeable layer	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]
Depth of high water table	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]	>100 cm [>40 in]

Group B: Soils in this group comprises of 10% to 20% clay and about 50% to 90% sand with loamy sand or sandy loam textures. When the soils are thoroughly wetted, they have moderately low runoff potential and the water transmission through the soil is unhindered. If the soil type is loam, silt loam, silt or sandy clay loam with low bulk density or more than 35% rock fragments and are well aggregated, then they can be placed under this group of soils. Also, as shown in the Tables 3-7 and 8, the depth to any water impermeable layer and the depth to the water table is greater than 50 centimeters [20 inches] and 60 centimeters [24 inches], respectively, the hydraulic conductivity for this case is more than 10 µm/s (1.42 in/h) and less than or equal to 40 µm/s (0.57 in/h). Furthermore, the hydraulic conductivity for the soils located deeper than 100 centimeters [40 inches] to a water impermeable layer exceeds 4 µm/s (0.57 in/h) but less than 10.0 µm/s (1.42 in/h).

Group C: Soils in this group comprises of 20% to 40% clay and less than 50% sand with loamy sand or sandy loam textures. When the soils are thoroughly wetted, they have moderately high runoff potential and the water transmission through the soil is quite hindered. If the soil type is loam, silt loam, sandy clay loam, clay loam, and silty clay loam with low bulk density or more than 35% rock fragments and are well aggregated, then they can be placed under this group. As shown in Tables 3-7 and 3-8, when the soil under this group is least saturated at 50 centimeters [20 inches], the hydraulic conductivity ranges between 1.0 μm/s (0.14 in/h) and 10.0 μm/s (1.42 in/h). Also, the depth to any water impermeable layer and the depth to the water table is greater than 50 centimeters [20 inches] and 60 centimeters [24 inches], respectively. The hydraulic conductivity for the soils located deeper than 100 centimeters [40 inches] to a water impermeable layer exceeds 0.4 μm/s (0.06 in/h) but less than 4.0 μm/s (0.57 in/h).

Group D: Soils in this group comprises of more than 40% clay and less than 50% sand with clayey textures. When the soils are thoroughly wetted, they have high runoff potential; also the water transmission through the soil is hindered or unhindered. Shrinking and swelling tendency of this type of soils under this category is considered to be high. As shown in Tables 3-7 and 3-8 when the soil under this group at a depth between 50 centimeters[20 inches] and 100 centimeters [40 inches] have hydraulic conductivity less than or equal to 1.0 μm/s (0.14 in/h). The hydraulic conductivity for the soils located within 100 centimeters [40 inches] or restricted is less than or equal to 0.4 μm/s (0.06 in/h).

In this study, hydrologic soil group data for Mahoning County was retrieved from the NRCS soil database (Appendix D). The soil is labeled with the hydrologic soil group letter (A, B, C, or D). In the next step, a quarter foot buffer was created around the pipelines to convert them from lines to polygons. Thereafter, “Merge” command was used to combine soil and pipeline files. Finally, the file with details of hydrologic soil classification for each pipe segment was created. The map with type of soils around the pipelines is shown in Fig. 3-44.

Majority of the soils in downtown area was determined as category A. As shown in Fig. 3-44, loamy soil was observed on the both banks of the Mahoning River. Soil type C and D are found to be on the majority of the south side of downtown Youngstown. Infiltration rate of C and D is lesser than group A and B according to NRCS soil classifications. These results indicated that there is less chance of occurring I&I problems in the sewer lines due to soil type. However, the susceptibility of I&I also depends on other factors such as sewer type, pipe age and empirical operation coefficient. Therefore, the chances of I&I problem cannot be made solely from the soil type.

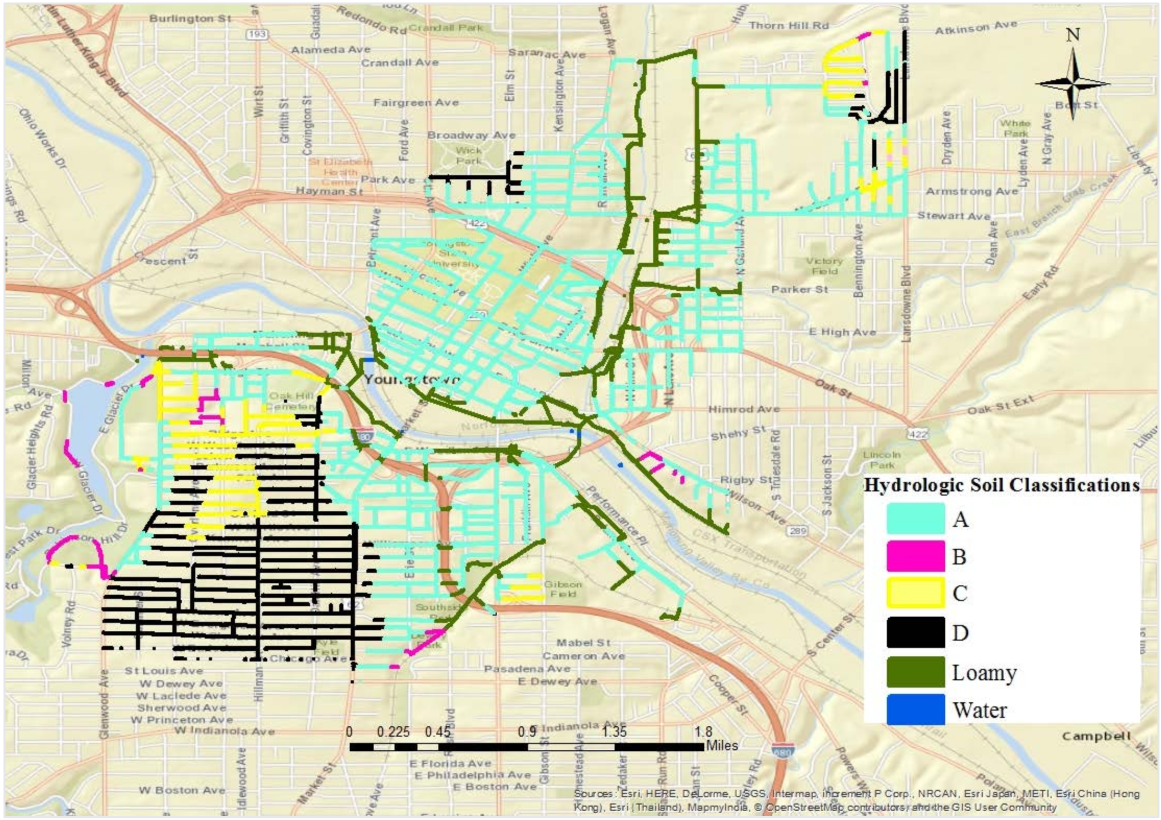


Figure 3-44: Hydrologic soil classification for Youngstown area

3.2.4 Sewer Classifications

In this study, sewer lines were classified into two groups (group 1 and group 2) based on their sizes. Overall, the sizes of sewer lines used in the study ranges from 0 inches to 68 inches. Zero inches indicate the missing information. The size range from 1 inch to 18 inches is part of the first group and assigned as group 1. While more than 18 inches is categorized as the second group and assigned as group 2. A larger diameter pipe can carry more discharge then the smaller size. Therefore, the accumulation of I&I in these larger diameter pipe network will be greater in compared to the smaller size. As shown in Fig. 3-45, most of the pipe sizes were 7 to 21 inches.

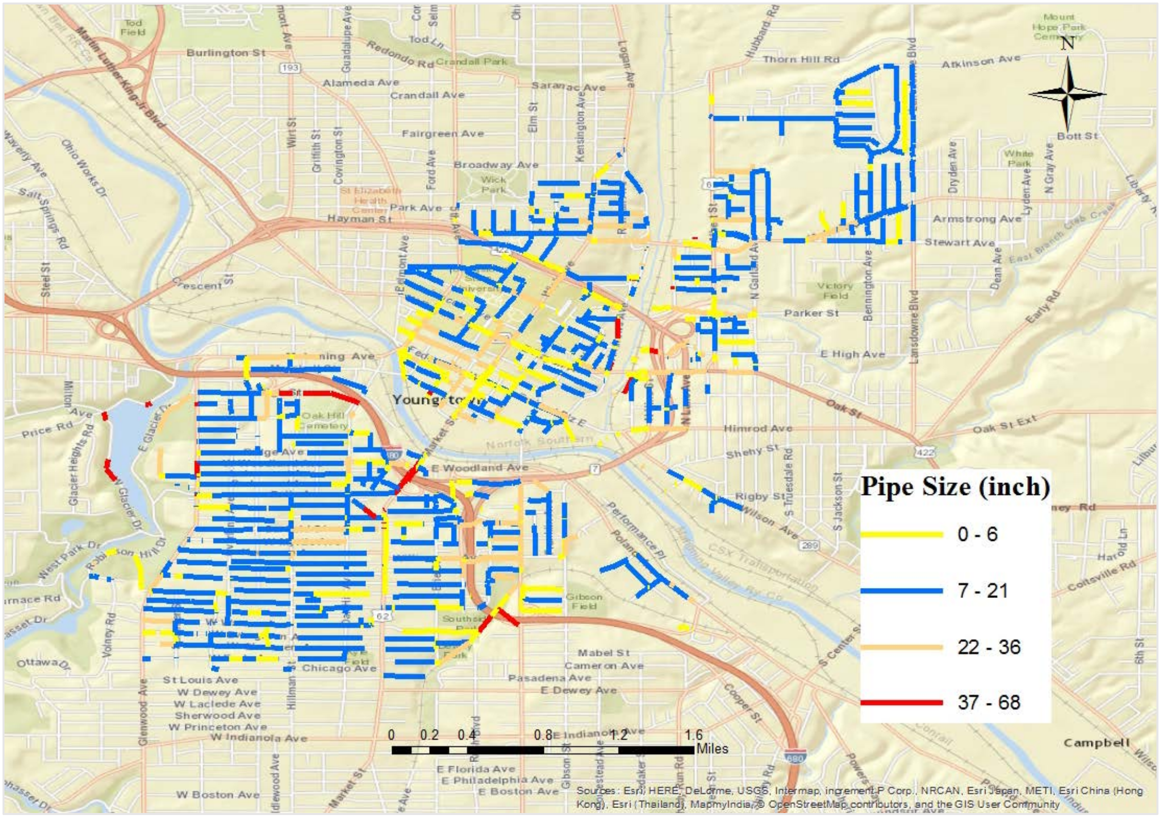


Figure 3-45: Pipe size distribution

3.2.5 Model Interface

This section includes detailed description of the merging various parameters process for the model. The central feature of this project is to create a simplistic model that combines the parameters and make it user friendly. By creating a user friendly model, it can be easily managed by various types of users. The model allows the users to have control over the inputs. The weighted value assigned for different parameters and its range are the major functional variations which will alter the nature of the results, but the summary of the results in the end must be the same. For example, by altering the weightage value for the parameters; soil type, empirical coefficient, sewer type, and pipe age, a depiction of I&I susceptible areas can be created. This means, whichever parameter has a higher or lower emphasis then the higher or less weightage must be maintained accordingly. Then a similar result in nature will be created, describing the areas that have high or low susceptibility to I&I problems.

The model consists of two steps. First step includes, identifying the parameter with the highest influence on the model. The highest weight is assigned to the emphasized parameter and other parameters are distributed and compiled to accomplish the remaining percentage value. The sum of total weightage distribution should be equal to one in each case. Table 3-9 shows the examples of the weightage value used in model. The detailed calculations and corresponding results are summarized in Appendix C and Appendix D under Excel Spreadsheet Directions section.

Table 3-9: Weighted value matrix for the model

Weightage Value for the Comparison Analysis				
Emphasis	Pipe Age	Soil Type	Equally Weighted	Sewer Group
Pipe Age	0.6	0.2	0.25	0.2
Empirical Value	0.1	0.1	0.25	0.1
Sewer Type	0.1	0.1	0.25	0.6
Soil Type	0.2	0.6	0.25	0.1
Sum	1	1	1	1
	OK	OK	OK	OK

Table 3-10 describes the second step. In this step, depending on the functional value evaluated for each parameter, user assigns a certain numbers ranging from 1 (being excellent condition) to 10 (being very poor condition) for each parameter. The functional values for each parameter are defined as the values or categories, which directly affect

I&I. For example, numbers of pipe age, soil types (A, B, C, D), empirical values, and the type of sewer.

Table 3-10: Value parameter for age, sewer system, and soil type

FID	Pipe Size (mm)	Pipe Grade (%)	Age (years)	Value Parameter	Sewer System	Value Parameter	Operational Performance Values	Soil Classification	Value Parameter
0	457.2	3.12	110	8	Group 1	8	8.00	D	10
1	609.6	3.33	112	8	Group 2	10	8.40	A	4
2	0	0	112	8	NA	10	7.77	A	4
3	381	0.89	117	9	Group 1	8	7.00	D	10
4	0	0	112	8	NA	10	7.37	A	4

Value ranging from 1 being less susceptible to I&I to 10 being high susceptible to I&I problem is given to each parameter. For example, age of the pipe was found to be ranging from 67 years to 137 years. Since the older pipes have more chances of I&I problem in comparison to newer pipes, a value of 5 was given to 67 years old pipes while 10 was given to the oldest pipe. Table 3-11 shows the assigned value for the age of the pipe in this study.

Table 3-11: Assigned value for pipe age

Pipe Age (Years)	67	$<67\leq96$	$<96\leq106$	$<106\leq112$	$<112\leq119$	$<119\leq134$
Assigned Value	5	6	7	8	9	10

A value was assigned for the type of sewer and was also expressed in a similar way. A parametric value of 10 was assigned to group 2. The concept behind this assignment was that the group 2 pipes should carry more discharge in compared to group 1 pipes. There is higher chance of inflow and infiltration in main lines than the group 1 lines. Smaller pipes are connected by a bigger lines, therefore, group 1 pipes could carry I&I causing the group 2 to have a higher inflow. Group 1 was given 8 as value parameter. The assignment of a value totally depends on user's choice; however, the evaluated final value (importance/effect), after using weighted parameter, should resemble the same result.

Similarly, D type of soil was given 4 as a value parameter and type A of soil was given 10 as value parameter. Since "A" type of soils have more infiltration capacity in compare to D, a higher value is given to A. In other word, type "A" soil has more contribution to I&I problem in compare to type D soil. Table 3-12 shows the different value parameter.

Table 3-12: Assigned value for soil types

Type of Soil	A	B	C	D
Assigned Value	10	8	6	4

Weighted parameters ranging from 4 to 10 for the calculated empirical coefficients in Fig. 3-43 are also provided. Assigned values and corresponding range of empirical coefficients is shown in Table 3-13.

Table 3-13: Assigned value for empirical performance value

Operational Performance Value	0≤8	8.1≤12	12.1≤18	18.1≤48
Assigned Value	10	8	7	4

As discussed above, high empirical performance value indicates good condition of pipe (Chughati et al. 2007). For instance the weightage value 10 implies for the poor condition of the pipe whereas 1 implies the excellent condition.

Finally, the model creates a total weighted values summing of each 4 parameters. The final results produce a number ranging from 1 to 10. Low number represents pipe segments with minimum susceptibility to I&I, while high numbers shows pipe segment with the most susceptibility to I&I problem i.e. very poor condition. Table 3-14 gives the example of the four weighted parameters for the pipe segment named as FID 0. The sum of the value showed that the total sum of the final weighted value is 8.4.

Since the sum of the total value is 8.4, the pipe FID 0 has relatively higher chance of I&I. After analyzing all pipe segments, the final calculated values are uploaded back to GIS in attribute table of the sewer lines. A final map was then generated based upon the different assumed values made during the calculations process. The results are discussed in the following section.

Table 3-14: Sample calculation for FID 0 (Pipe Segment)

Parameter	Value Parameter	Weightage	Weighted Value
Pipe Age	8	0.6	4.8
Empirical Value	8	0.1	0.8
Sewer Group	8	0.1	0.8
Soil Type	10	0.2	2
Sum			8.4

3.2.6 Analysis Results

Following the process discussed above, the resulting weighted values are used in GIS to generate maps for various scenarios. The pipe segments were defined in certain given ranges and then coded with different colors. As explained in the previous section 3.2.2, the lower number indicates the good condition of the pipes in terms of I&I problems while higher number indicates the poor condition. More detailed results are discussed in the subheadings below.

The pipe segments which fall in the higher range may be prioritized for the future I&I field testing. Since the results shown in this section are an estimate, the field verification process should be followed to verify and refine the model. The research team in Civil Engineering Department at Youngstown State University is currently working on a proposal to perform the field I&I testing. The results discussed in this study will be used as a preliminary study, and thus the scope of this study is limited to the qualitative approach of I&I analysis.

3.2.6.1 Age

Pipe age is a very important factor for its condition, more specifically, cracks and its structural integrity. Aged pipes have more cracks resulting higher level of infiltration (Boersma 2012). Considering the pipe age as a main factor contributing to I&I problems, the weightage value for pipe age was assigned as 60%. The remaining 40% weightage was distributed to other factors; empirical value (10%), Sewer group (10%), and soil type (20%). As shown in Fig. 3-46, the pipes are labeled in red, blue, green, orange, and grey. These colors represent conditions of pipe as very poor, poor, average, good, and excellent, respectively. The majority of pipes surrounding the downtown area are determined to be in very poor conditions. As described in Fig. 3-46, based upon the analysis, excellent and good conditions were not observed. Minimal length of the pipe was noticed to be in average conditions.

As shown in Fig. 3-47, approximately 72 % of sewer lines are determined to be in very poor condition when the age factor is considered to be the main parameter influencing on the I&I. Similarly, 27% of sewer lines are noticed to be in poor condition. A minute amount (417 m) of the pipelines was observed to be in average condition with value 4.1 to 6.

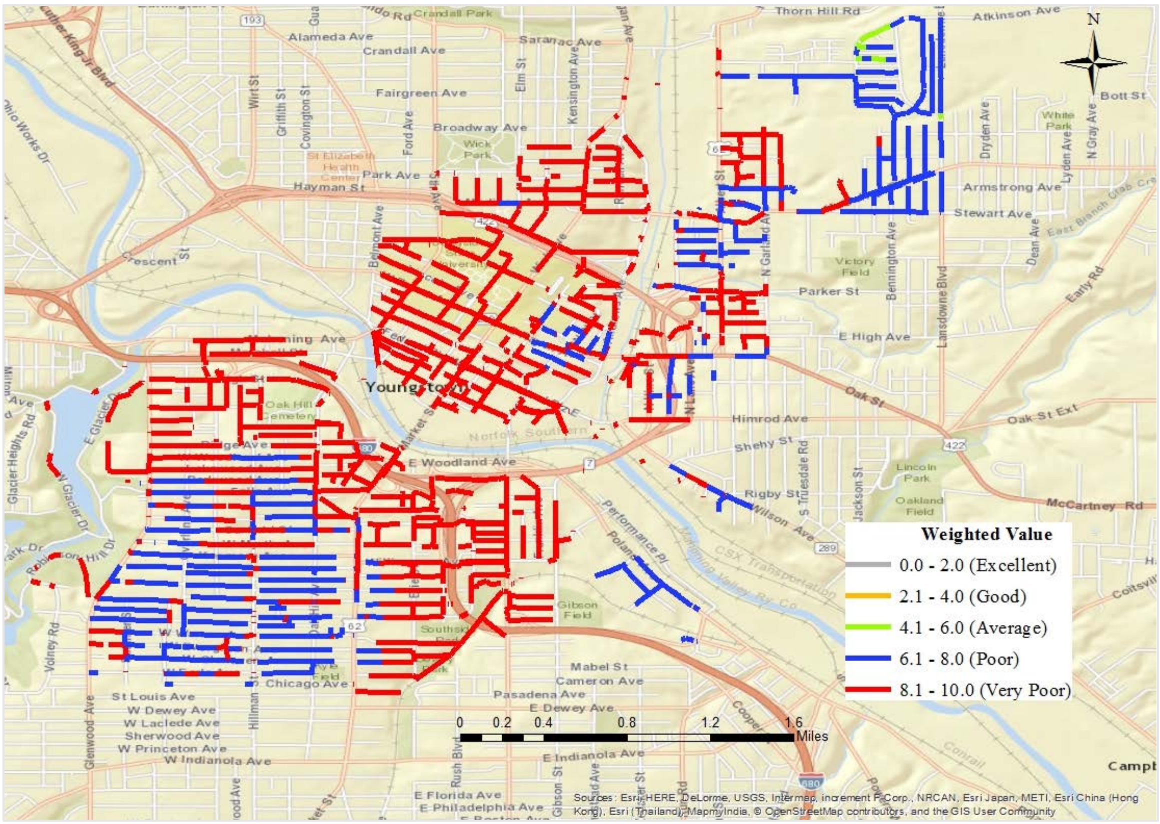


Figure 3-46: Map with age emphasis

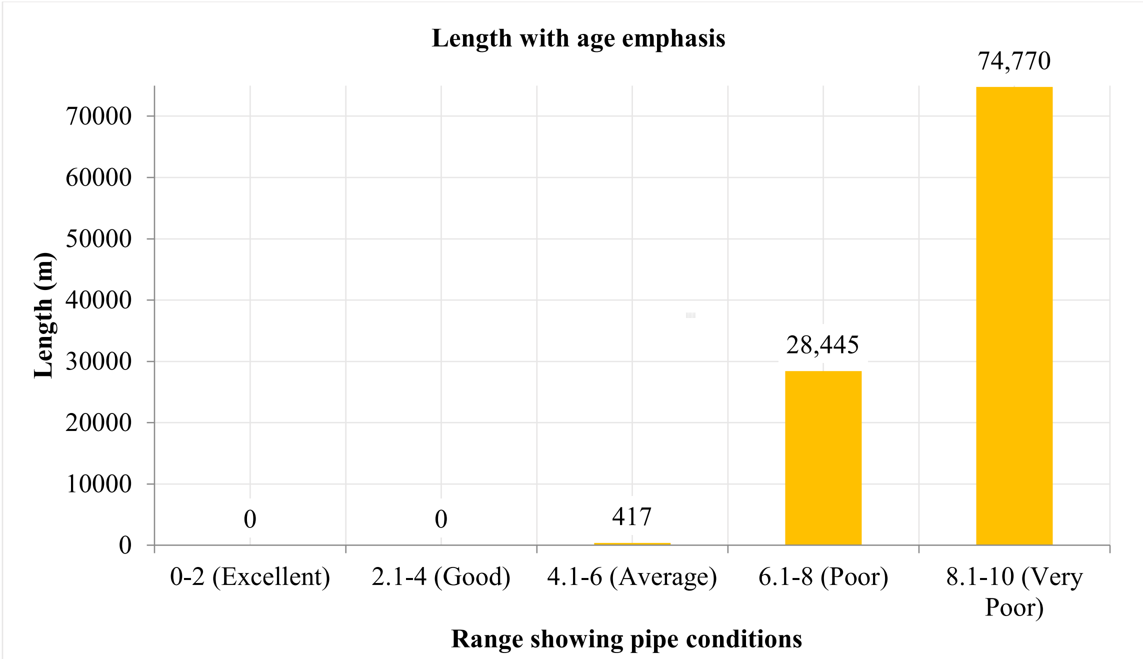


Figure 3-47: Pipe condition based on age factor

3.2.6.2 Empirical value

In this model, the empirical performance value, pipe age, sewer group, soil type was given weightage of 50%, 20%, 10%, and 20%, respectively (to create 100%). The result shown in Fig. 3-48 demonstrates that the majority of the pipelines in downtown and south side of Mahoning river were determined to be in poor (6.1-8.0) to very poor (8.1 -10) conditions. The result considers the effect of all the parameters such as pipe age, diameter, length, and slope associated with equation 1.1. However, the pipe age is still considered to be the main influencing factor to the I&I problem, since the pipe age is the main factor which directly affects the structural performance of the sewer pipelines (Chughtai et al. 2007).

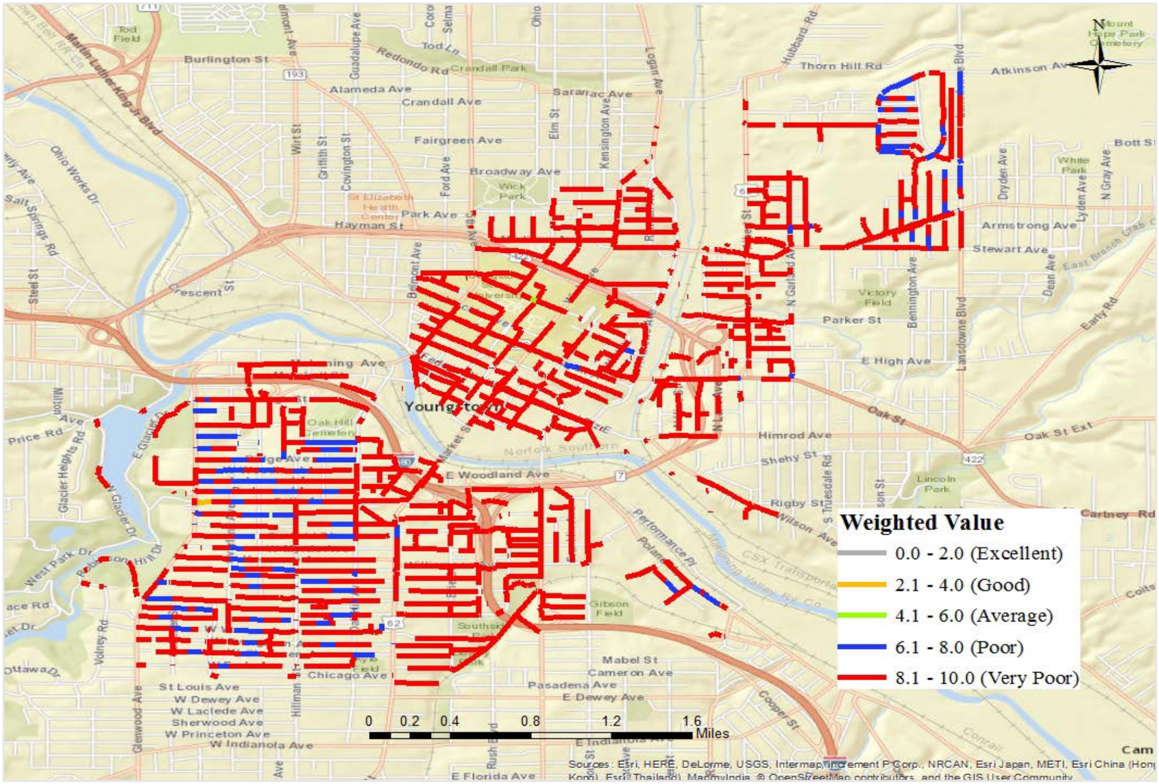


Figure 3-48: Map with empirical value emphasis

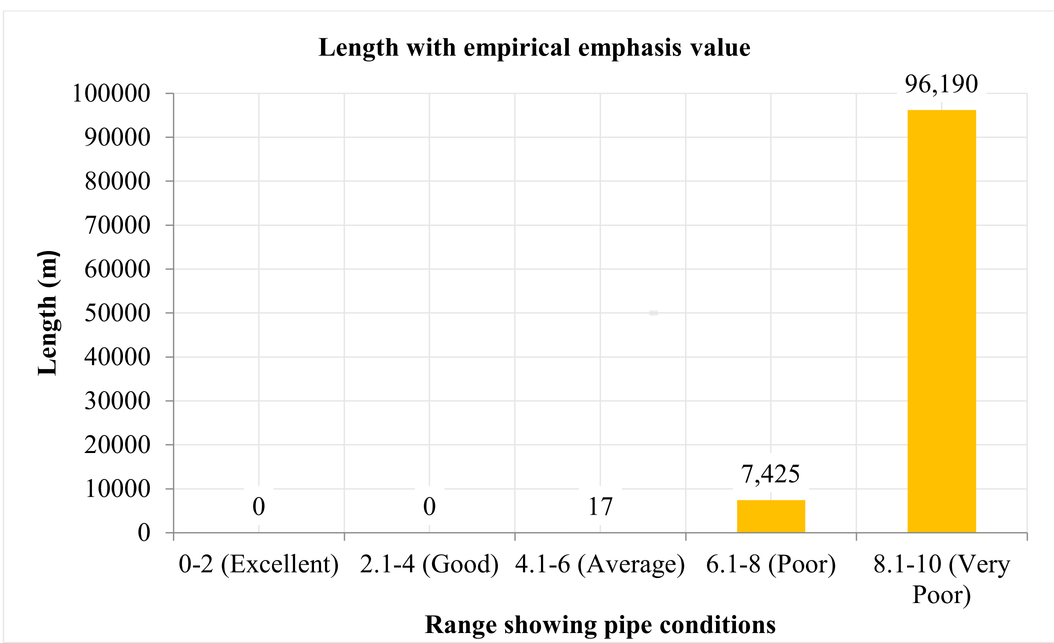


Figure 3-49: Pipe condition based on empirical coefficient factor

As shown in Fig. 3-49, majority of the pipelines which are depicted with the red color have a total length of 96,190 m and are in very poor condition. Based upon the analysis, none of the pipelines with such a good (less than 4) empirical factor have been determined. As discussed earlier, since the age is the major contributing factor in calculation of empirical coefficient, the results also agreed with the fact that most of the pipelines are older than 100 years. This indicates that there are very few pipelines with good empirical value or less aged pipelines. More empirical values were defined with low parametric numbers (less than 5) and high empirical values were expressed with high parametric value (more than 5) in the model. Large amount of pipelines with high parametric value (8.1-10) describing low empirical coefficient (Fig. 3-49) stipulates that most of the pipelines are structurally deficient.

3.2.6.3 Soil Type

As shown in Table 3-15, 60% weightage was given to soil type. Similarly, 20% for pipe age, 10% for empirical value, and 10% for sewer group were assigned as weightage value to generate this model. As explained in section 3.2.3, soils around the sewer lines are one of the important factors for I&I problem. Infiltration rate is the measure of how fast the water moves into ground and is the function of soil gradation (percentage of sand, silt, and clay), and clay mineralogy (NRCS 2008). The results from the model are shown in Fig. 3-50. The pipelines in downtown and south sides were determined to be more vulnerable to I&I. However, sewer lines of Overland Avenue which runs North-South direction, Garfield Street, W Myrtle Avenue, and Kenmore Avenue running East-West direction were found to be in average condition with value 4.1- 6.0. The majority of the sewer lines are in very poor conditions.

Table 3-15: Weightage distribution matrix

	Soil Type Emphasis
Pipe Age	0.2
Empirical Value	0.1
Sewer Group	0.1
Soil Type	0.6

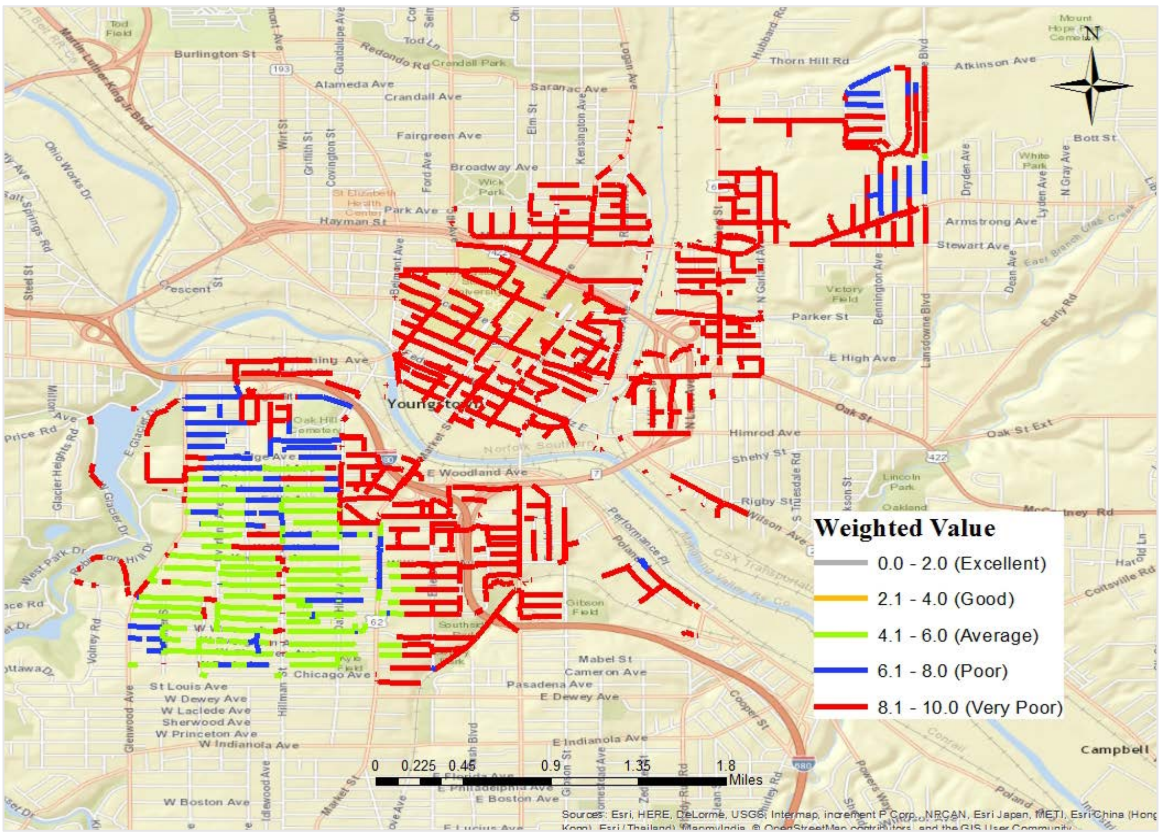


Figure 3-50: Map with soil type emphasis

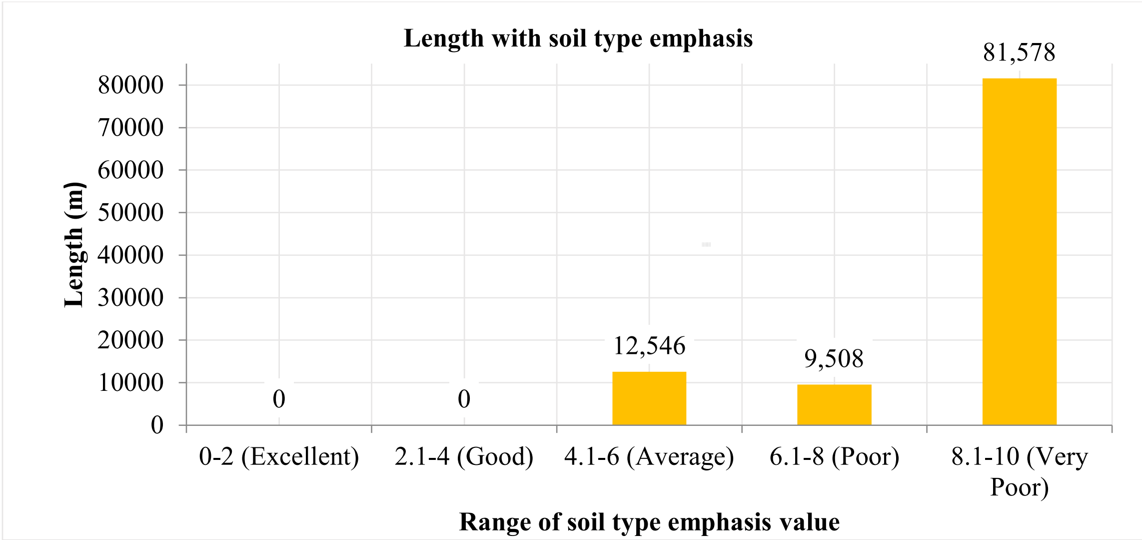


Figure 3-51: Pipe condition based on soil factor

As shown in Fig. 3-51, 81,500 m out of 103,600 m of total length was determined to be in very poor condition. Out of the total length, only 12.1% was determined to be in average condition when the soil type was emphasized with 60% weightage value.

3.2.6.4 Equal weight of all parameters

In this model, pipe age, empirical value, sewer group, and soil type were given equal weightage as shown in Table 3-16. The result for this model is shown in the Fig. 3-52. Fig. 3-53 illustrates the results of analysis based on the equal weight of all factors

Most of the pipelines are determined to be in very poor conditions. Out of 103,600 m of pipe, 86,000 m of pipe are determined to be in very poor condition, which equates to a value greater than 80%. Similarly, 16% of the piping was found to be in poor condition and piping, ranging from excellent to average was not noticed.

Table 3-16: Weightage distribution matrix

	Equally Weighted
Pipe Age	0.25
Empirical Value	0.25
Sewer Group	0.25
Soil Type	0.25

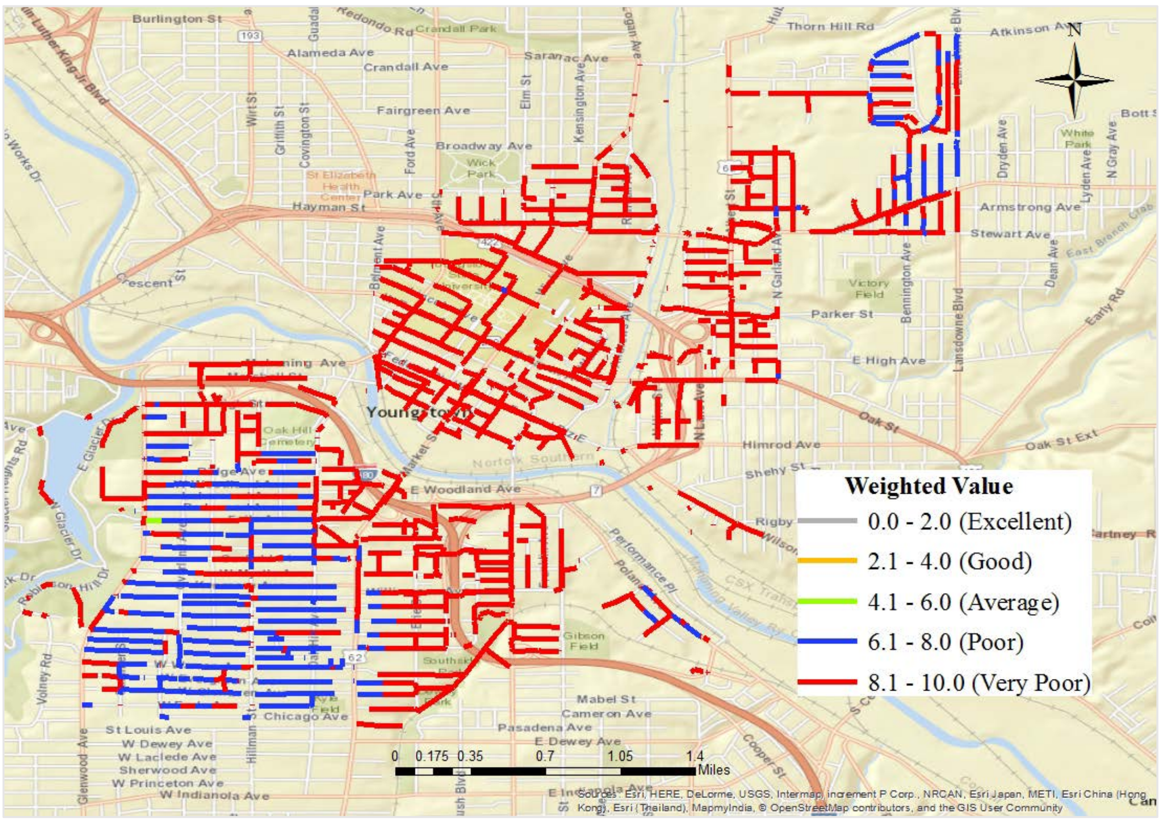


Figure 3-52: Map with equally emphasis

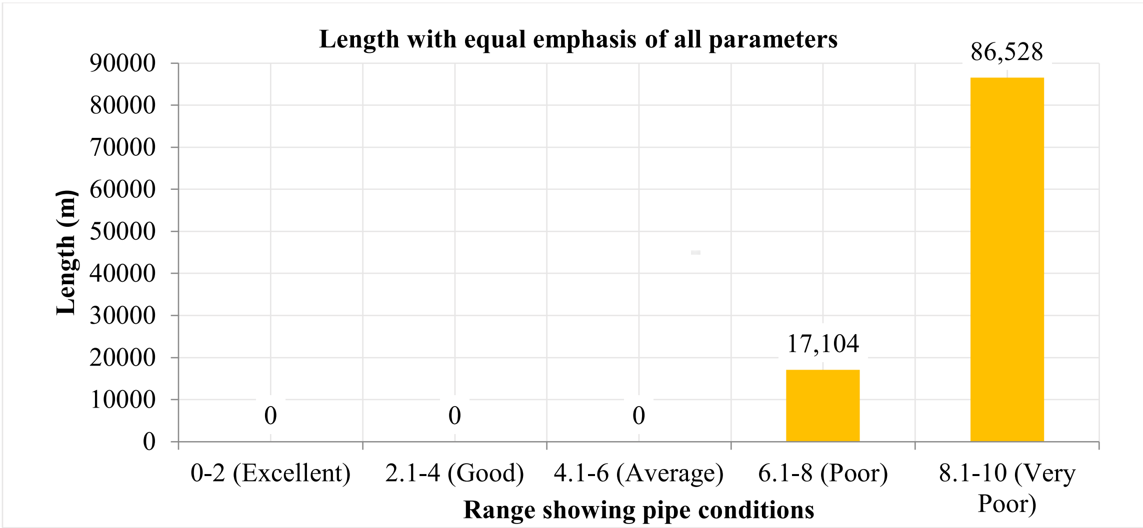


Figure 3-53: Pipe condition based on effect of all factors

Chapter 4 Conclusions and Recommendations

4.1 Conclusions

Overall, the first section provided snapshot of open cut method and trenchless technologies used to construct or rehabilitate the underground infrastructures such as water mains, waste water, and storm water in Canadian municipalities. Comparative study between the 2013/2014 and 2014/2015 surveys concluded that there is increasing demand of the trenchless technologies. However, due to lack of appropriate knowledge, skills, and education, trenchless technology is still over shadowed by open cut method. Moreover, many municipalities have not enough budgets to properly maintain their infrastructure. Also, the municipalities do not have long term (5-10 years) plan budget for the rehabilitation and reconstruction of the utility systems. Study showed that level of service of the municipality's management is not satisfactory due to not having the separate asset management group in their municipalities. Budget and educations were discovered as the major factors for not being effective use of trenchless technology. Trenchless technology was determined to be very effective method in installation of deep pipe network especially in congested urban area. Infiltration and inflow, flow capacity, pipe collapse, and intrusion of roots were noted to be the major issues in the pipe network. In addition, municipalities found that governmental regulations, appropriate public education, specialized training encompassing trenchless methods, and direct access to government grants could be the major factors contributing to remove the water and sewer backlog in the pipe network. Trenchless method was determined to be the environmental friendly in comparison to open cut method. Finally, the survey also revealed that, CIPP was the most popular method of rehabilitation among various other trenchless methods. This part of the study lacked a pertinent question involving combined sewer systems. Therefore, a suggestion was made to ask the respondents what type of sewer system is in use. This intern would enhance the survey; so that the entire populous would be represented in the future study.

The second section of this research provided a user friendly qualitative model to obtain I&I susceptible areas in a specific municipalities such as Youngstown. This model showed possible areas of interest in the study area based upon, some important but not all parameters involved in I&I for specific pipe segment. Based upon vulnerability to I&I problem in the piping segments, different maps were generated for the Youngstown areas. These maps can be used to prioritize the segment that needs I&I field testing. From this study, downtown and the surrounding areas of Youngstown were identified as having high I&I susceptibility. These results are useful to prioritize the segments which need I&I field testing. Most of the pipes were found to have an age between 112 to 119 years. The pipelines located in downtown area and encompassing the Mahoning River are encased in soils with high infiltration capacity. These areas were found to be areas of high concern when describing susceptibility to I&I problem. Field testing is needed to be carried out in those areas where I&I problem are of major concern. By evaluating the current condition of the pipelines in terms of susceptibility to I&I, we can decrease the cost associated with I&I problems in both present and future. The initial cost is relatively low when compared to the overall cost. It can be observed, the age of pipes can correlate directly to I&I problems and consequently public health. The sewage plant, in question, can be over-burdened by these excess inflows. Thus causing, the excess sewage water that can’t be handled by the water channels surrounding the Youngstown area. In the future, this model can be applied to other municipalities to examine the possible problems associated with all type of underground pipe network considering the other factors which were not considered in this study, such as sewer classifications, pipe material, design method, proximity of underground structure, and etc.

Overall, the entire scope of this research has addressed the issues, such as I&I, involved with the underground pipe network along with the effective methods of construction and rehabilitation for sustainable development of the underground infrastructures.

4.2 Recommendations

Based on the results obtained from the survey results 2014/15, expecting more refined and precise results in coming survey 2016/17, some recommendations have been suggested in this section. A recommendation is to inquire if the municipality's sewer system is combined or separate. The survey negated this specific question, which caused an entire populous (participating municipalities) to not be represented or misrepresented in the survey.

By understanding which type of system a municipality has, the survey questionnaire can be designed around this. By design, then the participants can have questions tailored towards the desired issues. For example, combined sewer systems may have different issues than the separate sanitary system. The current questionnaire neglected to ask specific questions, such as the length and age of combined sewer system and the percentage of rehabilitated or replaced by trenchless or open cut method. The questionnaire could have also asked when each municipality started using the trenchless/open cut method technology. That way, a time frame can be established to understand how the use of each technology is playing a role in the municipality of interest.

The use of trenchless technologies also depends on the type of pipelines (material specific), along with the length, diameter, and location of pipes. The current survey, failed to address these specific parameters, which could give insight into why such technologies are used or are not in use, currently. Therefore, it is strongly recommended to ask such questions addressing all the parameters described above.

To understand the progress that has been made currently and the future demand of trenchless technologies, it is recommended to design a question addressing the use of trenchless methods to rehabilitate/replace utility pipe network. The question need to address the percentage of pipe network (or length of pipe network), which have been rehabilitated or replaced using trenchless methods before certain year (5 to 10 years) and currently. The following questions are recommended.

i. What percentages of pipelines were constructed (5 to 10) years ago and renovated using trenchless technologies?

	Water Distribution		Wastewater Network		Stormwater Network	
	New Construct ion	Renovati on	New Construct ion	Renovati on	New Construct ion	Renov ation
0 – 9 %	☐	☐	☐	☐	☐	☐
10 – 19 %	☐	☐	☐	☐	☐	☐
20 – 29 %	☐	☐	☐	☐	☐	☐
30 – 39 %	☐	☐	☐	☐	☐	☐
40 – 49 %	☐	☐	☐	☐	☐	☐
50 – 59 %	☐	☐	☐	☐	☐	☐
60 – 69%	☐	☐	☐	☐	☐	☐
70 – 79 %	☐	☐	☐	☐	☐	☐
80 – 89 %	☐	☐	☐	☐	☐	☐
90 – 100 %	☐	☐	☐	☐	☐	☐

ii. What percentages of pipelines were newly constructed and renovated using trenchless technologies?

	Water Distribution		Wastewater Network		Stormwater Network	
	New Construction	Renovation	New Construction	Renovation	New Construction	Renovation
0 – 9 %	☐	☐	☐	☐	☐	☐
10 – 19 %	☐	☐	☐	☐	☐	☐
20 – 29 %	☐	☐	☐	☐	☐	☐
30 – 39 %	☐	☐	☐	☐	☐	☐
40 – 49 %	☐	☐	☐	☐	☐	☐
50 – 59 %	☐	☐	☐	☐	☐	☐
60 – 69%	☐	☐	☐	☐	☐	☐
70 – 79 %	☐	☐	☐	☐	☐	☐
80 – 89 %	☐	☐	☐	☐	☐	☐
90 – 100 %	☐	☐	☐	☐	☐	☐

Some recommendations are also suggested based upon the results obtained from chapter two. Prioritization for field testing of the pipe segments based up on their current conditions (very good to very poor) is strongly recommended. Moreover, I&I field testing is needed to be carried out to those areas where I&I problem is identified as vulnerable.

4.3 Limitations

This study was conducted in a through manner. However, there were some limitations of this study. For the first chapter, the questionnaire was designed by Centre for

Advancement of Trenchless Technology (CATT) and was distributed to only Canadian Municipalities. Even though, 126 municipalities were participants, the response count for some questions was determined to be less than the total number of participants. Therefore, some of the results mentioned in this study may not be representative of the whole population. Thus, it is not possible to generalize all of our results to all municipalities and the entire populous in North America. Future studies are encouraged to conduct this type of survey in such way that the results could represent the whole populations and municipalities addressing the different problems and issues.

The questions asked in the asset management and financial sections were exploratory type of questions. Unlike to descriptive type of research (conclusive in nature due to its quantitative nature), exploratory research is more flexible that provides to consider about various aspects of the problems. On the other hand, such exploratory research are unstructured, leading to only tentative results that the results may have limited value in decision making process. This means even though the results shown above has statistically significant association based on the data used for the study, there is a chance of potential bias or confounding in a study and that can cause a reported association to be misleading.

In second chapter, date of construction was not available in the shape file and the map provided by City of Youngstown did not have date of construction on file for most of the pipe segments. Manual input of the data and assumption of the date of construction and rehabilitation probably caused the slight error in the model. This is a qualitative approach and just provides a preliminary estimate for the area of I&I susceptibility. I&I is a complex phenomenon and can be affected by various factors such as quality of pipe material, quality of construction, proximity of the underground structure, properties of the soil, type of sewer, structural condition (empirical coefficient), and etc. However, only the important factors mentioned in section 3.5 were considered in this model. Other factors such as sewer subsystem, type of waste, depth of pipe, frost conditions, and proximity to other underground utilities were not considered in this study. Accuracy of the generated map is somewhat susceptible to the individual judgment of the researcher (giving weighted value).

The Manning's roughness coefficient (n) was assumed to be 0.011, assuming vitrified clay for the pipe material. Since, the Manning's roughness coefficient is different depending on the pipe material; the used value in this study may have differed from actual value of the pipelines in Youngstown. This study has generated several maps on different scenarios (pattern of combination of parameter) as mentioned above in the result section of this report. The verification of the results is necessary for the reliability of the study.

REFERENCES

Allouche, E. N., & Gilchrist, A. (2004). Quantifying construction related social costs. In *Proceeding of No-Dig Conference 2004*.

American Water Works Association (AWWA) (2001). Reinvesting in Drinking Water Infrastructure: Dawn of the Replacement Era. Retrieved from http://www. awwa. org/Advocacy/govtaff/infrastructure.

Apeldoorn, S. (2013). Trenchless versus traditional-comparing costs: SASTT. *IMIESA*, 38(4), 55-57.

Ariaratnam, S. T. (2010). Survey questionnaire results of the current level of knowledge on trenchless technologies in China. *Tunneling and Underground Space Technology*, 25(6), 802-810.

Ariaratnam, S. T., & Sihabuddin, S. S. (2009). Comparison of emitted emissions between trenchless pipe replacement and open cut utility construction. *Journal of Green Building*, *4*(2), 126-140.

Ariaratnam, S. T., El-Assaly, A., & Yang, Y. (2001). Assessment of infrastructure inspection needs using logistic models. *Journal of Infrastructure Systems*, 7(4), 160-165.

Ariaratnam, S. T., Lueke, J. S., & Allouche, E. N. (1999). Utilization of trenchless construction methods by Canadian municipalities. *Journal of construction engineering and management*, 125(2), 76-86.

ASCE Committee. (2014) Standard Design and Construction Guidelines for Microtunneling (ASCE/CI 36-14). American Society of Civil Engineers.

Bialas, A. (2016). Risk Management in Critical Infrastructure—Foundation for Its Sustainable Work. Sustainability, 8(3), 240.

Boersma A. (2012). *Inflow and Infiltration: A Qualitative Approach to Determining Areas of Highest Inflow and Infiltration in the Milwaukee Metropolitan Sewerage District's Jurisdiction*. Retrieved from http://www.ce.utexas.edu/prof/maidment/giswr2012/TermPaper/Boersma.pdf

Brodsky, R., LeBlanc, R., Luvisi, K., Coleman, Bob., Dusle, T., Finger, P., CaCava, J., (2014, November). *Inflow and Infiltration (I&I) Evaluation and Recommendations for the City of Waltham.* Retrieved from http://www.city.waltham.ma.us/sites/walthamma/files/file/file/ii_guidance_documents_-_bound_submission_2014-11-20_1.pdf

Chughtai, F., & Zayed, T. (2007). Sewer pipeline operational condition prediction using multiple regression. In *Pipelines 2007: Advances and Experiences with Trenchless Pipeline Projects* (pp. 1-11).

City of Superior (n.d.). *Inflow and Infiltration: Rainwater entering the sanitary sewer system*. Retrieved from www.ci.superior.wi.us/sfcp

Downey, D. (2006). Trenchless technology: a modern solution for clean-flowing cities. In *Proceedings of the Institution of Civil Engineers-Civil Engineering* (Vol. 159, No. 5, pp. 26-30). Thomas Telford Ltd.

Emas, R. (2015). The concept of sustainable development: definition and defining principles. *Florida International University.*

Fenner, R. A. (2000). Approaches to sewer maintenance: a review. Urban water, 2(4), 343-356.

Folkman, S. (2012). Water Main Break Rates in the USA and Canada: A Comprehensive Study, April 2012.

Forrer, J., Kee, J. E., Newcomer, K. E., & Boyer, E. (2010). Public–private partnerships and the public accountability question. *Public Administration Review*, 70(3), 475-484.

German, I., & ÖPP, Ö. P. P. (2001). Public-private partnerships.

Greater Ohio Policy Center (2015). November). *An Assessment of Ohio Cities Water and Sewer Infrastructure and Brownfield Sites Development: Needs and Gaps*. Retrieved from http://www.greaterohio.org/files/pdf/water-and-sewer-infrastructure-report

Hasegawa, K., Wada, Y., & Miura, H. (1999, August). New assessment system for premeditated management and maintenance of sewer pipe network. In *Proc. the Eighth International Conference on Urban Storm Drainage*.

Hashemi, B., Najafi, M., & Mohamed, R. (2008). Cost of underground infrastructure renewal: a comparison of open-cut and trenchless methods. In Pipelines 2008: Pipeline Asset Management: *Maximizing Performance of our Pipeline Infrastructure* (pp. 1-11).

HDR | Archer. (2010, April). *I/I Assessment and Reduction Plan Cameron, Missouri HDR Project No. 13695*. Retrieved from http://www.cameron-mo.com/DocumentCenter/Home/View/856

Inflow and Infiltration (I&I) (n.d.) Retrieved July 08, 2017, from http://cityofreseville.com/2762/inflow-and-infiltration-II

Islam, A., Allouche, E., & Matthews, J. (2014). Assessment of social cost savings in trenchless projects. *North American Society for Trenchless Technology* (NASST), Orlando, FL.

Jung, Y. J., & Sinha, S. K. (2004). Trenchless Technology: An Efficient and Environmentally Sound Approach for Underground Municipal Pipeline Infrastructure Systems. No Dig, 1-7.

Kerr Wood Leidal Assoc. (2011). *Inflow and Infiltration Management Plan Template - Working Draft. Prepared for Metro Vancouver*. Burnaby: Metro Vancouver.

Koo, D. H., Song, H. M., Cho, J. I., & Jang, C. K. (2011). Development of an Automated Air Pressure Inversion System Using Vertical Roller Brackets (ABL System) for Steam Cured CIPP Installation. In ICPTT 2011: *Sustainable Solutions For Water, Sewer, Gas, And Oil Pipelines* (pp. 1335-1343).

Kramer, S. R., & Gary, G. A. (2000). Comparison of Trenchless vs. Open-Cut Construction Methods for the Replacement of a Leaking Water Distribution System. In Environmental and Pipeline Engineering 2000 (pp. 289-298).

Kulnadaivel, G, (2004), "*Sewer Pipeline Condition Prediction using Neural Network Models*", Master's Thesis, Michigan State University, USA.

Li, Q. S., & Wang, T. C. (2013). Construction and Sustainable Development of Pipe Network of Underground Drainage System. *In Applied Mechanics and Materials* (Vol. 438, pp. 1076-1079). Trans Tech Publications.

Linkov, I., Wenning, R. J., & Kiker, G. A. (Eds.). (2007). *Managing critical infrastructure risks*. Springer Science & Business Media.

Ma, B., & Najafi, M. (2008). Development and applications of trenchless technology in China. *Tunneling and Underground Space Technology*, 23(4), 476-480.

Matthews, J. C., Allouche, E. N., & Sterling, R. L. (2015). Social cost impact assessment of pipeline infrastructure projects. *Environmental Impact Assessment Review*, 50, 196-202.

Matthews, J., Condit, W., Wensink, R., & Lewis, G. (2012). Performance evaluation of innovative water main rehabilitation cured-in-place pipe lining product in Cleveland, *OH. Ohio, Report EPA/600/R-12/012, US Environmental Protection Agency (USEPA), Edison, NJ.*

May, R. W., Martin, P., & Price, N. J. (1998). Low-cost options for prevention of flooding from sewers. CIRIA.

McHugh, M. L. (2013). The chi-square test of independence. *Biochemia medica: Biochemia medica*, *23*(2), 143-149.

McKim, R. A. (1997). Bidding strategies for conventional and trenchless technologies considering social costs. *Canadian journal of civil engineering*, 24(5), 819-827.

Morrow, Matthew (2016). America's Water Infrastructure Is in Need of a Major Overhaul. Retrieved 07, 2017 from, Fox Business News

Najafi, M. (2014, May). Trenchless Construction Technology and Issues. Paper presented at 15th Annual Public Works Roundup. Ruthe Jackson Center, Grand Prairie, Texas. Retrieved from http://www.nctcog.org/envir/SEEDevEx/pubworks/documents/2014

Najafi, M., & Kim, K. O. (2004). Life-cycle-cost comparison of trenchless and conventional open-cut pipeline construction projects. *In Pipeline Engineering and Construction*: What's on the Horizon? (pp. 1-6).

NRCS, U. (2009). *Part 630 Hydrology National Engineering Handbook.*

ODOT Hydraulics Manual (2014 April). *Appendix A-Hydraulic Roughness (Manning's n) Values of Conduits and Channels*. Retrieved from http://www.oregon.gov/ODOT/GeoEnvironmental/Docs_Hydraulics_Manual/Hydraulics-08-A

Pipes – Clay. (n.d.). Retrieved July 08, 2017, from http://www.sewerhistory.org/photosgraphics/pipes-clay

Popawala, R. D. (2013). Integrated sustainable urban water network using statistical and analytical heirarchy process modeling technique: a case study of Surat city.

Raynaud, O., Joannis, C., Schoefs, F., & Billard, F. (2008). A model-based assessment of infiltration and inflow in the scope of controlling separate sanitary overflows at pumping stations. In *11th international conference on urban drainage (ICUD), Edinburgh (UK), Proceedings on CD*.

Rush, J., Farr, A., Muenchmeyer, G.P., Mathews, J.C., Shirodkar, D., Boudreaux, E.…Cote B. (2013). A Supplement of Trenchless Technology: *Pipe Relining Guide 2013*. Retrieved from www.trenchlesstechnology.com

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at https://websoilsurvey.sc.egov.usda.gov/. Accessed [May/18/2017]

Sterling, R., & Thorne, J. D. (1999). *Trenchless Technology: Applications in Public Works*. American Public Works Association.

Sterling, R., Wang, L., & Morrison, R. (2009). Rehabilitation of wastewater collection and water distribution systems: State of technology review report. *US Environmental Protection Agency, Edison, NJ.*

Tafuri, A. N., & Selvakumar, A. (2002). Wastewater collection system infrastructure research needs in the USA. *Urban water*, 4(1), 21-29.

The aging water infrastructure: Out of sight, out of mind? (n.d.). Retrieved July 07, 2017, from https://dupress.deloitte.com/dup-us-en/economy/issues-by-the-numbers/us-aging-water-infrastructure-investment-opportunities.html

Tighe, S., Lee, T., McKim, R., & Haas, R. (1999). Traffic delay cost savings associated with trenchless technology. *Journal of infrastructure systems*, 5(2), 45-51.

Toronto, City of. “About the Sewers on Your Street.” Stormwater Management WaterCityofToronto,www1.toronto.ca/wps/portal/contentonly?vgnextoid=fc8807ceb6f8e310VgnVCM10000071d60f89RCRD. Accessed 27 June 2017

United Nations General Assembly. (1987). Report of the world commission on environment and development: Our common future. Oslo, Norway: *United Nations General Assembly*, Development and International Co-operation: Environment.

United States Environmental Protection Agency. (1999). Collection Systems O&M Fact Sheet-Trenchless Sewer Rehabilitation. Retrieved from www3.epa.gov/npdes/pubs

US Department of Agriculture, National Resources Conservation Service (2008 June). Soil Quality Indicators

US Environmental Protection Agency. (2015). Condition Assessment of Underground Pipes (600-R-09-049) Retrieved from https://www3.epa.gov/region1/sso/pdfs/condition-assessment-underground-pipes

Wastewater | ASCE's 2017 Infrastructure Report Card. (n.d.). Retrieved from https://www.infrastructurereportcard.org/cat-item/wastewater/

Water Infrastructure | ASCE's 2017 Infrastructure Report Card. (n.d.). Retrieved from https://www.infrastructurereportcard.org/cat-item/drinking-water/

West Virginia University. (1999). Infiltration and Inflow can be costly for the communities. *PIPELINE* (VOL. 10, No. 2)

Zaneldin, E. K. (2007). Trenchless construction: an emerging technology in United Arab Emirates. *Tunneling and underground space technology*, 22(1), 96-105.

APPENDICES

APPENDIX A: Survey Questionnaire 2014/15

CATT's Second Annual Municipal Buried Infrastructure Survey - Fiscal Year

1.

The objective of this anonymous survey is to provide a broad-based summary of market conditions in Canada's water and wastewater sector. Your response will help to assess the short-term outlook of market activity in the water and wastewater buried infrastructure field. The information will be useful for a variety of stakeholders – city engineers/managers, contractors, consultants, manufacturers and political decision makers – for market analysis and assessment.

The collected data will be used in aggregate and no individual responses will be disclosed. You may also choose to fill out your information at the end of the survey to enter into prize drawings for smartphones and/or tablets.

Page 1

CATT's Second Annual Municipal Buried Infrastructure Survey - Fiscal Year

2. Background Information

*1. What province or territory are you located in?

*2. What is the population of your municipality?

- < 50,000 (Small Municipality)
- 50,000 - 300,000 (Medium Municipality)
- > 300,000 (Large Municipality)

Page 2

CATT's Second Annual Municipal Buried Infrastructure Survey - Fiscal Year

3. SM (Small Municipality) Asset Management and Network Financial Information

3. Is asset management a separate group in your municipality or is it part of water/wastewater operations?

- ◯ Separate Group
- ◯ Water/wastewater Operations

Other (please specify)

4. What is the asset management (AM) maturity level? (Advanced means that you know the current condition of your system well, have defined level of service, developed condition assessment and operation, maintenance, and renewal plans, and have access to funds to implement and monitor the AM plan).

- ◯ No asset management
- ◯ Basic asset management
- ◯ Advanced asset management

If you choose "no asset management", please explain why?

5. During the current fiscal year, what is your municipality's estimated budget for capital works for rehabilitation and/or replacement of the following networks?

	< $500,000	$500,000 to $1 million	$1 million to $2 million	$2 million to $4 million	$4 million to $6 million	> $6 million
Water Distribution Network	◯	◯	◯	◯	◯	◯
Wastewater Network	◯	◯	◯	◯	◯	◯
Stormwater Network	◯	◯	◯	◯	◯	◯

Page 3

6. Does your municipality/utility have sufficient funds to meet operation and maintenance (O&M) expenditures?

- ◯ We do not have sufficient funds to meet O&M requirements
- ◯ We have just enough funds to meet O&M requirements
- ◯ We have sufficient funds to meet O&M requirements

Other comments (please specify)

7. Does your municipality/utility have sufficient funds to meet capital expenditures for the next 5-10 years?

- ◯ We do not have sufficient funds
- ◯ We have just enough funds
- ◯ We have sufficient funds

Other comments (please specify)

8. Rate the importance of the following with respect to removing water and sewer infrastructure backlog within your network.

	1 (Not Critical)	2	3	4	5 (Very Critical)
Increased water/sewer rates	◯	◯	◯	◯	◯
Access to government grants	◯	◯	◯	◯	◯
Government regulations	◯	◯	◯	◯	◯
Public private partnerships	◯	◯	◯	◯	◯
Access to long-term financing	◯	◯	◯	◯	◯
Public education	◯	◯	◯	◯	◯
Professional education	◯	◯	◯	◯	◯
Creating stormwater fee	◯	◯	◯	◯	◯

Other (please specify)

CATT's Second Annual Municipal Buried Infrastructure Survey - Fiscal Year

4. MM (Medium Municipality) Asset Management and Network Financial Information

9. Is asset management a separate group in your municipality or is it part of water/wastewater operations?

- ◯ Separate Group
- ◯ Water/wastewater Operations

Other (please specify)

10. What is the asset management (AM) maturity level? (Advanced means that you know the current condition of your system well, have defined level of service, developed condition assessment and operation, maintenance, and renewal plans, and have access to funds to implement and monitor the AM plan).

- ◯ No asset management
- ◯ Basic asset management
- ◯ Advanced asset management

If you choose "no asset management", please explain why?

11. During the current fiscal year, what is your municipality's estimated budget for capital works for rehabilitation and/or replacement of the following networks?

	< $500,000	$500,000 to $1 million	$1 million to $2 million	$2 million to $4 million	$4 million to $6 million	> $6 million
Water Distribution Network	◯	◯	◯	◯	◯	◯
Wastewater Network	◯	◯	◯	◯	◯	◯
Stormwater Network	◯	◯	◯	◯	◯	◯

12. Does your municipality/utility have sufficient funds to meet operation and maintenance (O&M) expenditures?

- ◯ We do not have sufficient funds to meet O&M requirements
- ◯ We have just enough funds to meet O&M requirements
- ◯ We have sufficient funds to meet O&M requirements

Other comments (please specify)

13. Does your municipality/utility have sufficient funds to meet capital expenditures for the next 5-10 years?

- ◯ We do not have sufficient funds
- ◯ We have just enough funds
- ◯ We have sufficient funds

Other comments (please specify)

14. Rate the importance of the following with respect to removing water and sewer infrastructure backlog within your network.

	1 (Not Critical)	2	3	4	5 (Very Critical)
Increased water/sewer rates	◯	◯	◯	◯	◯
Access to government grants	◯	◯	◯	◯	◯
Government regulations	◯	◯	◯	◯	◯
Public private partnerships	◯	◯	◯	◯	◯
Access to long-term financing	◯	◯	◯	◯	◯
Public education	◯	◯	◯	◯	◯
Professional education	◯	◯	◯	◯	◯
Creating stormwater fee	◯	◯	◯	◯	◯

Other (please specify)

5. LM (Large Municipality) Asset Management and Network Financial Information

15. Is asset management a separate group in your municipality or is it part of water/wastewater operations?

- ○ Separate Group
- ○ Water/wastewater Operations

Other (please specify)

16. What is the asset management (AM) maturity level? (Advanced means that you know the current condition of your system well, have defined level of service, developed condition assessment and operation, maintenance, and renewal plans, and have access to funds to implement and monitor the AM plan).

- ○ No asset management
- ○ Basic asset management
- ○ Advanced asset management

If you choose "no asset management", please explain why?

17. During the current fiscal year, what is your municipality's estimated budget for capital works for rehabilitation and/or replacement of the following networks?

	< $500,000	$500,000 to $1 million	$1 million to $2 million	$2 million to $4 million	$4 million to $6 million	> $6 million
Water Distribution Network	○	○	○	○	○	○
Wastewater Network	○	○	○	○	○	○
Stormwater Network	○	○	○	○	○	○

18. Does your municipality/utility have sufficient funds to meet operation and maintenance (O&M) expenditures?

- ◯ We do not have sufficient funds to meet O&M requirements
- ◯ We have just enough funds to meet O&M requirements
- ◯ We have sufficient funds to meet O&M requirements

Other comments (please specify)

19. Does your municipality/utility have sufficient funds to meet capital expenditures for the next 5-10 years?

- ◯ We do not have sufficient funds
- ◯ We have just enough funds
- ◯ We have sufficient funds

Other comments (please specify)

20. Rate the importance of the following with respect to removing water and sewer infrastructure backlog within your network.

	1 (Not Critical)	2	3	4	5 (Very Critical)
Increased water/sewer rates	◯	◯	◯	◯	◯
Access to government grants	◯	◯	◯	◯	◯
Government regulations	◯	◯	◯	◯	◯
Public private partnerships	◯	◯	◯	◯	◯
Access to long-term financing	◯	◯	◯	◯	◯
Public education	◯	◯	◯	◯	◯
Professional education	◯	◯	◯	◯	◯
Creating stormwater fee	◯	◯	◯	◯	◯

Other (please specify)

6. SM (Small Municipality) Water Distribution System

21. What is the estimated total length of watermains in your municipality?

	< 300km	300-500km	500-800km	>800km
Total Length	◯	◯	◯	◯

22. What is the average age of watermains in your municipality?

	<30 Years	30-50 Years	50-70 Years	>70 Years
Average age of pipes	◯	◯	◯	◯

23. What percentage of the following pipe diameters makes up the total watermains' network in your municipality?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
300 - 600mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
600 - 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
> 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

24. What length (in total) of watermains were rehabilitated or replaced using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	◯	◯	◯	◯	◯	◯
Trenchless	◯	◯	◯	◯	◯	◯

Other (please specify method and length)

25. Please rank the methods (1 being the primary method) that you see being used for watermains' renovation and construction in your utility/municipality (check N/A if not used at all).

Rank	Method	N/A
☐	Open cut	☐ N/A
☐	Directional drilling	☐ N/A
☐	Cured In Place Pipe (CIPP)	☐ N/A
☐	Micro-tunneling/Tunneling	☐ N/A
☐	Sliplining	☐ N/A
☐	Cement mortar lining	☐ N/A
☐	Spray-on or Spray In Place Pipe (SIPP) lining	☐ N/A
☐	Other methods	☐ N/A

26. If "Other Methods" was selected in the above question, what other methods were used for watermains renovation and construction?

27. Rate the benefit of the following trenchless construction methods for watermain renovation/construction in your network.

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	○	○	○	○	○
Micro-tunneling/Tunneling	○	○	○	○	○
Sliplining	○	○	○	○	○
Cured In Place Pipe (CIPP)	○	○	○	○	○
Cement mortar lining	○	○	○	○	○
Spray-on or Spray-in Place Pipe (SIPP) lining	○	○	○	○	○

28. What are the critical issues in your watermain network?

	1 (Not Critical)	2	3	4	5 (Very Critical)
Improving water quality	○	○	○	○	○
Reducing pipe leakage	○	○	○	○	○
Reducing the number of annual watermain breaks	○	○	○	○	○
Increasing fire flows	○	○	○	○	○
Pipe structural integrity	○	○	○	○	○

7. MM (Medium Municipality) Water Distribution System

29. What is the estimated total length of watermains in your municipality?

	< 300km	300-500km	500-800km	>800km
Total Length	◯	◯	◯	◯

30. What is the average age of watermains in your municipality?

	<30 Years	30-50 Years	50-70 Years	>70 Years
Average age of pipes	◯	◯	◯	◯

31. What percentage of the following pipe diameters makes up the total watermains' network in your municipality?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
300 - 600mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
600 - 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
> 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

32. What length (in total) of watermains were rehabilitated or replaced using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	◯	◯	◯	◯	◯	◯
Trenchless	◯	◯	◯	◯	◯	◯

Other (please specify method and length)

33. Please rank the methods (1 being the primary method) that you see being used for watermains' renovation and construction in your utility/municipality (check N/A if not used at all).

Rank	Method	N/A
☐	Open cut	☐ N/A
☐	Directional drilling	☐ N/A
☐	Cured in Place Pipe (CIPP)	☐ N/A
☐	Micro-tunneling/Tunneling	☐ N/A
☐	Sliplining	☐ N/A
☐	Cement mortar lining	☐ N/A
☐	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
☐	Other methods	☐ N/A

34. If "Other Methods" was selected in the above question, what other methods were used for watermains renovation and construction?

35. Rate the benefit of the following trenchless construction methods for watermain renovation/construction in your network.

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	○	○	○	○	○
Micro-tunneling/Tunneling	○	○	○	○	○
Sliplining	○	○	○	○	○
Cured in Place Pipe (CIPP)	○	○	○	○	○
Cement mortar lining	○	○	○	○	○
Spray-on or Spray-in Place Pipe (SIPP) lining	○	○	○	○	○

36. What are the critical issues in your watermain network?

	1 (Not Critical)	2	3	4	5 (Very Critical)
Improving water quality	○	○	○	○	○
Reducing pipe leakage	○	○	○	○	○
Reducing the number of annual watermain breaks	○	○	○	○	○
Increasing fire flows	○	○	○	○	○
Pipe structural integrity	○	○	○	○	○

8. LM (Large Municipality) Water Distribution System

37. What is the estimated total length of watermains in your municipality?

	< 300km	300-500km	500-800km	>800km
Total Length	○	○	○	○

38. What is the average age of watermains in your municipality?

	<30 Years	30-50 Years	50-70 Years	>70 Years
Average age of pipes	○	○	○	○

39. What percentage of the following pipe diameters makes up the total watermains' network in your municipality?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	○	○	○	○	○	○	○	○	○	○
300 - 600mm	○	○	○	○	○	○	○	○	○	○
600 - 900mm	○	○	○	○	○	○	○	○	○	○
> 900mm	○	○	○	○	○	○	○	○	○	○

40. What length (in total) of watermains were rehabilitated or replaced using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	○	○	○	○	○	○
Trenchless	○	○	○	○	○	○

Other (please specify method and length)

41. Please rank the methods (1 being the primary method) that you see being used for watermains' renovation and construction in your utility/municipality (check N/A if not used at all).

Rank	Method	N/A
☐	Open cut	☐ N/A
☐	Directional drilling	☐ N/A
☐	Cured in Place Pipe (CIPP)	☐ N/A
☐	Micro-tunneling/Tunneling	☐ N/A
☐	Sliplining	☐ N/A
☐	Cement mortar lining	☐ N/A
☐	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
☐	Other methods	☐ N/A

42. If "Other Methods" was selected in the above question, what other methods were used for watermains renovation and construction?

43. Rate the benefit of the following trenchless construction methods for watermain renovation/construction in your network.

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	○	○	○	○	○
Micro-tunneling/Tunneling	○	○	○	○	○
Sliplining	○	○	○	○	○
Cured in Place Pipe (CIPP)	○	○	○	○	○
Cement mortar lining	○	○	○	○	○
Spray-on or Spray-in Place Pipe (SIPP) lining	○	○	○	○	○

44. What are the critical issues in your watermain network?

	1 (Not Critical)	2	3	4	5 (Very Critical)
Improving water quality	○	○	○	○	○
Reducing pipe leakage	○	○	○	○	○
Reducing the number of annual watermain breaks	○	○	○	○	○
Increasing fire flows	○	○	○	○	○
Pipe structural integrity	○	○	○	○	○

9. SM (Small Municipality) Wastewater Collection System

45. What is the average age of wastewater pipes in your municipality?

	<30 Years	30-50 Years	50-70 Years	>70 Years
Average age of Pipes	○	○	○	○

46. What is the estimated total length of wastewater network in your municipality?

	< 300km	300-500km	500-800km	>800km
Total Length	○	○	○	○

47. What percentage of the following pipe diameters makes up the total wastewater pipe network in your municipality?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	○	○	○	○	○	○	○	○	○	○
300 - 600mm	○	○	○	○	○	○	○	○	○	○
600 - 900mm	○	○	○	○	○	○	○	○	○	○
> 900mm	○	○	○	○	○	○	○	○	○	○

48. What length of wastewater pipes were renovated or replaced using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	○	○	○	○	○	○
Trenchless	○	○	○	○	○	○

Other (please specify method and length)

49. Please rank the methods (1 being the primary method) that you see being used for wastewater network construction/renovation in your network (check N/A if not used at all)

Rank	Method	
☐	Open cut	☐ N/A
☐	Directional drilling	☐ N/A
☐	Cured in Place Pipe (CIPP)	☐ N/A
☐	Micro-tunneling/Tunneling	☐ N/A
☐	Sliplining	☐ N/A
☐	Cement mortar lining	☐ N/A
☐	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
☐	Other methods	☐ N/A

50. If "Other Methods" was selected in the above question, what other methods were used for wastewater network construction/renovation?

51. Rate the benefit of the following trenchless construction methods for wastewater pipes' renovation/construction in your network (1 Not Beneficial, 5 Very Beneficial).

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	○	○	○	○	○
Tunnelling	○	○	○	○	○
Slplining	○	○	○	○	○
Cured in Place Pipe (CIPP)	○	○	○	○	○
Grout in Place Pipe (GIPP)	○	○	○	○	○
Other	○	○	○	○	○

(please specify)

52. What are the critical issues in your wastewater collection system? (1 Not Critical, 5 Very Critical)

	1 (Not Critical)	2	3	4	5 (Very Critical)
Infiltration	◯	◯	◯	◯	◯
Inflows	◯	◯	◯	◯	◯
Encrustration	◯	◯	◯	◯	◯
Surcharging	◯	◯	◯	◯	◯
Pipe collapse	◯	◯	◯	◯	◯
Flow capacity	◯	◯	◯	◯	◯
Roots	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

10. MM (Medium Municipality) Wastewater Collection System

53. What is the average age of wastewater pipes in your municipality?

	<30 Years	30-50 Years	50-70 Years	>70 Years
Average age of Pipes	◯	◯	◯	◯

54. What is the estimated total length of wastewater network in your municipality?

	< 300km	300-500km	500-800km	>800km
Total Length	◯	◯	◯	◯

55. What percentage of the following pipe diameters makes up the total wastewater pipe network in your municipality?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
300 - 600mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
600 - 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
> 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

56. What length of wastewater pipes were renovated or replaced using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	◯	◯	◯	◯	◯	◯
Trenchless	◯	◯	◯	◯	◯	◯

Other (please specify method and length)

57. Please rank the methods (1 being the primary method) that you see being used for wastewater network construction/renovation in your network (check N/A if not used at all)

Rank	Method	N/A
☐	Open cut	☐ N/A
☐	Directional drilling	☐ N/A
☐	Cured in Place Pipe (CIPP)	☐ N/A
☐	Micro-tunneling/Tunneling	☐ N/A
☐	Sliplining	☐ N/A
☐	Cement mortar lining	☐ N/A
☐	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
☐	Other methods	☐ N/A

58. If "Other Methods" was selected in the above question, what other methods were used for wastewater network construction/renovation?

59. Rate the benefit of the following trenchless construction methods for wastewater pipes' renovation/construction in your network (1 Not Beneficial, 5 Very Beneficial).

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	○	○	○	○	○
Tunnelling	○	○	○	○	○
Sliplining	○	○	○	○	○
Cured in Place Pipe (CIPP)	○	○	○	○	○
Grout in Place Pipe (GIPP)	○	○	○	○	○
Other	○	○	○	○	○

(please specify)

60. What are the critical issues in your wastewater collection system? (1 Not Critical, 5 Very Critical)

	1 (Not Critical)	2	3	4	5 (Very Critical)
Infiltration	◯	◯	◯	◯	◯
Inflows	◯	◯	◯	◯	◯
Encrustration	◯	◯	◯	◯	◯
Surcharging	◯	◯	◯	◯	◯
Pipe collapse	◯	◯	◯	◯	◯
Flow capacity	◯	◯	◯	◯	◯
Roots	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

11. LM (Large Municipality) Wastewater Collection System

61. What is the average age of wastewater pipes in your municipality?

	<30 Years	30-50 Years	50-70 Years	>70 Years
Average age of Pipes	◯	◯	◯	◯

62. What is the estimated total length of wastewater network in your municipality?

	< 300km	300-500km	500-800km	>800km
Total Length	◯	◯	◯	◯

63. What percentage of the following pipe diameters makes up the total wastewater pipe network in your municipality?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
300 - 600mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
600 - 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
> 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

64. What length of wastewater pipes were renovated or replaced using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	◯	◯	◯	◯	◯	◯
Trenchless	◯	◯	◯	◯	◯	◯

Other (please specify method and length)

65. Please rank the methods (1 being the primary method) that you see being used for wastewater network construction/renovation in your network (check N/A if not used at all)

Rank	Method	N/A
▾	Open cut	☐ N/A
▾	Directional drilling	☐ N/A
▾	Cured in Place Pipe (CIPP)	☐ N/A
▾	Micro-tunneling/Tunneling	☐ N/A
▾	Sliplining	☐ N/A
▾	Cement mortar lining	☐ N/A
▾	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
▾	Other methods	☐ N/A

66. If "Other Methods" was selected in the above question, what other methods were used for wastewater network construction/renovation?

67. Rate the benefit of the following trenchless construction methods for wastewater pipes' renovation/construction in your network (1 Not Beneficial, 5 Very Beneficial).

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	○	○	○	○	○
Tunnelling	○	○	○	○	○
Sliplining	○	○	○	○	○
Cured in Place Pipe (CIPP)	○	○	○	○	○
Grout in Place Pipe (GIPP)	○	○	○	○	○
Other	○	○	○	○	○

(please specify)

68. What are the critical issues in your wastewater collection system? (1 Not Critical, 5 Very Critical)

	1 (Not Critical)	2	3	4	5 (Very Critical)
Infiltration	◯	◯	◯	◯	◯
Inflows	◯	◯	◯	◯	◯
Encrustration	◯	◯	◯	◯	◯
Surcharging	◯	◯	◯	◯	◯
Pipe collapse	◯	◯	◯	◯	◯
Flow capacity	◯	◯	◯	◯	◯
Roots	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

12. SM (Small Municipality) Storm Water Collection System

69. What is the estimated total length of storm water network in your municipality/utility?

	< 300km	300-500km	500-800km	>800km
Total Length	○	○	○	○

70. What percentage of the following pipe diameters makes up the total stormwater pipe network in your municipality/utility?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	○	○	○	○	○	○	○	○	○	○
300 - 600mm	○	○	○	○	○	○	○	○	○	○
600 - 900mm	○	○	○	○	○	○	○	○	○	○
> 900mm	○	○	○	○	○	○	○	○	○	○

71. What length of stormwater pipes were replaced/renovated in the past year using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	○	○	○	○	○	○
Trenchless	○	○	○	○	○	○

Other (please specify method and length)

72. Please rank the methods (1 being the primary method) that you see being used for stormwater network construction/renovation in your network (check N/A if not used at all)

▾	Open cut	☐ N/A
▾	Directional drilling	☐ N/A
▾	Cured in Place Pipe (CIPP)	☐ N/A
▾	Micro-tunneling/Tunneling	☐ N/A
▾	Sliplining	☐ N/A
▾	Cement mortar lining	☐ N/A
▾	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
▾	Other methods	☐ N/A

73. If "Other Methods" was selected in the above question, what other methods were used for wastewater network construction/renovation?

74. Rate the benefit of the following trenchless construction methods for wastewater pipes' renovation/construction in your network (1 Not Beneficial, 5 Very Beneficial).

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	◯	◯	◯	◯	◯
Tunnelling	◯	◯	◯	◯	◯
Sliplining	◯	◯	◯	◯	◯
Cured in Place Pipe (CIPP)	◯	◯	◯	◯	◯
Grout in Place Pipe (GIPP)	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

75. What are the critical issues in your stormwater collection system?

	1 (Not Critical)	2	3	4	5 (Very Critical)
Infiltration	◯	◯	◯	◯	◯
Inflows	◯	◯	◯	◯	◯
Encrustration	◯	◯	◯	◯	◯
Surcharging	◯	◯	◯	◯	◯
Pipe collapse	◯	◯	◯	◯	◯
Flow capacity	◯	◯	◯	◯	◯
Roots	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

CATT's Second Annual Municipal Buried Infrastructure Survey - Fiscal Year

13. MM (Medium Municipality) Storm Water Collection System

76. What is the estimated total length of storm water network in your municipality/utility?

	< 300km	300-500km	500-800km	>800km
Total Length	◯	◯	◯	◯

77. What percentage of the following pipe diameters makes up the total stormwater pipe network in your municipality/utility?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
300 - 600mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
600 - 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
> 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

78. What length of stormwater pipes were replaced/renovated in the past year using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	◯	◯	◯	◯	◯	◯
Trenchless	◯	◯	◯	◯	◯	◯

Other (please specify method and length)

79. Please rank the methods (1 being the primary method) that you see being used for stormwater network construction/renovation in your network (check N/A if not used at all)

▾	Open cut	☐ N/A
▾	Directional drilling	☐ N/A
▾	Cured In Place Pipe (CIPP)	☐ N/A
▾	Micro-tunneling/Tunneling	☐ N/A
▾	Sliplining	☐ N/A
▾	Cement mortar lining	☐ N/A
▾	Spray-on or Spray In Place Pipe (SIPP) lining	☐ N/A
▾	Other methods	☐ N/A

Page 29

80. If "Other Methods" was selected in the above question, what other methods were used for wastewater network construction/renovation?

81. Rate the benefit of the following trenchless construction methods for wastewater pipes' renovation/construction in your network (1 Not Beneficial, 5 Very Beneficial).

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	◯	◯	◯	◯	◯
Tunnelling	◯	◯	◯	◯	◯
Sliplining	◯	◯	◯	◯	◯
Cured in Place Pipe (CIPP)	◯	◯	◯	◯	◯
Grout in Place Pipe (GIPP)	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

82. What are the critical issues in your stormwater collection system?

	1 (Not Critical)	2	3	4	5 (Very Critical)
Infiltration	◯	◯	◯	◯	◯
Inflows	◯	◯	◯	◯	◯
Encrustration	◯	◯	◯	◯	◯
Surcharging	◯	◯	◯	◯	◯
Pipe collapse	◯	◯	◯	◯	◯
Flow capacity	◯	◯	◯	◯	◯
Roots	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

14. LM (Large Municipality) Storm Water Collection System

83. What is the estimated total length of storm water network in your municipality/utility?

	< 300km	300-500km	500-800km	>800km
Total Length	◯	◯	◯	◯

84. What percentage of the following pipe diameters makes up the total stormwater pipe network in your municipality/utility?

	0 - 10%	10 - 20%	20 - 30%	30 - 40%	40 - 50%	50 - 60%	60 - 70%	70 - 80%	80 - 90%	90 - 100%
< 300mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
300 - 600mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
600 - 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
> 900mm	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

85. What length of stormwater pipes were replaced/renovated in the past year using the following methods?

	< 0.5km	0.5 to 1.0km	1.0 to 2.0km	2.0 to 3.0km	3.0 to 4.0km	> 4.0km
Open Cut	◯	◯	◯	◯	◯	◯
Trenchless	◯	◯	◯	◯	◯	◯

Other (please specify method and length)

86. Please rank the methods (1 being the primary method) that you see being used for stormwater network construction/renovation in your network (check N/A if not used at all)

Rank	Method	N/A
▾	Open cut	☐ N/A
▾	Directional drilling	☐ N/A
▾	Cured in Place Pipe (CIPP)	☐ N/A
▾	Micro-tunneling/Tunneling	☐ N/A
▾	Sliplining	☐ N/A
▾	Cement mortar lining	☐ N/A
▾	Spray-on or Spray in Place Pipe (SIPP) lining	☐ N/A
▾	Other methods	☐ N/A

87. If "Other Methods" was selected in the above question, what other methods were used for wastewater network construction/renovation?

88. Rate the benefit of the following trenchless construction methods for wastewater pipes' renovation/construction in your network (1 Not Beneficial, 5 Very Beneficial).

	1 (Not Beneficial)	2	3	4	5 (Very Beneficial)
Directional drilling	◯	◯	◯	◯	◯
Tunnelling	◯	◯	◯	◯	◯
Sliplining	◯	◯	◯	◯	◯
Cured in Place Pipe (CIPP)	◯	◯	◯	◯	◯
Grout in Place Pipe (GIPP)	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

89. What are the critical issues in your stormwater collection system?

	1 (Not Critical)	2	3	4	5 (Very Critical)
Infiltration	◯	◯	◯	◯	◯
Inflows	◯	◯	◯	◯	◯
Encrustration	◯	◯	◯	◯	◯
Surcharging	◯	◯	◯	◯	◯
Pipe collapse	◯	◯	◯	◯	◯
Flow capacity	◯	◯	◯	◯	◯
Roots	◯	◯	◯	◯	◯
Other	◯	◯	◯	◯	◯

(please specify)

15. SM (Small Municipality) General Perception

90. Rank the barriers to the use of trenchless renovation and construction methods.

- Cost
- Lack of sufficient knowledge/training
- Consultants' lack of knowledge
- Contractors' availability

91. Are there any other barriers for adopting trenchless technologies?

92. How important is the offering of Continuing Education Units (CEU's) for staff training/education?

- Very Important
- Important
- Not Important

93. How much budget is allocated for training/education of water/wastewater staff?

- < $5,000
- $5,000-$10,000
- $10,000-$20,000

Other (please specify)

94. Rate the effectiveness of trenchless technologies from the following perspectives:

	1 (Not Effective)	2	3	4	5 (Very Effective)
Cost effectiveness	○	○	○	○	○
Depth of pipeline	○	○	○	○	○
Reducing urban congestion	○	○	○	○	○
Environmental impact	○	○	○	○	○

95. Do you expect consultants to help with policy and decision-making with respect to the following:

- [ ] Increased water/sewer rates
- [ ] Access to government grants
- [ ] Government regulations
- [ ] Public private partnerships
- [ ] Access to long-term financing

96. Overall, how much are you satisfied with contractors' performance?

	1 (Not Satisfied)	2	3 (Somewhat Satisfied)	4	5 (Very Satisfied)
Open cut	○	○	○	○	○
Trenchless	○	○	○	○	○
Project management	○	○	○	○	○
Innovative design/solutions	○	○	○	○	○

Comments

97. Overall, how much are you satisfied with the consultants' performance?

	1 (Not Satisfied)	2	3 (Somewhat Satisfied)	4	5 (Very Satisfied)
Open cut	○	○	○	○	○
Trenchless	○	○	○	○	○
Project management	○	○	○	○	○
Innovative design/solutions	○	○	○	○	○

Comments

16. MM (Medium Municipality) General Perception

98. Rank the barriers to the use of trenchless renovation and construction methods.

- Cost
- Lack of sufficient knowledge/training
- Consultants' lack of knowledge
- Contractors' availability

99. Are there any other barriers for adopting trenchless technologies?

100. How important is the offering of Continuing Education Units (CEU's) for staff training/education?

- Very Important
- Important
- Not Important

101. How much budget is allocated for training/education of water/wastewater staff?

- < $5,000
- $5,000-$10,000
- $10,000-$20,000

Other (please specify)

102. Rate the effectiveness of trenchless technologies from the following perspectives:

	1 (Not Effective)	2	3	4	5 (Very Effective)
Cost effectiveness	○	○	○	○	○
Depth of pipeline	○	○	○	○	○
Reducing urban congestion	○	○	○	○	○
Environmental impact	○	○	○	○	○

103. Do you expect consultants to help with policy and decision-making with respect to the following:

- [ ] Increased water/sewer rates
- [ ] Access to government grants
- [ ] Government regulations
- [ ] Public private partnerships
- [ ] Access to long-term financing

104. Overall, how much are you satisfied with contractors' performance?

	1 (Not Satisfied)	2	3 (Somewhat Satisfied)	4	5 (Very Satisfied)
Open cut	○	○	○	○	○
Trenchless	○	○	○	○	○
Project management	○	○	○	○	○
Innovative design/solutions	○	○	○	○	○

Comments

105. Overall, how much are you satisfied with the consultants' performance?

	1 (Not Satisfied)	2	3 (Somewhat Satisfied)	4	5 (Very Satisfied)
Open cut	○	○	○	○	○
Trenchless	○	○	○	○	○
Project management	○	○	○	○	○
Innovative design/solutions	○	○	○	○	○

Comments

17. LM (Large Municipality) General Perception

106. Rank the barriers to the use of trenchless renovation and construction methods.

- Cost
- Lack of sufficient knowledge/training
- Consultants' lack of knowledge
- Contractors' availability

107. Are there any other barriers for adopting trenchless technologies?

108. How important is the offering of Continuing Education Units (CEU's) for staff training/education?

- Very important
- Important
- Not important

109. How much budget is allocated for training/education of water/wastewater staff?

- < $5,000
- $5,000-$10,000
- $10,000-$20,000

Other (please specify)

110. Rate the effectiveness of trenchless technologies from the following perspectives:

	1 (Not Effective)	2	3	4	5 (Very Effective)
Cost effectiveness	○	○	○	○	○
Depth of pipeline	○	○	○	○	○
Reducing urban congestion	○	○	○	○	○
Environmental impact	○	○	○	○	○

111. Do you expect consultants to help with policy and decision-making with respect to the following:

- [ ] Increased water/sewer rates
- [ ] Access to government grants
- [ ] Government regulations
- [ ] Public private partnerships
- [ ] Access to long-term financing

112. Overall, how much are you satisfied with contractors' performance?

	1 (Not Satisfied)	2	3 (Somewhat Satisfied)	4	5 (Very Satisfied)
Open cut	○	○	○	○	○
Trenchless	○	○	○	○	○
Project management	○	○	○	○	○
Innovative design/solutions	○	○	○	○	○

Comments

113. Overall, how much are you satisfied with the consultants' performance?

	1 (Not Satisfied)	2	3 (Somewhat Satisfied)	4	5 (Very Satisfied)
Open cut	○	○	○	○	○
Trenchless	○	○	○	○	○
Project management	○	○	○	○	○
Innovative design/solutions	○	○	○	○	○

Comments

18. Thank you for taking the time to fill this survey.

114. Please fill out the information and your name will be entered into the draw for smartphones and/or tablets.

Name:	
Company:	
Address 1:	
Address 2:	
City/Town:	
State/Province:	
ZIP/Postal Code:	
Country:	
Email Address:	
Phone Number:	

APPENDIX B: Sample details of excel sheet calculations

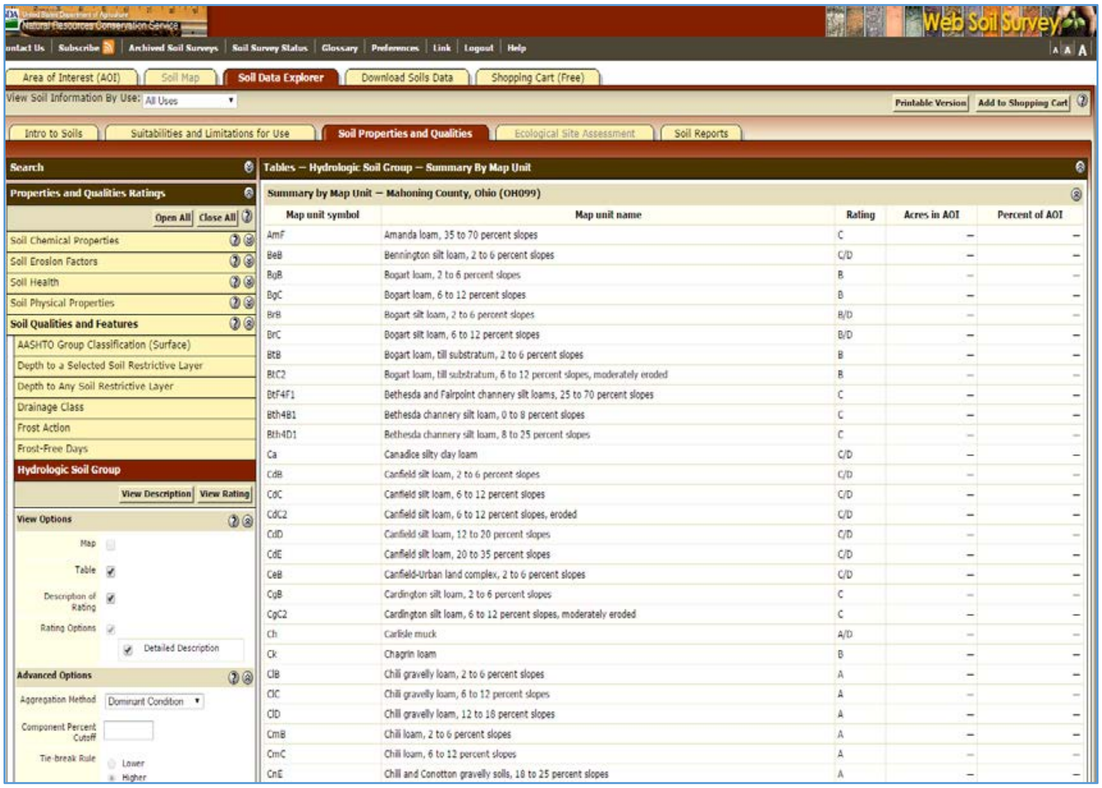
FID	Pipe length(m)	Pipe Size (mm)	Pipe Grade (%)	Age (years)		Sewer System		Operational Performance Values		Soil Classifications		Age Emphasis	Soil Type Emphasis	Equally Weighted	Empirical Value Emphasis
0	131.6736	457.2	3.12	110	8	Group 1	8	8	10	D	4	7.40	5.80	7.50	8.20
1	17.6784	609.6	3.33	112	8	Group 2	10	8.4	8	A	10	8.60	9.40	9.00	8.60
2	0	0	0	112	8		10	7.78	10	A	10	8.80	9.60	9.50	9.60
3	67.056	381	0.89	117	9	Group 1	8	7	10	D	4	8.00	6.00	7.75	8.40
4	0	0	0	112	8		10	7.4	10	A	10	8.80	9.60	9.50	9.60
5	0	0	0	112	8		10	0	10	D	4	7.60	6.00	8.00	8.40
6	0	0	0	117	9		10	0	10	A	10	9.40	9.80	9.75	9.80
7	0	0	0	127	10		10	0	10	A	10	10.00	10.00	10.00	10.00
8	124.968	304.8	4.17	117	9	Group 1	8	9	8	D	4	7.80	5.80	7.25	7.40
9	0	0	0	117	9		10	9.4	8	A	10	9.20	9.60	9.25	8.80
10	86.2584	381	1.22	117	9	Group 1	8	8	10	C	6	8.40	7.20	8.25	8.80
11	14.6304	203.2	0.5	117	9	Group 1	8	7.66	10	A	10	9.20	9.60	9.25	9.60
12	0	381	0	121	10	Group 1	8	7.20	10	C	6	9.00	7.40	8.50	9.00
13	95.4024	457.2	2.92	95	6	Group 1	8	8	10	A	10	7.40	9.00	8.50	9.00
14	95.4024	0	0.5	117	9		10	7.55	10	D	4	8.20	6.20	8.25	8.60
15	0	0	0	117	9		10	0	10	A	10	9.40	9.80	9.75	9.80
16	89.916	381	3.26	92	6	Group 1	8	8	10	A	10	7.40	9.00	8.50	9.00
17	76.8096	381	3.1	117	9	Group 1	8	7.56	10	D	4	8.00	6.00	7.75	8.40
18	100.8888	381	4.8	117	9	Group 1	8	8.49	8	C	6	8.20	7.00	7.75	7.80
19	0	381	0.2	127	10	Group 1	8	9.64	8	A	10	9.60	9.60	9.00	8.80
20	117.0432	381	0.73	121	10	Group 1	8	0.15	10	A	10	9.80	9.80	9.50	9.80
21	0	0	0	117	9		10	7.47	10	D	4	8.20	6.20	8.25	8.60

NOTE: "Zero" in the table resembles there is no such information was available.

APPENDIX C: Sample weightage calculations (Matrix weightage for different parameters)

Weightage Value for the Comparison Analysis				
	Pipe Age	Soil Type Emphasis	Equally Weighted	Empirical Weighted
Pipe Age	0.6	0.2	0.25	0.2
Empirical Value	0.1	0.1	0.25	0.5
Sewer Type	0.1	0.1	0.25	0.1
Soil Type	0.2	0.6	0.25	0.2
Sum	1	1	1	1
	OK	OK	OK	OK

APPENDIX D: Retrieved data from NRCS database

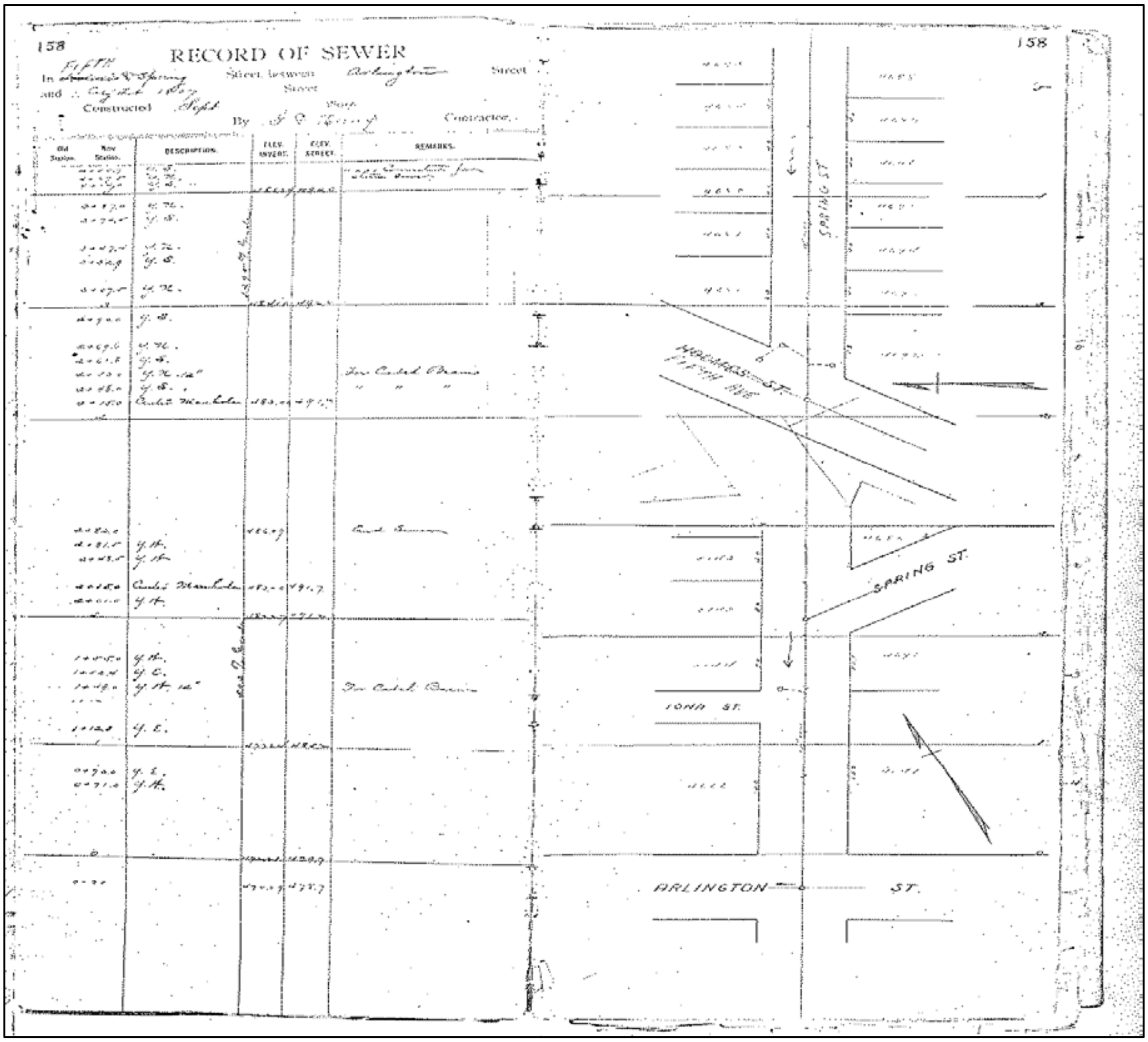


Tables — Hydrologic Soil Group — Summary By Map Unit

Summary by Map Unit — Mahoning County, Ohio (OH099)

Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
AmF	Amanda loam, 35 to 70 percent slopes	C	—	—
BeB	Bennington silt loam, 2 to 6 percent slopes	C/D	—	—
BgB	Bogart loam, 2 to 6 percent slopes	B	—	—
BgC	Bogart loam, 6 to 12 percent slopes	B	—	—
BrB	Bogart silt loam, 2 to 6 percent slopes	B/D	—	—
BrC	Bogart silt loam, 6 to 12 percent slopes	B/D	—	—
BtB	Bogart loam, till substratum, 2 to 6 percent slopes	B	—	—
BtC2	Bogart loam, till substratum, 6 to 12 percent slopes, moderately eroded	B	—	—
BtF4F1	Bethesda and Fairpoint channery silt loams, 25 to 70 percent slopes	C	—	—
Bth4B1	Bethesda channery silt loam, 0 to 8 percent slopes	C	—	—
Bth4D1	Bethesda channery silt loam, 8 to 25 percent slopes	C	—	—
Ca	Canadice silty clay loam	C/D	—	—
CdB	Canfield silt loam, 2 to 6 percent slopes	C/D	—	—
CdC	Canfield silt loam, 6 to 12 percent slopes	C/D	—	—
CdC2	Canfield silt loam, 6 to 12 percent slopes, eroded	C/D	—	—
CdD	Canfield silt loam, 12 to 20 percent slopes	C/D	—	—
CdE	Canfield silt loam, 20 to 35 percent slopes	C/D	—	—
CeB	Canfield-Urban land complex, 2 to 6 percent slopes	C/D	—	—
CgB	Cardington silt loam, 2 to 6 percent slopes	C	—	—
CgC2	Cardington silt loam, 6 to 12 percent slopes, moderately eroded	C	—	—
Ch	Carlisle muck	A/D	—	—
Ck	Chagrin loam	B	—	—
ClB	Chili gravelly loam, 2 to 6 percent slopes	A	—	—
ClC	Chili gravelly loam, 6 to 12 percent slopes	A	—	—
ClD	Chili gravelly loam, 12 to 18 percent slopes	A	—	—
CmB	Chili loam, 2 to 6 percent slopes	A	—	—
CmC	Chili loam, 6 to 12 percent slopes	A	—	—
CnE	Chili and Conotton gravelly soils, 18 to 25 percent slopes	A	—	—

APPENDIX E: Sample file for age of pipelines



Youngstown
STATE UNIVERSITY

One University Plaza, Youngstown, Ohio 44555
Office of Research
330.941.2377
www.ysu.edu

August 4, 2017

Dr. Jai K. Jung, Principal Investigator
Mr. Janga B. Thapa, Co-investigator
Department of Civil & Environmental Engineering
UNIVERSITY

RE: HSRC PROTOCOL NUMBER: 007-2018
TITLE: Trenchless Survey Questionnaire Data Analysis for North American Municipalities

Dear Dr. Jung and Mr. Thapa:

The Institutional Review Board has reviewed the abovementioned protocol and determined that it is exempt from full committee review based on a DHHS Category 3 exemption.

Any changes in your research activity should be promptly reported to the Institutional Review Board and may not be initiated without IRB approval except where necessary to eliminate hazard to human subjects. Any unanticipated problems involving risks to subjects should also be promptly reported to the IRB.

The IRB would like to extend its best wishes to you in the conduct of this study.

Sincerely,

Mr. Michael A. Hripko
Associate Vice President for Research
Authorized Institutional Official

MAH:cc

c: Dr. AKM Anwarul Islam, Chair
Department of Civil & Environmental Engineering