Development of Unit Price Indices and Estimating Inflation for Potable Water and Wastewater Pipeline Capital Works Construction

by

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Author’s Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contribution

Sections 3 and 5 of Chapter 4 of this thesis have been incorporated in a published paper which was co-authored by myself, my supervisors Dr. Unger and Dr. Knight, Dr. Rehan an Associate Professor at the University of Engineering and Technology, Peshawar, Dr. Younis the Managing Director at the Centre for Advancement of Trenchless Technologies, and Mr. Budimir a PhD student. The methodology to calculate unit price indices was developed by Dr. Unger, Dr. Knight, Dr. Rehan, Dr. Younis and myself. The scaling relationships were developed by Dr. Unger and Dr. Rehan. The methodology to calculate unit price indices was documented by myself and Dr. Younis. The unit cost database developed to calculate unit price indices was developed by Dr. Unger, Dr. Knight, Dr. Rehan and Mr. Budimir and revised, updated and expanded by myself.

Abstract

The importance of sustainable financial management of water and wastewater pipeline infrastructure has grown in recent years due to the increasing backlog of maintenance, renewal and replacement of aging water and wastewater infrastructure. As the water and wastewater infrastructure age, the condition of the water and wastewater infrastructure will continue to deteriorate increasing the cost for renewal and replacement. In response to the aging and deteriorating potable water and wastewater infrastructure Public Sector Accounting Board PS3150 and Regulation 453/07 under the Ontario Safe Drinking Water Act were established. PS3150 requires local governments to report their tangible capital assets along with their depreciation on financial statements. One key component of this reporting is determining the need for and cost of the replacement of these assets. Ontario Regulation 453/07 requires public utilities to prepare and submit long term financial plans for water systems. One key principle of the financial plans is that the expenses of operating water systems should be paid by revenues generated from providing the water systems.

A crucial aspect of PS3150, Ontario regulation 453/07 and the financial management of water and wastewater infrastructure are accurate estimates of future capital works construction prices. Historically, construction indices are used to forecast construction prices. Engineering New Record (ENR) Construction Cost Index (CCI), Federal Highway Administration (FWHA) composite National Highway Construction Cost Index (NHCCI) and Consumer Price Index (CPI) have been used to estimate future construction prices of water and wastewater infrastructure in Canada. However, these indices do not accurately represent the circumstance of the water and wastewater infrastructure construction sector, which can lead to errors and inaccuracies in construction price forecasts. It is recommended sector specific construction indices be used to forecast construction prices. However, there are few construction indices available for the water and wastewater infrastructure sector and available indices are not based on actual construction data.

This thesis presents a methodology to accurately estimate future construction prices for water and wastewater pipeline capital works based on actual construction price data. The methodology contains three components: construction data processing, development of unit price indices for watermain and sanitary sewer construction, and estimation of inflation in watermain and sanitary sewer construction. The data processing component cleans and transforms actual construction price data from the City of Niagara Falls from 1981 to 2014 into a centralized, organized and auditable

construction price dataset. Based on the construction price dataset, unit price indices specific to the watermain and sanitary sewer construction sector were developed. Unit price indices were developed and calculated for watermain projects, pipes, valves, and hydrants, and sanitary sewer projects, pipes, and maintenance holes. Geometric Brownian Motion was used to estimate inflation in and forecast future construction prices for watermain and sanitary sewer capital works construction based on the developed unit price indices. A Microsoft Access relational database containing the data processing function, calculation of watermain and sanitary sewer unit price indices, and estimation of inflation was developed to improve the accuracy, efficiency and consistency of the methodology. Additionally, the methodology allows contractor markup in watermain and sanitary sewer construction and factors influencing watermain and sanitary sewer unit price indices to be examined.

The inflation of watermain reference project construction is 5.79% per annum from 1982-2014, while the inflation of sanitary sewer reference project capital works construction is 4.66% per annum from 1981-2014. The inflation rates of watermain pipe, valve and hydrant construction from 1982-2014 are 6.36%, 5.09%, and 2.81% per annum, respectively. The inflation rates of sanitary sewer pipe and maintenance hole construction from 1981-2014 are 7.41% and 5.25% per annum, respectively.

Inflation of watermain and sanitary sewer reference projects is above inflation of CPI, NRBCPI and LDCCT at 2.25%, 3.17% and 3.77% per annum, respectively, but below inflation of S&P/TSX composite index at 6.90% per annum. This indicates when forecasting future prices within a construction sector, the use of a proxy index will result in inaccurate estimates of future construction prices. In the water and wastewater pipeline construction sector the use of CPI, NRBCPI or LDCCT will result in significant underestimation of future construction prices. To obtain accurate estimates of future construction prices it is important to use sector specific indices which the developed unit price indices represent for the water and wastewater pipeline construction sector.

In this thesis contractor markup is defined as a financial premium in excess of market inflation in the form of a per annum interest rate surcharge. Contractor markup includes risk premiums, overhead and profit. The contractor markups for watermain and sanitary sewer projects are 3.54% and 2.41%, respectively.

As the number of tender bids submitted for a project increase, the unit price of reference projects generally decreases. This is caused by an increase in the competition among contractors resulting in a decrease in the unit prices of the reference projects as bidders attempt to win the project.

The Infrastructure Stimulus Fund increased the total number of projects and the total value of projects in 2009 and 2010 but did not significantly alter the watermain and sanitary sewer unit price indices.

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Finally, I would like to thank my fiancé, friends and family who have encouraged and supported me throughout my academic studies.

Dedication

To my Fiancée, Mother, Father, and Brother for their support and encouragement every step of the way.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ARIMA .... Auto-Regressive Integrated Moving Average
BCI .... Building Cost Index
BIS .... UK Department of Business, Innovation and Skills
BLS .... Bureau of Labor Statistics
BPI .... Bid Price Index
BR .... Bureau of Reclamation
CCI .... Construction Cost Index
CCT .... Construction Cost Trends
CPI .... Consumer Price Index
DOT .... Department of Transportation
ENR .... Engineering News Record
EPA .... Environmental Protection Agency
FHWA .... Federal Highway Administration
GARCH .... Generalized Autoregressive Conditional Heteroskedastic
GBM .... Geometric Brownian Motion
HCCI .... Highway Construction Cost Index
ISF .... Infrastructure Stimulus Fund
K-S test .... Kolmogorov-Smirnov test
NHCCI .... National Highway Construction Cost Index
NRBCPI .... Non-Residential Building Construction Price Index
PPI .... Producer Price Index
PSAB .... Public Sector Accounting Board
SARIMA .... Seasonal Auto-Regressive Integrated Moving Average
S&P/TSX .... S&P Toronto Stock Exchange
TPI .... Tender Price Index
VAR .... Multivariate Autoregressive Model
UK .... United Kingdom
US .... United States

Chapter 1
Introduction

1.1 Background and Motivation

Potable water and wastewater systems are an integral part of society. Components of potable water and wastewater systems can include pipelines, aqueducts, reservoirs, tanks, wells, pumping stations, hydrants, valves, treatment systems and treatment plants (Amant, 2007; Canada Infrastructure, 2016; CICA, 2007). The successful management of potable water and wastewater infrastructure has led to an improvement in the quality of life over the past decades (Karamouz, Moridi, & Nazif, 2010). There are many elements of successful management of potable water and wastewater infrastructure including financial management. Financial management is probably the most important element of potable water and wastewater infrastructure management (Grigg, 1986).

In Canada and the United States (US) there is a growing backlog of deferred maintenance, renewal and replacement of aging potable water and wastewater infrastructure (AWWA, 2011; Canada Infrastructure, 2016; CICA, 2007). The Canadian Infrastructure Report Card (Canada Infrastructure, 2016) reports that 29% of potable water infrastructure and 35% of wastewater infrastructure is in very poor, poor or fair condition. As the existing potable water and wastewater systems continue to age, potentially beyond their service life, the condition of the system components will continue to deteriorate. This increases the backlog, and cost, for renewal and replacement of water and wastewater systems (Canada Infrastructure, 2016; CICA, 2007). For example, the American Water Works Association (2011) estimates the cost to replace all watermain pipes in the US at over $1 trillion over a 25 year period. Furthermore, water and wastewater infrastructure may require updates to meet population growth, climate change and environmental regulations (Canada Infrastructure, 2016). This backlog and increasing requirements is causing financial stress on local governments which puts the sustainability and affordability of water services at risk (CICA, 2007; MOE, 2007). Therefore, a long term goal of potable water and wastewater systems is achieving financial sustainability (MOE, 2007).

For sustainable financial management of potable water and wastewater infrastructure local governments must consider the existing infrastructure, the operating cost of the infrastructure and the need for and cost of replacing the infrastructure (Amant, 2007; CICA, 2007). For this reason, starting January 1, 2009, the Public Sector Accounting Board (PSAB) statement PS3150 requires local governments to present information about their tangible capital assets with their depreciation over their useful life on summary financial statements. This ensures the information is complete, reliable and unbiased (CICA, 2007; Government of Prince Edward Island, n.d.). In addition to PS3150, the Province of Ontario under the Safe Drinking Water Act created Regulation 453/07 to ensure the financial sustainability of potable water systems. Regulation 453/07 requires public utilities to prepare and submit long term financial plans for water systems. The development of financial plans is guided by nine principles. One key principle is revenues collected from providing water services should be sufficient, and used, to pay for the expenses of providing water services. Although Regulation 453/07 only has requirements for potable water systems, it is recommended the same principles be applied to wastewater systems. This joint planning of potable water and wastewater systems is especially applicable to approximately half of Ontario municipalities with integrated systems (MOE, 2007).

A crucial aspect in the development of financial plans and understanding future financial requirements is accurate predictions of future construction, operation and maintenance costs. Accurate construction cost estimates are important for assisting with budgeting for future years (Akintoye & Skitmore, 1994; Ng, Cheung, Skitmore, & Wong, 2004). Future budgets are especially important during the early program and project planning stages at the budget determines the number and size of renewal and replacement projects that can be undertaken in the future. Possible consequences of underestimating construction costs include reduced project scope, cancellation of the project or requiring additional funding (Shrestha, Jeong, & Gransberg, 2016). For example, the Dallas/Fort Worth metropolitan area experienced significant increases in the construction costs of potable water and wastewater pipelines around 2007. This caused some municipalities to re-bid or cancel projects due to budgetary constraints (Paris & Hampson, 2007).

In the construction industry, accurate estimates of construction cost can be challenging, especially when prepared under conditions of high uncertainty (Hwang, 2011). Construction cost responds quickly to economic changes and are influenced by a variety of economic factors further complicating construction cost estimates (Hwang, 2011; Phillips, 1982). For example, in the United States the inflation of highway construction costs has been viewed as a function of the general inflation of producer prices (Phillips, 1982). However, assuming construction costs inflate at the same rate as general inflation can lead to poor estimates of future construction costs (Wilmot & Cheng, 2003). This is demonstrated in comparisons of the Federal Highway Administration (FHWA) Composite Bid Price Index (BPI) with Consumer Price Index (CPI) (Wilmot & Cheng, 2003) and Producer Price Index (PPI) (Phillips, 1982). Additionally, Philips (1982) stated “inflation has clearly hampered the ability of local, state and federal governments to preserve the U.S. roadway network" which may be caused by contractors passing costs onto clients when the costs exceed bid prices. Furthermore, Arditi, Akan and Gurdamar (1985) found inflation was one of the top factors causing cost overruns in Turkish public projects form 1970-1980.

Accurate construction cost forecasting improves the quality of information available to decision makers leading to more accurate construction cost estimates (Akintoye & Skitmore, 1994). Historically, the basis for forecasting future construction costs is a construction index which represents the cost or price of a set of construction pay items over time (Wilmot & Cheng, 2003). Construction indices have several uses in addition to forecasting construction costs. Construction indices are an important tool for analyzing the real output of the construction industry and companies, for relative performance and productivity measures, to assist in the development of government policies and programs, to adjust contracts for cost fluctuations and inflation, to estimate inflation of capital works construction and to determine the markup contractors add to projects (BIS, 2010; Mohammadian & Seymour, 1997; Wilmot & Cheng, 2003). Further, construction indices can also be used as indicators of market conditions, track relative price changes, update historical cost data and monitor relative inflation changes (Shrestha et al., 2016; Yu & Ive, 2008). A survey of public and private sectors in the construction industry in the United Kingdom (UK) (BIS, 2013) found that construction price and cost indices are commonly used for forecasting, pre-contract estimates, contract pricing, industry trends and market information. The survey also reported construction price and cost indices being used for informed decision making, comparison and benchmarking, estimating and setting costs, life cycle cost analysis, budgeting, feasibility studies, checking historical trends, converting between new and old prices, and deflating current prices. Additionally, in the United States, state department of transportations (DOTs) use highway construction cost indexes during the early stage of project planning for cost estimation, as a cost inflation factor for future projects, to establish trends in the construction market and indicate their purchasing power (Shrestha et al., 2016).

From the wide range of applications it can be seen that construction indices have a crucial role in the construction industry. However, Pieper (1991) noted that the complexity and heterogeneity in the construction industry causes the development of accurate construction indices to be very difficult. This highlights the need for each construction sub-sector to have a specific cost or price indices to measure price changes (Yu & Ive, 2008). This difficulty is further compounded by a lack of resources dedicated to developing construction indices (Pieper, 1991).

1.2 Research Objectives and Scope

The primary objective of this thesis is to assist in the sustainable financial management of potable water and wastewater systems by examining and increasing knowledge of the financial component of potable water and wastewater pipeline capital works construction. The specific objectives of this research are to use actual potable water and wastewater pipeline construction price data to:

- Create centralized, organized and auditable construction price data using a customized data processing function
- Develop construction unit price indices for potable water and wastewater pipeline projects and its components
- Estimate the inflation of the construction unit price indices for potable water and wastewater pipeline projects and its components and compare to inflation in other well-known indices
- Automate the three above processes in a database specific to the potable water and wastewater construction sector
- Forecast and compare future construction prices of potable water and wastewater pipeline using construction unit price indices for potable water and wastewater pipelines and other well-known indices
- Determine the markup contractors add to their tender bids in potable water and wastewater pipeline construction
- Investigate factors which influence water and wastewater pipeline tender bid prices

1.3 Terminology

The three main categories of construction indexes are input price indices, output price indices and seller price indices. Input price indices measure the changes in the price of inputs to the construction process such as materials and labour (OECD, 1997). This can also be thought of as the costs incurred by a contractor during the construction process (BIS, 2010). These prices do not generally include changes due to productivity, profit, contractor overhead, market conditions, changes in technology, competitiveness of contractors and markups and therefore do not reflect the changes in price a client pays (Mohammadian & Seymour, 1997; OECD, 1997; Pieper, 1991). Output price indices measure the changes of construction output or completed construction which reflects the prices paid by the purchaser or client to the contractor for the construction work (Mohammadian & Seymour, 1997; OECD, 1997). These generally include materials, labour, equipment, overheads, profits, productivity, and market conditions. Seller's price indices measure the changes of the total sale price the final owner pays for output of the construction process. This generally includes land, seller expenses, seller's profit, and taxes in addition to components of output price indices. Figure 1.1 displays the relationship between input price indices, output price indices, and seller price indices and is adapted from OECD (1997).

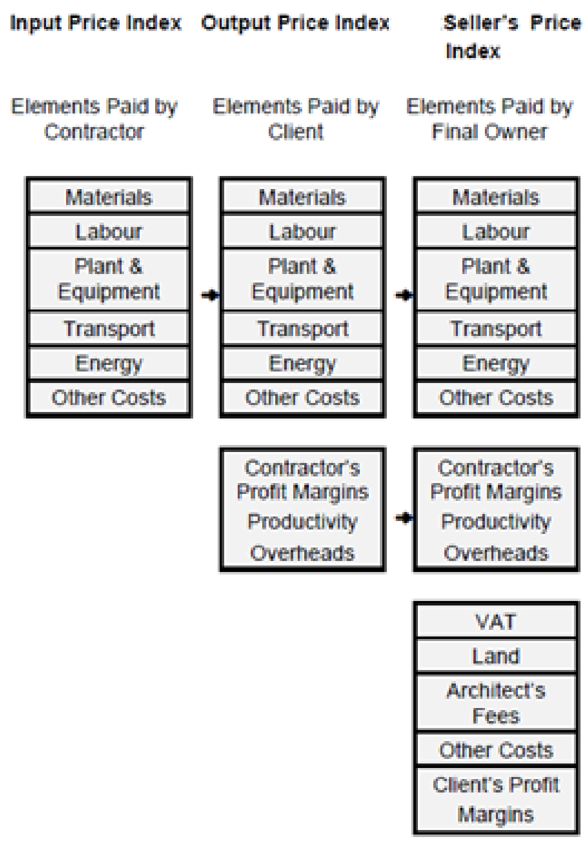

Figure 1.1 – Comparison of input price, output price and seller price indices (OECD, 1997).

At Statistics Canada, construction indices can be categorized as an input cost indices, output cost indices or implicit cost indices which correspond to input price indices, output price indices and seller price indices, respectively (Mohammadian & Seymour, 1997). The Department for Business Innovation and Skills in the United Kingdom categorizes construction indices as building or resource cost indices, tender prices indices or output price indices which correspond to input price indices, output price indices and seller price indices, respectively (BIS, 2010, 2013).

For this work, cost represents the cost to the contractor for inputs to the construction activity, price represents the price paid to the contractor by the client for the construction activity, and seller price represents the total price paid by the final purchaser or owner. Therefore input price indices, output price indices and seller’s price indices will be referred to as cost indices, price indices and seller’s price indices, respectively. Furthermore, indexes, indices and index numbers have the same meaning and are all plurals of index (Crowe, 1965). In this work, potable water pipelines are also referred to as water pipelines or watermains, while wastewater pipelines are also referred to as sanitary sewers.

1.4 Thesis Organization

This thesis is organized into seven chapters and two appendices. Chapter 2 provides background information related to construction indices, forecasting construction costs, estimating inflation in the construction sector, and contractor markup. This chapter also presents the theory of index numbers and research related to developing and constructing indices. In Chapter 3, a description and the source of the data used in this work is presented. Chapter 4 develops the research methodology which includes creating a data processing function, developing and constructing water and wastewater pipeline construction price indices, and estimating inflation to forecast construction costs. The integration and automation of the methodology in a database is also presented. Chapter 5 contains a detailed description of the results for the data processing function, unit price indices for water and wastewater pipeline construction, inflation in the water and wastewater pipeline construction sector, estimates of future water and wastewater construction costs, and contractor markup. Chapter 6 presents an analysis and discussion of the results. Chapter 7 summarizes the findings and conclusions of the research and offers recommendations for future work. Appendix A contains the calculated unit price indices for watermain reference project and standard components. Appendix B contains the calculated unit price indices for sanitary sewer reference project and standard components.

Chapter 2
Literature Review

2.1 Overview

The literature review in this chapter presents the current state of knowledge of contractor markup in the construction industry and forecasting of capital works construction costs and prices. The basis for determining contractor markup and forecasting construction costs is the estimation of inflation in construction costs and prices using a construction index. First, currently available construction indices are highlighted. Second, the most common formulae for the construction of an index are reviewed and the development of new construction indices observed in the literature is highlighted. Third, methods for forecasting future costs and estimating inflation from the relevant literature are presented. Fourth, the contractor markup in the construction industry as determined in previous studies is presented. Finally, the current state of knowledge presented in this chapter will be summarized and gaps in the literature identified.

2.2 Existing Construction Cost and Price Indices

As discussed in Section 1.3, construction indices can be categorized as cost indices, price indices and seller price indices. In a review of construction indices developed by member nations, the Organization for Economic Co-operation and Development (1997) found of the 65 construction indices from 24 nations that 35 were cost indices, 27 price indices and only 3 seller price indices. This section will present existing indices currently available in the construction industry. The development and construction of new construction indices is discussed in Section 2.3.

The most commonly used construction index is Engineering News Record (ENR) Construction Cost Index (CCI) which is considered to be an indicator of changes in the general construction industry (Ashuri & Lu, 2010; Joukar & Nahmens, 2016; Shahandashti & Ashuri, 2013; Sliter, 1974). ENR CCI began in 1921 and was designed to be "a national index of general construction costs in the United States" (Sliter, 1974). ENR CCI consists of 200 hours of common labour, 2500 pounds of structural steel, 1088 board feet of 2x4 lumber and 6 barrels of Portland cement. ENR Building Cost Index (BCI) was developed in the late 1930s and consists of the same components as ENR CCI except common labour is substituted for 66 hours of skilled labour. The ENR data has also been used to develop other construction indices (Sliter, 1974). For example, the Environmental Protection Agency (EPA) sewer construction cost index is based on ENR data and is an average of index for sewer lines and sewage treatment plant construction (Pieper, 1991). However construction indices which rely on ENR data may not be representative of the actual cost to the contractor as ENR price reports are based on wholesale prices (Sliter, 1974).

A commonly used construction index for the road construction sector is the Federal Highway Administration (FWHA) National Highway Construction Cost Index (NHCCI) in the United States. The FWHA NHCCI began in 1987 as the Federal Highway Administration (FWHA) Bid Price Index (BPI) for highway construction based on the unit prices of six categories in winning contracts (Shrestha et al., 2016). The FWHA NHCCI was later developed, based on 31 categories, to replace the BPI. The NHCCI can also be compared to the BPI for historical purposes. Despite the name, the NHCCI is a price index meaning it includes contractor profit and overhead (FHWA, 2014; Shrestha et al., 2016). The NHCCI represents the trends of highway construction from a national level but does not reflect local state conditions. To overcome this states may create their own Highway Construction Cost Index (HCCI). In a survey with 34 state representative responses, Shrestha et al. (2016) found that 21 states calculate their own HCCI.

The Bureau of Reclamation (BR) in the US publishes construction cost trend (CCT) indices for 35 types of water projects in the western US including dams, pumping plants, power plants, canals, distribution pipelines, and laterals and drains (Remer, Lin, Yu, & Hsin, 2008; USBR, 2016). The BR CCT was originally developed from actual field cost data. However due to the decline in number and magnitude of construction projects in recent years, the BR CCT is developed from producer price indexes from the US Department of Labour Bureau of Labor Statistics, Department of Agriculture Land, and Rental Prices and ENR cost data. When available, actual field is used to confirm the index (USBR, 2016).

In the United States the Census Bureau publishes the two indices in the new residential construction sector. The single family houses under construction represents a price index while the single family houses sold represents a seller price index (Remer et al., 2008; USCB, 2016). The Census Bureau published a composite construction cost index but this index has not been updated since 2003 (Remer et al., 2008). The Hand-Whitman Public Utility CCI contains construction cost indices for electric gas, water and telephone utility construction for six geographic regions in the United States. The Handy-Whitman Public Utility CCIs are developed from other sources such as ENR material cost data, labour cost statistics, and equipment costs from nationally recognized manufacturers. The Marshall and Swift BCI tracks the costs of 5 types of buildings in 100 US cities combined into regional, district and national indices. The building types are fire-proof steel, reinforced concrete, masonry, wood and pre-engineered steel frames. Both the Hand Whitman Public Utility CCI and Marshall and Swift BCI are comprised of material, labour and equipment costs (Remer et al., 2008).

Statistics Canada publishes a total of five construction indices. The cost indices include the Construction Union Wage Rate Index and Electric Utility Construction Price Index (EUCPI). The price indices include Apartment Building Construction Price Index (ABCPI) and Non-Residential Building Construction Price Index (NRBCPI). The NRBCPI is comprised of commercial, industrial and institutional buildings. The New Housing Price Index (NHPI) is a seller price index (OECD, 1997; Statistics Canada, 2016a). In the United Kingdom the Building Cost Information Service of the Royal Institution of Chartered Surveyors publishes cost and price indices (RICS, 2015). The cost indices are resource costs indices of non-housing building, house building, road construction, infrastructure, maintenance for non-housing building, maintenance for house building and all construction. The price indices are tender price indices of public sector non-house building, public sector house building, road construction and all construction (BIS, 2010; RICS, 2015). The cost and price indices were developed by the Department for Business, Enterprise and Regulatory Reform which was replaced by the Department for Business, Innovation and Skills (BIS) (BIS, 2010). The BIS published the cost and prices indices until the end of 2014 (RICS, 2015). Furthermore, Remer, Lin, Yu and Hsin (2008) compile a comprehensive list of cost factors, indices and location factors available internationally and in the United States. The 2008 paper is an update of an earlier 2003 paper, which itself is an update of an earlier 1998 paper.

After reviewing available existing construction indices in 1991, multiunit residential construction and most types of nonresidential buildings are the sectors lacking their own construction index (Pieper, 1991). Many of the existing construction indices are too general and do not accurately represent the circumstances for water and wastewater infrastructure (MOE, 2007). Of the available construction indices in the water and wastewater infrastructure sector, most are compiled for dams, pumping plants, treatment plants and large distribution or transmission pipelines. Furthermore, these indices are not derived from actual construction cost data. There is no known construction cost or price index for water or wastewater sewer pipelines capital works construction based on actual construction cost or price data.

2.2.1 Proxy Indices

If a sector specific index is not available a proxy index may be used. A proxy index is an index based on a different sector than the one it is used to deflate (Pieper, 1991). The selection of a proxy index should be based the particular application for which the index is needed (Mohammadian & Seymour, 1997). For example, cost indices should not be used to represent price movements for finished construction work (OECD, 1997). However, construction indices are most effective when used in the construction sector for which the index was developed (Mohammadian & Seymour, 1997). Therefore it is recommended that sector specific construction indices be used due to the complexity and heterogeneity of the construction industry. This may require the development of a sector specific construction index if one does not already exist and an appropriate proxy index is not available (Mohammadian & Seymour, 1997; Pieper, 1991; Yu & Ive, 2008).

ENR CCI is commonly used by public and private organizations as a proxy index for construction costs (Ashuri & Lu, 2010; Eskaf, 2012). In Canada, the FWHA composite BPI has been used to deflate costs in the water and wastewater sector (Amant, 2007). CPI has also been used to deflate costs in the water and wastewater sector in Canada (Government of Prince Edward Island, n.d.). In the United States costs indices have been used for deflating the prices of the building industry (Yu & Ive, 2008). In 1991, it was found that the Bureau of Economic Analysis in the United States relies heavily on the use of proxy indexes with about half of all new construction is deflated using proxy indexes (Pieper, 1991). A survey of state DOTs revealed the use of third party indexes to keep track of construction market changes, as an indicator of overall market conditions, for a side by side comparison with their own HCCI and to determine an inflation rate of construction projects. These third party indexes include NHCCI, Bureau of Labor Statistics (BLS) Consumer Price Index, ENR CCI, RS Means Cost Index, BLS PPI for Other Nonresidential Construction (BONS), ENR BCI, BLS PPI for Nonresidential maintenance and repair construction (BMNR) and neighbouring state HCCIs (Shrestha et al., 2016).

Sliter (1974) stated that “selecting an index demands that the user know the components that go into it and how closely they represent the situation.” The selection of an inappropriate index can lead to errors and inaccuracies (Mohammadian & Seymour, 1997). For example ENR CCI does not account for asphalt but includes timber meaning it is more relevant to building construction than highway construction (Shrestha et al., 2016). When comparing CPI with FHWA composite BPI, the FHWA composite BPI was found to behave more erratically and display different short and long term trends. Furthermore, a comparison of state highway composite BPI to FHWA composite BPI noted varying highway construction cost trends (Wilmot & Cheng, 2003). This demonstrates the use of a proxy index, even within the same construction sector the proxy index was developed, can lead to errors and inaccuracies. Many of the available construction cost or price indexes are too general and do not accurately represent the circumstances for water and wastewater infrastructure (MOE, 2007). Therefore the development of construction indices specific to water and wastewater infrastructure construction is recommended. This is supported by Mohammadian and Seymour (1997) and Yu and Ive (2008) who state there is an important need to develop appropriate indexes for different sectors of the construction industry.

2.3 Development and Calculation of Construction Indices

If a sector specific index is not available and available proxy indices are deemed unrepresentative of the situation or circumstances then it is necessary to develop and calculate a new construction cost index or construction price index. The following sub-sections will overview the formulae available to calculate index numbers, which form the basis of an index, and review the development and calculation of new construction indices from the literature.

2.3.1 Index Number Formulae

Index numbers "represent the general level of magnitude of the changes" in costs and prices (Crowe, 1965). Index numbers are used to measure the change in costs and prices of a set of related variables over time or to compare the costs and prices across geographical regions (BIS, 2010; Selvanathan & Rao, 1994). There are three main ways to construct index numbers: price levels, price relatives or price aggregates. Price levels are the price p of a commodity n at a time period t represented as p_n^t (Afriat & Milana, 2009; Balk, 2008). Price relatives compare the price in one period to another period to measure the percentage change or relative change of the price of a single commodity (Balk, 2008; Crowe, 1965; Mudgett, 1951; Persons, 1928). Price relatives are the ratio of price p of a commodity n in a time period t to the price of the same commodity in a base time period $t = 0$ represented as p_n^t/p_n^0 (Allen, 1975; Crowe, 1965). Price levels have reference to a single period, while price relatives have reference to two periods and is in principle the ratio of two price levels (Afriat & Milana, 2009). Price aggregates are the ratio of average price of a "basket of goods" or group of commodities in a time period t to the average price of the same "basket of goods" or group of commodities in a base time period $t = 0$ represented as $\sum p_n^t/\sum p_n^0$ (Crowe, 1965; Mudgett, 1951).

Price relatives and price aggregates are similar with price relatives representing one commodity and price aggregates representing a group of commodities. To derive index numbers as price relatives or price aggregates atomistic or functional approaches can be used (Balk, 2008; Selvanathan & Rao, 1994). The atomistic approach assumes no functional relationship between price and quantity data, while the functional approach assumes price and quantity are functionally related. Atomistic approach include both stochastic and test approaches (Selvanathan & Rao, 1994). The methods which use price levels are generally stochastic (Balk, 2008). The stochastic approach assumes the price change in a commodity is a function of the underlying rate of inflation, or common component, and other specific components which are random and non-random (Balk, 2008; Selvanathan & Rao, 1994). Therefore with the stochastic approach, the rate of inflation can be estimated by taking some form of the average of all price changes (Selvanathan & Rao, 1994). Selvanathan and Rao (1994) derived several index number formulae using both atomistic and functional approaches.

An index number formula is used to calculate an index number based on price relatives or price aggregates. A review of index numbers formulae reveals many different formulae to construct index numbers including but not limited to Laspeyres, Paasche, Fisher, Tornqvist, Marshall-Edgeworth, Walsh, Geary-Khamis, and Lowe indices (Balk, 2008; Białek, 2012; International Labour Office, 2004). The three best known and most used index formulae are Laspeyres, Paasche and Fisher (Forsyth & Fowler, 1981). Laspeyres and Paasche index formulas are the weighted average of price relatives or price aggregates using the base period and current period as weights, respectively. At a time period *t*, the Laspeyres index formula L is the ratio of base period quantities q_n^0 at current period prices p_n^t to base period quantities q_n^0 at base period prices p_n^0 represented as $L = p_n^t q_n^0 / p_n^0 q_n^0$. At a time period *t*, the Paasche index formula *P* is the ratio of current period quantities q_n^t at current period prices p_n^t to current period quantities q_n^t at base period prices p_n^0 represented as $P = p_n^t q_n^t / p_n^0 q_n^t$ (Afriat & Milana, 2009; Allen, 1975; Balk, 2008; Crowe, 1965; Forsyth & Fowler, 1981; Mudgett, 1951). However, the Laspeyres index formula overestimates price changes, while the Paasche index formula underestimates price changes (Mudgett, 1951). The Fisher index formula *I* is the geometric mean of the Laspeyres and Paasche indexes represented as $I = \sqrt{L \times P}$. The Fisher index formula is also known as the "ideal" index formula and overcomes some limitations of other index formulas (Afriat & Milana, 2009; Allen, 1975; Balk, 2008; Crowe, 1965; Forsyth & Fowler, 1981; Mudgett, 1951). To create an index, the index formulae can be extended to runs or sequences of index numbers (Allen, 1975). The index can be developed as fixed base index numbers, linked index numbers or chain base index numbers. Fixed base index numbers select a base period and all changes are measured from the base period. In other words, the index number for each period is calculated by comparing to the base period (Balk, 2008; Crowe, 1965; Mudgett, 1951; Selvanathan & Rao, 1994). Linked index numbers are similar to fixed base index numbers but the base period is updated to link together new and old runs of index numbers (Balk, 2008; Crowe, 1965). Chain base index numbers select the previous period as the base period for the current period (Balk, 2008; Crowe, 1965; Mudgett, 1951; Selvanathan & Rao, 1994). This can also be viewed as linked index numbers where the linking interval is one period (Balk, 2008).

2.3.2 Developing Construction Indices

The construction industry has been described as "very broad and highly diversified with considerable variations in operating patterns from region to region and from one type of construction to another (Mohammadian & Seymour, 1997)." The wide variety of work carried out in the construction industry and the heterogeneity between construction projects makes it difficult to develop sector specific construction indices (BIS, 2010; Mohammadian & Seymour, 1997; Pieper, 1991). This difficulty is compounded by a historical lack of dedicated resources to the development and construction of construction indices (Pieper, 1991). With this in mind, Mohammadian and Seymour (1997) and Yu and Ive (2008) state there is an important need to develop appropriate indexes for different sectors of the construction industry.

According to the OECD (1997) there are several important elements of a construction index. These are construction type, geographic coverage, which items to include in the index, weights, basis of prices (tender, winning bid, invoice), data collection, index review, index formulae and frequency of index. Therefore, when developing a construction index, the diversity of construction activity, selection and availability of prices, range of items to be included in index, geographic representation and types of construction firms to include in the index development must be considered (OECD, 1997). Furthermore, Shrestha, Jeong & Gransber (2016) highlighted several points to consider when constructing a CCI. Selecting a frequency of quarterly or less allows seasonal effects in the construction market to be observed. If using the baskets of construction items, the categories should be selected to ensure the changes in construction cost and construction market are properly represented in the CCI. To use the item data directly, the items should occur frequently and represent a significant portion of the cost of the bid. Additionally, Crowe (1965) states index numbers should relevant, representative, reliable and comparable Persons (1928) highlights five difficulties in developing index numbers. These difficulties include defining the goods to include in the index, having prices and quantities that exactly correspond, dealing with zero quantities, changes to the goods over time, and obtaining suitable indices for a series of time periods.

The development of construction indices is not without issues. One issue faced when developing a construction cost or price index is the wide variety of work carried out in the construction industry, even within a specific sector of the industry. For example, projects within a specific sector may have varying size, design, construction methods, complexity and site conditions which can have an influence on contractor cost. Another issue faced is that construction projects have a time period from start to finish and costs may occur at different times. For example tender prices are work that is yet to be completed and work may be paid out as it completed (BIS, 2010). Actual project data can contain a large number, potentially thousands, of individual price item lines. Due to this the process of cleaning and transforming actual project data to a dataset which can be used in construction index calculation is a challenging task (Shrestha et al., 2016). The change in construction technology, practices and techniques within a construction sector also presents challenges when developing a construction index. This can cause the construction index to lose its relevance if the new construction technology, practices and techniques vary more and more from those at the base period. It is recommended that the compilation of a construction index be reviewed, and revised if necessary, at least every five to ten years to account for changes in the construction sector (OECD, 1997).

When developing a construction index, the construction index will fall into one of three categories: cost indices, price indices and seller price indices. A description of these indices is discussed in Section 1.3.The desired category of index is based on the intended use of the index, preferred properties of the index and available data (OECD, 1997; Selvanathan & Rao, 1994). The BIS (2010) presents price indices as the most beneficial construction index while Pieper (1991) stated "cost indexes are obviously the least desirable method of deflation." To assist in determining the desired construction index category the advantages and disadvantages of each category are presented.

An advantage of cost indices is the ease and low cost of development and construction. A disadvantage is cost indices for the same type of construction may differ significantly due to their inputs and weights (Mohammadian & Seymour, 1997). Furthermore cost indices are believed to understate the change in construction inflation and be insensitive to changes in competitive conditions as cost indices do not include profit, overhead and market conditions. Another disadvantage is many cost indices do not use actual transaction costs but use instead union wage scales, list prices of materials or other types of quoted prices (Pieper, 1991). By using other indices to construct a cost index, any inherent inaccuracies in the other indices can be compounded (BIS, 2010).

The BIS (2010) highlights nine advantages of output price indices. A major advantage is price indices are based on actual construction data and are not based on other indices or data sources. This ensures the index represents the movements in actual construction prices (BIS, 2010). Price indices are further divided into three types according to their method of construction: bid/unit price indices, hedonic price indices and estimation/model indices (Pieper, 1991). Bid/Unit price indexes are based on contractors' bid prices for a project which are often broken down into a cost for each item (Mohammadian & Seymour, 1997). Hedonic price approaches are based on the concept that a large number of a heterogeneous product can be represented by a smaller number of characteristics (Goodman, 1978). Hedonic price indexes are derived by fitting a regression equation to construction price observations and other relevant characteristics and parameters to estimate the price of construction items, basket of items or project (Mohammadian & Seymour, 1997). Model price indexes are derived from a survey of contractors and engineers who estimate the construction cost for specific model projects which are representative of a construction sector. The construction costs may be for an entire project or for components of the project (Mohammadian & Seymour, 1997).

An advantage of bid/unit price indices is bid/unit price indices represent the actual price paid by the client for construction work as bid/unit price indices are derived from actual contractor bids (BIS, 2010; Mohammadian & Seymour, 1997). Also, bid/unit price indices generally allow for quick and easy updating of the index (Mohammadian & Seymour, 1997). A disadvantage of bid/unit price indices is the difficultly in identifying a relatively homogeneous physical measure and when heterogeneity occurs, the price index will be biased when quality change occurs within the item categories (Pieper, 1991). Additionally, bid/unit price indices require large amount of representative data which can be difficult for some construction sectors (BIS, 2010). Therefore bid/unit price indexes are best utilized when there are a large number of projects for a relatively homogenous construction type (Mohammadian & Seymour, 1997).

Hedonic price indices include only physical characteristics and ignore quality characteristics leading them to be similar to quantity based indices. A disadvantage of hedonic price indices is the difficulty in quantifying construction characteristics such as building design and construction quality (Pieper, 1991). Another disadvantage is hedonic price indexes require a large number of construction cost observations which can be difficult for some construction sectors (Mohammadian & Seymour, 1997; Pieper, 1991).

An advantage of model/estimation price indices is the model project is homogeneous removing the heterogeneity found in the specific construction sector (Mohammadian & Seymour, 1997). A disadvantage is the prices are not based on actual construction bids. The contractor has no incentive to bid as low as possible to win the project and they are not required to actually build based on the submitted bid. This may cause the contractor to bid differently than they would on an actual project. Additionally there is no obvious way to weight the responses as there is no winning bid. Estimation indexes are not commonly used and at times it has recommended they only be used as a last resort (Pieper, 1991).

An advantage of seller price indices is seller price indices are sensitive to changes in demand levels, productivity and profits. A disadvantage is seller price indices require large amount of representative data. As seller price indices are derived from price indices, seller price indices require representative data for the price index plus additional data to convert price index to a seller price index (Mohammadian & Seymour, 1997).

When constructing an index the selection of an index formula, such as those presented in Section 2.3.1, is based on the availability of data (Selvanathan & Rao, 1994). The majority of existing construction indices are based on Laspeyres, Paashe, and Fisher index formulae with the data collected at specific, regular time intervals for a specified basket of goods. However, when the data is diverse, sparse or irregularly spaced in time Laspeyres, Paashe, and Fisher index formulae do not accurately reflect cost or price changes (Rehan et al., 2016). For example, Yu and Ive (2008) found the Paasche index formula is not applicable to measure price changes in mechanical and electrical items in building construction due to the diversity in available items and changes in technology.

2.3.3 Calculating Construction Indices

Although there are many sources in the literature which discuss index properties and the development of an index, there are few studies which discuss the actual methodology of calculating a construction index or present the creation and calculation of a new construction index. Studies of this type are presented below.

Shrestha, Jeong & Gransber (2016) presents a methodology for calculating HCCIs for state DOTs. This methodology is applicable to calculating a construction price index for any construction industry in which contracts are awarded by an item bidding process. The bid data is first obtained from the client, which could be a municipal, regional, provincial, state or federal government or private company. Next the bid data is cleaned and transformed into a formatted dataset which can be used for construction price index calculation. Based on the intended use of the construction price index and the dataset the frequency (daily, monthly, quarterly, annually, biannually) of construction price index calculation is determined. At this point the methodology follows one of two procedures; create baskets of construction items or use item level data directly (market basket). When using item data directly the frequency of each item is analyzed and the average unit price of each bid item is calculated. When creating a basket of construction items the basket categories are determined, items are identified for each category, the frequency of items in each category is analyzed and the average unit price of all items in a category are calculated. Finally, for either procedure, an index number formula is selected and the CCI is calculated. The authors further state “there is a need to automate data cleaning, transformation and HCCI calculation.”

Somerville (1999) developed a cost levels series for new single family residences by individual unit in Baltimore, Cincinnati and Houston. Coefficients from hedonic cost regressions based on construction cost data were used to create the cost levels series for a standardized structure. The developed cost levels series produce better results for estimating housing supply (housing starts) when compared to RS Means CCI. Somerville developed the new cost levels series due to previous studies which found that housing starts did not fall with an increase in construction costs, as expected, when a proxy index was used. This further highlights the need to use industry specific indices instead of proxy indices.

Salvo, Marina & De Ruggiero (2014) developed an index for housing prices using a price relatives approach with a vector of weights to take into account the reliability of the market data. The use of weighting factors ensures outliers are not dismissed but their negative effects are mitigated. This means the entire original data is maintained in the index.

To assist in forecasting future highway construction costs in Louisiana, Wilmot and Cheng (2003) created the Louisiana Highway Construction Index based on the 2 827 highway and bridge contracts containing 119, 607 individual pay items from 1984 to 1997 with a Paasche index formula.

2.4 Forecasting Construction Prices

Forecasting future construction prices and estimating inflation are important tools to improve the information available to decision makers and improve the quality of decision making in water and wastewater management (Akintoye & Skitmore, 1994). Historically indices, such as indices discussed in Sections 2.2 and 2.2.1, are used in forecasting of future construction costs (Eskaf, 2012; Wilmot & Cheng, 2003; Yu & Ive, 2008). Once a construction cost or price index is selected, the forecasting requires the use of robust objective methods (Ng et al., 2004). The literature review reveals several techniques to forecast future construction costs and estimate inflation. The most common methods are regression analysis, time-series forecasting models and neural network models (Ashuri & Lu, 2010; Lowe, Emsley, & Harding, 2006; Wilmot & Cheng, 2003). Examples of these forecasting techniques are presented below.

Regression analysis assumes the predicted values are determined by independent explanatory variables. Time series methods forecast future trends based on past values and corresponding errors. Time series methods are commonly used to forecast future values because they only require the historical information of the value itself, and not information from other input explanatory variables (Ashuri & Lu, 2010). Until recently time series methods of forecasting were not commonly used in the construction industry, despite being a well-established method of forecasting in other domains (Hwang, 2011). Neural network models are based upon mathematical models with no implicit functional form. Unlike regression analysis and time series models, neural network models do not assume that past trends are unchanging. However neural network models operate under the same assumption that the relation between construction cost and factors is constant in time (Joukar & Nahmens, 2016; Wilmot & Mei, 2005).

Philips (1982) created a regression model to estimate the inflation rate of capital costs of U.S. highway construction (FWHA composite BPI) based upon the inflation rates of the general producer sector of the U.S. economy (US BLS PPI). The estimated inflation rate is used to forecast future highway construction costs. The model is based upon the view that increases in highway cost is a function of the general inflation for producer prices. The model provides short term estimates of future cost increases in capital costs for U.S. highway for high, medium and low producer price inflation. The model found that the FWHA composite BPI responds directly to the PPI with the highway inflation rate being 1.5 times higher.

Lowe, Emsley and Harding (2006) constructed six linear regression models to predict building construction cost based on data collected from 286 building construction projects in the United Kingdom. The models were developed with forward and backward stepwise regression methods from 41 input variables identified in the literature as predictor variables which are likely known at an early estimating stage. It should be noted that the number of input variables in each modeled varied with the smallest number of variables, largest number of variables and total number of variables used being 8, 14 and 19, respectively. The six models were found to underestimate the cost of expensive projects and overestimate the cost of inexpensive projects. The six linear regression models performed slightly poorer than neural network models, but the differences were insignificant.

Marchionni, Cabral, Amado and Covas (2016) conducted univariate and multivariate linear regression analysis to determine cost functions for assets of water supply systems based on hydraulic and physical characteristics. The cost functions were calculated from 130 contracts for water supply system construction from 2005 to 2014 in Portugal transformed to 2014 costs using the inflation rates for capital costs of infrastructure in the public sector in Portugal.

A multivariate regression model for estimating the preliminary construction costs of water treatment plants in 2011 dollars is presented by Sharma, Najafi and Qasim (2013). The model is composed of 78 univariate generalized regression construction cost equations representing the unit operations and processes in a water treatment plant. The previously complied cost data (Gumerman et. al., 1979), obtained from equipment manufacturers, plant construction costs and unit takeoffs for construction of treatment processes, were brought to 2011 dollars using ENR and BLS indexes. To estimate construction costs beyond 2011, from 2011 cost estimates, the authors recommend the use of ENR CCI for short term (within eight years) due to simplicity and both ENR and BLS indexes for long term estimates (beyond eight years). When comparing the construction cost estimation model results with real world construction costs the estimates were +/- 33% for nine out of ten projects.

Wilmot and Cheng (2003) developed a multivariate regression model to estimate the future overall highway construction cost in Louisiana on an annual basis. The model consists of five components estimated using least squares regression: embankment material, concrete pavement, asphalt pavement, reinforcing steel concrete and structural. Each component was estimated from past data with 11 independent input variables and their contribution to the overall model determined from the newly developed Louisiana Highway Construction index discussed in Section 2.3.2. From the model, under optimistic scenarios, the average growth rate of highway construction costs in Louisiana is 3.3% per year which is greater than the general inflation rate from 1992 to 1997 of 2.5% per year.

Ng, Cheng, Skitmore and Wong (2004) developed an integrated regression analysis and time series model to forecast the Tender Price Index for Hong Kong construction projects using quarterly data from 1980 to 1998. The regression analysis model is multivariate based on tender price index (TPI), best lending rates, BCI, composite CPI, implicit gross domestic product deflator and the Hong Kong stock market. The time series model is based on stochastic Auto-Regressive Integrated Moving Average (ARIMA) approach. The integrated regression analysis and time series model was found to be more accurate than the regression analysis and time series models individually.

Ashuri and Lu (2010) created a univariate time series model based on Seasonal ARIMA (SARIMA) to forecast ENR CCI. ENR CCI monthly data from 1975 to 2008 was used for in-sample and out-sample forecasting. The SARIMA model was found to be more accurate in predicting CCI than ENR expert forecasts but did not perform well when CCIs make discrete jumps.

Hwang (2011) developed two dynamic time series models, a univariate autoregressive moving average model (ARMA) and multivariate autoregressive model (VAR), to estimate construction costs based on forecasting construction indexes. The ARIMA model utilized monthly ENR CCI data from 1960 to 2006, while the VAR model utilized ENR CCI data and CPI data from the same period. CPI data was included in the VAR model under the theory that construction costs are influenced by general inflation. When comparing the two models it was observed that historical CCI values alone resulted in a better prediction of future CCI values than CCI and CPI together.

Xu and Moon (2013) present a co-integrated vector auto-regression model based on a model of stationary time series to forecast construction cost trends in ENR CCI using monthly data of ENR CCI and CPI from January 1975 to June 2010. CCI data from January 1975 to December 2005 is used for estimating the model and in sample forecasting, while CCI data from December 2006 to June 2010 is used for out-sample forecasting. CPI data was co-integrated with the model because CPI "plays a particularly significant role in forecasting the CCI." The model was shown to be more accurate than exponential smoothing models but all models performed poorly beyond 2008, two years into the forecast.

Shahandashti and Ashuri (2013) developed five vector error correction multivariate time series models for forecasting future construction costs which co-integrate explanatory variables. Each of the five models co-integrates different combinations of the time series of the explanatory variables to forecast construction costs, in this case ENR CCI. The explanatory variables are CPI, Housing Starts, Building Permits, Producer Price Index and Crude Oil Price. It was concluded the vector error correction multivariate models are more accurate than univariate time series models.

Joukar and Nahmens (2016) construct a Generalized Autoregressive Conditional Heteroskedastic (GARCH) model to forecast ENR CCI and compare to previous time series models. ENR CCI shows substantial periods of volatility which cannot be accounted for in previous multivariate and univariate time series models. Monthly ENR CCI data from January 1978 to July 2014 is utilized for in-sample and out-sample forecasting. For in-sample forecasting, the GARCH model provides is slightly more accurate than exponential smoothing and SARIMA models. For out-sample for forecasting, the GARCH model is more accurate than exponential smoothing but similar to SARIMA model predictions. However the SARIMA model cannot provide the volatility of the series while the GARCH model can.

Williams (1994) developed two back-propagation neural network models, one and six months ahead, to predict changes in ENR CCI. Historical trends in ENR CCI, prime lending rate, housing starts, and month of the year were used as model inputs. In a comparison of back-propagated neural network models to exponential smoothing and regression models, the neural network models were found to be the least accurate in predicting ENR CCI.

Wilmot and Mei (2005) developed an artificial neural network model to estimate the future overall highway construction cost in Louisiana on an annual basis. This basis of this model is the same as the multivariate regression model from Wilmot and Cheng (2003). The five components, embankment material, concrete pavement, asphalt pavement, reinforcing steel concrete and structural, are each modeled with an artificial neural network model. The neural network models relate the construction costs to the cost of construction material, labour and equipment, the characteristics of the contract and the contracting environment. An average growth rate of highway construction costs in Louisiana was observed to be 3.4% per year. This is similar to the 3.3% per year observed in Wilmot and Cheng (2003) but lower than the LHCI growth of 3.7% per year and greater than the general inflation rate of 2.5% per year from 1992 to 1997.

Hegazy and Ayed (1998) present a three layer neural network model to manage construction cost data and develop a parametric cost-estimating model for highway projects. The model was developed from tender bids for eighteen highway construction projects in Newfoundland, Canada over a five year span. Back-propagation, simplex optimization and genetic algorithm procedures were three different methods tested to determine the optimum weight of the model, with simplex optimization being selected.

Lowe, Emsley and Harding (2006) state the "ease of operation, familiarity, speed and a satisfactory degree of accuracy, in conjunction with the availability of design information" are important factors to consider when selecting a forecasting model. Neural network models are less accurate in predicting construction indices when compared to other forecasting models (Williams, 1994). Although most models are accurate in predicting short term trends, they may have difficulty predicting medium and long term trends (Xu & Moon, 2013). The choice of a construction index can also influence the accuracy of the forecasting model. For example, ENR CCI is subject to short and medium variations which can be problematic for some models (Shahandashti & Ashuri, 2013).

The properties of a construction index can also influence the selection of a forecasting model. The studies presented in this section limit their scope to forecasting a specific construction index or construction type based on historical cost data, most commonly ENR CCI and building construction, respectively. The same modeling approach presented in these studies can be applied to other construction indexes or construction cost data, assuming the data requirements of the specific model is met (Shahandashti & Ashuri, 2013). Based on the models presented the in the literature review regression models, time series models and neural network models have specific data requirements to be accurate. Multivariate regression and neural network models require not only construction index data but data for all input variables (Marchionni et al., 2016; Sharma et al., 2013; Wilmot & Cheng, 2003). To have accurate and reliable results from time series models the data must be stationary and non-seasonal. Non-stationary and seasonal data, such as ENR CCI, can be transformed to fulfill time series data requirements (Ashuri & Lu, 2010; Joukar & Nahmens, 2016; Xu & Moon, 2013). In the literature the use of regression analysis, time series method, and neural network model forecasting techniques is limited to large historical datasets which are regularly spaced in time with one index value per time period. For time series methods, the tests for stationarity and seasonality data, and their transformation if necessary, is only conducted on datasets which fall into this category. The regression analysis, time series method, and neural network model forecasting techniques in the literature are not used on sparse, irregularly spaced datasets.

2.5 Contractor Markup

In the construction industry contracts and projects are generally awarded through a competitive bidding process (Abotaleb & El-adaway, 2016; Mochtar & Arditi, 2001; Wu, Liu, & Picken, 2006). Typically the project is awarded to the lowest bid where the contractor has added a markup to their unit costs (Mochtar & Arditi, 2001). To determine the markup in contractor bids requires an understanding of bidding and markup strategies. However, understanding bidding and markup strategies is difficult due to the complexity of the construction industry (Ahmad & Minkarah, 1988; Tarek Hegazy & Moselhi, 1994; Laryea & Hughes, 2008). With regards to bidding and markup strategies, the complexity is highlighted by the lack of consensus on the definition of markup, the different methods contractors use to make bidding and markup decisions, and the many factors influencing the contractors' bidding and markup decisions.

Based on a survey of 78 general contractors in Canada and the US, Hegazy and Moselhi (1995) noted that contractors define markup differently. Markup has been defined as profit only, profit plus contingency, profit plus general overhead, profit plus general overhead and contingency, and profit plus general overhead, project overhead and contingency. Tenah and Coulter (1999) define markup as the amount added to the estimated direct cost consisting of job and project overheads, project contingencies and profit. From personal construction bidding experience, Connolly (2006) states the three components of markup is contingency on the cost of the work, contingency on the cost of risk and the price of profit. Hosny and Elhakeem (2012) state markup is generally composed of risk contingency and profit. This highlights the lack of consensus of a definition of markup.

Mochtar and Arditi (2001) classified bidding methods into cost-based, market-based and hybrid based on a survey of pricing practices of 91 of the top 400 general contractors in the US. In cost-based bidding methods a detailed cost estimate is performed and a markup is set based on the company's preference. In market-based bidding methods the cost and markup is set fully based on market conditions and costs are adjusted to fit targets only after the contract is awarded. Hybrid bidding methods are a combination of cost- and market-based bidding methods. The most common bid method in the construction industry is cost-based with markup considering market conditions in addition to the company's preferences. In addition to various bidding methods there are also different methods to calculate markup. Markup can be calculated as a percentage of direct costs plus project overhead and general overhead, a percentage of directs costs plus project overhead or a percentage of direct costs (Hegazy & Moselhi, 1995). In a review of the literature, Laryea and Hughes (2008) identified nine methods contractors use to price risk and contingencies. Kim & Shim (2016) discuss proportional and non-proportional markup distribution approaches for construction projects. Proportional markup distribution is a balanced distribution of total markup to each item based the item's percentage to the total project costs. Contractors may use non-proportional markup distribution such as front-end loading the markup on early activities and decrease markup on late activities in an attempt to improve their cash flow compared to proportional markup distribution. Furthermore, for bidding and markup decisions contractors often rely on their own experience, judgement, intuition and a subjective assessment of the competition despite the availability of bidding models and statistical techniques (Ahmad & Minkarah, 1988; Hegazy & Moselhi, 1995; Mochtar & Arditi, 2001). This is supported by Laryea and Hughes (2008) who stated "there is no evidence that the pricing process is indeed systematic in nature" after a review of how contractors price work.

There have been many studies which discuss the factors which influence contractor markup strategies and decisions (Ahmad & Minkarah, 1988; Dulaimi & Shan, 2002; Liu & Ling, 2005; Mochtar & Arditi, 2001; Shash, 1993; Ye, Li, & Shen, 2013). A brief overview of the most significant factors is presented below. Ahmad and Minkarah (1988) surveyed general contractors in the US to rank 31 factors which affect percent markup decisions. Interestingly, degree of hazard and degree of difficulty which are both factors related to risk, were identified as the top two factor influencing percent markup decisions. Carr (1983) examined the how the number of competitors for a contract can influence markup. As the number of competitors for a contract increases, a contractor will decrease their markups to undercut other competitors in an attempt to win the contract. Dulaimi and Shan (2002) surveyed medium and large contractors in Singapore to rank 40 factors which influence percent markup decisions. The highest ranked factors for medium contractors are the overall economy, the need for work and establishing relationships with clients, while for large contractors the most important factors are the degree of difficulty of the project, the overall economy and competitiveness of the competitors. Shash (1993) identified 55 factors influencing bid and markup decision making in a survey of UK contractors. The highest ranked factors influencing markup decisions is degree of difficulty, risk owing to the nature of the project and current work load. Another important factor is the time period allowed for the contractors to prepare a bid (Ahmad & Minkarah, 1988; Laryea & Hughes, 2008). Due to constrained time periods to prepare and submit a bid, contractors are forced to make assumptions for the project which could lead to serious liabilities creating the use of contingencies and a higher markup. Based on this review of the literature the most significant factors influencing contractor markup strategies and decision degree of difficulty, risk of project and construction work, and number and competitiveness of contractors.

Many studies in the literature are concerned with estimating the optimum markup size to assist contractors in the bidding decision by finding a balance between profit and the probability of winning the contract (Abotaleb & El-adaway, 2016; Chao, 2007; Christodoulou, 2004; Hosny & Elhakeem, 2012; Liu & Ling, 2005). The optimum markup results in an optimum bid value which is low enough for a contractor to win the project but high enough to generate more profit (Chao, 2007; Christodoulou, 2004; Hosny & Elhakeem, 2012). However, these studies are not concerned with the actual size of the markup that contractors add to their winning bids. A large amount of the studies concerned with the actual size of a contractor's markup are based on questionnaire surveys or exploratory interviews, not on actual construction price data from the contractors or their clients (Laryea & Hughes, 2008). Two such studies are discussed below.

Neufville and King (1991) conducted a survey of thirty New England contractors to assess and analyze a bid simulation exercise in an effort to determine risk and need-for-work markup premiums. The risk and need-for-work markup premiums were concluded to be around 3%, independently and additively, of the total cost of the project. The risk markup premium only reflects increases in profit to cover risk and does include adjustments to direct costs to cover risk, such as lowered productivity or added contingency. If a contractor is busy with other projects a need-for-work premium which reflects a lack of enthusiasm for more work and creates additional incentives for the work if they are awarded the contract. Laryea and Hughes (2008) conducted exploratory interviews with five UK construction firms and determined risk margins of approximately 2-3% in construction project bids.

2.6 Summary and Conclusions

The information presented in the literature review can be summarized in the following points:

- The most common types of construction indices are cost or price indices. The majority of available construction indices are for non-residential building, residential building and highway construction sectors. There are few construction indices for the water and wastewater infrastructure sector. The available construction indices for the water and wastewater infrastructure sector are not based on actual construction data and are cost indices.

- A proxy index can be used in the absence of a sector specific index. In Canada, ENR CCI, FWHA composite NHCCI or BPI and CPI have been used in the water and wastewater infrastructure sector. However these indices are considered too general and do not accurately represent the circumstances for the water and wastewater infrastructure construction sector. As construction indices are most effective when used in the construction sector for which they were developed, the development of sector specific indices is recommended.
- Price indices based on actual construction data are the recommended type of construction index as these indices best represent the actual price changes and movements in a construction sector. However, indices based on actual construction data are the most difficult to develop and construct.
- The important elements of a construction index are: construction type, geographic coverage, items included in the index, weights, basis of prices, data collection, index review, index formulae, and frequency of index.
- Laspeyres, Paasche and Fisher are the most common and well-known index formulae.
- The forecasting of future construction costs and prices is most commonly conducted with regression, time series and neural network models. These models have specific data requirements which includes large historical datasets regularly spaced in time. However, when the data is diverse, sparse or irregularly spaced in time Laspeyres, Paasche and Fisher index formulae do not accurately reflect cost or price changes.
- Contractors will add a markup to their bids to account for profit, overhead and risk contingency. There are few studies concerned with the actual size markup contractors add to their bids. The majority of studies concerned with the actual size of a contractor’s markup are based on questionnaire surveys or exploratory interviews, not on actual construction price data from the contractors or their clients. Two such studies have found risk markup to be around 3% and approximately between 2-3%.

The literature review reveals a lack of construction indices for the water and wastewater pipeline construction sector. The few available construction indices for the water and wastewater infrastructure sector are cost indices, not price indices, meaning the index represents the costs to the contractor and not the prices paid by a client such as a local government or water utility. Furthermore the few construction indices for the water and wastewater infrastructure sector are not developed from actual construction data. Therefore, there is a need to develop a construction price index for the water and wastewater pipeline construction sector based on actual construction data. The properties of such an index are influenced by the properties of the available construction price dataset. The literature review identified a shortcoming in the forecasting of future construction costs in the water and wastewater pipeline construction sector. Currently, forecasting water and wastewater pipeline construction costs and prices is completed using a proxy index when the use of a sector specific construction index is recommended. The use of a proxy index can result in errors and inaccuracies in forecasts construction costs and prices. Furthermore, the selection of a forecasting method is determined by the properties of the construction index on which the forecasting is based. The literature review also revealed a lack of knowledge on the actual markup contractors add to their bids based on actual construction price data.

Chapter 3
Data

3.1 Overview

This chapter presents the data used in this work. First, capital works construction price data from the City of Niagara Falls is presented. This construction price data is the basis for developing sector specific indices for the watermain and sanitary sewer construction sectors, which in turn are the basis for estimating the inflation and future values of construction prices in the watermain and sanitary sewer construction sectors. Next, general market indices are presented including Consumer Price Index (CPI), Canadian Non-Residential Building Construction Price Index (NRBCPI), United States Bureau of Reclamation Construction Cost Trends (CCT), and S&P Toronto Stock Exchange (S&P/TSX) Composite Index. The price changes and inflation in these general market indices is compared with the price changes and inflation in the water and wastewater pipeline construction sector represented by the newly developed indices.

3.2 Capital Works Construction Cost Data

Tender bid summaries and contractor progress payments were provided by the City of Niagara Falls, Ontario, Canada for capital pipeline and road construction projects via the open cut construction method from 1981 to 2014. The contract for a project is composed of item lines contained in sections. Sections commonly include watermain construction, sanitary sewer construction, storm sewer construction and road construction as well as general item and provisional item sections. Other sections observed in projects include electrical work, landscaping and storm water management facility construction. Each item line contains an item number, item description, quantity, measurement unit and an item price which is either lump sum, each or unit price based on the measurement unit. Projects are awarded to a contractor by a competitive bidding process where the contractor who bid the lowest total price is awarded the work. Tender bid summaries contain the total bid price and item bid price for each item line for each contractor who bid on the project. Contractor progress payments represent the actual payments to the awarded contractor for completed work. Construction price data was obtained from the tender bid of the winning (lowest bid) contractor in the tender bid summary and directly from contractor progress payments. The construction prices include a markup to direct costs to account for project risk, overheads, and market conditions. The construction price data is assumed to represent prevailing market costs as the construction price data is based on winning tender bids and actual contractor payments. Of the provided projects, 217 projects were relevant to watermain and sanitary sewer construction containing a total 53 482 item lines. The construction price data will be used to create a construction price dataset which is the basis for developing construction price indexes for the water and wastewater pipeline construction sector. The newly developed indexes will be used for estimating inflation and forecasting future construction costs in the water and wastewater pipeline construction sector.

3.3 Consumer Price Index

Consumer price indexes are an indicator of the changes in the prices of goods and services which consumers' purchase. CPIs are used as a measure of the rate of general inflation in the economy and an indicator of the purchasing power of consumers' income (International Labour Office, 2004; Statistics Canada, 2016b). In Canada, consumer price index (CPI) is obtained by comparing the cost of a basket of goods and services at two different points in time where the basket of goods and services is equal in quantity and quality for each point in time (Bank of Canada, 2016; Statistics Canada, 2016b). In this work, CPI will be used as a benchmark to compare the prices changes and inflation of the general economy to water and wastewater pipeline construction sector represented by the newly developed indices. It has been reported, as shown in Section 2.2.1, that CPI is used as a proxy index to deflate or estimate construction costs if not sector specific index is available (Eskaf, 2012; Government of Prince Edward Island, n.d.; MOE, 2007; Pieper, 1991). Based on the comparison of CPI to water and wastewater pipeline construction price indices, the validity of using CPI as a proxy index for the water and wastewater pipeline construction sector can also be determined. In this work, CPI will be represented by yearly data for Bank of Canada's Core Index with inflation estimated from the1984 to 2014 interval. The Bank of Canada's Core Index was chosen because this index focuses on the underlying trends of inflation while reducing the temporary changes in total CPI (Bank of Canada, 2016).

3.4 Non-Residential Building Construction Price Index

Non-residential building construction price indexes are used to monitor changes in the construction market and estimate inflation of construction projects (Shrestha et al., 2016). The Statistics Canada Non-Residential Building Construction Price Index (NRBCPI) measures the change in prices for constructing commercial, industrial and institutional buildings (Statistics Canada, 2016c). The NRBCPI is an estimation/model price index is constructed from a survey of general and trade contractors who are primarily involved in the construction of non-residential buildings. Contractors are surveyed for various locations and submit the price which the contractor would bid on a fixed specification and quantity for each item (Mohammadian & Seymour, 1997; Pieper, 1991; Statistics Canada, 2016c). The survey data represents actual bids meaning the bid includes costs for materials, labour, equipment and markup including overhead, profit and market conditions. The index excludes the cost of land, land assembly, design, development and real estate fees (Statistics Canada, 2016c). The estimation/model price index approach was chosen due to the heterogeneity in the materials, size and construction methods for the non-residential building construction sector (Mohammadian & Seymour, 1997). Price changes and inflation in the non-residential building construction sector is estimated from yearly Statistics Canada NRBCPI from 1984 to 2014 to compare with the water and wastewater pipeline construction sector represented by the newly developed indices.

3.5 Lateral and Drains Construction Cost Trends

Construction Cost Trends (CCT) for water lateral and drains are published by the Bureau of Reclamation through the United States Department of the Interior. The CCT track the change in dollar value for construction of 35 types of water infrastructure within 17 western states in which the BR operates. The CCTs are cost indices which consist of contractor labour and equipment costs and contractor supplied materials and equipment. Originally the CCT were based on actual construction costs for each water infrastructure type. However, in recent years the CCT is calculated from the US BLS PPIs, Department of Agriculture Land and Rental Prices and ENR data due to the number and magnitude of construction projects decreasing. Engineering judgement is also used to adjust the results. When available, actual construction cost data is used to verify the calculated index value. The lateral and drain (LD) CCT was selected because it most closely resembles the water and wastewater pipeline capital works construction data. Distribution pipeline CCT are available but was not selected as this data closely resembles trunk or transmission pipeline construction which is not present in the provided capital works construction cost data. Cost changes and inflation for lateral and drain construction in the western US is estimated from yearly BR LDCCT data from 1984 to 2014 to compare with the water and wastewater pipeline construction sector represented by the newly developed indices (USBR, 2016).

3.6 S&P Toronto Stock Exchange Composite Index

The relationship between municipalities and contractors can be considered as comparable to the relationship between consumers and publicly traded companies. As stated earlier, construction work is generally awarded through a competitive bidding process (Abotaleb & El-adaway, 2016; Mochtar & Arditi, 2001; Wu et al., 2006). Included in the contractor's bid is a markup to their unit costs to account for profit, overhead, risk and market conditions (Connolly, 2006; Hegazy & Moselhi, 1995; Tenah & Coulter III, 1999). To minimize their expense, municipalities will award the construction work to the contractor who submitted the least cost bid under the traditional contract award system present in many municipalities (Mochtar & Arditi, 2001). This competitive bidding process effectively forces the contractors to be accountable and competitive in the amount of added markup in an attempt to win the construction work, if no collusion is present. Similar to contractors, companies add a markup to their goods and services to account for profit, overhead, risk and market conditions. Customers, similar to municipalities, can purchase goods and services from different companies to minimize their expenses. A lack of purchases for goods and services would minimize a companies' revenue and therefore minimize their share price. The competitive market therefore forces companies to be accountable and competitive in their prices and markups to maximize revenue and therefore maximize share price.

It is hypothesized that the same circumstances which establish the financially sustainable markup in water and wastewater pipeline capital works competitive bidding also translates into the value of the share prices of the construction companies completing the work. Balatbat, Lin and Carmichael (2010) found the performance of publically listed Australian construction companies is comparable to the largest traded shares on the Australian Securities Exchange. In Canada, this would translate to the performance of construction companies being comparable to the companies traded on the Toronto Stock Exchange. Therefore, returning to the above hypothesis, it is theorized that the inflation in water and wastewater pipeline construction is comparable to the inflation in the share prices of companies traded on the Toronto Stock Exchange represented by the S&P/TSX composite index. This hypothesis was previously presented by Younis, Rehan, Unger, Yu, and Knight (2016). Yearly S&P/TSX composite index data from 1984 to 2014 is used to estimate inflation to compare with the water and wastewater pipeline construction sector represented by the newly developed indices.

Chapter 4
Research Methodology

4.1 Overview

This chapter presents the methodology to develop construction price indices for, and estimate inflation in, the water and wastewater pipeline construction sector based on fragmented actual construction price data for the open cut construction method. This requires an understanding of contractors' bidding strategy, watermain and sanitary sewer construction and engineering judgement. The chapter first presents the development of a customized data processing function which cleans and transforms actual construction cost data from tender bid summaries to an auditable construction price dataset. Second, based on the construction price dataset, the development and calculation of construction price indices for watermain and sanitary sewer construction is presented. Third, the inflation and volatility in these indices is estimated and future construction prices are forecast using Geometric Brownian Motion. Finally, a Microsoft Access relational database is presented which integrates and automates the data processing function, calculation of construction prices indices, estimation of inflation and volatility and forecasting of future construction prices.

4.2 Data Processing

The process of cleaning and transforming actual construction cost data into a dataset has been identified as one of the more difficult and challenging tasks in the calculation of a construction cost index. To improve the efficiency and accuracy of construction cost index calculation there is a need to automate the data cleaning and transformation process. To meet the construction cost data processing needs an automated data processing function was developed. The purpose of the data processing function is to clean and transform the tender bid summaries from the City of Niagara Falls into an auditable dataset which is then imported into the database. This data processing function is separated into two processes: tender bid summary cleaning and transformation process and dataset import process. Although this data processing function has been developed specifically for City of Niagara Falls tender bid summaries, the structure of the data processing function and dataset has been developed to accommodate the inclusion of information from other sources. However, the data processing function would require slight modifications to clean, transform and import construction price information from other sources with respect to the format of the new information.

The cleaning and transformation process converts City of Niagara Falls tender bid summaries into a construction price dataset. The automation of the cleaning and transformation process increases the speed and efficiency of tender bid data processing. The automation also increases dataset accuracy by removing potential human errors due to the hand processing of tender bid data. The dataset is the basis for developing construction price indexes for the water and wastewater pipeline construction sector. This dataset can also assist with additional tangible capital asset accounting requirements as per PSAB PS3150 (Amant, 2007; CICA, 2007; Government of Prince Edward Island, n.d.).

The construction price dataset is composed of item lines where each item line contains a field for: item number, item description, item quantity, measurement unit, item unit price, depth if applicable, section, tender date, contract ID, allocation number, contractor and city. This is similar to a tender bids summary which is composed of item lines separated into sections where each item line contains an item number, item description, item quantity, measurement unit and an item unit price. The necessary data for each item line in the dataset is extracted from the item lines of the tender bid summary, or the tender bid summary as a whole.

The items contained within tender bids, and therefore item numbers and item descriptions, are not consistent across different cities. Within a single city item numbers and item descriptions may vary over time due to item number scheme changes. For example, the City of Niagara Falls introduced a new item number scheme in 2009. Table 4.1 describes the sections in tender bid summaries for pre- and post-2009 number schemes for the City of Niagara Falls. Identifying which item number scheme, and corresponding, sections are present in a City of Niagara Falls tender bid summary is important as the section label determines the first character of an item number. To ensure item identification in the tender bid dataset is consistent dataset item numbers, sections, allocations, and item descriptions were created. To import construction price data from other sources into the dataset would require the item lines from the other sources to be matched to corresponding dataset item numbers and item descriptions. Without this dataset identification system it would be very difficult, if not impossible, to compare tender bid summaries with different item number schemes. For example, in a 2007 Niagara Falls tender bid summary item number B2.a has a description of ‘Water Valve and Box – 100mm diameter’ while for a 2010 Niagara Falls tender bid summary, the same item number B2.a would have a description of ‘Road Excavation and Removals – complete roadway excavation and disposal’. The item number D2.a in a 2010 Niagara Falls tender bid summary has a description of ‘Water Valves and Valve Boxes – 100mm diameter’ corresponding to the item number

B2.a in a 2007 Niagara Falls tender bid summary. An item line's dataset item number is determined from the tender bid summary item number and keywords in the tender bid summary item description. Following the above example, item number B2.a for a 2007 Niagara Falls tender bid summary and item number D2.a for a 2010 Niagara Falls tender bid summary would both have a dataset item number of B2.a and dataset item description of 'Water Valve and Box – 100mm diameter'. The dataset item numbers and item descriptions were developed by surveying all items in the City of Niagara Falls tender bid summaries. This ensures each potential item in a tender bid summary has a corresponding unique dataset item number and item description. There are currently 1,164 dataset item numbers and this can be expanded as new items appear in tender bid summaries.

Table 4.1 – Sections in Niagara Falls Tender Bid Summaries, Pre -and Post-2009

Pre-2009 Sections		**Post-2009 Sections**	
Section Label	**Section Description**	**Section Label**	**Section Description**
A	General	A	General
B	Watermain	B	Road
C	Sanitary Sewer	C-SA	Sanitary Sewer
D	Storm Sewer	C-ST	Storm Sewer
E	Road	D	Watermain
F	Provisional Items	E	Electrical
M	Miscellaneous/Other	M	Miscellaneous/Other

Each item in the dataset belongs to a section and allocation. Items in the general and provisional sections have no allocation. The dataset sections and corresponding allocations are summarized in Table 4.2 below.

Table 4.2 – Summary of Dataset Sections and Allocation Numbers

Section Label	Section Description	Allocation Description	Allocation Number
A and F	General and Provisional	No Allocation	0
B	Watermain	Watermain Pipes	1
B	Watermain	Valves	2
B	Watermain	Hydrants	3
B	Watermain	Water Services	4
C	Sanitary Sewer	Sanitary Sewer Pipes	5
C	Sanitary Sewer	Sanitary Maintenance Holes	6
C	Sanitary Sewer	Sanitary Sewer Laterals	7
D	Storm Sewer	Storm Sewer Pipes	8
D	Storm Sewer	Storm Maintenance Holes	9
D	Storm Sewer	Storm Sewer Laterals	10
D	Storm Sewer	Inlet Systems	11
E	Road	Sidewalk	12
E	Road	Roads	13
E	Road	Maintenance	14
M	Miscellaneous	Miscellaneous	15

The construction price dataset contains only construction price data for the lowest tender bid for a project where, in a competitive bidding process, the lowest tender bid is the winning tender bid. The winning tender bid is selected as it best represents prevailing market prices at the time of the bid. Item unit price and contractor are the only dataset fields to contain data unique to the winning tender bid. All other dataset fields are the same for all tender bids for a project. The tender item number, item quantity, measurement unit and item unit price is extracted from each item line in the tender bid summary. If applicable, the installation depth for each item is extracted from the tender item description. The tender data, contract ID and city are extracted from the tender bid summary header. As previously discussed, for each line the tender item number and keywords in the tender item description determines the dataset item number for each line. The dataset item number determines the dataset item description, section and allocation. The data processing function cleaning and transformation process of tender bid summary data into an auditable tender bid dataset is summarized in Figure 4.1 and Figure 4.2.

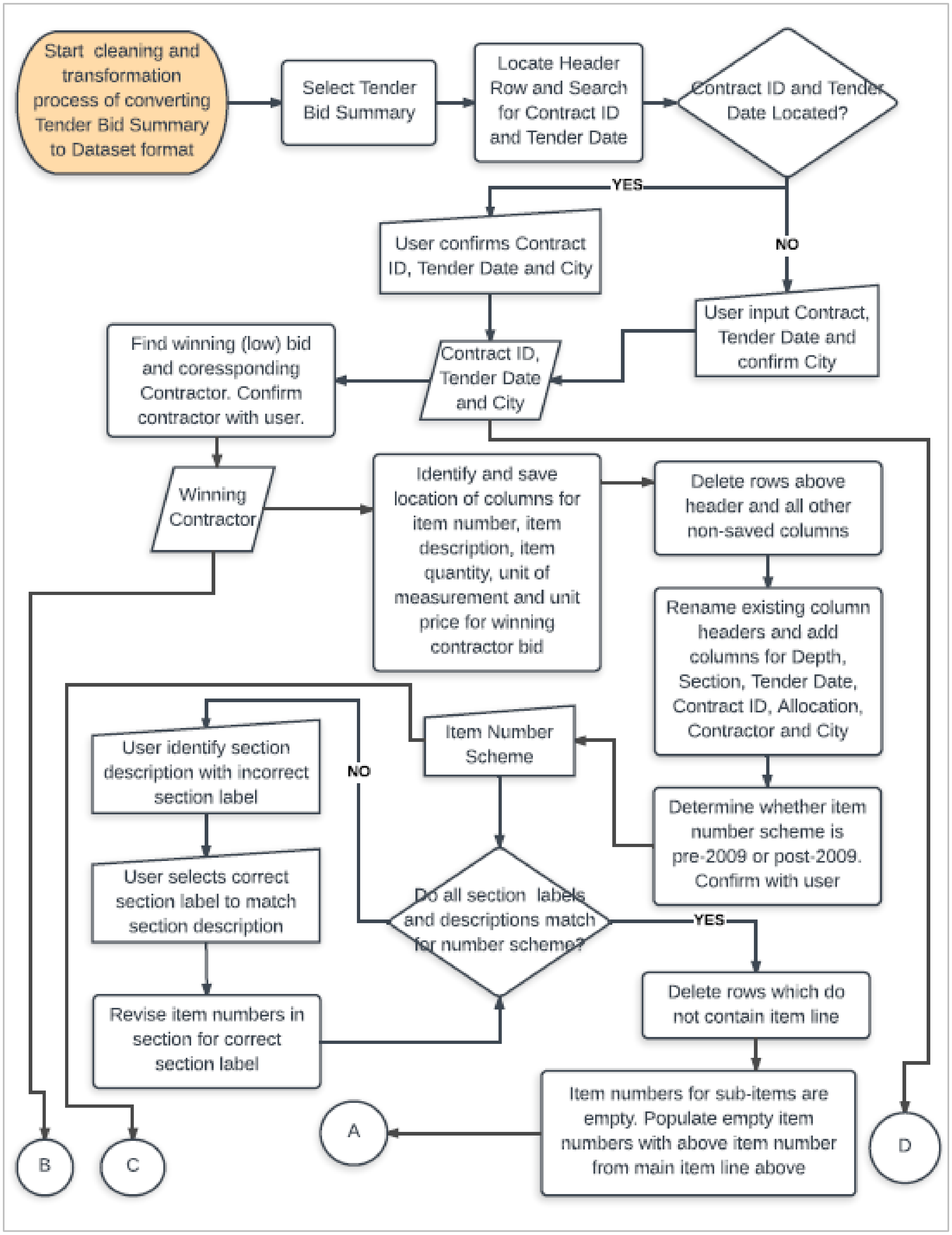

Figure 4.1 –Cleaning and transformation process of tender bid summary to dataset, Part 1.

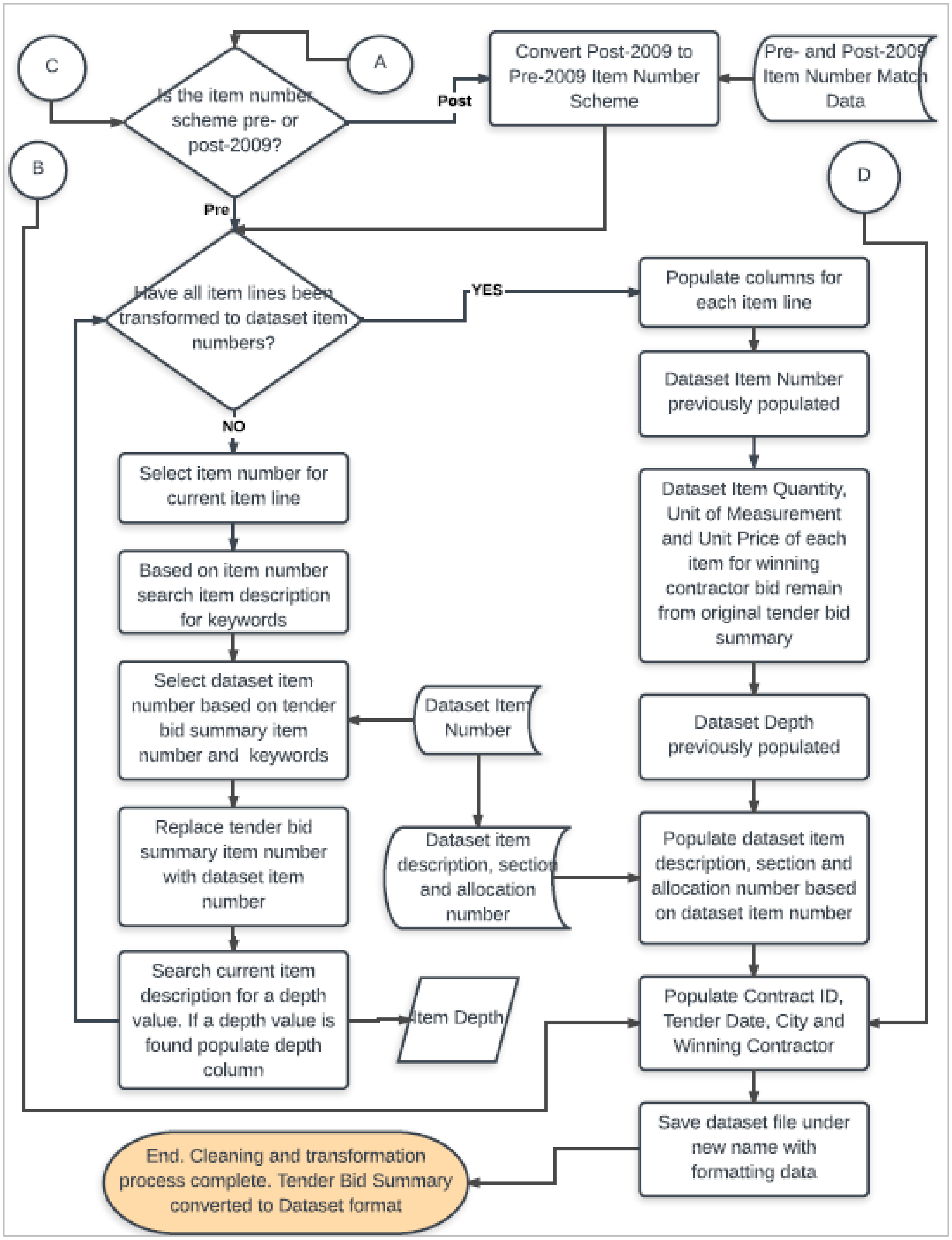

Figure 4.2 –Cleaning and transformation process of tender bid summary to dataset, Part 2.

The import process inputs construction price datasets for each tender bid summary into the capital works database. The first step of the import process is to check if the tender bid summary has already been cleaned and transformed into a dataset format. If the tender bid is in dataset format the dataset is imported into the database. If the tender bid summary is not in dataset format, the cleaning and transformation process is completed before importing the tender bid dataset into the database. The dataset is imported into three tables in the database: price data table, city table and contractor table. The price data table is populated with each dataset item line with contract ID, dataset item number, item quantity, measurement unit, item unit price and depth. The city table is populated with contract ID and city. The contractor table is populated with contract ID, tender date and winning contractor. Dataset item description, section and allocation number are not imported into the database as the relation to dataset item number is consistent and unchanging across all tender bid summaries. This relation of dataset item description, section and allocation number to dataset item numbers is represented in an item table in the database. The data processing function import process is summarized in Figure 4.3.

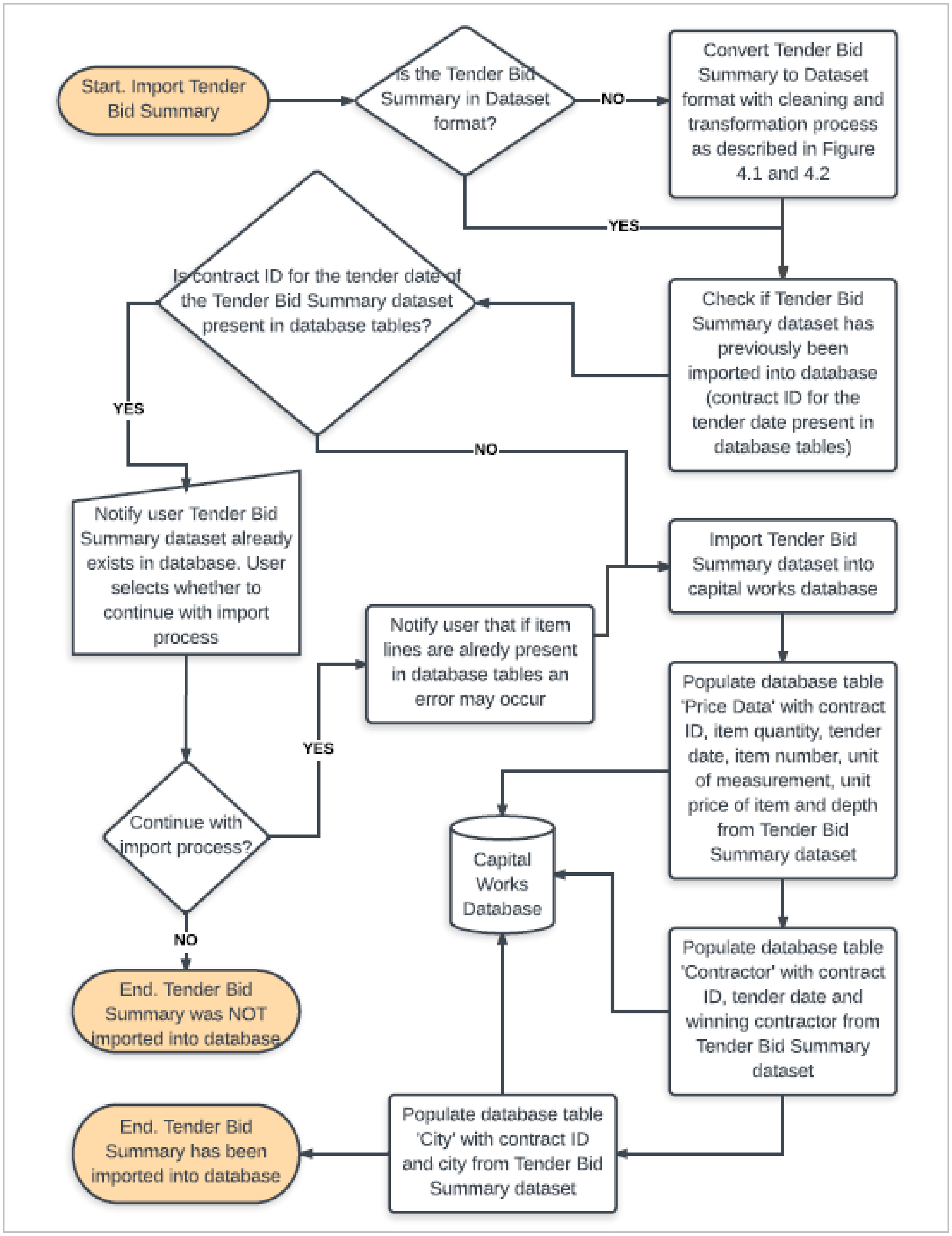

Figure 4.3 –Import process of tender bid summary into capital works database

4.3 Development of Watermain and Sanitary Sewer Unit Price Indices[1]

4.3.1 Overview

It has previously been shown that indices exist for general construction, non-residential building construction, residential building construction, highway construction, and treatment plant construction. However, there are very few indices which address water and wastewater infrastructure construction with available indices not being based on actual construction cost data. There is no known construction index for water or wastewater pipelines capital works construction based on actual construction cost or price data. Sliter (1974) has stated that "developing an index that accurately reflects types of construction while not limiting its usefulness by being too specific is a problem confronting the compliers of all indexes". This is not a concern as the purpose of this work is to develop specific indices for the construction of water and wastewater pipelines as the currently available construction indexes do not accurately represent this construction sector (MOE, 2007).

This section presents the development and calculation of indices for standard components of water and wastewater pipeline construction projects via the open cut construction method. Unit price indices are calculated for watermain pipe, watermain valves, watermain hydrants, watermain projects, sanitary sewer pipes, sanitary sewer maintenance holes and sanitary sewer projects. The indices are compiled from the construction price dataset based on City of Niagara Falls winning bids from tender bid summaries and progress payments, and RS Means data. Therefore the construction indices developed from the dataset are construction price indices representing the price paid by a client to the contractor for the construction work. Furthermore, the price indices are a compilation of bid/unit price indices and hedonic prices indices as the price indices are based on unit prices of construction tender bids with regression relationships to scale standard component to a common size. It should be noted that the same methodology used to calculate water and wastewater pipeline construction indices for the City of Niagara Falls can be applied to calculate water and wastewater pipeline construction indices for other cities based on their construction cost or price data.

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[1] The contents of this section of the chapter are incorporated in a manuscript of an article published by Taylor & Francis in Journal of Cost Analysis and Parametrics on August 10, 2016, available online: http://www.tandfonline.com/doi/full/10.1080/1941658X.2016.1201023. R. Rehan, R. Younis, A. J. A. Unger, B. Shapton, F. Budimir and M. A. Knight, "Development of Unit Cost Indices and Database for Water and Wastewater Pipelines Capital Works"

4.3.2 Elements of Watermain and Sanitary Sewer Unit Price Indices

The characteristics of the construction price data determine several elements of the price indices including data collection, basis of prices, index formulae, frequency of index and geographic coverage. The construction price data is supplied by the City of Niagara Falls and is collected from the City of Niagara Falls when available. The basis of the price indices is the construction price dataset which contains winning bids from tender bid summaries and invoices from progress payments. The dataset contains construction price data for projects which are irregularly spaced in time and, at times, sparse. Therefore the price index cannot be constructed as price relatives or price aggregates using the Laspeyres, Paasche or Fisher index formulae. The price indices are constructed as price levels which represent the unit price of a standard component at a certain time period. A price level is calculated for each construction project that contains the standard components. This means the frequency of the price index is sporadic and uneven as the construction projects occur irregularly in time and are, at times, sparse. The geographic coverage of the price indices is the City of Niagara Falls as the price indices are developed from City of Niagara Falls construction price data. However, these price indices may be used as proxy index for other cities, regions or municipalities until water and wastewater pipeline construction indices can be developed for the specific city, region or municipality using their own construction cost data and the methodology presented here. The use of a proxy index developed in the same construction sector is recommended over a proxy index developed in other construction sectors.

An important element of construction indices is the items included in the construction index. The water and wastewater pipeline construction price indices use bid items directly from watermain pipe, watermain valve, watermain hydrant, water service, sanitary sewer pipe, sanitary sewer maintenance hole and sanitary sewer lateral item categories. The observed unit prices of bid items in these item categories are surcharged with a proportional amount of the total price of general and provisional items. This ensures the full unit price of each item is captured in the price indices. Items in these categories are frequently found in watermain and sanitary sewer construction projects and with the inclusion of general and provisional items the changes in construction prices and the construction market are properly represented (Shrestha et al., 2016).

4.3.3 Watermain and Sanitary Sewer Unit Price Indices

Price indices are developed for each standard component of water and wastewater pipeline projects. Standard components were selected based on the most commonly observed items from all tender bid summaries and progress payments. The watermain pipe index includes items from the watermain pipe and water service item categories. The sanitary sewer pipe index includes items from the sanitary sewer pipe and sanitary sewer lateral item categories. Watermain valve, watermain hydrants and sanitary sewer maintenance hole indices include items from watermain valve, watermain hydrant and sanitary sewer maintenance hole item categories, respectively. The observed unit price of items in each standard component category cannot be compared as the items have varying size and material. For example, watermain pipes have diameters from 100 to 300 millimetres and the unit price of a 100 millimetre watermain pipe cannot be compared to the unit price of a 300 millimetre diameter watermain pipe with. Standard component items are scaled to a “reference” size to be consistent across all projects which allows for a comparison of unit prices and calculation of a price index. The reference size for watermain pipe is 150 millimetre diameter PVC, for watermain valve is 150 millimetre diameter, for sanitary sewer pipe is 375 millimetre diameter PVC and sanitary sewer maintenance hole is 1200 millimetre diameter at a 5 metre depth. Watermain hydrants are a standard size and are therefore not scaled. The reference sizes of the standard components were selected based on the most commonly observed item sizes from all of the tender bid summaries and progress payments. The reference size of each unit price index is summarized in Table 4.3.

Price indices are also developed for watermain and sanitary sewer “reference” projects which are composed of standard components. The purpose of developing a reference project is to be able to track the unit price of a section of watermain and sanitary sewer pipeline networks with consistent components. The standard components for watermain projects are pipes, valves and hydrants. The standard components of sanitary sewer projects are pipes and maintenance holes. The watermain reference project consists of a 1 metre length of 150 millimetre diameter PVC pipe, with one 150 millimetre diameter valve for every 100 metres of pipe, and one hydrant for every 150 metres of pipe. The sanitary sewer reference project consists of a 1 metre length of 375 millimetre diameter PVC pipe with one 1200 millimetre diameter maintenance hole at 5 metre depth for every 75 metres of pipe. The dimensions of the standard components in the reference projects are selected based on the most commonly observed item dimensions from all of the tender bid summaries and progress payments. The standard component items included in each price reference project index with reference sizes are summarized in Table 4.3.

Table 4.3 – Items included in each unit price index with reference size

Unit Price Index	Item Categories Included	Reference Size
Watermain Pipe	Watermain pipe surcharged with water services	1m length of 150mm diameter PVC
Watermain Valve	Watermain valve	150mm diameter
Watermain Hydrant	Watermain hydrant	Standard
Watermain Project	Watermain pipe surcharged with water services, watermain valve and watermain hydrant	1m length of 150mm diameter PVC pipe with one 150mm valve every 100m of pipe and one hydrant every 150m of pipe
Sanitary Sewer Pipe	Sanitary sewer pipe surcharged with sanitary sewer laterals	1m length of 375mm diameter PVC
Sanitary Sewer Maintenance Hole	Sanitary sewer maintenance hole	1200mm diameter with 5m depth
Sanitary Sewer Project	Sanitary sewer pipe surcharged with sanitary sewer laterals and sanitary sewer maintenance hole	1m length of 375mm diameter PVC pipe with one 1200mm diameter,5m depth maintenance hole every 75m of pipe

4.3.4 Calculation of Watermain and Sanitary Sewer Unit Price Indices

In this section, the procedure to calculate unit price indices for water and wastewater pipeline construction is described in detail. The described procedure is completed for each project represented in the construction price dataset to compute the unit price levels at each project's date.

The construction price dataset consists of item lines for many projects concerned with watermain, sanitary sewer, storm sewer and road capital works. The item lines contain the project date represented as time period *t*; the unit price of a particular item *n* during time period *t* represented as u_n^t; the total quantity of item *n* during time period *t* as q_n^t; the resulting total price of item *n* at time period *t* as p_n^t; and, the dataset item number for a particular item *n* as s_n which is part of a project identified by a contract ID at time period *t* as ID^t where the project resides in city C. A project may include multiple progress payments which represent payments to the contractor at different time periods. These multiple progress payments were aggregated to the project completion date. According to the dataset item number s_n the particular item *n* is categorized into one of the following sections: Section A – General Items; Section B – Watermains; Section C – Sanitary Sewers; Section D – Storm Sewers; Section E – Roads; and, Section F – Provisional Items. Items in Section B – Watermains are assigned to one of four standard item categories based the allocation number which is determined by the dataset item number s_n of a particular item *n*. The watermain standard item categories are pipe (Allocation 1), valves (Allocation 2), hydrants (Allocation 3), and water services (Allocation 4). . Items in Section C – Sanitary Sewers are assigned to one of three standard item categories based the allocation number which is determined by the dataset item number s_n of a particular item n. The sanitary sewer standard item categories are pipe (Allocation 5), maintenance holes (Allocation 6), and laterals (Allocation 7). This list is referred to as standard item category K and is detailed as:

$$K \in \left\{ \begin{matrix} \text{watermain pipe (WM-pipe), valves (WM-valve),} \\ \text{hydrants (WM-hydrant), water services (WM-services),} \\ \text{sanitary sewer pipe (SS-pipe), maintenance hole (SS-MH), laterals (SS-laterals)} \end{matrix} \right\}$$

To determine the revised unit prices of items in standard item categories, first map the total prices $p_{n,j}^t$ of construction items n in Sections j = B and C to the total prices $p_{k,j}^t$ of standard items k within standard item categories K of watermain and sanitary sewer projects. This is accomplished using the following steps:

i. For all items n in N_j, where N_j is the set of all construction items n in Sections j = B, C, compute the total cost of each item:

$$p_{n,j}^t = u_{n,j}^t q_{n,j}^t \tag{1}$$

ii. Identify the unique item number $s_{n,j}$ of each construction item n in N_j.

iii. For all items n in N_j map each item $n \mapsto k$ and $p_{n,j}^t \mapsto p_{k,j}^t$ based on $s_{n,j}$. By extension $u_{n,j}^t \mapsto u_{k,j}^t$ and $q_{n,j}^t \mapsto q_{k,j}^t$ will also be mapped. Let N_K be the set of all standard items k in a given standard item category K.

Second, determine the revised unit prices of standard items k by correcting for sharing of general and provisional costs between the standard watermain and sanitary sewer items. All watermain and sanitary sewer item total prices were surcharged by a fraction of the total price of the Section A – General Items and Section F – Provisional Items sections of the project. The fraction was specified by the percent of the total price of Sections B, C, D and E that each watermain and sanitary sewer item total price represented. The revised total price of each item was then divided by the number of units of the item to obtain a revised unit price. This is accomplished using the following steps:

i. For all items n in N_i, where N_i is the set of all items n in Sections i = A, F, compute total price of each item:

$$p_{n,i}^t = u_{n,i}^t q_{n,i}^t \tag{2}$$

ii. Map total cost of all items n in N_i to each standard item k. That is map $\sum_{N_i} p_{n,i}^t \mapsto p_{k,n,i}^t$ using:

$$p_{k,i}^t = \left(\sum\nolimits_{N_i} p_{n,i}^t\right) \times f_k^t \tag{3}$$

where:

$$f_k^t = \frac{p_{k,j}^t}{\sum_{N_H} p_n^t} \tag{4}$$

is the percent of the total cost of Sections B, C, D and E that the total cost of each watermain and sanitary sewer standard item k represents and N_H is the set of all construction items n in H where H represents Sections B, C, D and E combined.

iii. For items in Sections $j =$ B, C, surcharge the total prices of standard items $p_{k,j}^t$ (as determined above) with $p_{k,n,i}^t$. That is, the revised total price $\hat{p}_{k,j}^t$ of standard items is given as:

$$\hat{p}_{k,j}^t = p_{k,j}^t + \left[p_{k,A}^t + p_{k,F}^t\right] \tag{5}$$

where k is the standard item.

iv. Find the revised unit price $\hat{u}_k^t$ as:

$$\hat{u}_k^t = \hat{p}_{k,j}^t / q_{k,j}^t \tag{6}$$

for standard items k in Sections B and C.

Next, to calculate the surcharged unit prices of standard components the standard item categories K were reduced to standard component categories K'. The list of standard component categories is detailed as:

$$K' \in \left\{ \begin{matrix} \text{watermain pipe (WM-pipe)}, \text{valves (WM-valve)}, \text{hydrants (WM-hydrant)}, \\ \text{sanitary sewer pipe (SS-pipe)}, \text{maintenance hole (SS-MH)} \end{matrix} \right\}.$$

Standard items k were mapped to standard component elements k' where $N_{K'}$ is the set of all standard component elements k' in a given standard component category K'. Watermain pipe and sanitary sewer pipe elements are further surcharged with the total cost of all items in water service and lateral standard item categories, respectively. The surcharge for each watermain pipe element was proportional to the watermain pipe element's contribution to the total price of all elements in the watermain pipe standard component category. The surcharge for each sanitary sewer pipe is distributed in a similar method. The calculation of surcharged unit prices of standard components is accomplished using the following steps:

i. For all items k in $N_{K=WM-valve,WM-hydrant}$ map each item $k \mapsto k'$. The revised unit price is now a surcharged unit price $\hat{u}_k^t \mapsto \hat{u}_{k'}^t$. By extension $u_k^t \mapsto u_{k'}^t$ and $q_k^t \mapsto q_{k'}^t$ will also be mapped.

ii. For all watermain pipe elements k' in $N_{K'=\text{WM}-\text{pipe}}$ mapped from watermain pipe standard items k in $N_{K=WM-pipe}$, compute the surcharged unit price $\hat{u}_{k'}^{t}$ of each item as:

$$\hat{u}_{k'}^{t} = \hat{u}_{k}^{t} + f_{k,K=\text{WM-pipe}}^{t} \tag{7}$$

where $\hat{u}_{k}^{t}$ is the revised unit price of the watermain pipe standard item k and $f_{k,K=\text{WM-pipe}}^{t}$ is the allocation of water service standard items to the watermain pipe standard item k calculated as:

$$f_{k,K=\text{WM-pipe}}^{t} = \frac{p_{k,B}^{t}}{\sum_{N_{K=\text{WM}-\text{pipe}}} p_{k,B}^{t}} \times \frac{\sum_{N_{K=\text{WM}-\text{services}}} \hat{p}_{k,B}^{t}}{q_{k,B}^{t}} \tag{8}$$

Here, $p_{k,B}^{t}$ represents the total price of the watermain pipe item k, $\sum_{N_{K=\text{WM}-\text{pipe}}} p_{k,B}^{t}$ represents the total price of all watermain pipe standard items, $\sum_{N_{K=\text{WM}-\text{services}}} \hat{p}_{k,B}^{t}$ represents the total revised price of all water service standard items, and $q_{k,B}^{t}$ is the pipe length of standard item k. It can be noted that $p_{k,B}^{t}$ and $\sum_{N_{K=\text{WM}-\text{pipe}}} p_{k,B}^{t}$ can be substituted with the revised price $\hat{p}_{k,B}^{t}$ and $\sum_{N_{K=\text{WM}-\text{pipe}}} \hat{p}_{k,B}^{t}$, respectively, and the surcharge result will be identical.

iii. For all items k in $N_{K=SS-MH}$ map each item $k \mapsto k'$. The revised unit price is now a surcharged unit price $\hat{u}_{k}^{t} \mapsto \hat{u}_{k'}^{t}$. By extension $u_{k}^{t} \mapsto u_{k'}^{t}$ and $q_{k}^{t} \mapsto q_{k'}^{t}$ will also be mapped.

iv. For all sanitary sewer pipe elements k' in $N_{K'=SS-\text{pipe}}$ mapped from sanitary sewer pipe standard items k in $N_{K=SS-pipe}$, compute the surcharged unit price $\hat{u}_{k'}^{t}$ for each item as:

$$\hat{u}_{k'}^{t} = \hat{u}_{u}^{t} + f_{k,K=\text{SS-pipe}}^{t} \tag{9}$$

where $\hat{u}_{k}^{t}$ is the revised unit price of the sanitary sewer pipe standard item k and $f_{k,K=\text{SS-pipe}}^{t}$ is the allocation of lateral elements to the sanitary sewer pipe item k calculated as:

$$f_{k,K=SS\text{-pipe}}^{t} = \frac{p_{k,C}^{t}}{\sum_{N_{K=SS-\text{pipe}}} p_{k,C}^{t}} \times \frac{\sum_{N_{K=SS-\text{laterals}}} \hat{p}_{k,C}^{t}}{q_{k,C}^{t}} \tag{10}$$

Here, $p_{k,C}^{t}$ represents the total price of the sanitary sewer pipe item k, $\sum_{N_{K=\text{SS}-\text{pipe}}} p_{k,C}^{t}$ represents the total cost of all sanitary sewer pipe standard items,

$\sum_{N_{K=\mathrm{SS-laterals}}} \hat{p}_{k,C}^{t}$ represents the total revised price of lateral standard items, and $q_{k,C}^{t}$ is the pipe length of standard item k. It can be noted that $p_{k,C}^{t}$ and $\sum_{N_{K=\mathrm{SS-pipe}}} p_{k,C}^{t}$ can be substituted with the revised price $\hat{p}_{k,C}^{t}$ and $\sum_{N_{K=\mathrm{SS-pipe}}} \hat{p}_{k,C}^{t}$, respectively, and the allocation result will be identical.

The surcharging procedure retains the total bid value of the project, with the total (and unit) price of each item in the watermain and sanitary sewer sections being increased. The loading of unit prices described above generates a spread between the observed dataset unit price $u_{k'}^{t}$ and the computed surcharged unit price $\hat{u}_{k'}^{t}$ for all items k' in $N_{K'}$. This surcharge spread $\mathcal{S}_{k'}^{t}$ represents the increase in the unit price of each standard component item k' in $N_{K'}$ to ensure the total bid value of the project is retained and is calculated as:

$$\mathcal{S}_{k'}^{t} = \hat{u}_{k'}^{t} - u_{k'}^{t} \tag{11}$$

The scaling of observed dataset unit price for all standard component items k' in $N_{K'}$ to reference sizes is conducted using scaling relationships. The scaling relationships were previously developed for watermain pipes, valves, sanitary sewer pipes, and sanitary sewer maintenance holes by Rehan et al. (2016). The development of scaling relationships is summarized briefly below with a detailed description available in Rehan et al. (2016). The scaling relationships are developed from regression models for standard component categories K'which describe unit price $Y_{[K']}$ as a function of size $X_{[K']}$. The scaling relationships are based on RS Means cost data, City of Niagara Falls progress payment unit price data and City of Niagara Falls tender bid unit price data for 2007. RS Means location factors for 2007 are applied to RS Means cost data to account for different locations. Watermain pipe and valves are scaled based on pipe and valve diameter ranging from 100 to 300 millimetres, while hydrants are not scaled. Sanitary sewer pipes are scaled based on pipe diameter and material type with PVC pipe diameter ranging from 100 to 450 millimetres and concrete pipe diameter ranging from 300 to 900 millimetres. Sanitary sewer maintenance holes are scaled based on maintenance hole diameter and depth with diameter ranging from 1200 to 1800 millimetres and depth ranging from 1.2 to 13.2 metres. The scaling of the observed unit price of a standard component item k' to a reference size is accomplished using the following steps:

i. For all items k' in $N_{K'}$ break down the observed unit price of each item $u_{obs,k'}^{t}$ into labour, material and equipment components, for the observed item size using:

$$\left[u_{v,k'}^{t}\right]_{obs} = u_{obs,k'}^{t} \times f_{v,K'} \tag{12}$$

where v takes on values m, l and e for material, labour and equipment, respectively; K' is the standard component category in which standard component item k' resides; the component v portion of the observed unit price is $\left[u_{v,k'}^{t}\right]_{obs}$; and f is the fraction of the regression estimated unit price attributed to component v. The fractions are computed as:

$$\text{Material: } f_{m,K'} = \frac{\left[p_{m,K'}\right]_{RSM_{obs}} \times \left[LF_{m,C}\right]_{RSM}}{Y_{\left[K'\right]_{OBS}}} \tag{13}$$

$$\text{Labour: } f_{l,K'} = \frac{\left[p_{l,K'}\right]_{RSM_{obs}} \times \left[LF_{l,C}\right]_{RSM}}{Y_{\left[K'\right]_{OBS}}} \tag{14}$$

$$\text{Equipment: } p_{e,K'} = Y_{\left[K'\right]_{OBS}} - \left[p_{m,K'}\right]_{RSM_{obs}} \times \left[LF_{m,C}\right]_{RSM} - \left[p_{l,K'}\right]_{RSM_{obs}} \times \left[LF_{l,C}\right]_{RSM} \text{ ; } f_{e,k} = \frac{p_{e,K'}}{Y_{\left[K'\right]_{OBS}}} \tag{15}$$

where the subscripts m, l and e represent material, labour and equipment; $\left[p_{(.),K'}\right]_{RSM_{obs}}$ is the material and labour price from RS Means database for the observed item size; $\left[LF_{(.),C}\right]_{RSM}$ is the material and labour location factor from the RS Means database for the city *C* where project which contains standard component item k' resides; and $Y_{\left[K'\right]_{OBS}}$ is the regression unit price for observed item size.

ii. Individually scale the labour, material and equipment unit price components of standard component item k' to the reference size:

$$\left[u_{v,k'}^{t}\right]_{ref} = \frac{\left\{p_{v,k'}^{t}\right\}_{RSM_{ref}}}{\left\{p_{v,k'}^{t}\right\}_{RSM_{obs}}} \times \left[u_{v,k'}^{t}\right]_{obs} \tag{16}$$

where $\left\{p_{v,k'}^{t}\right\}_{RSM_{ref}}$ is the RS Means price of component v for the reference size; $\left\{p_{v,k'}^{t}\right\}_{RSM_{obs}}$ is the RS Means price of component v for the observed item size; and $\left[u_{v,k'}^{t}\right]_{ref}$ is the unit price of component v scaled to the reference size.

iii. Compute the scaled unit price at the reference size of standard component item k' by summing the individually scaled labour, material and equipment unit prices:

$$\left[u_{k'}^{t}\right]_{ref} = \sum_{v} \left[u_{v,k'}^{t}\right]_{ref} \tag{17}$$

The surcharge spread from equation (11) is added to the scaled unit price at the reference size from equation (17) to calculate the unit price level of each standard component item k'. The purpose of this is to capture the total project price despite the fact that it no longer represents the total bid value from the progress payments or tender bid. To calculate the unit price level of standard component K', the unit price level of all standard component items k' in $N_{K'}$ is combined. The calculation of unit price level for standard component K' is accomplished in the following steps:

i. For all items k' in $N_{K'}$, compute the unit price level $\left[upl_{k'}^{t}\right]_{ref}$ of each item:

$$\left[upl_{k'}^{t}\right]_{ref} = \sum_{v}\left[u_{v,k'}^{t}\right]_{ref} + \mathcal{S}_{k'}^{t} \tag{18}$$

ii. Compute the unit price level $\left[upl_{K'}^{t}\right]_{ref}$ of standard component K' by averaging the unit price levels of all standard component items k' in $N_{K'}$:

$$\left[upl_{K'}^{t}\right]_{ref} = \textstyle\sum_{N_{K'}}\left[upl_{k'}^{t}\right]_{ref}. \tag{19}$$

The unit price level for watermain reference project is computed from unit price levels of pipe, valve and hydrant standard components. The unit price level for sanitary sewer reference project is computed from the unit price levels of pipe and maintenance hole standard components. This procedure is conducted for each project represented in the construction price dataset to create a unit price level at time t for pipe, valve, hydrant, and reference project for watermain construction and pipe, maintenance hole and reference project for sanitary sewer construction. The unit price levels of all projects are then combined to create unit price indexes for pipe, valve, hydrant, and reference project for watermain construction and pipe, maintenance hole and reference project for sanitary sewer construction spanning from the time of the earliest to most recent project represented in the construction price dataset.

4.4 Estimating Inflation and Forecasting Construction Costs

The basis of any quantitative forecasting technique is a reliable time series of past observations and that the factors determining the patterns observed in that time series are likely to continue to exist (Vose, 2008). Lowe, Emsley and Harding (2006) state the selection of a forecasting technique is determined “by its ease of operation, familiarity, speed and a satisfactory degree of accuracy, in conjunction with the availability of design information.”

Geometric Brownian motion (GBM) is a well-known time series mathematical model and a fundamental process for financial modeling (Brigo, Dalessanddro, Neugebauer, & Triki, 2009; Vose, 2008). GBM is the most widely used model of stock price behaviour and has also been used to model the price of rice, labour costs and financial index data (Hsu & Wu, 2011; Hull, 2012). GBM has also been applied to study the stochastic processes in biology, physics, astronomy, economics, epidemiology, ecology, mechanics, and mathematical finance (Hsu & Wu, 2011; Iacus, 2008). For example, GBM is the underlying process of the Black-Scholes formula for pricing derivative contracts (Brigo et al., 2009). Sypkens (2010) used GBM to analyze and model the Financial Times Stock Exchange 100 Index which represents the top 100 companies listed on the London Stock Exchange. Beleski (2006) used GBM to analyze and model the inflation from the consumer price index and examine inflation linked financial products including stock options, bonds, swaps, and interest rates cap and floor.

Geometric Brownian motion is selected as the forecasting technique for water and wastewater pipeline construction prices as GBM is a well-established method to model and analyze the time varying behaviour of financial indices which include CPI and stock market indices, stock prices and interest rates. GBM allows the identification of inflation (rate of appreciation) and volatility to quantify long term trends. Furthermore GBM can be applied to time series which are either regularly or irregularly spaced in time. The use of GBM as a technique to model and forecast construction indices was previously identified and implemented by Younis et al. (2016).

4.4.1 Geometric Brownian Motion with Drift

GBM describes the random behaviour or instantaneous movements of an asset price level S_t over time as (Brewer, Feng, & Kwan, 2012; Brigo et al., 2009; Hull, 2012; Ladde & Wu, 2009; Seydel, 2012; Vose, 2008):

$$dS_t = \mu S_t dt + \sigma S_t dW_t \tag{20}$$

where S_t is the stock price, μ and σ are constants which represent the drift (rate of appreciation or inflation) parameter and volatility parameter, respectively, t is time and W_t is a standard Wiener process or Brownian motion, a special diffusion process characterized by independently identically distributed increments having distribution normal distribution $N(0, dt)$. dW_t represents an increment in a standard Wiener process or Brownian motion characterized as $dW_t = \epsilon\sqrt{dt}$, where ε is a random draw from the standard normal distribution (Brewer et al., 2012).

The two crucial parameters in GBM are drift μ and volatility σ which represent the expected return and standard deviation of returns of the underlying asset per annum, respectively (Brewer et al., 2012). Volatility can also be described as the likelihood that something will suddenly change or change in an extreme way. This assists with quantifying the risk of overestimation or underestimation of the asset price level (Joukar & Nahmens, 2016). Drift and volatility parameters are stated in annual terms and remain constant in the series time interval (Brewer et al., 2012; Brigo et al., 2009).

The drift μ and volatility σ parameters of an index are estimated by calibrating the GBM model to the historical values of the index available (Brewer et al., 2012; Brigo et al., 2009). When calibrating GBM to the historical values of an index, the first data point is fit exactly in time and has a volatility of zero at this point meaning the first data point is assumed correct (Iacus, 2008; Vose, 2008). Once the GBM model has been calibrated and parameters estimated, forecasts can be conducted to estimate the future expected and potential values of the index (Brewer et al., 2012; Brigo et al., 2009). Different calibration methods for parameter estimation are required for indices which are frequent and regularly spaced in time, and sparse and irregularly spaced in time (Vose, 2008). These methods are described below.

4.4.1.1 Parameter Estimation for Indices Regularly Spaced in Time

For indices which are frequent and regularly spaced in time, GBM drift and volatility parameters are estimated using maximum likelihood estimation. In this work these indices include CPI, NRBCPI, LCDDT and S&P/TSX composite index. The basic concept of maximum likelihood estimation is to find estimates of GBM parameters for the probability density function that will maximize the actual probability of being able to generate the observed index values (Brigo et al., 2009; Vose, 2008).

Maximum likelihood estimation is used to estimate the GBM drift and volatility parameter in the following steps (Brigo et al., 2009; Teka, 2013; Vose, 2008):

i. For GBM as shown in equation (20), maximum likelihood estimation is completed on log-values rather than raw values. Let the log return of index value S_{t_i} at time t_i be represented by random variable x_{t_i} given as:

$$x_{t_i} = \ln\left(S_{t_i}\right)/\ln\left(S_{t_{i-1}}\right) \tag{21}$$

where x_{t_i} is normally distributed for all $x_{t_1}, x_{t_2}, \dots, x_{t_n}$ and independence is assumed for all $x_{t_1}, x_{t_2}, \dots, x_{t_n}$.

ii. With normality and independence the likelihood function is given as:

$$L(\theta\ ) = \ f_\theta\left(x_{t_1}, x_{t_2}, \dots, x_{t_n}\right) = \prod_{i=1}^{n} f_\theta\left(x_{t_i}\right) \tag{22}$$

where $\theta = \ (\mu, \sigma)$ and f_θ is the probability density function given as:

$$f_\theta\left(x_{t_i}\right) = \frac{1}{x_{t_i}\sigma\sqrt{2\pi\Delta t}} \exp\left[-\frac{\left(x_{t_i} - \left(\mu - \frac{1}{2}\sigma^2\right)\Delta t\right)^2}{2\sigma^2\Delta t}\right] \tag{23}$$

iii. The θ parameters are found by maximizing the likelihood function using numerical optimization. For GBM, the log return increments x_{t_i} are normal independently identically distributed random variables determined by mean and variance. The mean m and variance v parameters of x_{t_i} are computed as:

$$m_{x_{t_i}} = \left(\mu - \frac{1}{2}\sigma^2\right)\Delta t \tag{24}$$

$$v_{x_{t_i}} = \ \sigma^2\Delta t \tag{25}$$

iv. For GBM, to solve for the closed form solution of mean m and variance v, the derivative of the probability density function in equation (23) is taken with respect to m and v and setting the resulting derivatives equal to zero. The sample mean and variance are estimated as:

$$\hat{m}_{x_{t_i}} = \sum_{i=1}^{n} \frac{x_{t_i}}{n} \tag{26}$$

$$\hat{v}_{x_{t_i}} = \ \sum_{i=1}^{n} \frac{\left(x_{t_i} - \hat{m}\right)^2}{n} \tag{27}$$

v. By solving equations (26) and (27) and substituting into the re-arranged equations (24) and (25) the drift μ and volatility σ parameters can be estimated as:

$$\mu = \frac{\widehat{m_{x_{t_i}}}}{\Delta t} + \frac{1}{2}\sigma^2 \tag{28}$$

$$\sigma = \sqrt{\frac{\hat{v}_{x_{t_i}}}{\Delta t}} \tag{29}$$

4.4.1.2 Parameter Estimation for Indices Irregularly Spaced in Time

The unit price indices of pipe, valve, hydrant, and reference project for watermain construction and pipe, maintenance hole and reference project for sanitary sewer construction are sparse and irregularly spaced in time. The use of maximum likelihood estimation is difficult, or potentially infeasible, for large irregularly spaced datasets due to computational limitations (Fuentes, 2007). Therefore estimation of GBM drift and volatility parameters for these indices cannot be conducted using maximum likelihood estimation. Vose (2008) presents a method for GBM drift and volatility parameter estimation when data is missing or irregularly spaced in time. This method is used to estimate GBM drift μ and volatility σ parameters in the following steps:

i. Similar to maximum likelihood estimation, the method describes by Vose (2008) is completed on log-values rather than raw values. Let the log return of index value S_{t_i} at time t_i to index value S_{t_0} at time t_0 be represented by random variable ξ_{t_i} given as:

$$\xi_{t_i} = \ln\left(S_{t_i}\right)/\ln\left(S_{t_0}\right) \tag{30}$$

which is normally distributed with mean m and variance v:

$$m_{\xi_{t_i}} = \left(\mu - \frac{1}{2}\sigma^2\right)\Delta t \tag{31}$$

$$v_{\xi_{t_i}} = \sigma^2 \Delta t \tag{32}$$

ii. The random variables ξ_{t_i} are transformed to standard normal N(0,1) variables z_i using the standard deviate for normal distribution given as:

$$\mathrm{z}_{t_i} = \left(\frac{\xi_{t_i} - m_{\xi_{t_i}}}{\sqrt{v_{\xi_{t_i}}}}\right) \tag{33}$$

iii. The drift μ and volatility σ parameters are estimated by varying μ and σ to have a mean of z_{t_i} equal to zero and a variance of z_{t_i} equal to one by minimizing $(|\mu| + |\sigma|)$. The optimization problem is presented below (Vose, 2008):

$$\begin{aligned} &\text{minimize } (|\mu| + |\sigma|) \\ &\text{such that} \\ &\mathrm{E}\left[\mathrm{z}_{t_i}\right] = 0, \\ &Var\left[\mathrm{z}_{t_i}\right] = 1 \end{aligned} \tag{34}$$

$-3 \leq z_{t_i} \leq 3$ else z_{t_i} is discarded

Here the first two constraints are the identities of a normal distribution. As previously discussed contractors may share costs between construction items in an attempt to improve their cash flow or gain a bidding advantage (S.-J. Kim & Shim, 2016). This sharing of costs may impact the prices of watermain and sanitary sewer items causing them to be excessively high or low. The third constraint was implemented to exclude unit price levels from the analysis which have been influenced by this sharing of costs.

4.4.2 Forecasting Future Index Values

Using stochastic calculus and integrating the result between two time instants $t_i = T$ and $t_{i-1} = 0$ the solution to GBM in equation (20) forecasts the index value S_T at time = T as (Brewer et al., 2012; Brigo et al., 2009; Iacus, 2008):

$$S_T = S_0 \exp\left(\left[\mu - \frac{1}{2}\sigma^2\right]T + \sigma W(T)\right) \tag{35}$$

where the S_0 is the index value at time = 0, μ is the drift parameter, σ is the volatility parameter and $W(T)$ is a random draw from the standard normal distribution. Equation (35) represents the continuous solution to equation (20). The discrete solution to forecast the index value S_{t_i} between time instants $t_0 < t_1 < \cdots < t_n$ is solved as (Brewer et al., 2012; Brigo et al., 2009):

$$S_{t_i} = S_{t_{i-1}} \exp\left(\left[\mu - \frac{1}{2}\sigma^2\right]\Delta t + \sigma Z_i \sqrt{\Delta t}\right) \tag{36}$$

where $\Delta t = t_i - t_{i-1}$ and $Z_1, Z_2, \dots, Z_n$ are independent random draws from the standard normal distribution.

Equations (35) and (36) forecast potential future index values. However, the purpose of forecasting is to estimate future expected index value. For GBM the expected future index value is equivalent to the mean (or first statistical moment) of S_T. This is equivalent to the GBM solution from equation (35) with no uncertainty or a volatility of zero. The expected future value for S_T at time = T is given as (Brewer et al., 2012; Brigo et al., 2009; Iacus, 2008; Vose, 2008):

$$\mathrm{E}(S_T) = S_0 \exp(\mu T) \tag{37}$$

while the variance of S_T is given as (Brewer et al., 2012; Brigo et al., 2009; Iacus, 2008; Vose, 2008):

$$\mathrm{Var}(S_T) = S_0{}^2[\exp(2\mu T)][\exp(\sigma^2 T) - 1] \tag{38}$$

4.4.3 Applicability of GBM Model

The use of GBM to model a time series assumes the GBM model is applicable to represent the time series. This assumption suggests the mean (Equations (24) and (31)) and variance (Equations (25) and (32)) of the GBM model are applicable to represent the time series and therefore the estimates of the drift parameter, volatility parameter and future expected values are valid. To ensure the applicability of GBM for modeling, the following assumptions must be checked (Brigo et al., 2009; Ruppert & Matteson, 2015; Tsay, 2005):

1. The log returns of the index values follow a normal distribution (or equivalently, the index values follow a lognormal distribution);
2. The process increments are independent; and

Normality of a time series can be investigated using the Kolmogorov-Smirnov (K-S) test, Shapiro-Wilk test, Lilliefors test, Anderson-Darling test, Jarque-Bera test and Cramer-von Mises test (Massey, 1951; Miller, 1956; Razali & Wah, 2011; Ruppert & Matteson, 2015). The Shapiro-Wilk test is the preferred normality test as it is equally or more powerful than the other tests. However, all tests have low power for small sample sizes (Razali & Wah, 2011; Ruppert & Matteson, 2015). Normality can also be examined using quantile-quantile (Q-Q) plots where the quantiles of the time series are plotted against the quantiles of a chosen comparison distribution, in this case the standard normal distribution. The Q-Q plot will be linear if the chosen comparison distribution provides a good fit to the time series (Brigo et al., 2009; Ruppert & Matteson, 2015). In statistics, the independence of process increments means there is no autocorrelation in the time series. Autocorrelation plots are a common method to check for autocorrelation in a time series. The assumption of independence is acceptable if no significant lags exist in the autocorrelation plot and there is no serial correlation between process increments. Independence of process increments can also be checked with the Ljung-Box test (Ruppert & Matteson, 2015; Tsay, 2005).

4.5 Water and Wastewater Pipeline Capital Works Database[2]

A relational database was developed in Microsoft Access to automate the tender bid summary data processing function, calculation of water and wastewater construction unit price indices and estimation of inflation and volatility of water and wastewater construction unit price indices. This database is derived from a unit cost database developed by Rehan et al. (2016) which only included the calculation of water and wastewater construction unit price indices. The calculation of water and wastewater construction unit price indices in the unit cost database has been revised and updated, with the tender bid summary data processing function and estimation of inflation and volatility of water and wastewater construction price indices being incorporated to create the water and wastewater pipeline capital works database. These processes are automated with programming routines written in Visual Basic for Applications (VBA). This fulfills the need identified by Shrestha et al. (2016) to automate the data cleaning, transformation and index calculation processes while increasing the efficiency, consistency and accuracy of construction unit price index calculation and estimates of inflation and volatility. The database also contains the construction price data from tender bid summaries and progress payments; construction materials, equipment and labour cost data with location factors from RS Means and regression relationships for scaling of unit prices; database item numbers, descriptions, allocations and sections; and relation of tender bid item numbers to dataset item numbers. The construction price data is stored in three tables: price data table, city table and contractor table. The price data table contains contract ID, dataset item number, item quantity, measurement unit, item unit price and depth for each item line from tender bid summaries and progress payments. The city table contains contract ID and city. The contractor table contains contract ID, tender date and winning contractor. The data processing function populates these three tables with construction price data from tender bid summaries. The user interface of database form for the data processing function is shown in Figure 4.4. When the *Import Tender Summary* command is executed the cleaning, transformation and import process discussed in Section 4.2 is conducted. In addition to

[2] A portion of the contents of this section of the chapter are incorporated in a manuscript of an article published by Taylor & Francis in Journal of Cost Analysis and Parametrics on August 10, 2016, available online: http://www.tandfonline.com/doi/full/10.1080/1941658X.2016.1201023. R. Rehan, R. Younis, A. J. A. Unger, B. Shapton, F. Budimir and M. A. Knight, “Development of Unit Cost Indices and Database for Water and Wastewater Pipelines Capital Works”

populating the database tables, an Excel spreadsheet of the cleaned and transformed construction price data is created.

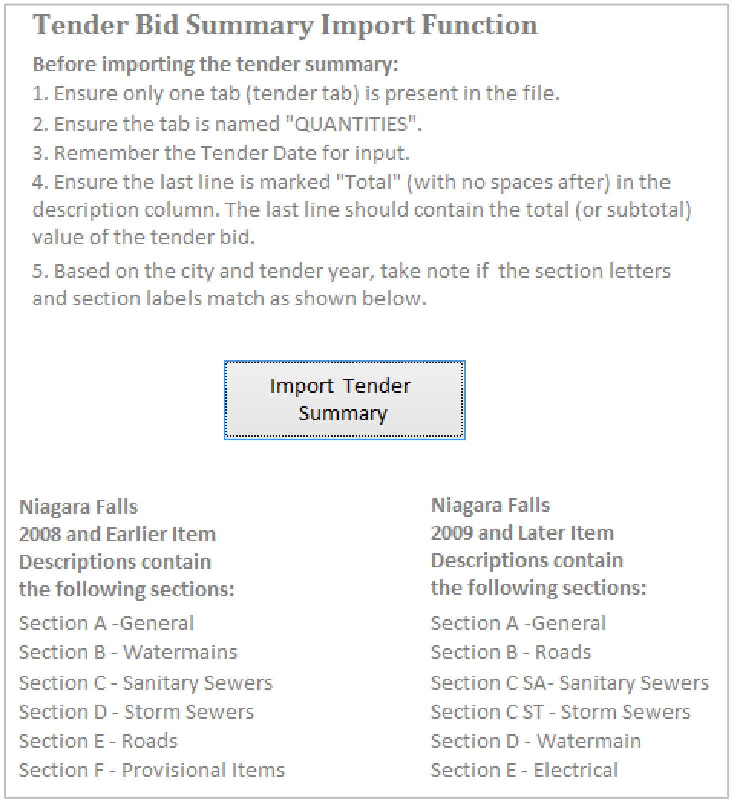

Figure 4.4 – Data processing function form for City of Niagara Falls tender bid summaries

RS Means location factors are related to cities in the city table by a reference city match table. Construction materials, equipment and labour cost data are connected to item sizes via dataset item numbers within the VBA routine for the construction price indices calculation. Dataset item information is contained in two tables: item table and allocation table. The item table consists of dataset item number, item description, section and allocation, while the allocation table contains allocation and allocation description. Each of the tables to relate tender bid item numbers to dataset item numbers contains the item number for specific tender bid summaries and the corresponding dataset item number. The structure of the relational database tables discussed above is presented in Figure 4.5. A primary key (PK) is a column (or field) in a database table whose value uniquely identifies each row (record) in the database table. A foreign key (FK) identifies a column (or field) in a database table which is a unique column (or field) or primary key in another database table. The relationships between the database tables are classified as one ( ) to many ( ) relationships which indicate that rows (or records) from one table is mapped exactly to one row (or record) in another table. For example, the items from the item table are mapped to exactly one standard component allocation in the allocation table, or each standard component allocation in the allocation table contains many construction items in the item table.

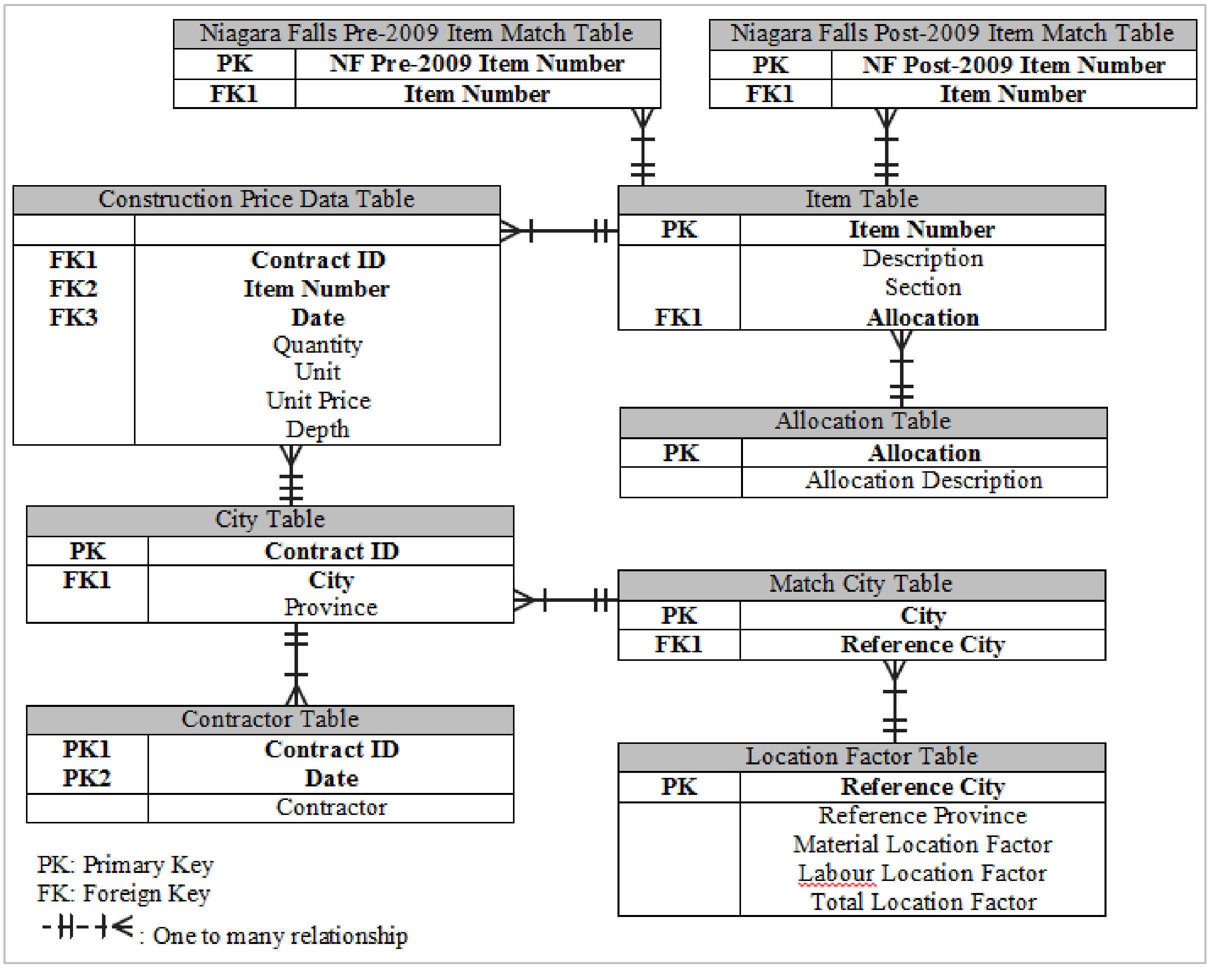

Figure 4.5 –Database table relationships (adapted from (Rehan et al., 2016))

The calculation of water and wastewater pipeline construction unit price indices and estimation of inflation and volatility of water and wastewater construction unit price indices is automated in the same database process. The user interface of the database forms for watermain and sanitary sewer construction price analysis is shown in Figure 4.6 and Figure 4.7, respectively.

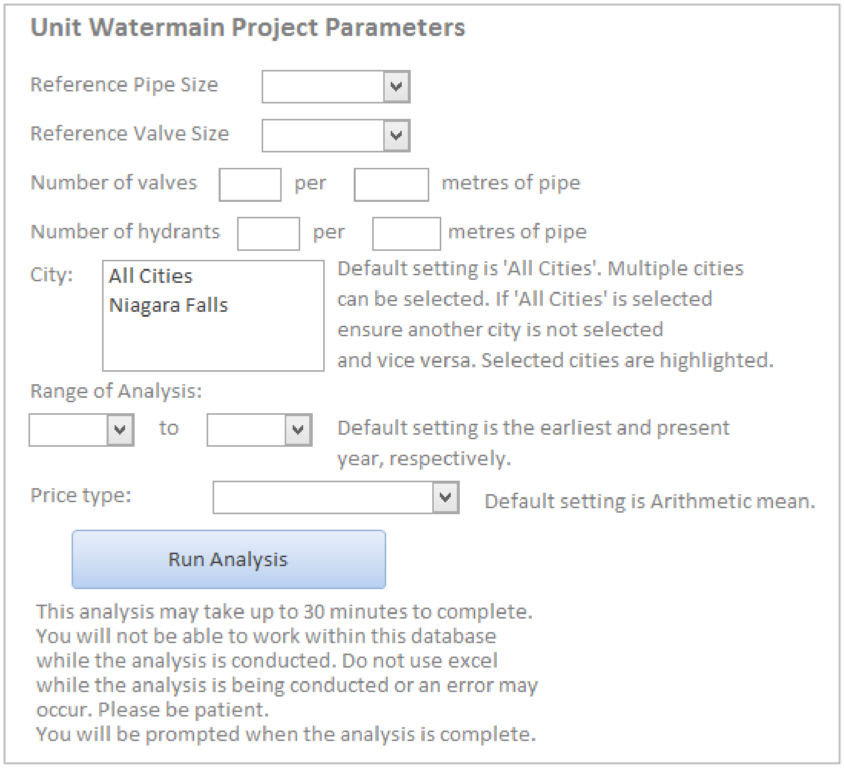

Figure 4.6 – Database user interface for watermain construction price analysis

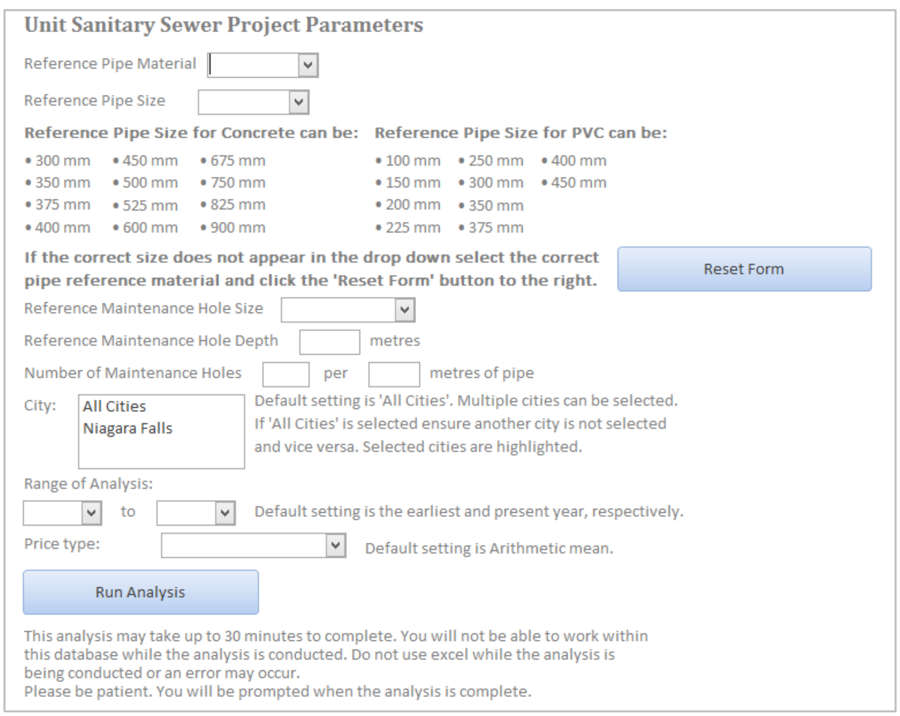

Figure 4.7 – Database user interface for sanitary sewer construction price analysis

The watermain construction price analysis requires the user to specify the components of a reference watermain project which includes reference pipe size, reference valve size, number of valves per metre length of pipe and number of hydrants per metre length of pipe. The sanitary sewer construction price analysis requires the user to specify the components of a reference sanitary sewer project which includes reference pipe size and material, reference maintenance hole size and depth, and number of maintenance holes per metre length of pipe. Both forms allow the user to customize the data from which cities should be included and the year range of analysis. This allows construction unit price indices and inflation estimates to be calculated for a specific city or grouping of cities over a specific time frame. When *Run Analysis* command is executed the water and wastewater construction price indices are calculated from the raw construction price data as discussed in Section 4.3.4. Next, the estimation of inflation and volatility using GBM is conducted from the calculated water and wastewater construction unit price indices as discussed in Section 4.4.1.2. Finally, the forecasting and plotting of expected future index values and ten scenarios of potential future index values as discussed in Section 4.4.2 is completed using the inflation and volatility parameter estimates. The results of the calculation of construction unit price indices, estimation of inflation and volatility and forecasting of future index values for water and wastewater construction is presented in an Excel spreadsheet. The database also contains a process to automatically update the item table with new and revised dataset item numbers, descriptions, sections and allocations.

Chapter 5
Results

5.1 Overview

The results presented in this chapter are derived from the methodology presented in the previous chapter. First, the cleaning and transformation of tender bid summaries into an auditable construction price dataset which is then imported into a capital works database is shown. Second, the calculated construction unit price indices for watermain and sanitary sewer standard components and reference projects are presented. Third, the results of GBM calibration for watermain and sanitary sewer construction unit price indices and general market indices to estimate of inflation and volatility are shown. Next, future expected values of construction prices are forecast using GBM and the estimated inflation in watermain and sanitary sewer construction unit price indices and general market indices. Finally, the contractor markup for water and wastewater construction projects is estimated.

5.2 Data Processing Function

The automated data processing function cleans and transforms tender bid summaries from the City of Niagara Falls into an auditable construction price dataset which is then imported into a capital works database. The automated data processing function results are demonstrated using an example tender bid summary. The example tender bid summary has been adapted from an actual tender bid summary for confidentiality and is shown in Figure 5.1.The data processing function is separated into two automated processes: tender bid summary cleaning and transformation process and dataset import process. The result of the cleaning and transformation process (construction price dataset) for the example tender bid summary is shown in Figure 5.2. The result of the import process for the example tender bid summary is shown in Figure 5.3.

SCHEDULE OF QUANTITIES AND UNIT PRICES
CONTRACT 2010-121-06 TENDER CHECK
MUNICIPAL SERVICES IMPROVEMENTS
FIRST ST. FROM SIXTH AVE. TO TENTH AVE. and
TENTH AVE. FROM FIFTH STREET TO SEVENTH ST.

All Tenderers are to note that the Supplementary Special Provisions have underwent a revision as of March 2012. The City will not be responsible for any bidder not being aware of the changes from previous tender documents. Any tender prices bid should be reflective of the requirements and provisions as detailed herein. The following General Requirements should be considered as amendments and/or extensions to the Special Provisions - General, as listed in the Niagara Peninsula Standard Contract Document, latest revision.

					CONTRACTOR 1		CONTRACTOR 2		CONTRACTOR 3		CONTRACTOR 4	
ITEM NO.	SPEC NO.	DESCRIPTION	ESTIMATED QUANTITY	UNIT	UNIT PRICE	TOTAL PRICE	UNIT PRICE	TOTAL PRICE	UNIT PRICE	TOTAL PRICE	UNIT PRICE	TOTAL PRICE
		SECTION 'A' - GENERAL										
A1	A1	Bonding	1	L.S.	$44,500.00	$44,500.00	$34,000.00	$34,000.00	$9,999.75	$9,999.75	$17,308.10	$17,308.10
A2	A2 SSP	Pre-condition survey	1	L.S.	$3,400.00	$3,400.00	$1,500.00	$1,500.00	$1,200.00	$1,200.00	$1,044.75	$1,044.75
A3	A3 SSP	Site Office	1	L.S.	$1,000.00	$1,000.00	$2,000.00	$2,000.00	$2,500.00	$2,500.00	$500.00	$500.00
A4	A4 SSP	Construction layout and record information -										
		a) layout	1	L.S.	$4,200.00	$4,200.00	$8,000.00	$8,000.00	$4,100.00	$4,100.00	$4,042.50	$4,042.50
		b) progress and final record photography	1	L.S.	$100.00	$100.00	$750.00	$750.00	$700.00	$700.00	$250.00	$250.00
		c) record survey and drawings	1	L.S.	$1,700.00	$1,700.00	$2,500.00	$2,500.00	$1,750.00	$1,750.00	$1,627.50	$1,627.50
A5	A5 SSP	Clearing and grubbing										
		a) Remove existing trees	5	Each	$100.00	$500.00	$100.00	$500.00	$400.00	$2,000.00	$300.00	$1,500.00
		b) Remove existing stumps	6	Each	$75.00	$450.00	$200.00	$1,200.00	$300.00	$1,800.00	$300.00	$1,800.00
		vegetation	10	m^2	$75.00	$750.00	$20.00	$200.00	$50.00	$500.00	$50.00	$500.00
A8	A8	Construction signs, traffic control and traffic										

Figure 5.1 – Example tender bid summary for import function demonstration

Item	Description	TotalQuantity	MeasurementUnit	UnitPrice	Depth	Section	CompDate	ContractID	SerialNu	Allocation	Contractor	City
A1	Bonding	1	L.S.	$44,500.00	0	General	6/30/2010	2010-121-06	1	0	Contractor 1	Niagara Falls
A2	Pre-condition survey	1	L.S.	$3,400.00	0	General	6/30/2010	2010-121-06	2	0	Contractor 1	Niagara Falls
A4	Site Office	1	L.S.	$1,000.00	0	General	6/30/2010	2010-121-06	3	0	Contractor 1	Niagara Falls
A5	Construction layout and "as constructed" for all items				0	General	6/30/2010	2010-121-06	4	0	Contractor 1	Niagara Falls
A5.a	Construction layout and "as constructed" for all items-layout	1	L.S.	$4,200.00	0	General	6/30/2010	2010-121-06	5	0	Contractor 1	Niagara Falls
A5.c	Construction layout and "as constructed" for all items-progress and final record photography	1	L.S.	$100.00	0	General	6/30/2010	2010-121-06	6	0	Contractor 1	Niagara Falls
A5.d	Construction layout and "as constructed" for all items-record survey and drawings	1	L.S.	$1,700.00	0	General	6/30/2010	2010-121-06	7	0	Contractor 1	Niagara Falls
F14	Cleaning and grubbing				0	Provisional Items	6/30/2010	2010-121-06	8	0	Contractor 1	Niagara Falls
F9	Tree Removal	5	Each	$100.00	0	Provisional Items	6/30/2010	2010-121-06	9	0	Contractor 1	Niagara Falls
F14.b	Cleaning and grubbing-Remove existing	6	Each	$75.00	0	Provisional Items	6/30/2010	2010-121-06	10	0	Contractor 1	Niagara Falls
F14.c	Cleaning and grubbing-Remove existing brush, shrubs & vegetation	10	m^2	$75.00	0	Provisional Items	6/30/2010	2010-121-06	11	0	Contractor 1	Niagara Falls
A7.c	Traffic Control-Construction signs, traffic control and traffic management plan	1	L.S.	$15,000.00	0	General	6/30/2010	2010-121-06	12	0	Contractor 1	Niagara Falls
F10	Contingency Allowance	1	L.S.	$75,000.00	0	Provisional Items	6/30/2010	2010-121-06	13	0	Contractor 1	Niagara Falls
F4	Trench or road sub-excavation including placement of 50 mm crusher run stone	10	m^3	$35.00	0	Provisional Items	6/30/2010	2010-121-06	14	0	Contractor 1	Niagara Falls
F5	15 MPa Concrete	10	m^3	$125.00	0	Provisional Items	6/30/2010	2010-121-06	15	0	Contractor 1	Niagara Falls
F8	Test Holes				0	Provisional Items	6/30/2010	2010-121-06	16	0	Contractor 1	Niagara Falls
F8.a	Test Holes-Maximum 0.5 m deep	1	Each	$50.00	0	Provisional Items	6/30/2010	2010-121-06	17	0	Contractor 1	Niagara Falls
F8.b	Test Holes-Maximum 1.0 m deep	1	Each	$100.00	0	Provisional Items	6/30/2010	2010-121-06	18	0	Contractor 1	Niagara Falls
F8.c	Test Holes-Maximum 2.0 m deep	1	Each	$125.00	0	Provisional Items	6/30/2010	2010-121-06	19	0	Contractor 1	Niagara Falls
F8.d	Test Holes-Maximum 4.0 m deep	2	Each	$200.00	0	Provisional Items	6/30/2010	2010-121-06	20	0	Contractor 1	Niagara Falls
F8.f	Test Holes-Via Hydro Vac. any depth	3	Hour	$185.00	0	Provisional Items	6/30/2010	2010-121-06	21	0	Contractor 1	Niagara Falls
E1	Road Excavation and removals				0	Roads	6/30/2010	2010-121-06	22	13	Contractor 1	Niagara Falls

Figure 5.2 – Construction price dataset created from cleaning and transformation process for example tender bid summary

tblCostData | tblContractor | tblCity

ContractID	Quantity	CompDate	ItemNumbe	Unit	UnitPrice	Depth
2010-121-06	1	6/30/2012	A1	L.S.	$44,500.00	0
2010-121-06	1	6/30/2012	A2	L.S.	$3,400.00	0
2010-121-06	7600	6/30/2012	A3.b	t	$7.00	0
2010-121-06	1	6/30/2012	A4	L.S.	$1,000.00	0
2010-121-06	1	6/30/2012	A5.a	L.S.	$4,200.00	0
2010-121-06	1	6/30/2012	A5.c	L.S.	$100.00	0
2010-121-06	1	6/30/2012	A5.d	L.S.	$1,700.00	0
2010-121-06	1	6/30/2012	A7.c	L.S.	$15,000.00	0
2010-121-06	215	6/30/2012	B1.a.2	m	$108.00	0
2010-121-06	1	6/30/2012	B2.b	Each	$950.00	0
2010-121-06	2	6/30/2012	B24.d.1	Each	$1,050.00	0
2010-121-06	5	6/30/2012	B29	Hour	$100.00	0
2010-121-06	1	6/30/2012	B3.a	Each	$4,400.00	0
2010-121-06	1	6/30/2012	B3.b.1	Each	$490.00	0
2010-121-06	1	6/30/2012	B3.b.2	Each	$550.00	0
2010-121-06	1	6/30/2012	B3.b.3	Each	$600.00	0
2010-121-06	1	6/30/2012	B31.c	Each	$300.00	0
2010-121-06	1	6/30/2012	B31.f	Each	$450.00	0
2010-121-06	1	6/30/2012	B32	Each	$50.00	0
2010-121-06	100	6/30/2012	B4.a.1	m	$92.00	0
2010-121-06	9	6/30/2012	B6.a.2	Each	$137.00	0
2010-121-06	9	6/30/2012	B6.b.2	Each	$60.00	0
2010-121-06	9	6/30/2012	B7.b	Each	$145.00	0
2010-121-06	91.2	6/30/2012	C1.c	m	$185.00	3

tblCostData | tblContractor | tblCity

ContractID	CompDate	Contractor
2010-121-06	6/30/2010	Contractor 1

tblCostData | tblContractor | tblCity

ContractID	City	Province
2010-121-06	Niagara Falls	ON

Figure 5.3 – Example tender bid summary input into capital works database

5.3 Watermain and Sanitary Sewer Construction Unit Price Indices

Construction unit price indices represented as unit price levels for watermain standard components and reference projects are shown in Figure 5.4, with maximum and minimum of each unit price level. Watermain standard components are watermain pipe, valve and hydrant. The reference size for watermain pipe is 150 millimetre diameter PVC and for watermain valve is 150 millimetre diameter. Watermain hydrants are a standard size and are therefore not scaled. The watermain reference project consists of a 1 metre length of 150 millimetre diameter PVC pipe, with one 150 millimetre diameter valve for every 100 metres of pipe, and one hydrant for every 150 metres of pipe. Appendix A contains the construction unit price indices for watermain standard components and reference project along with maximum and minimum of each unit price level.

Construction unit price indices represented as unit price levels for sanitary sewer standard components and reference project are shown in Figure 5.5 with maximum and minimum of each unit price level. Sanitary seweer standard components are sanitary sewer pipe and maintenance hole. The reference size for sanitary sewer pipe is 375 millimetre diameter PVC and sanitary sewer maintenance hole is 1200 millimetre diameter at a 5 metre depth. The sanitary sewer reference project consists of a 1 metre length of 375 millimetre diameter PVC pipe with one 1200 millimetre diameter maintenance hole at 5 metre depth for every 75 metres of pipe. Appendix B contains the construction unit price indices for sanitary sewer standard components and reference project along with maximum and minimum of each unit price level.

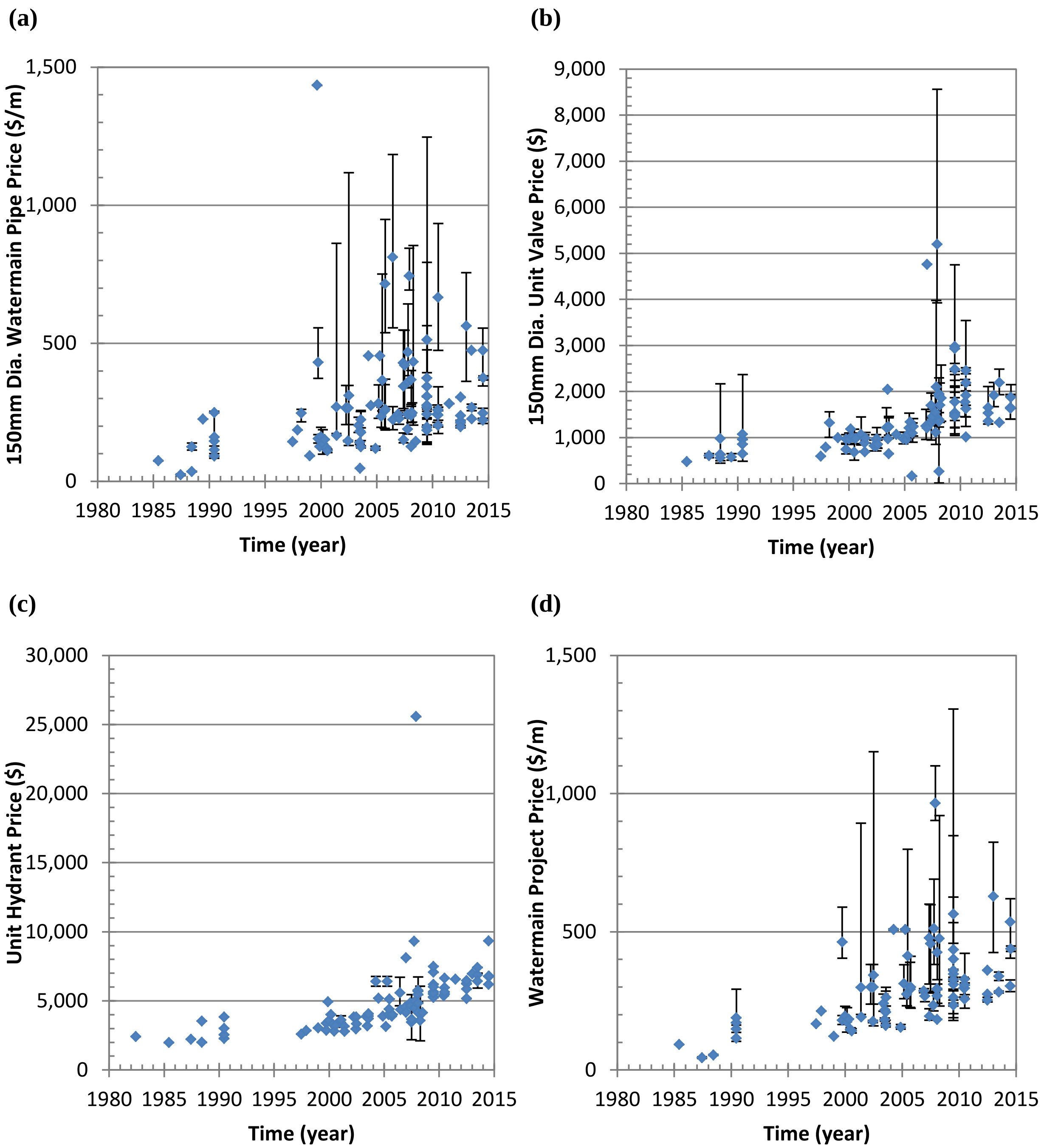

Figure 5.4 – Construction unit price indices for watermain pipe (a), valve (b) and hydrant (c) standard components, and watermain project (d) at reference sizes with maximum and minimum unit prices at each index point

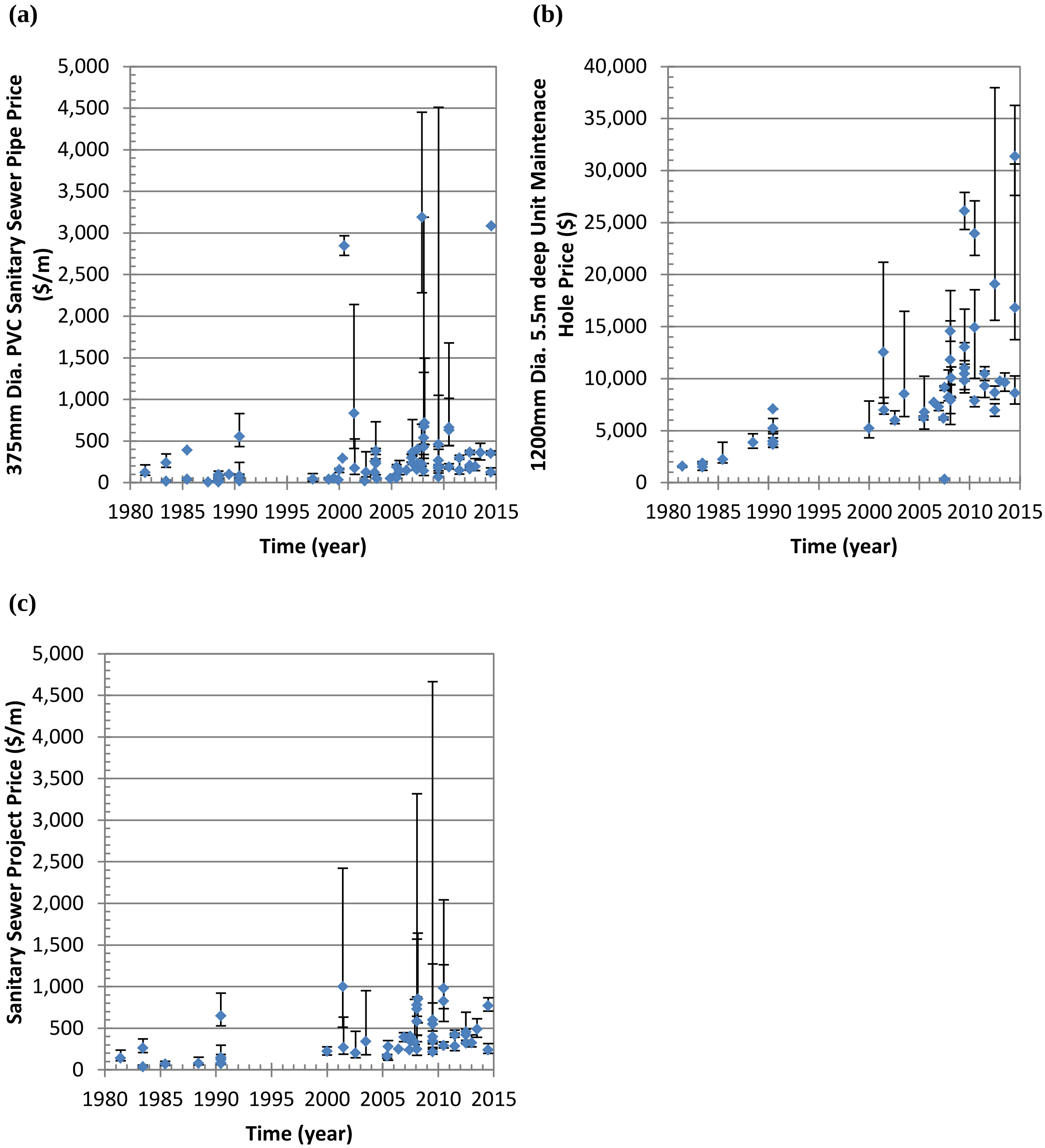

Figure 5.5 – Construction unit price indices for sanitary sewer pipe (a) and sanitary sewer maintenance hole (b) standard components, and sanitary sewer project (c) at reference sizes with maximum and minimum unit prices for each index point

5.4 Estimating Inflation in Watermain, Sanitary Sewer, and General Market Indices

The inflation and volatility parameters are estimated from the calibration of GBM to the unit price indices of the watermain and sanitary sewer stand components and reference project construction are presented in Table 5.1. Table 5.1 also shows the estimated inflation and volatility parameters from calibrating GBM to the index values of the general market indices presented in this work. For each watermain, sanitary sewer and general market index, Table 5.1 contains the parameter estimation method, and inflation and volatility per annum with 95 percent confidence intervals.

Table 5.1 – Inflation and volatility estimation results for watermain, sanitary sewer and general market indices

Index	Estimation Method	Inflation Per Annum (α)	Volatility Per Annum (σ)
CPI	Equations (28) & (29) on CPI_i	0.0225±0.0034	0.0094±0.0032
NRBCPI	Equations (28) & (29) on $NRBCPI_i$	0.0317±0.0140	0.0377±0.0127
LDCCT	Equations (28) & (29) on $LDCCT_i$	0.0377±0.0114	0.0309±0.0104
S&P/TSX	Equations (28) & (29) on $S\&P/TSX_i$	0.0690±0.0502	0.1236±0.0416
Watermain Pipe	Equation (34) on $WM\text{-}pipe_i$	0.0636±0.0319	0.0987±0.0687
Watermain Valve	Equation (34) on $WM\text{-}valve_i$	0.0509±0.0183	0.0572±0.0395
Watermain Hydrant	Equation (34) on $WM\text{-}hydrant_i$	0.0281±0.0144	0.0506±0.0352
Watermain Project	Equation (34) on $WM\text{-}project_i$	0.0579±0.0245	0.0766±0.0532
Wastewater Pipe	Equation (34) on $SS\text{-}pipe_i$	0.0525±0.0927	0.2746±0.1918
Wastewater Maintenance Hole	Equation (34) on $SS\text{-}MH_i$	0.0741±0.0245	0.0803±0.0560
Wastewater Project	Equation (34) on $SS\text{-}project_i$	0.0466±0.0494	0.1627±0.1134

All values after ± indicate 95% confidence intervals.

5.4.1 Inflation in General Market Indices

The inflation estimates for general market indices are shown in Figure 5.6 as curves representing the expected index values calculated from Equation (37) with the inflation per annum from Table 5.1 for CPI (Figure 5.6a), NRBCPI (Figure 5.6b), LDCCT (Figure 5.6c), and S&P/TSX composite index (Figure 5.6d). The expected value curves are plotted against the index values represented as symbols.

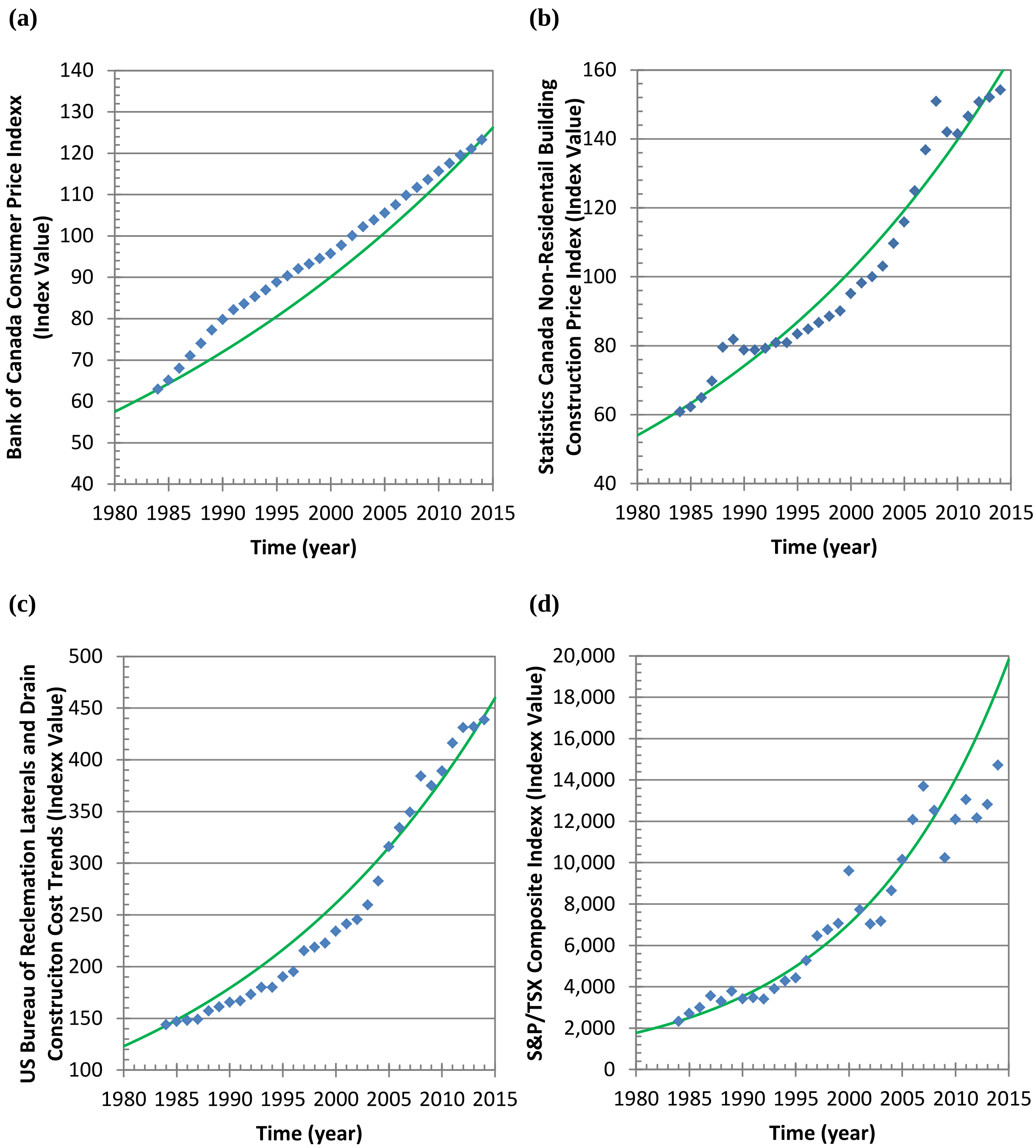

Figure 5.6 – Estimated index values for Bank of Canada CPI (a), NRBCPI (b), USBR LDCCT (c), and S&P/TSX (d) indices based on inflation estimates from GBM calibration. The curves represent expected index values and symbols represent index values

To check the applicability of the GBM model to represent CPI, NRBCPI, LDCCT and TSX composite index the normality and independence of log return increments is tested. The Shapiro-Wilk test results and Q-Q plots to check the assumption of normality and Ljung-Box test results and ACF plots to check the assumption of independence can be found in Appendix C. The p-values of the Shapiro-Wilk test for log returns of CPI, NRBCPI, LDCCT and TSX composite index are 4.77×10^{-5}, 0.1911, 0.2196 and 0.171, respectively. The p-values of NRBCPI, LDCCT and TSX composite index are all above the commonly used significance level of 0.05 indicating the log returns of NRBCPI, LDCCT and TSX composite index are normally distributed. The p-value of CPI is below the significance level of 0.05 indicating the log returns of CPI are not normally distributed. These results are confirmed by Q-Q plots for the log returns of NRBCPI, LDCCT and TSX composite index approximate to a straight line and are within 95% confidence intervals, while the Q-Q plot for log returns of CPI deviates from a straight line outside the 95% confidence intervals at high quantiles. Figure C.1, Figure C.2, Figure C.3 and Figure C.4 in Appendix C display the Q-Q plots for log returns of CPI, NRBCPI, LDCCT and TSX composite index, respectively.

The p-values of the Ljung-Box test for log returns of CPI, NRBCPI, LDCCT and TSX composite index are 1.368×10^{-12}, 0.1265, 0.959 and 0.5907, respectively. The p-values of NRBCPI, LDCCT and TSX composite index are all above the commonly used significance level of 0.05 indicating the log returns of NRBCPI, LDCCT and TSX composite index are independent. The p-value of CPI is below the significance level of 0.05 indicating the log returns of CPI are not independent. These results are confirmed by autocorrelation plots for the log returns of NRBCPI, LDCCT and TSX composite index where no significant lags are observed indicating the assumption of independence of log returns is acceptable (Brigo et al., 2009). The autocorrelation plot of CPI displays significant lags at lag 1, lag 2 and lag 3 above the 95% confidence intervals indicating correlation between process increments and the assumption of independence of log returns is not acceptable (Brigo et al., 2009). Figure C.5, Figure C.6, Figure C.7 and Figure C.8 in Appendix C display the autocorrelation plots for log returns of CPI, NRBCPI, LDCCT and TSX composite index, respectively. Benth (2004) highlights reasons for using GBM to model financial indices despite the long term dependency regularly present in financial data. These include closed-form solutions for many option price cases, ability to realistically model the dynamic behaviour of stocks and a decrease in assumption shortcomings when compared to the assumptions for other models.

Therefore the GBM model is applicable to represent NRBCPI, LDCCT and TSX composite index. For the reasons outlined by Benth (2004) and to remain consistent with the model applicable to other indices in this work, GBM will be used to model CPI. However, future work should explore the applicability of other models to represent CPI.

5.4.2 Inflation in Watermain Components and Reference Project Indices

The inflation estimates for watermain standard component and reference project unit price indices are shown in Figure 5.7 as curves representing the expected value of the construction unit prices calculated from Equation (37) with the inflation per annum from Table 5.1 for watermain pipe (Figure 5.7a), valve (Figure 5.7b), hydrant (Figure 5.7c), and reference project (Figure 5.7d) unit price indices. The expected value curves are plotted against the unit price indices represented as symbols. The red symbols in Figure 1.1 – Comparison of input price, output price and seller price indices (OECD, 1997). Figure 5.7 indicate unit price index data which was discarded during the calibration of GBM to estimate inflation and volatility parameters as defined in Equation (34). The discarded data is primarily found at early time periods when the variance is small as the first index value provides the reference time.

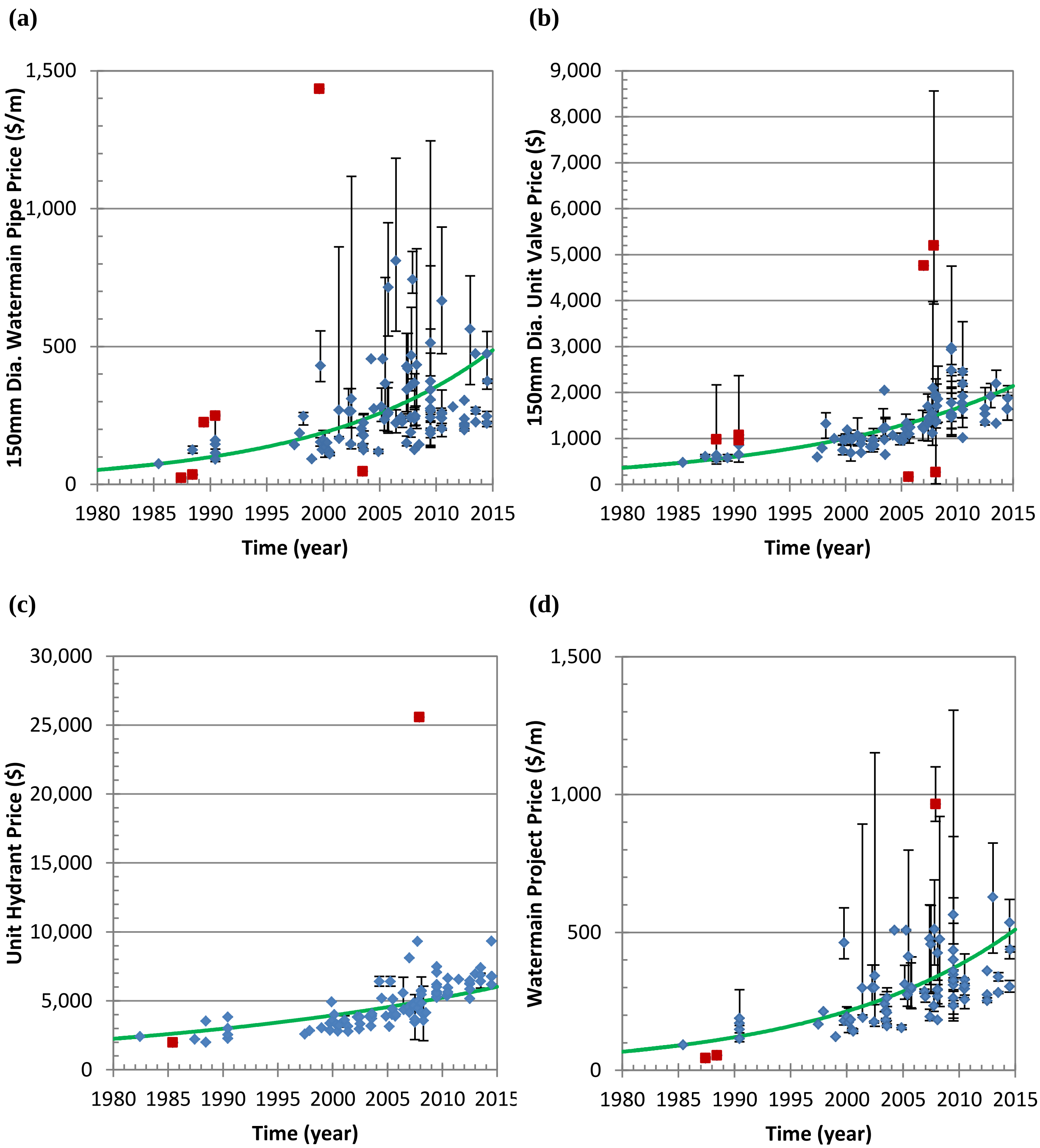

Figure 5.7 – Estimated index values for watermain pipe (a), valve (b), hydrant (c), and reference project (d) based on inflation estimates from GBM calibration. The curves represent expected index values and symbols represent index values with red symbols indicating data which was discarded during GBM parameter estimation

To check the applicability of the GBM model to represent watermain project, watermain pipe, watermain valve and watermain hydrant indices the normality and independence of log return increments is tested. The Shapiro-Wilk test results and Q-Q plots to check the assumption of normality and Ljung-Box test results and ACF plots to check the assumption of independence can be found in Appendix D. The p-values of the Shapiro-Wilk test for log returns of watermain project, watermain pipe, watermain valve, and watermain hydrant indices are 0.5747, 0.5978, 0.8471 and 0.02731, respectively. The p-values of watermain project, watermain pipe and watermain valve indices are all above the commonly used significance level of 0.05 indicating the log returns of watermain project, watermain pipe and watermain valve indices are normally distributed. These results are confirmed by Q-Q plots for the log returns of watermain project, watermain pipe and watermain valve indices which approximate to a straight line and are within 95% confidence intervals. Figure D.1, Figure D.2 and Figure D.3 in Appendix D display the Q-Q plots for log returns of watermain project, watermain pipe and watermain valve indices, respectively. The p-value of CPI is slightly below the significance level of 0.05 at 0.02731 indicating the log returns of watermain hydrant index are not normally distributed. However, most points in the Q-Q plot for log returns of watermain hydrant index approximate to a straight line within the 95% confidence intervals with light tails slightly deviating from a straight line outside the 95% confidence. Therefore, although not directly applicable, the GBM model provides a rough representation of the watermain hydrant index with respect to normality (Brigo et al., 2009). Figure D.4 in Appendix D displays the Q-Q plot for log returns of the watermain hydrant index.

The p-values of the Ljung-Box test for log returns of watermain project, watermain pipe, watermain valve and watermain hydrant indices are 1.973×10^{-4}, 1.473×10^{-5}, 0.2609, and 0.01908, respectively. The p-value of the watermain valve index is above the commonly used significance level of 0.05 indicating the log returns of the watermain valve index are independent. The p-values of watermain project, watermain pipe and watermain hydrant indices are below the significance level of 0.05 indicating the log returns of watermain project, watermain pipe and watermain hydrant indices are not independent. However, as the watermain indices contain multiple price levels at one time period the correlation between log returns is expected with significant lags occurring at low lags. The autocorrelation plot of log returns of the watermain project index displays significant lags at lag 1 above the 95% confidence intervals. The autocorrelation plot of log returns of the watermain pipe index displays significant lags at lag 1 above the 95% confidence intervals. The autocorrelation plot of log returns of the watermain valve index displays lags at lag 1and lag 2 above the 95% confidence intervals (Brigo et al., 2009). The lags observed in the log returns of watermain project, watermain pipe and watermain valve indices are deemed acceptable and as no other significant lags are observed in the autocorrelation plots the assumption of independence of log returns is acceptable. The autocorrelation plot of log returns of the watermain hydrant index displays significant lags at lag 1, lag 5 and lag 6 above the 95% confidence intervals (Brigo et al., 2009). Because several significant lags are observed the assumption of independence of log returns is not acceptable. Figure D.5, Figure D.6, Figure D.7 and Figure D.8 in Appendix D display the autocorrelation plots for log returns of watermain project, watermain pipe, watermain valve and watermain hydrant indices, respectively.

Therefore the GBM model is applicable to represent watermain project, watermain pipe and watermain valve indices. For the reasons outlined by Benth (2004) and to remain consistent with the model applicable to other indices in this work, GBM will be used to model the watermain hydrant index. However, future work should explore the applicability of other models to represent the watermain hydrant index.

5.4.3 Inflation in Sanitary Sewer Components and Reference Project Indices

Figure 5.8 displays the inflation estimates for sanitary sewer standard component and reference project unit price indices as curves representing the expected value of the construction unit prices calculated from Equation (37) with the inflation per annum from Table 5.1 for sanitary sewer pipe (Figure 5.8a), maintenance hole (Figure 5.8b), and reference project (Figure 5.8c) unit price indices. The expected value curves are plotted against the unit price indices represented as symbols. The red symbols in Figure 1.1 – Comparison of input price, output price and seller price indices (OECD, 1997). Figure 5.8 indicate unit price index data which was discarded during the calibration of GBM to estimate inflation and volatility parameters as defined in Equation (34). The discarded data is primarily found at early time periods when the variance is small as the first index value provides the reference time.

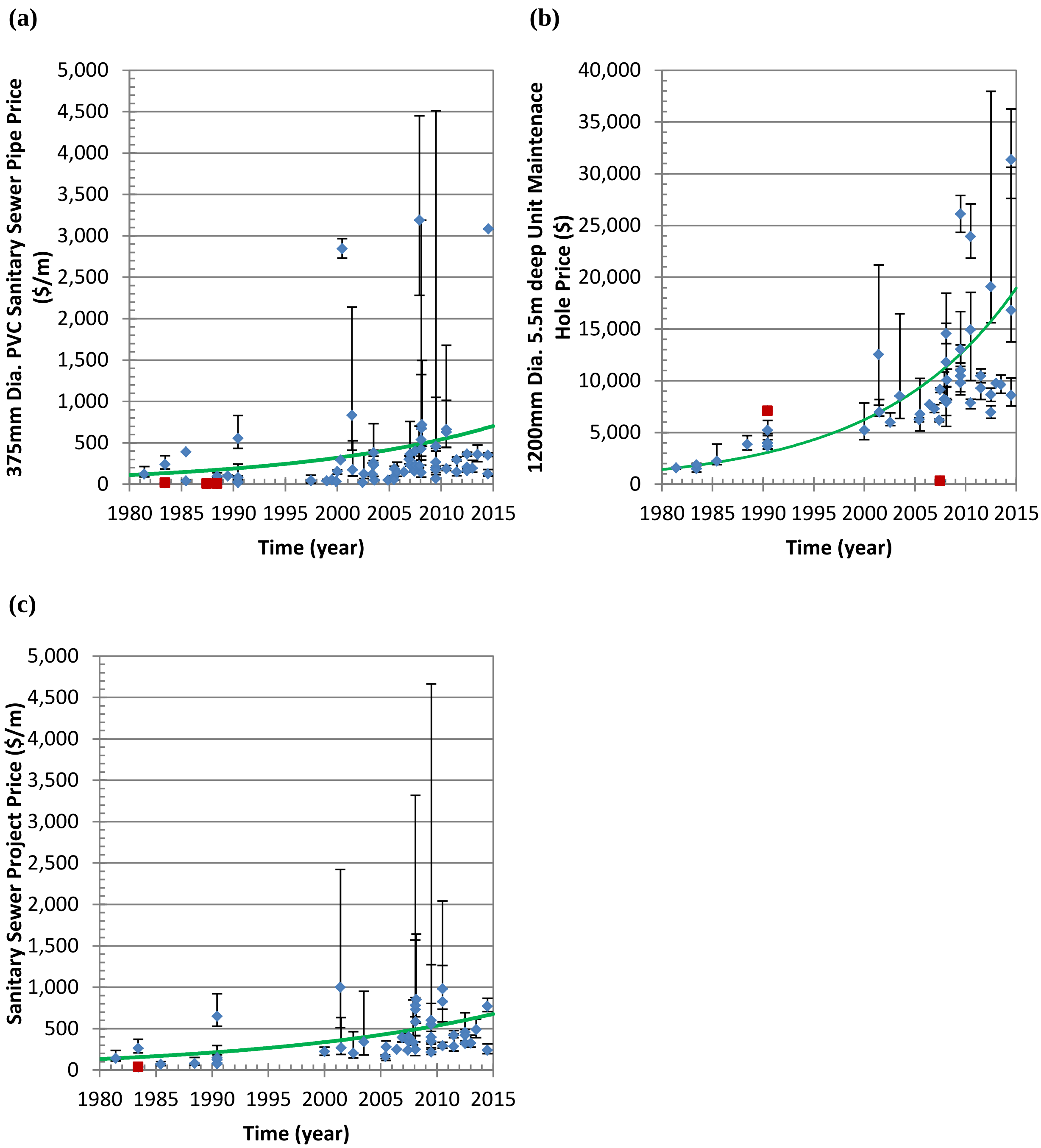

Figure 5.8 – Estimated index values for sanitary sewer pipe (a), maintenance hole (b), and reference project (c) based on inflation estimates from GBM calibration. The curves represent expected index values and symbols represent index values with red symbols indicating data which was discarded during GBM parameter estimation

To check the applicability of the GBM model to represent sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices the normality and independence of log return increments is tested. The Shapiro-Wilk test results and Q-Q plots to check the assumption of normality and Ljung-Box test results and ACF plots to check the assumption of independence can be found in Appendix E. The p-values of the Shapiro-Wilk test for log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices are 0.3388, 0.9144 and 0.3711, respectively. The p-values of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices are all above the commonly used significance level of 0.05 indicating the log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices are normally distributed. These results are confirmed by Q-Q plots for the log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices which approximate to a straight line and are within 95% confidence intervals. Figure E.1, Figure E.2 and Figure E.3 in Appendix E display the Q-Q plots for log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices, respectively.

The p-values of the Ljung-Box test for log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices are 0.02703, 0.01219 and 0.0243, respectively. The p-values of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices are slightly below the significance level of 0.05 indicating the log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole are not independent. However, as the sanitary sewer indices contain multiple price levels at one time period the correlation between log returns is expected with significant lags occurring at low lags. The autocorrelation plots for log returns of the sanitary sewer project and sanitary sewer maintenance hole indices display significant lags at lag 1 above the 95% confidence intervals (Brigo et al., 2009). The lags observed in the log returns of sanitary sewer project and sanitary sewer maintenance hole indices are deemed acceptable and as no other significant lags are observed in the autocorrelation plots the assumption of independence of log returns is acceptable. The autocorrelation plot for log returns of the sanitary sewer pipe index displays no significant lags indicating the assumption of independence of log returns is acceptable (Brigo et al., 2009). Figure E.4, Figure E.5 and Figure E.6 in Appendix E display the autocorrelation plots for log returns of sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices, respectively.

Therefore the GBM model is applicable to sanitary sewer project, sanitary sewer pipe and sanitary sewer maintenance hole indices.

5.5 Estimating Future Watermain and Sanitary Sewer Construction Prices

The annual inflation rates of the general market indices as well as watermain and sanitary sewer reference projects shown in Table 5.1 can be used to estimate future construction prices. The general market indices represent proxy indices in the forecasting of future construction prices. To compare the forecasting of the expected future construction prices with these inflation rates a construction price of one dollar at the end of the beginning of the third quarter of 2014 is inflated. The beginning of the third quarter of 2014 is selected as the beginning of forecasting as this is the latest date for watermain and sanitary sewer construction price data. Expected future values are estimated from Equation (37). Figure 5.9 shows the forecasting of expected future costs for one dollar from the beginning of the third quarter of 2014 to the beginning of the third quarter of 2034.

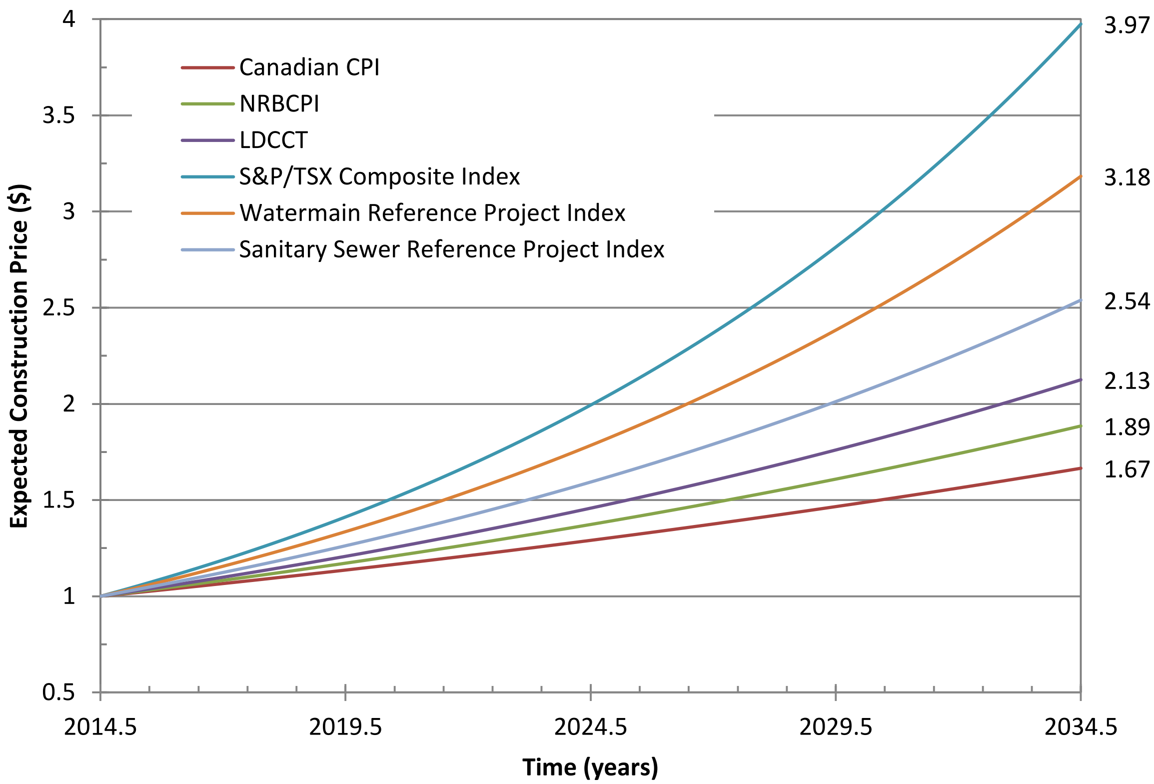

Figure 5.9 – Expected future construction price of $1 at the beginning of the third quarter of 2014 inflated using general market indices, and watermain and sanitary sewer reference project indices

Figure 5.9 illustrates how the estimates of future construction prices can differ significantly based on the index selected to inflate current construction prices. This is further demonstrated in Figure 5.10 and Figure 5.11 which forecast expected future values of watermain and sanitary sewer reference projects, respectively, based on their most current value at the middle of 2014.

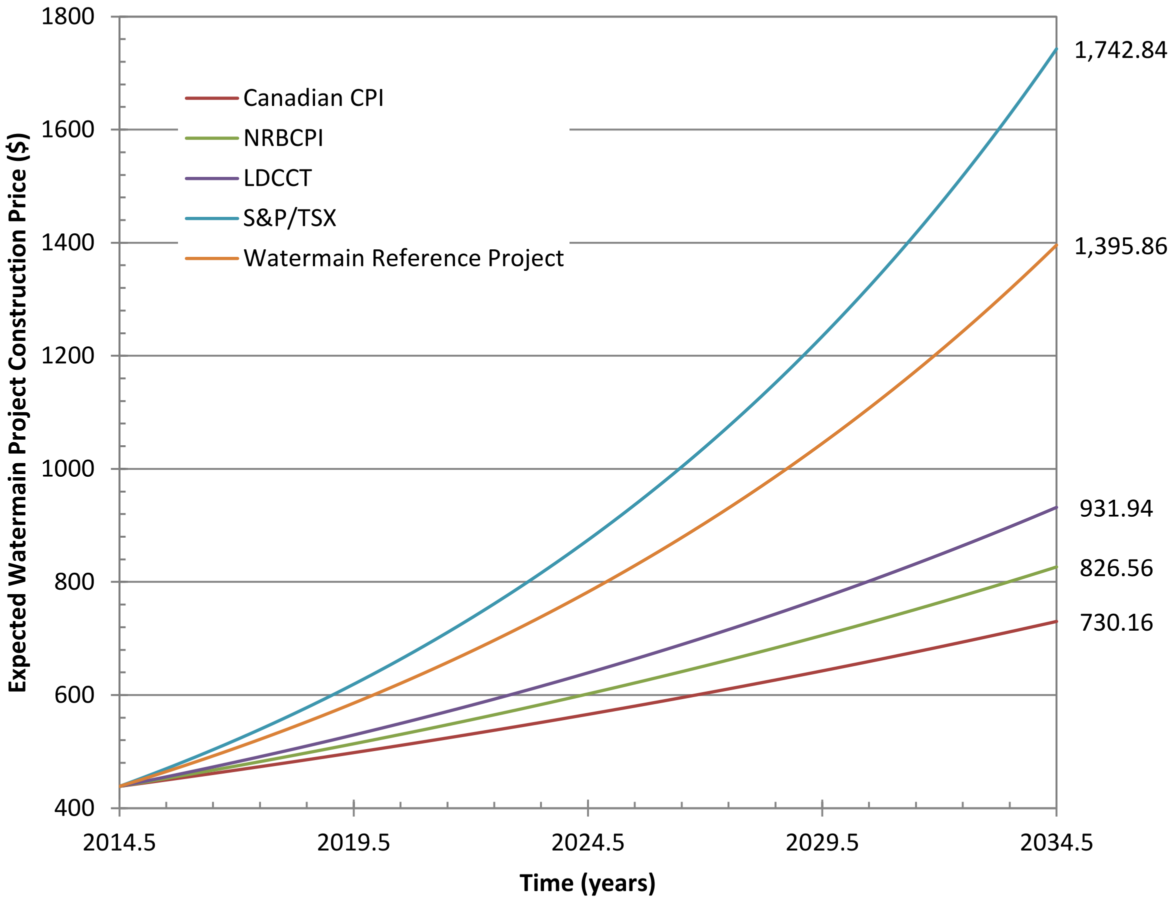

Figure 5.10 – Expected future watermain reference project price based on the price at the middle of 2014 inflated using general market indices and reference project index

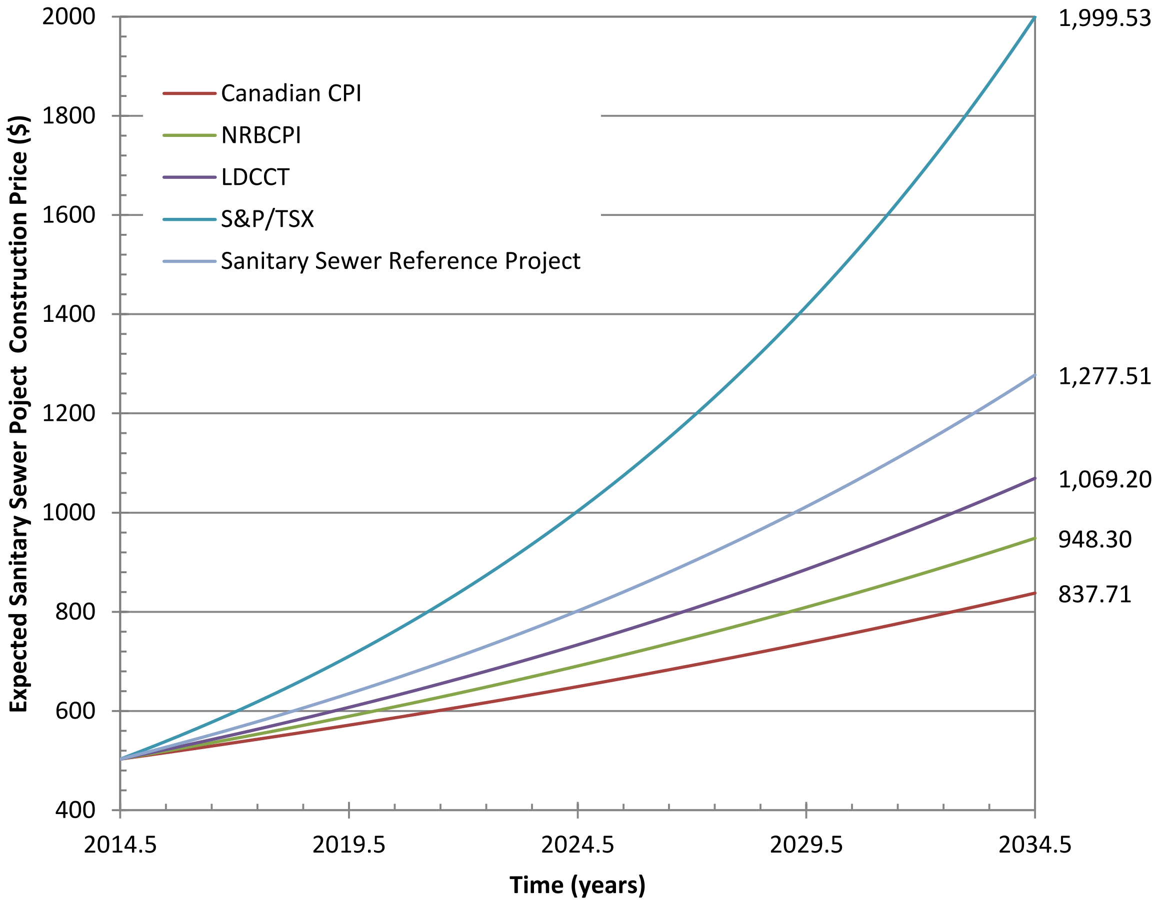

Figure 5.11 – Expected future sanitary sewer reference project price based price at the middle of 2014 inflated using general market indices and sanitary sewer reference project index

5.6 Contractor Markup in Water and Wastewater Pipeline Construction

In this work contractor markup is defined as a financial premium spread in excess of market inflation in the form of a per annum interest rate surcharge. This definition of contractor markup was previously identified and implemented by Younis et al. (2016). The contractor markup includes risk premiums, overhead, and profit which are added to direct project costs. The direct costs plus contractor markup represents the price paid by the client to the contractor for the completed work water and wastewater pipeline construction. Market inflation can be estimated using a market index relevant to the specific construction sector such as CPI, NRBCPI, USBR LDCCT, and ENR CCI. This definition is consistent with the financial sector where the loan interest rate applied to borrowed funds is defined as a markup over the base interest rate. The markup includes a bank's administrative and overhead costs, risk premiums related to the type of loan and creditor, target rate of profit and market conditions (Männasoo, 2013; Rochon, 1999). In this work contractor markup is estimated as an interest rate spread between the inflation in reference project unit price indices and CPI. The contractor markup for watermain and sanitary sewer construction projects is estimated as 3.54% and 2.41%, respectively.

Chapter 6
Discussion

6.1 Overview

This chapter presents a discussion of the results presented in the previous chapter. First, the results of the data processing function and calculation of water and wastewater pipeline construction unit price indices is briefly discussed. Second, the estimates of inflation in watermain construction unit price indices, sanitary sewer construction unit price indices, and general market indices are contrasted and compared. Third, the forecasting of future construction prices using proxy and sector specific indices is examined. Next, the contractor markup in watermain and sanitary sewer construction projects is discussed and compared to estimates of contractor markup from the literature. Finally, the influence the infrastructure stimulus funding on water and wastewater infrastructure construction programs and the unit prices of water and wastewater pipeline construction projects is discussed.

6.2 Data Processing

The automated data processing function was successful in creating auditable construction price data from City of Niagara Falls tender bid summaries. The construction price data was cleaned and transformed into an auditable construction price dataset which was imported into the capital works database. The transformation and import process was completed with significantly more speed, efficiency and accuracy when compared to the previous method of processing the tender bid summaries by hand.

Although the data processing function represents progress in the data processing of construction cost and price data there are some limitations. In its current version the automated data processing function cannot clean, transform and import construction price data from City of Niagara Falls progress payments. Furthermore, in its current version the data processing function cannot import tender bid summaries or progress payments from other sources. However, the structure of the data processing function has been developed such that updates can be applied to allow the transformation and import of construction price data from progress payments and tender bid summaries from other sources. The data processing function would require two updates. First, the item numbers and descriptions from the new source must be matched to dataset item numbers, descriptions and allocations. Second, the format of the progress payment or tender bid summary must be examined to determine the location of item number, item description, item quantity and item unit price as well as contract ID, city, tender date and contractor. The location of this data would then be programmed into the import function to allow progress payments or tender bid summaries of the same format to be automatically imported.

6.3 Water and Wastewater Pipeline Unit Price Index

The watermain and sanitary sewer construction unit price indices were calculated from winning tender bids and progress payments from winning tender bids meaning the indices represent the prevailing market unit price at a point in time. The unit price includes direct costs such as labour, material and equipment plus a markup to account for project risk, overheads, and profit. However, for some index values there is a large range in the unit prices indicated by the maximum and minimum bars. This large range is attributed to the different strategies contractors employ to attempt to gain an advantage in the competitive bidding process and obtain the lowest bid. This large range can also be attributed to contractors attempting to receive the larger payments at an early stage of the project in order to improve their cash flow. One method a contractor can use to achieve these objectives is sharing the costs between watermain, sanitary sewer, storm sewer and road sections and sharing the costs between items within an individual section. For example, in developing scaling relationships for watermain valves Rehan et al. (2016) found the observed unit price in tender bid summaries is comparable to RS Means material prices. Rehan et al. (2016) concluded the labour and equipment costs of installing a watermain valve are passed to the labour and equipment costs of installing watermain pipe, inflating the cost of installing watermain pipe. Another method a contractor can use to achieve these objectives is front loaded unbalanced markup. Front loaded markup distribution is further discussed in Section 6.6. The large range in sanitary sewer pipe unit price levels can also be attributed to not scaling observed unit prices by depth when calculating the unit price levels. By calculating unit price levels as the geometric average of standard component unit prices the effect of the large range of unit prices for some index values is reduced and assumed negligible. By discarding excessively high or low unit price levels in the estimation of inflation and volatility using GBM the influence of highly inflated or deflated unit prices is reduced and assumed negligible.

6.4 Inflation Estimates

The following section presents a discussion of the estimated inflation rates for the unit price indices of watermain and sanitary sewer standard components and reference project construction. The estimated inflation is compared against estimated inflation rates of the general market indices. The volatilities of watermain construction unit price indices, sanitary sewer construction unit price indices and general market indices are also briefly discussed.

Of the general market indices, the Bank of Canada CPI has the lowest inflation of 2.25% per annum, while the S&P/TSX composite index has the highest inflation of 6.90% per annum. The NRBCPI and LDCCT have similar inflation rates of 3.17% per annum and 3.77% per annum, respectively. Interestingly, the LDCCT has a higher inflation rate than NRBCPI, despite the fact that LDCCT is a construction cost index and NRBCPI is a construction price index. However, there are three factors which influence this result. First, the geographic region of LDCCT is the western United States, while the geographic region for NRBCPI is across Canada. Second, LDCCT represents the construction of laterals and drains of water infrastructure systems, while the NRBCPI represents the construction of non-residential buildings such as commercial, industrial and institutional structures. Third, the NRBCPI is an estimation/model price index constructed from a survey of general and trade contractors, while the LDCCT is calculated based on other indices. Similar to inflation rates, the Bank of Canada CPI has the lowest volatility of 0.94% per annum , while the S&P/TSX composite index has the highest volatility of 12.36% per annum. The NRBCPI and LDCCT have volatilities of 3.77% per annum and 3.09% per annum, respectively. The inflation rates and volatilities of the general market indices are summarized in Table 5.1.

Of the watermain unit price indices, the watermain pipe unit price index has the highest inflation of 6.36% per annum which is comparable to the inflation in the S&P/TSX Composite Index of 6.90% per annum. This confirms the previously presented hypothesis that inflation in water pipeline construction bid prices is comparable to the inflation in the price of shares traded on the Toronto Stock Exchange. The watermain hydrant unit price index has the lowest inflation of 2.81% per annum which is comparable to inflation in CPI of 2.25% per annum. This indicates three possibilities. Either the construction price of watermain hydrants inflates at close to the same rate as the general economy, or a portion of the installation and/or markup for watermain hydrants has been passed onto other construction elements, or a combination of the two possibilities exists. The watermain valve unit price index has an inflation of 5.09% per annum which is higher than the inflation of 3.17% per annum and 3.77% per annum in NRBCPI and LDCCT, respectively. The watermain reference project unit price index has an inflation rate 5.79% per annum slightly less than inflation in the watermain pipe index and higher than inflation in watermain valve and hydrant construction price indices. This is expected as the watermain reference project unit price index is a combination of watermain pipe, valve and hydrant unit price indices with the watermain pipe unit price index having the greatest contribution to the reference project index. Inflation in the watermain reference project unit price index of 5.79% per annum is higher than inflation in the LDCCT of 3.77% per annum as expected. The LDCCT includes costs for labour, materials and equipment while the watermain reference project includes costs for labour, material and equipment plus a markup to account for risk, overhead and profit. However, the watermain reference project unit price index and LDCCT are computed in different geographic locations. Furthermore, inflation in the watermain reference project unit price index is higher than inflation in NRBCPI and CPI. Similar to inflation rates, the watermain pipe unit price index has the highest volatility of 9.87% per annum, while the watermain hydrant unit price index has the lowest volatility of 5.06% per annum. The watermain valve and watermain reference project unit price indices have volatilities of 5.72% per annum and 7.66% per annum, respectively. The volatility of the watermain pipe unit price index is mitigated by the volatility of the watermain valve and hydrant unit price indices causing the volatility in the watermain reference project unit price index to reside between these indices. The inflation rates and volatilities of watermain construction unit price indices are summarized in Table 5.1.

Of the sanitary sewer unit price indices, the sanitary sewer maintenance hole unit price index has the highest inflation of 7.41% per annum, while the sanitary sewer reference project unit price index has the lowest inflation of 4.66% per annum. The sanitary sewer pipe unit price index has an inflation rate of 5.25% per annum. Inflation in the sanitary sewer reference project unit price index is less than both the inflation in the sanitary sewer pipe and maintenance hole indices. This is caused by data points which were discarded in the estimation of inflation in sanitary sewer pipe and maintenance hole indices now meeting the criteria to be included in the estimation of inflation in the sanitary sewer reference project unit price index. Although inflation in the sanitary sewer reference project unit price index is approximately one percent less than inflation in the watermain reference project unit price index, it is still higher than inflation in LDCCT, NRBCPI and CPI. The sanitary sewer pipe unit price index has the highest volatility of 27.46% per annum, while the sanitary sewer maintenance hole unit price index has the lowest volatility of 8.03% per annum. The sanitary sewer reference project unit price index has a volatility of 16.27% per annum. Volatility in the sanitary sewer reference project index is between the volatilities of sanitary sewer pipe index and sanitary sewer maintenance hole index where the volatility of former is mitigated by the volatility of the latter. When computing the unit price indices, sanitary sewer pipes are scaled based on material and diameter, while maintenance holes are scaled based on diameter and depth. The volatility of maintenance hole construction unit price index is in the same general range of other construction unit price indices while the sanitary sewer pipe unit price index experiences high volatility. The high volatility observed in sanitary sewer pipe construction unit price index can be attributed to not scaling by depth when calculating unit price levels. Developing a scaling relationship for the depth of sanitary sewer pipe unit prices may lower the volatility in the sanitary sewer pipe index and by extension may also lower volatility in the sanitary sewer reference project index. The inflation rates and volatilities of sanitary sewer construction price indices are summarized in Table 5.1.

6.5 Forecasting Future Construction Prices

The forecasting of future construction prices using the inflation rates for CPI, NRBCPI, LDCCT, S&P/TSX composite index, watermain reference project unit price index and sanitary sewer reference project unit price index is shown in Figure 5.9, Figure 5.10, and Figure 5.11. The figures illustrates that the future construction prices estimated using inflation rates for CPI, NRBCPI, and LDCCT are significantly less than future construction prices estimated using inflation rates for watermain reference project construction unit price index, sanitary sewer reference project construction unit price index, and S&P/TSX composite index. For example, over the twenty year time period the future construction price estimated using CPI is approximately 51.4% and 65.7% of the future construction price estimated using watermain and sanitary sewer reference project, respectively. Therefore using a proxy index, such as CPI or NRBCPI, instead of a sector specific index to forecast future watermain and sanitary sewer construction prices can lead to a significant underestimation of these future construction costs. This is confirmed by Wilmot and Cheng (2003) and Phillips (1982) who found that assuming construction costs inflate at the same rate as general inflation can lead to poor estimates of future construction costs. Wilmot and Cheng (2003) demonstrated this by comparing FHWA Composite Bid Price Index (CBPI) with CPI, while Phillips (1982) compared FHWA CBPI to Producer Price Index (PPI). Furthermore, future construction price estimates paid by the client (municipality) to a contractor can also be underestimated when using an input cost index, such as LDCCT, in place of an output price index, such as watermain or sanitary sewer reference construction unit price indices.

In watermain and sanitary sewer systems, revenues are generated through user rates. Increases to the user rates is based on estimated future costs to attempt to ensure future revenues are sufficient to pay for future costs of the systems. The underestimation of future costs and prices can therefore result in budgetary deficits when the future revenues are not sufficient to pay actual future costs of the systems. Furthermore estimates of future construction costs influence the choice of project financing such as pay as you go, debt financing, or capital reserving, with accurate construction costs improving the quality of data available to decision makers and managers of asset management plans (Rehan, Knight, Unger, & Haas, 2014; Rehan, Unger, Knight, & Haas, 2015, 2014).

6.6 Contractor Markup

The contractor markup for watermain and sanitary sewer construction projects is 3.54% and 2.41%, respectively, estimated as an interest rate spread between the inflation in CPI and reference project unit price indices. The contractor markup includes risk premiums, overhead, and profit with a contractor's tender bid composed of direct costs plus the contractor markup. Historical construction price data from actual construction projects was used to determine the contractor markup in watermain and sanitary sewer construction meaning the estimates of contractor markup represent the actual and real world markup contractors add to their tender bids for watermain and sanitary sewer construction. This is in contrast to existing studies which determine contractor markup based on questionnaire surveys or exploratory interviews with contractors and construction firms (Laryea & Hughes, 2008; Neufville & King, 1991). Furthermore the estimated contractor markup is representative of competitive markup as the historical construction cost data is taken from winning tender bids and progress payments for winning tender bids where the construction work was awarded in a competitive bidding process. In a competitive bidding process contractors submit a tender bid, which consists of direct costs and markup, with the construction work awarded based on the lowest tender bid (Mochtar & Arditi, 2001). This competitive bidding process effectively forces the contractors to not inflate the total bid value and be accountable and competitive in the amount of added markup in an attempt to win the construction work. Therefore the competitive bidding process results in a winning tender bid which represents a competitive and fair market price, which includes a competitive and fair market markup.

Identifying the reasons why markup between watermain and sanitary construction varies in the same construction project is difficult as the pricing process is not systematic in nature with contractors often relying on their own experience, judgement and intuition in markup decisions (Ahmad & Minkarah, 1988; Tarek Hegazy & Moselhi, 1995; Laryea & Hughes, 2008; Mochtar & Arditi, 2001). One potential explanation for differences in markup between watermain and sanitary sewer construction is contractors using a front-loaded unbalanced markup distribution. In front-loaded markup distribution contractors increase the markup of early construction activities while decreasing the markup of later construction activities. This allows contractors to improve their cash flow by receiving larger payments at the early stages of a construction project (S.-J. Kim & Shim, 2016). Front-loading markup unbalanced distribution can occur between the construction of watermains and sanitary sewers as these are often combined in the same construction project along with storm sewers and roads.

The contractor markup of 3.54% and 2.41% for watermain and sanitary sewer construction projects, respectively, is comparable to risk premiums reported by Neufville and King (1991) and Laryea and Hughes (2008). Neufville and King (1991) reported risk premiums to be around 3%, while Laryea and Hughes (2008) determined risk margins of approximately 2-3% in construction project bids. However, Neufville and King (1991) and Laryea and Hughes (2008) reported risk margins were determined through a simulation exercise survey and exploratory interviews, respectively, while this work is based on historical construction price data from actual construction projects. Furthermore, the markup reported by Neufville and King (1991) and Laryea and Hughes (2008) account for risk premiums only, where the markup in this work accounts for risk premiums, overhead and profit. It should also be noted that in this work contractor markup is defined as an interest rate spread between the inflation in construction costs and the general market, while Neufville and King (1991) and Laryea and Hughes (2008) report risk premiums as a fixed percentage of the total cost of the project.

6.7 Infrastructure Stimulus Funding

The purpose of recent infrastructure stimulus funding is to provide a short term boost to existing infrastructure spending in an attempt to stimulate to the economy and employment in a time of recession (Hanak, 2009; Infrastructure Canada, 2009b, 2015; D. Y. Kim, Persad, Harrison, & Loftus-otway, 2014). Many studies in the literature are concerned with the impact infrastructure stimulus funding has on employment numbers and economic conditions (Feyrer & Sacerdote, 2011; D. Y. Kim et al., 2014; Matthews, 2011). However, these studies are not concerned with influence infrastructure stimulus funding has on construction programs and prices of construction projects. In this section the influence of the Government of Canada's Infrastructure Stimulus Fund (ISF) on the City of Niagara Falls' water and wastewater infrastructure construction program and the unit prices of water and wastewater pipeline reference projects is discussed.

In January 2009 the Government of Canada announced the (ISF) as part of Canada's Economic Action Plan in an attempt to provide a short term boost to the Canadian Economy in a time of recession. The ISF made available 4 billion dollars in funding to provincial, territorial and municipal governments for construction ready projects, also known as shovel ready projects. The projects were focused on the improvement, renewal and rehabilitation of existing assets and infrastructure such as water, wastewater, public transit, highways, roads, culture, parks, parks and trails, and community services. To ensure the ISF provides economic stimulus quickly, projects were required to be completed within the 2009 and 2010 construction seasons and must not have proceeded to construction without the federal and provincial funding (Day & Pelletier, 2009; Infrastructure Canada, 2009b, 2015). Additionally, the Government of Ontario made available an additional 1.5 billion dollars in infrastructure funding by matching the Ontario portion of the ISF (Day & Pelletier, 2009). The short-term nature of ISF projects is a departure from traditional infrastructure funding which focuses on projects with long term objectives and high benefit-cost ratios (Infrastructure Canada, 2012).

The ISF resulted in many projects proceeding towards construction in an attempt to obtain federal and provincial funding. In Ontario, there were more than 2 700 project applications were submitted with a total value of approximately 6.5 billion dollars. From these applications, 1 190 projects were selected with 188 projects, or 16% of projects, from the water and wastewater infrastructure sector (Government of Ontario, 2009; Infrastructure Canada, 2009a). By comparison the water and wastewater infrastructure sector composed 33% of all ISF projects in Canada (Infrastructure Canada, 2012). The Governments of Canada and Ontario provided approximately 1.85 billion dollars in funding for ISF projects in Ontario (Government of Ontario, 2009; Infrastructure Canada, 2009a). The breakdown of funding for ISF projects in Ontario is 34% federal, 28% provincial, 33% municipal, and 5% other sources (Infrastructure Canada, 2012). In Ontario, ISF projects in the water and wastewater infrastructure sector received the second most federal and provincial funding of any sector at approximately 563 million dollars for the selected 188 projects (Government of Ontario, 2009; Infrastructure Canada, 2009a).

In the City of Niagara Falls two projects containing water and wastewater infrastructure components received federal and provincial funding under the ISF. The two projects are the Drummond Road Reconstruction and Niagara Falls Downtown Infrastructure Revitalization (Day & Planche, 2009; Infrastructure Canada, 2017; Larocque, 2009). It should be noted that the Drummond

Road Reconstruction and Niagara Falls Downtown Infrastructure Revitalization are categorized as a wastewater project and a highway and road project, respectively, even though these projects contain sections for the construction of watermain, sanitary sewer, storm sewer and road components. The cost of Drummond Road Reconstruction is approximately 6.3 million dollars with Governments of Canada and Ontario each providing approximately 2.1 million dollars in funding (Larocque, 2009). The cost of the Niagara Falls Downtown Infrastructure Revitalization is approximately 2.667 million dollars with the Governments of Canada and Ontario each providing approximately 889 thousand dollars in funding (Day & Planche, 2009; Infrastructure Canada, 2017). The Drummond Road Reconstruction was separated into two projects tendered in 2009 and 2010 while the Niagara Falls Downtown Infrastructure Revitalization was completed as one project tendered in 2009.

Capital works projects from 2007 to 2014 in the City of Niagara Falls were analyzed to determine the influence of the ISF on the City of Niagara Falls capital works program and unit prices of water and wastewater capital works projects. Table 6.1 shows the total number of capital works projects in the City of Niagara Falls from 2007 to 2014. The projects are separated into water and wastewater capital works projects, and road and bridge capital works projects. It should be noted that water and wastewater capital works projects contain watermain, sanitary sewer, storm sewer and road construction while road and bridge capital works projects contain only road and bridge construction.

Table 6.1 – Number of City of Niagara Falls Capital Works Projects from 2007 to 2014

Year	Water and Wastewater Capital Works Projects	Road and Bridge Capital Works Projects	Total
2007	11	7	18
2008	3	8	11
2009	9	6	15
2010	6	6	12
2011	2	6	8
2012	6	9	15
2013	3	5	8
2014	5	5	10
Average	5.6	6.5	12.1

The total number of capital works projects in 2009 at 15 and in 2010 at 12 are above and approximately equal to, respectively, the average total number of capital works projects from 2007 to 2014 at 12.1. Similarly, the number of water and wastewater capital works projects in 2009 at 9 and in 2010 at 6 are above and approximately equal to, respectively, the average number of water and wastewater capital works projects from 2007 to 2014 at 5.6. However, the number of road and bridge projects in 2009 at 6 and 2010 at 6 are approximately equal to the average number of road and bridge projects from 2007 to 2014 at 6.5.

In 2011, 2013 and 2014 the total number of capital works projects is 8, 8, and 10, respectively, which is below the average number of capital works projects from 2007 to 2014 at 12.1. The exception is 2012 which contained 15 capital works projects. Similarly, the number of water and wastewater capital works projects in 2011 at 2, 2013 at 3 and 2014 at 5 are below the average number of water and wastewater projects from 2007 to 2014 at 5.6. The exception is 2012 which contained 6 water and wastewater capital works projects and is approximately equal to the average. However, the number of road and bridge capital works projects in 2011, 2013 and 2014 are 6, 5, and 5, respectively, which is approximately equal to or slightly below the average number of road and bridge capital works projects from 2007 to 2014 at 6.5. The exception is 2012 which contained 9 road and bridge capital works projects which is above the average.

The results indicate the total number of capital works projects and the number of water and wastewater capital works projects was higher than normal during ISF years of 2009 and 2010 and lower than normal in post ISF years of 2011, 2013 and 2014. This suggests that the City of Niagara Falls decreased the inventory of future water and wastewater capital works projects to obtain federal and provincial funding for shovel ready projects whose construction was planned in the near future. This is expected as the ISF federal and provincial funding provided funds for shovel ready projects which otherwise would not have been constructed in 2009 and 2010, increasing the number of capital works projects above normal levels. This trend was also observed at the Texas Department of Transportation where the inventory of highway and road construction projects was reduced to use up federal stimulus funding on shovel ready projects. This resulted in the number of construction projects post-federal stimulus funding being less than normal (D. Y. Kim et al., 2014). Interestingly, the number of road and bridge capital works projects did not vary significantly before, during and after ISF construction years. It should also be noted that there was an increase in water and wastewater, and road and bridge capital works projects in 2012 compared to other post ISF years of 2011, 2013 and 2014. However, as shown in Table 6.3, 2012 contains the lowest average price of water and wastewater, and road and bridge capital works construction projects. This indicates the increase in capital works projects is not caused by an increase budget or available funding but by increasing the number of capital works projects constructed with lower tender prices.

Table 6.2 and Table 6.3 show total tender bid price per year and average tender bid price per year of capital works projects in the City of Niagara Falls from 2007 to 2014.

Table 6.2 – Total Tender Price of Capital Works Projects per Year from 2007 to 2014

Year	Total Tender Price of Water and Wastewater Projects	Total Tender Price of Road and Bridge Projects	Total Tender Price of All Projects
2007	$15,598,042.93	$5,346,273.30	$20,944,316.23
2008	$7,390,392.94	$3,724,487.65	$11,114,880.59
2009	$10,057,198.30	$1,771,757.53	$11,828,955.83
2010	$15,329,817.22	$6,791,351.89	$22,121,169.11
2011	$2,096,578.93	$4,780,303.20	$6,876,882.13
2012	$4,089,801.28	$2,823,310.88	$6,913,112.16
2013	$2,124,056.06	$4,525,170.46	$6,649,226.52
2014	$5,905,507.35	$2,474,049.50	$8,379,556.85
Average	$7,823,924.38	$4,029,588.05	$11,853,512.43

Table 6.3 – Average Tender Price of Capital Works Projects from 2007 to 2014

Year	Average Tender Price of Water and Wastewater Projects	Average Tender Price of Road and Bridge Projects	Average Tender Price of All Projects
2007	$1,418,003.90	$763,753.33	$1,163,573.12
2008	$2,463,464.31	$465,560.96	$1,010,443.69
2009	$1,117,466.48	$295,292.92	$788,597.06
2010	$2,554, 969.54	$1,131,891.98	$1,843,430.76
2011	$1,048,289.47	$796,717.20	$859,610.27
2012	$681,633.55	$313,701.21	$460,874.14
2013	$708,018.69	$905,034.09	$831,153.32
2014	$1,181,101.47	$494,809.90	$837,955.69

2009 and 2010 have the third and second highest total tender prices of water and wastewater capital works projects from 2007 to 2014. Additionally, 2009 and 2010 have the third and first highest total tender prices of all capital works projects from 2007 to 2014. Furthermore, 2010 contained the highest average tender price of water and wastewater, and road and bridge capital works projects. This is expected as ISF federal and provincial funding increased the amount of funds available for capital works projects in 2009 and 2010. The total tender prices of road and bridge projects did not vary significantly from 2007 to 2014. Furthermore, the average tender price of road and bridge capital works projects is below the average of water and wastewater capital works projects in seven of the eight years from 2007 to 2014. This is potentially a result of the shovel ready project provision of the ISF. D. Y. Kim et al. (2014) found shovel ready project provisions mean there is not time to develop complex projects such as bridges and new capacity roads. Therefore, much of available stimulus funding is spent on lower cost surfacing projects.

The total tender price of all capital works projects in ISF construction years 2009 and 2010 are similar to the total tender price of all capital works in 2008 and 2007, respectively. Additionally 2010 and 2007 have similar total tender prices of water and wastewater capital works projects. However, in post ISF construction years the total tender price of water and wastewater, and road and bridge capital works projects is significantly lower than total tender prices during and before ISF implementation. Prior to implementation of the US federal infrastructure stimulus package infrastructure providers were worried the spotlight on large short term investment in infrastructure would reduce the amount of future regular funding (Hanak, 2009). Based on the results presented above for the City of Niagara Falls, the ISF has resulted in lower infrastructure spending post-ISF than pre-ISF confirming the suspicion of infrastructure providers. It is important that stimulus short term funding for infrastructure should not distract policy makers from the long term challenges of infrastructure finance (Grigg, 1994; Hanak, 2009).

As discussed in Section 2.5 contractor markup and therefore tender bid price and unit prices are influenced by a contractors need for work and current work load. If contractors are busy with other projects a need-for-work premium may be added to the tender price bid which reflects a lack of enthusiasm for more work and creates additional incentives for the work if they are awarded the contract. Neufville and King (1991) found need-for-work premiums to be approximately 3% of the total tender bid for a project. The ISF caused an increase in the number of infrastructure projects available, in the City of Niagara Falls, surrounding region and across the country, decreasing contractors need for work and increasing contractors work load. Therefore, it was expected that this increase in available work would cause unit prices to increase due to need-for-work premiums. However, no relationship was observed between the number of projects available in a year and the unit prices of watermain and sanitary sewer standard components and reference project. This indicates the increase in the number of infrastructure capital works projects in the City of Niagara Falls was not significant enough to cause an increase in unit prices of watermain and sanitary sewer standard components and reference projects above increases in unit prices due to annual inflation.

Table 6.4 displays the average number of submitted tender bids per project for City of Niagara Falls water and wastewater capital works projects from 2007 to 2014. The table indicates that the number of submitted tender bids did not vary significantly before, during and after the implementation of the ISF. Therefore the minor increase in the number of infrastructure capital works projects did not influence the number of tender bids submitted for a project. However, the total tender bid price of a project was found to influence the number of tender bids submitted for that project and is discussed in the next section.

Table 6.4 – Average Number of Submitted Tender Bids per Project from 2007 to 2014

Year	Average Number of Tender Bids Submitted per Water and Wastewater Project
2007	6.91
2008	7.67
2009	7.22
2010	7.00
2011	6.00
2012	7.17
2013	8.00
2014	4.40
Average	6.80

6.8 Number of Submitted Tender Bids

The minor increase in the number of water and wastewater capital works projects due to the ISF was found to have no effect on the unit prices of watermain and sanitary sewer reference projects. However, the number of submitted tender bids is found to influence the unit prices of watermain and sanitary sewer reference projects. This is expected as previous studies, discussed in Section 2.5, found the number of contractors and competitiveness of contractors to have an influence on contractor markup, and therefore tender bid prices (Carr, 1983; Dulaimi & Shan, 2002). As the number of tender bids submitted for a project increase, the unit price of reference projects is generally found to decrease. An increase in the number of tender bids submitted causes an increase in the competition among contractors resulting in a decrease in the unit prices of the reference projects as bidders attempt to win the project. This is consistent with Carr (1983) who found that as the number of competitors for a contract increases, a contractor will decrease their markup and therefore tender bid price to undercut other competitors in an attempt to win the contract. Figure 6.1 and Figure 6.2 display the general decrease of reference project unit prices as the number of tender bids submitted increases for watermain and sanitary sewer reference projects, respectively. This trend is observed for both watermain and sanitary sewer reference project unit prices. However the trend is more apparent for the watermain reference project than the sanitary sewer reference project.

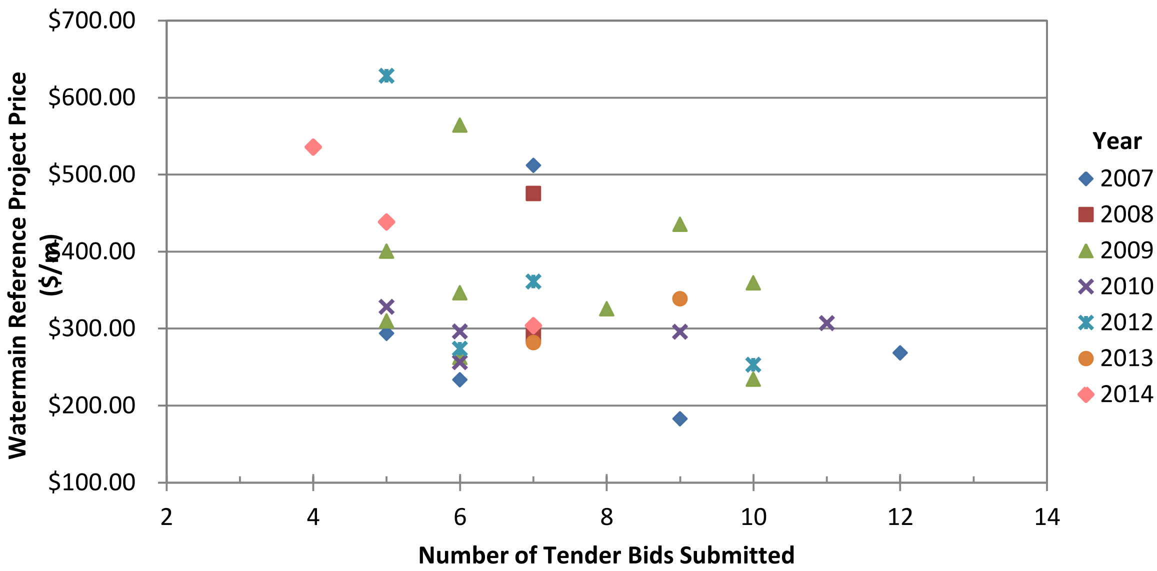

Figure 6.1 – General decrease in watermain reference project unit price as the number of tender bids submitted increases

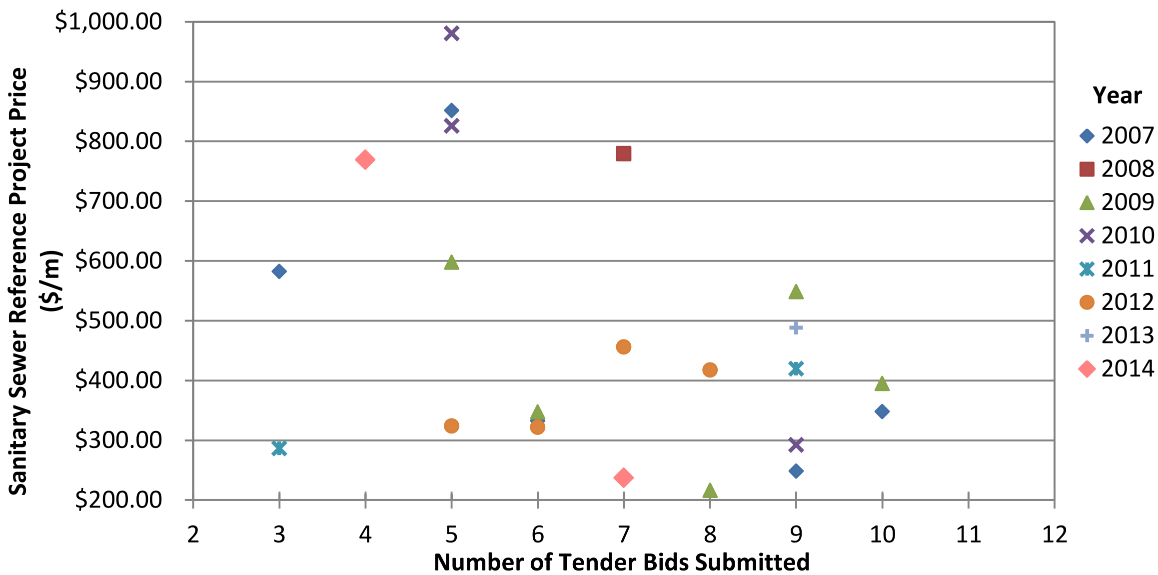

Figure 6.2 – General decrease in sanitary sewer reference project unit price as the number of tender bids submitted increases

While the unit price of reference projects is found to be influenced by the number of tender bids submitted, the number of tender bids submitted for a project is found to be influenced by the total tender bid price of water and wastewater capital works projects. The number of tender bids submitted is generally observed to decrease as the total tender bid price of water and wastewater capital works projects increase. This trend is displayed in Figure 6.3. It should be noted that for project tender bid prices above four million dollars this trend was not observed. However, determining a trend for projects with tender bid prices above four million dollars is problematic as only three projects have tender bid prices above four million dollars.

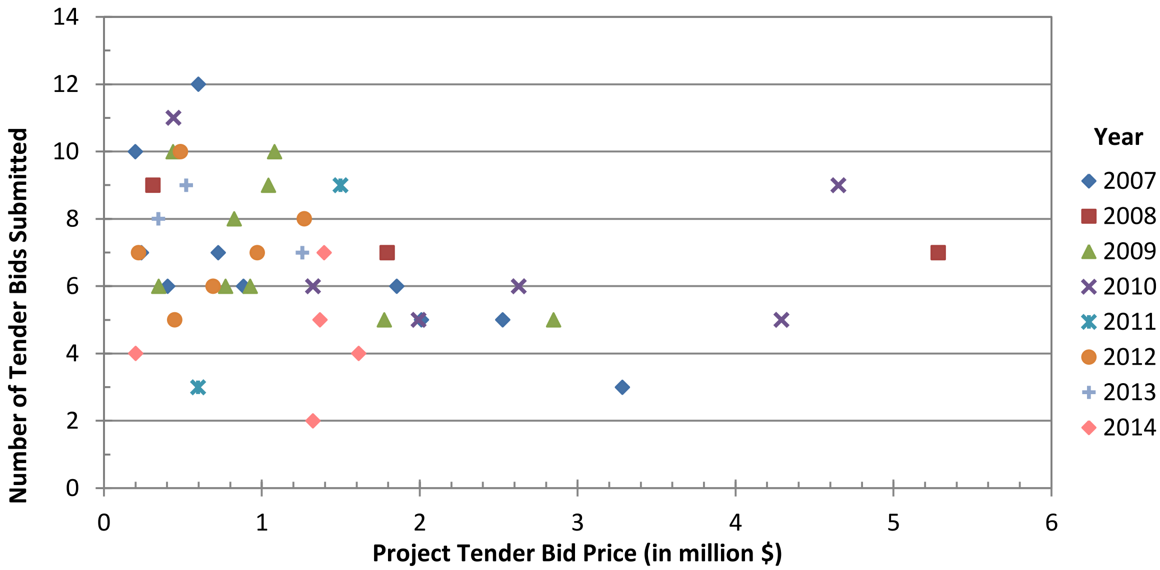

Figure 6.3 – General decrease in the number of tender bids submitted as water and wastewater project total tender bid prices increase

The observed decrease in the number of tender bids submitted as the project tender bid price increases can be explained by the increased risk and higher degree of difficulty associated with larger, higher price water and wastewater capital works projects. When increased risk and a higher degree of difficulty are associated with a project, there are potentially less contractors willing to accept the increased risk, resulting in less tender bids being submitted. Furthermore, there are potentially less contractors capable of constructing the more complex project, resulting in a decrease in the number of tender bids submitted for a project. This is consistent with previous studies, discussed in Section 2.5, which found contractor bid and markup decisions are influenced by degree of hazard, degree of difficulty, risk of project, and risk of construction work.

Chapter 7
Conclusions and Recommendations

7.1 Overview

The research presented in this thesis explores the financial component of water and wastewater pipeline capital works construction sector based on construction price data to assist in the sustainable financial management of water and wastewater pipeline systems. The importance of sustainable financial management of water and wastewater pipeline systems has grown in recent years due to the increasing backlog of maintenance, renewal and replacement of aging water and wastewater pipelines, and increased legislative requirements for the management of water systems. Specifically, the research presented in this thesis examines inflation, forecasting of future prices, contractor markup and factors influencing tender prices in the water and wastewater pipeline capital works construction sector. This chapter presents the main findings and conclusions of this research, followed by recommendations for future work.

7.2 Conclusions

Three processes form the basis of the research presented in this thesis: construction price data processing, development of construction unit price indices and estimation of inflation in construction unit price indices. The data processing function was developed to clean and transform the actual construction price data in the form of tender summaries and progress payments from the City of Niagara Falls from 1981 to 2014 into a centralized, organized and auditable construction price dataset. Watermain and sanitary sewer unit price indices for standard components and reference projects were developed from the construction price dataset and represent the construction price of watermain and sanitary sewer standard components and reference projects over time. Inflation in the watermain and sanitary sewer unit price indices was estimated using Geometric Brownian motion. To improve the speed, accuracy, efficiency and consistency of unit price index and inflation calculation, the data processing function, calculation of watermain and sanitary sewer unit price indices, and estimation of inflation in these indices was automated in a Microsoft Access relational database. Based on the water and wastewater pipeline capital works database, the main findings conclusions of the research are as follows:

- The inflation rates of watermain pipe, valve and hydrant capital works construction from 1982-2014 are 6.36%, 5.09%, and 2.81% per annum, respectively. Inflation of watermain pipe construction at 6.36% per annum is comparable to inflation of the S&P/TSX composite index at 6.90% per annum. Inflation of valves at 5.09% per annum is comparable to inflation of valve material costs indicating installation, equipment and markup costs for valves is passed to the cost of installing watermain pipe. Inflation in hydrant construction at 2.81% per annum is comparable to inflation of CPI at 2.25% per annum indicating hydrant construction inflates similar to CPI or a portion of construction costs is passed to the cost of installing watermain pipe.

- The inflation of sanitary sewer pipe and maintenance hole capital works construction from 1981-2014 is 7.41% and 5.25% per annum, respectively. Inflation of sanitary sewer maintenance hole construction at 7.41% per annum is comparable to inflation of the S&P/TSX composite index at 6.90% per annum, while inflation of sanitary sewer pipe construction at 5.25% per annum is comparable to inflation of valve construction at 5.09% per annum.

- The inflation of watermain reference project capital works construction is 5.79% per annum from 1982-2014, while the inflation of sanitary sewer reference project capital works construction is 4.66% per annum from 1981-2014. Inflation of watermain and sanitary sewer reference projects is above inflation of CPI at 2.25% per annum, NRBCPI at 3.17% per annum and LDCCT at 3.77% per annum, but below inflation of S&P/TSX composite index at 6.90% per annum.

- Forecasting future construction prices using a proxy index can result in inaccurate estimates of future construction prices. In the water and wastewater pipeline sector the use of CPI, NRBCPI or LDCCT as a proxy index will result in a significant underestimation of future construction prices. To obtain accurate estimates of future construction costs it is important to use relevant sector specific indices. The developed unit price indices fulfill the need for price indices in the water and wastewater pipeline construction sector.

- The developed unit price indices are most applicable to the City of Niagara Falls water and wastewater pipeline capital works construction as they are calculated using City of Niagara Falls construction price data. The unit price indices are a proxy index if used for the water and wastewater pipeline capital works construction of other geographic locations but are more applicable than using a proxy index from other construction sectors.

- In this work contractor markup is defined as a financial premium in excess of market inflation in the form of a per annum interest rate surcharge. Contractor markup includes risk premiums, overhead and profit. The contractor markup for watermain and sanitary sewer projects is 3.54% and 2.41%, respectively. These values are comparable to risk premiums reported by Neufville and King (1991) and Laryea and Hughes (2008) of approximately 3% and 2-3% respectively. However the risk premiums reported by Neufville and King (1991) and Laryea and Hughes (2008) are based on questionnaire surveys or exploratory interviews while contractor markup in this work is calculated from actual construction price data.
- Funding provided by the Infrastructure Stimulus Fund increased the total number of projects and the total tender bid value of projects in 2009 and 2010. However, the increased funding did not result in significant changes to the unit prices of watermain and sanitary sewer standard components and reference projects.
- As the number of tender bids submitted for a project increase, the unit price of reference projects generally decreases. This is caused by an increase in the competition among contractors resulting in a decrease in the unit prices of the reference projects as bidders attempt to win the project.

7.3 Recommendations for Future Work

Future work is recommended to further advance the development of unit price indices and estimation of inflation for the capital works construction of water and wastewater pipeline systems. The recommended future work includes:

- Revise the scaling relationship for sanitary sewer pipe to include depth similar to the inclusion of depth in the scaling relationship of maintenance holes. The inclusion of depth in the sanitary sewer pipe scaling relationship is needed as the construction price of sanitary sewer pipe is influenced by installation depth. The inclusion of depth in the sanitary sewer pipe scaling relationship may reduce the large range in sanitary sewer pipe unit price levels and decrease the volatility in the sanitary sewer pipe index.

- Expand the data processing function to accommodate construction price data from other sources such as municipal governments, regional governments and utilities. The expanded data processing function would be able to clean and transform tender bid summaries and progress payments from other sources into a construction price dataset which can be used to develop unit price indices and estimate inflation.
- Develop unit price indices and inflation estimates for watermain and wastewater pipeline capital works construction specific to other municipal governments, regional governments and utilities. This is conducted using the methodology described in this work based on construction price data from the municipal government, regional government or utility. This fulfills a need identified by BIS (2010) to show price changes of different construction sectors in different locations.
- Explore the applicability of other models to estimate inflation in the comparison indices and unit price indices of water and wastewater pipeline capital works construction such as GBM with mean reversion, GBM with jump diffusion and autoregressive models.

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Appendix A

Watermain Standard Component and Reference Project Unit Price Indices

Watermain pipe unit price index values have a reference size of 150 mm diameter. Watermain valve unit price index values have a reference size of 150 mm diameter. Watermain hydrant unit price index values are not scaled and therefore do not have a reference size. Watermain reference project consists of 1 metre of 150mm diameter pipe with 1-150mm diameter valve every 100 metres of pipe and 1 hydrant every 150 metres of pipe. The date of index values is shown in the first column (Time (Year)). Index values are shown in the second column (mean). Minimum observed index values are calculated as the second column (mean) minus the third column (- mean). Maximum observed index values are calculated as the second column (mean) plus the fourth column (+ mean).

Table A.1 – Watermain reference project unit price index values

Time (Year)	**Mean**	**−Mean**	**+ Mean**
1985.43	$92.14	$0.00	$0.00
1987.44	$44.51	$2.96	$3.29
1988.44	$54.08	$1.80	$1.91
1990.45	$148.53	$12.78	$14.40
1990.45	$171.21	$67.96	$121.36
1990.45	$114.45	$0.00	$0.00
1990.45	$188.55	$0.00	$0.00
1997.47	$166.69	$0.00	$0.00
1997.92	$212.84	$0.00	$0.00
1999.00	$122.13	$0.00	$0.00
1999.75	$462.78	$58.58	$126.65
1999.75	$180.11	$15.56	$17.25
2000.00	$194.66	$18.32	$35.78
2000.16	$174.15	$37.13	$51.14
2000.33	$183.65	$0.00	$0.00
2000.48	$146.75	$2.53	$5.74
2000.58	$141.59	$7.68	$8.16
2001.39	$298.94	$97.70	$594.47
2001.41	$191.50	$0.00	$0.00
2002.25	$299.24	$60.99	$82.88
2002.44	$175.35	$3.71	$3.88
2002.46	$299.24	$60.99	$82.88
2002.50	$342.88	$183.35	$809.06
2003.37	$240.21	$27.23	$34.11
2003.48	$181.75	$5.96	$6.22
2003.50	$216.90	$0.00	$0.00
2003.56	$209.41	$29.42	$75.78
2003.57	$161.39	$5.74	$6.57
2003.58	$262.29	$30.87	$36.68
2004.25	$507.94	$2.33	$2.47

(Continued)

Table A.1 (Continued)

Time (Year)	Mean	−Mean	+ Mean
2005.16	$312.87	$54.73	$67.73
2005.28	$507.94	$2.33	$2.47
2005.41	$273.83	$41.10	$37.18
2005.49	$413.00	$110.44	$385.10
2005.70	$291.36	$64.60	$98.25
2005.76	$299.61	$76.08	$111.60
2006.92	$285.40	$6.27	$8.56
2007.00	$266.88	$19.98	$18.68
2007.38	$477.68	$166.85	$122.20
2007.40	$194.80	$14.89	$26.84
2007.49	$456.54	$172.32	$141.33
2007.75	$233.62	$19.56	$44.59
2007.80	$511.84	$129.87	$178.24
2007.91	$965.36	$62.47	$135.24
2008.08	$425.20	$98.25	$44.50
2008.08	$293.80	$0.00	$0.00
2008.08	$268.54	$27.88	$42.74
2008.08	$182.93	$0.00	$0.00
2008.09	$291.69	$0.00	$0.00
2008.27	$475.38	$244.51	$444.94
2009.50	$435.60	$204.39	$190.34
2009.50	$346.52	$11.12	$17.71
2009.50	$309.94	$17.35	$18.69
2009.50	$325.74	$136.38	$521.64
2009.50	$359.24	$106.42	$174.31
2009.50	$262.36	$58.97	$58.77
2009.50	$234.31	$54.66	$52.34
2009.50	$564.27	$322.13	$741.45
2009.50	$400.61	$40.65	$57.80
2010.42	$296.37	$32.40	$38.77
2010.50	$328.40	$70.50	$94.01
2010.50	$295.78	$23.25	$34.34
2010.50	$307.19	$0.00	$0.00
2010.50	$256.26	$32.99	$58.38
2012.50	$273.62	$0.00	$0.00
2012.50	$360.88	$0.00	$0.00

(Continued)

Table A.1 (Continued)

Time (Year)	Mean	−Mean	+ Mean
2013.01	$628.25	$202.98	$196.30
2013.50	$338.65	$14.46	$15.36
2013.50	$281.82	$3.46	$3.75
2014.50	$303.85	$20.19	$22.00
2014.50	$535.43	$130.68	$83.76
2014.54	$438.46	$9.67	$10.17

Table A.2 – Watermain pipe unit price index values

Time (Year)	Mean	−Mean	+ Mean
1985.43	$74.23	$0.00	$0.00
1987.44	$23.62	$2.51	$2.81
1988.44	$35.20	$1.19	$1.23
1988.44	$124.93	$11.83	$14.26
1989.44	$225.35	$0.22	$0.22
1990.45	$248.14	$0.00	$0.00
1990.45	$113.37	$12.78	$14.40
1990.45	$145.36	$62.10	$108.41
1990.45	$91.03	$0.00	$0.00
1990.45	$159.97	$0.00	$0.00
1997.47	$143.48	$0.00	$0.00
1997.92	$185.98	$0.00	$0.00
1998.24	$246.40	$30.59	$14.14
1999.00	$91.88	$0.00	$0.00
1999.67	$1,433.81	$0.00	$0.00
1999.75	$430.62	$57.68	$125.64
1999.75	$153.60	$14.59	$16.12
1999.90	$125.29	$0.00	$0.00
2000.00	$161.12	$17.17	$34.47
2000.16	$135.66	$37.14	$51.14
2000.33	$151.54	$0.00	$0.00
2000.48	$121.20	$0.78	$0.79
2000.58	$110.30	$5.74	$6.06
2001.39	$269.08	$95.94	$592.70
2001.41	$165.98	$0.00	$0.00
2002.25	$265.54	$59.91	$81.62
2002.44	$146.11	$2.72	$2.78

(Continued)

Table A.2 (Continued)

Time (Year)	Mean	−Mean	+ Mean
2002.50	$310.86	$181.35	$806.63
2003.37	$202.32	$25.16	$29.75
2003.48	$140.02	$5.96	$6.23
2003.50	$47.22	$0.00	$0.00
2003.50	$181.36	$0.00	$0.00
2003.56	$176.89	$29.42	$75.78
2003.57	$124.31	$3.20	$4.58
2003.58	$222.88	$29.04	$34.41
2004.25	$454.59	$0.00	$0.00
2004.49	$274.29	$0.00	$0.00
2004.88	$118.99	$6.20	$8.31
2005.16	$282.30	$54.43	$67.43
2005.28	$454.59	$0.00	$0.00
2005.41	$235.08	$38.90	$33.96
2005.49	$365.42	$110.44	$385.10
2005.70	$254.48	$62.62	$96.02
2005.75	$714.50	$176.49	$234.39
2005.76	$260.50	$74.05	$109.83
2006.43	$811.33	$255.11	$372.12
2006.44	$223.17	$35.84	$47.21
2006.92	$242.63	$3.32	$4.93
2007.00	$227.02	$19.99	$18.67
2007.38	$428.32	$164.35	$119.47
2007.40	$150.53	$11.02	$24.33
2007.41	$344.08	$0.00	$0.00
2007.49	$419.66	$163.62	$127.73
2007.73	$242.60	$0.00	$0.00
2007.75	$188.26	$16.88	$40.98
2007.80	$467.59	$127.24	$174.80
2007.83	$360.19	$21.21	$22.53
2007.91	$742.91	$49.79	$101.58
2008.08	$367.42	$88.65	$34.43
2008.08	$247.68	$0.00	$0.00
2008.08	$238.07	$25.35	$33.09
2008.08	$125.87	$0.00	$0.00
2008.09	$241.82	$0.00	$0.00

(Continued)

Table A.2 (Continued)

Time (Year)	Mean	−Mean	+ Mean
2008.27	$432.95	$229.71	$421.29
2008.50	$144.08	$0.37	$0.37
2009.50	$373.56	$204.39	$190.34
2009.50	$266.77	$0.00	$0.00
2009.50	$242.90	$17.35	$18.69
2009.50	$275.45	$133.23	$517.18
2009.50	$307.40	$103.29	$168.37
2009.50	$196.20	$57.81	$57.54
2009.50	$184.21	$50.63	$46.23
2009.50	$512.62	$317.97	$733.63
2009.50	$342.80	$36.58	$51.18
2010.42	$242.87	$29.22	$33.85
2010.50	$259.63	$62.97	$83.13
2010.50	$665.53	$191.00	$267.88
2010.50	$240.06	$18.59	$28.32
2010.50	$257.35	$0.00	$0.00
2010.50	$202.39	$29.13	$53.25
2011.50	$281.38	$0.00	$0.00
2012.50	$218.27	$0.00	$0.00
2012.50	$304.09	$0.00	$0.00
2012.50	$211.52	$9.62	$10.08
2012.50	$197.37	$3.34	$5.39
2012.50	$238.08	$0.00	$0.00
2013.01	$562.68	$200.52	$193.46
2013.48	$473.56	$0.00	$0.00
2013.50	$267.35	$11.88	$12.44
2013.50	$225.70	$0.00	$0.00
2014.50	$222.07	$0.00	$0.00
2014.50	$246.08	$17.73	$19.10
2014.50	$220.79	$10.81	$5.61
2014.50	$474.01	$128.40	$81.11
2014.54	$374.52	$7.28	$7.42

Table A.3 – Watermain valve unit price index values

Time (Year)	Mean	−Mean	+ Mean
1985.43	$475.46	$0.00	$0.00
1987.44	$605.37	$44.07	$47.53
1988.44	$559.25	$61.15	$68.65
1988.44	$636.12	$0.00	$0.00
1988.44	$978.18	$536.10	$1,186.23
1989.44	$574.16	$67.02	$75.88
1990.45	$958.32	$0.00	$0.00
1990.45	$1,070.97	$586.35	$1,295.78
1990.45	$645.31	$0.00	$0.00
1990.45	$855.30	$0.00	$0.00
1997.47	$592.07	$0.00	$0.00
1997.92	$788.10	$0.00	$0.00
1998.24	$1,322.23	$316.48	$235.20
1999.00	$995.82	$0.00	$0.00
1999.75	$964.78	$91.20	$100.73
1999.75	$742.43	$97.31	$111.99
2000.00	$967.17	$115.21	$130.79
2000.16	$1,182.73	$0.00	$0.00
2000.33	$1,007.23	$0.00	$0.00
2000.48	$684.58	$174.66	$495.71
2000.58	$976.84	$108.43	$121.97
2001.08	$1,064.75	$226.05	$382.81
2001.39	$882.46	$176.68	$177.62
2001.41	$688.73	$0.00	$0.00
2001.48	$988.62	$106.87	$119.83
2002.25	$820.62	$108.70	$125.29
2002.44	$952.08	$98.61	$110.00
2002.46	$820.62	$108.70	$125.29
2002.50	$971.88	$199.90	$242.78
2002.56	$853.11	$85.70	$95.27
2003.37	$1,214.11	$207.33	$435.57
2003.48	$2,048.40	$0.00	$0.00
2003.50	$969.26	$0.00	$0.00
2003.56	$650.36	$0.00	$0.00
2003.57	$1,232.72	$253.96	$198.17
2003.58	$1,232.09	$182.41	$227.26
2004.25	$1,066.17	$0.00	$0.00

(Continued)

Table A.3 (Continued)

Time (Year)	Mean	−Mean	+ Mean
2005.16	$955.56	$30.11	$31.09
2005.28	$1,066.17	$0.00	$0.00
2005.41	$1,209.69	$219.58	$322.14
2005.49	$1,338.02	$0.00	$0.00
2005.65	$161.39	$0.00	$0.00
2005.70	$1,095.67	$198.18	$222.72
2005.75	$1,250.59	$0.00	$0.00
2005.76	$1,236.61	$203.25	$177.10
2006.92	$1,249.64	$295.26	$362.00
2007.00	$4,759.74	$0.00	$0.00
2007.00	$1,210.01	$0.00	$0.00
2007.38	$1,694.96	$249.61	$272.78
2007.40	$1,323.87	$377.60	$242.02
2007.49	$1,387.56	$23.68	$24.09
2007.50	$1,456.99	$196.32	$185.07
2007.75	$1,543.42	$267.24	$361.45
2007.80	$1,112.51	$262.55	$343.65
2007.83	$2,101.14	$574.15	$1,877.09
2007.91	$5,195.43	$1,269.17	$3,365.66
2008.08	$1,943.63	$400.08	$351.44
2008.08	$1,392.34	$0.00	$0.00
2008.08	$265.11	$252.80	$965.40
2008.08	$1,905.86	$0.00	$0.00
2008.09	$1,349.06	$0.00	$0.00
2008.16	$1,703.82	$374.79	$480.48
2008.27	$1,858.40	$503.78	$712.16
2009.50	$1,493.09	$0.00	$0.00
2009.50	$2,979.39	$1,111.02	$1,771.69
2009.50	$2,928.58	$0.00	$0.00
2009.50	$1,536.94	$315.71	$445.65
2009.50	$1,524.49	$313.15	$595.00
2009.50	$2,484.52	$116.13	$121.82
2009.50	$1,481.78	$402.67	$610.75
2009.50	$1,463.06	$415.44	$781.94
2009.50	$1,774.20	$406.54	$661.48
2010.42	$1,769.88	$317.59	$492.40

(Continued)

Table A.3 (Continued)

Time (Year)	Mean	−Mean	+ Mean
2010.50	$2,190.05	$178.22	$194.00
2010.50	$1,913.11	$465.95	$602.05
2010.50	$1,014.14	$0.00	$0.00
2010.50	$1,627.07	$386.28	$512.67
2012.50	$1,354.21	$0.00	$0.00
2012.50	$1,530.18	$0.00	$0.00
2012.50	$1,650.83	$358.61	$456.42
2013.01	$1,914.32	$245.90	$284.29
2013.50	$2,190.69	$257.94	$292.37
2013.50	$1,323.08	$0.00	$0.00
2014.50	$1,648.22	$246.68	$290.10
2014.50	$1,629.85	$227.60	$264.55
2014.54	$1,872.52	$239.21	$274.24

Table A.4 – Watermain hydrant unit price index values

Time (Year)	Mean	−Mean	+ Mean
1982.42	$2,406.49	$0.00	$0.00
1985.43	$1,972.64	$0.00	$0.00
1987.44	$2,224.76	$0.00	$0.00
1988.44	$1,993.05	$0.00	$0.00
1988.44	$3,536.85	$0.00	$0.00
1990.45	$3,836.46	$0.00	$0.00
1990.45	$2,270.95	$0.00	$0.00
1990.45	$2,544.22	$0.00	$0.00
1990.45	$3,004.25	$0.00	$0.00
1997.47	$2,593.84	$0.00	$0.00
1997.92	$2,846.21	$0.00	$0.00
1999.00	$3,042.98	$0.00	$0.00
1999.75	$3,377.84	$0.00	$0.00
1999.75	$2,863.76	$0.00	$0.00
1999.90	$4,939.30	$0.00	$0.00
2000.00	$3,580.78	$0.00	$0.00
2000.16	$4,000.01	$0.00	$0.00
2000.33	$3,305.27	$0.00	$0.00
2000.48	$2,805.65	$0.00	$0.00
2000.58	$3,227.97	$127.40	$132.63

(Continued)

Table A.4 ***(Continued)***

Time (Year)	**Mean**	**−Mean**	**+ Mean**
2001.39	$3,155.53	$0.00	$0.00
2001.41	$2,793.90	$0.00	$0.00
2002.25	$3,824.42	$0.00	$0.00
2002.44	$2,958.70	$0.00	$0.00
2002.46	$3,824.42	$0.00	$0.00
2002.50	$3,345.26	$0.00	$0.00
2003.37	$3,863.40	$0.00	$0.00
2003.48	$3,186.40	$0.00	$0.00
2003.50	$3,877.05	$0.00	$0.00
2003.56	$3,902.15	$0.00	$0.00
2003.57	$3,712.54	$0.00	$0.00
2003.58	$4,063.28	$0.00	$0.00
2004.25	$6,403.39	$349.75	$369.96
2004.49	$5,193.57	$0.00	$0.00
2004.88	$3,881.87	$0.00	$0.00
2005.16	$3,151.32	$0.00	$0.00
2005.28	$6,403.39	$349.75	$369.96
2005.41	$3,997.12	$0.00	$0.00
2005.46	$4,404.60	$0.00	$0.00
2005.49	$5,129.09	$0.00	$0.00
2005.70	$3,889.15	$0.00	$0.00
2005.76	$4,011.84	$0.00	$0.00
2006.44	$5,581.49	$940.15	$1,130.59
2006.49	$4,362.86	$0.00	$0.00
2006.92	$4,541.53	$0.00	$0.00
2007.00	$8,114.00	$0.00	$0.00
2007.00	$4,164.71	$0.00	$0.00
2007.38	$4,861.64	$0.00	$0.00
2007.40	$4,655.17	$14.26	$14.30
2007.49	$3,450.36	$1,268.16	$2,005.14
2007.50	$3,667.42	$0.00	$0.00
2007.73	$9,316.92	$0.00	$0.00
2007.75	$4,487.67	$0.00	$0.00
2007.80	$4,968.99	$0.00	$0.00
2007.91	$25,575.36	$0.00	$0.00
2008.08	$5,751.54	$840.23	$983.97

(Continued)

Table A.4 *(Continued)*

Time (Year)	Mean	−Mean	+ Mean
2008.08	$4,173.66	$0.00	$0.00
2008.08	$5,699.86	$0.00	$0.00
2008.09	$5,456.59	$0.00	$0.00
2008.27	$3,576.35	$1,464.64	$2,480.48
2008.50	$4,152.63	$0.00	$0.00
2009.50	$7,066.23	$0.00	$0.00
2009.50	$7,492.75	$0.00	$0.00
2009.50	$5,664.51	$0.00	$0.00
2009.50	$5,237.93	$0.00	$0.00
2009.50	$5,488.83	$0.00	$0.00
2009.50	$6,197.26	$0.00	$0.00
2009.50	$5,291.11	$0.00	$0.00
2009.50	$5,553.74	$0.00	$0.00
2009.50	$6,010.48	$0.00	$0.00
2010.42	$5,368.89	$0.00	$0.00
2010.50	$6,634.35	$0.00	$0.00
2010.50	$5,488.52	$0.00	$0.00
2010.50	$5,953.56	$0.00	$0.00
2010.50	$5,639.38	$0.00	$0.00
2011.50	$6,565.01	$0.00	$0.00
2012.50	$6,272.14	$0.00	$0.00
2012.50	$6,223.60	$0.00	$0.00
2012.50	$6,473.92	$0.00	$0.00
2012.50	$5,850.17	$0.00	$0.00
2012.50	$5,164.91	$0.00	$0.00
2013.01	$6,963.83	$0.00	$0.00
2013.48	$6,886.31	$0.00	$0.00
2013.50	$7,408.85	$0.00	$0.00
2013.50	$6,433.03	$517.99	$563.35
2014.50	$9,342.23	$0.00	$0.00
2014.50	$6,192.86	$0.00	$0.00
2014.50	$6,782.44	$0.00	$0.00
2014.50	$6,767.98	$0.00	$0.00
2014.54	$6,781.79	$0.00	$0.00

Appendix B

Sanitary Sewer Standard Component and Reference Project Unit Price Indices

Sanitary sewer pipe unit price index values have a reference size of 375 mm diameter and reference material of PVC. Sanitary sewer maintenance hole unit price index values have a reference size of 1200 mm diameter and 5 metre depth. Sanitary sewer reference project consists of 1 metre of 375mm diameter PVC pipe with 1-1200mm diameter 5 metre depth maintenance hole every 75 metres of pipe. The date of index values is shown in the first column (Time (Year)). Index values are shown in the second column (mean). Minimum observed index values are calculated as the second column (mean) minus the third column (- mean). Maximum observed index values are calculated as the second column (mean) plus the fourth column (+ mean).

Table B.1 – Sanitary sewer reference project unit price index values

Time (Year)	**Mean**	**−Mean**	**+ Mean**
1981.42	$141.72	$31.50	$94.16
1983.43	$36.59	$8.84	$19.60
1983.43	$261.58	$53.63	$108.77
1985.43	$67.33	$13.28	$36.04
1988.44	$76.90	$15.99	$76.03
1990.45	$125.31	$43.72	$171.97
1990.45	$647.31	$118.64	$275.79
1990.45	$81.28	$15.88	$71.59
1990.45	$73.25	$5.81	$5.13
1990.45	$145.22	$24.14	$40.20
2000.00	$221.31	$42.29	$54.84
2001.41	$998.37	$485.32	$1,424.91
2001.48	$266.57	$79.44	$366.72
2002.56	$202.91	$56.71	$261.66
2003.50	$341.42	$161.88	$610.14
2005.41	$164.27	$24.67	$18.78
2005.49	$276.57	$159.44	$76.33
2006.44	$249.25	$0.00	$0.00
2006.92	$393.74	$54.84	$51.25
2007.41	$237.82	$4.65	$6.89
2007.49	$347.44	$12.86	$12.29
2007.49	$402.72	$5.72	$1.65
2007.89	$332.26	$30.48	$514.04
2008.08	$582.01	$242.26	$989.09
2008.08	$730.32	$87.06	$146.11
2008.08	$248.37	$74.79	$169.38
2008.09	$779.01	$366.59	$2,537.14
2008.16	$851.63	$285.58	$792.30
2009.50	$548.65	$81.37	$256.36
2009.50	$347.19	$76.25	$926.25

(Continued)

Table B.1 ***(Continued)***

Time (Year)	Mean	−Mean	+ Mean
2009.50	$215.79	$27.48	$33.64
2009.50	$394.59	$62.24	$153.32
2010.50	$825.59	$246.00	$436.25
2010.50	$980.58	$246.93	$1,060.95
2010.50	$292.17	$30.01	$43.50
2011.50	$285.92	$54.09	$190.34
2011.50	$419.17	$29.36	$22.00
2012.50	$321.42	$9.91	$10.59
2012.50	$455.63	$30.41	$33.10
2012.50	$417.39	$62.20	$274.71
2013.01	$323.55	$48.95	$96.70
2013.50	$488.05	$97.27	$125.44
2014.50	$237.12	$38.30	$78.68
2014.50	$768.96	$64.56	$97.15

Table B.2 – Sanitary sewer pipe unit price index values

Time (Year)	Mean	−Mean	+ Mean
1981.42	$120.73	$30.28	$93.27
1983.43	$16.76	$4.86	$12.35
1983.43	$236.97	$52.89	$107.87
1985.43	$390.24	$0.00	$0.00
1985.43	$37.81	$8.99	$13.63
1987.44	$5.05	$1.42	$14.44
1988.44	$25.49	$8.68	$64.64
1988.44	$5.87	$0.22	$0.58
1988.44	$92.99	$42.28	$45.30
1988.44	$60.90	$9.49	$17.47
1989.44	$98.67	$6.61	$10.42
1990.45	$76.29	$40.26	$168.51
1990.45	$553.14	$118.63	$275.79
1990.45	$28.31	$8.04	$59.42
1990.45	$20.48	$1.99	$0.42
1990.45	$75.81	$17.44	$27.33
1997.47	$41.72	$27.55	$67.17
1999.00	$39.56	$5.06	$19.23

(Continued)

Table B.2 ***(Continued)***

Time (Year)	**Mean**	**−Mean**	**+ Mean**
1999.90	$32.09	$0.00	$0.00
2000.00	$151.83	$30.36	$19.66
2000.33	$289.37	$0.00	$0.00
2000.48	$2,845.28	$116.01	$120.94
2001.41	$831.40	$420.13	$1,309.31
2001.48	$173.69	$74.47	$350.46
2002.44	$20.30	$0.00	$0.00
2002.56	$123.41	$52.91	$249.01
2003.37	$121.59	$27.38	$133.73
2003.48	$254.10	$24.49	$32.91
2003.50	$378.98	$41.09	$32.57
2003.50	$227.95	$133.13	$504.15
2003.58	$49.80	$0.00	$0.00
2004.88	$48.14	$0.00	$0.00
2005.41	$81.32	$22.25	$16.30
2005.46	$53.53	$0.00	$0.00
2005.49	$186.44	$137.96	$30.10
2005.76	$143.77	$48.57	$124.00
2006.44	$146.42	$0.00	$0.00
2006.92	$296.49	$49.99	$46.14
2007.00	$232.60	$16.61	$104.53
2007.00	$361.87	$41.47	$397.60
2007.41	$155.27	$2.72	$5.59
2007.49	$225.42	$8.93	$10.28
2007.49	$398.63	$5.72	$1.65
2007.89	$222.79	$26.03	$478.90
2007.91	$3,187.04	$904.56	$1,263.03
2008.08	$424.76	$195.55	$900.30
2008.08	$536.50	$74.33	$132.48
2008.08	$140.45	$55.28	$151.51
2008.09	$673.55	$335.62	$2,517.42
2008.16	$717.45	$260.36	$778.04
2009.50	$200.74	$57.86	$232.39
2009.50	$173.70	$59.15	$877.49
2009.50	$458.03	$275.28	$4,053.16
2009.50	$69.43	$0.41	$0.41

(Continued)

Table B.2 ***(Continued)***

Time (Year)	Mean	−Mean	+ Mean
2010.50	$626.90	$180.78	$387.58
2010.50	$661.45	$219.24	$1,018.95
2010.50	$187.36	$22.48	$38.80
2011.50	$146.51	$45.36	$181.02
2011.50	$295.65	$15.15	$2.60
2012.50	$206.20	$1.47	$1.85
2012.50	$363.05	$23.03	$24.59
2012.50	$162.84	$15.61	$22.91
2013.01	$193.70	$48.95	$96.70
2013.50	$359.74	$86.11	$113.21
2014.50	$122.38	$24.33	$56.74
2014.50	$350.88	$14.80	$31.58
2014.54	$3,082.67	$0.00	$0.00

Table B.3 – Maintenance hole unit price index values

Time (Year)	Mean	−Mean	+ Mean
1981.42	$1,574.22	$91.51	$67.11
1983.43	$1,487.21	$298.70	$543.69
1983.43	$1,845.89	$56.14	$67.38
1985.43	$2,214.05	$321.77	$1,680.27
1988.44	$3,855.38	$547.98	$854.49
1990.45	$3,676.44	$259.82	$259.08
1990.45	$7,062.25	$0.00	$0.00
1990.45	$3,972.39	$587.88	$913.01
1990.45	$3,957.97	$286.84	$352.57
1990.45	$5,205.04	$501.78	$965.42
2000.00	$5,211.60	$894.68	$2,638.32
2001.41	$12,522.83	$4,889.74	$8,669.95
2001.48	$6,966.16	$372.94	$1,219.65
2002.56	$5,962.92	$285.59	$948.74
2003.50	$8,510.23	$2,155.78	$7,948.82
2005.41	$6,221.12	$181.40	$186.85
2005.49	$6,760.11	$1,611.17	$3,466.73
2006.44	$7,711.75	$0.00	$0.00
2006.92	$7,293.76	$364.33	$383.48

(Continued)

Table B.3 ***(Continued)***

Time (Year)	Mean	−Mean	+ Mean
2007.49	$9,150.97	$295.13	$151.23
2007.49	$306.65	$0.00	$0.00
2007.89	$8,210.19	$333.45	$2,635.25
2008.08	$11,793.99	$3,502.91	$6,659.75
2008.08	$14,536.87	$954.80	$1,021.92
2008.08	$8,094.30	$1,463.33	$1,340.33
2008.09	$7,909.00	$2,323.16	$1,478.98
2008.16	$10,063.11	$1,891.43	$1,069.40
2009.50	$26,093.35	$1,762.74	$1,798.42
2009.50	$13,011.58	$1,282.77	$3,657.52
2009.50	$10,454.94	$685.65	$921.07
2009.50	$10,977.29	$2,030.74	$2,491.68
2009.50	$9,810.94	$1,186.93	$1,280.78
2010.50	$14,902.00	$4,891.65	$3,649.89
2010.50	$23,934.82	$2,076.75	$3,149.93
2010.50	$7,860.45	$564.23	$352.41
2011.50	$10,455.99	$654.66	$698.39
2011.50	$9,264.16	$1,065.54	$1,454.48
2012.50	$8,641.94	$632.76	$655.62
2012.50	$6,943.39	$553.20	$638.02
2012.50	$19,091.47	$3,494.17	$18,884.72
2013.01	$9,738.52	$0.00	$0.00
2013.50	$9,623.95	$837.21	$916.99
2014.50	$16,790.53	$3,048.98	$13,839.74
2014.50	$8,605.74	$1,047.96	$1,645.29
2014.50	$31,356.44	$3,732.42	$4,917.48

Appendix C

Applicability of GBM to Comparison Indices

Table C.1 – Shapiro-Wilk and Ljung-Box Test p-values for Comparison Indices

Index	Shapiro-Wilk Test (p-value)	Ljung-Box Test (p-value)
CPI	4.777×10^{-5}	1.368×10^{-12}
NRBCPI	0.1911	0.1265
LDCCT	0.2196	0.959
TSX	0.171	0.5907

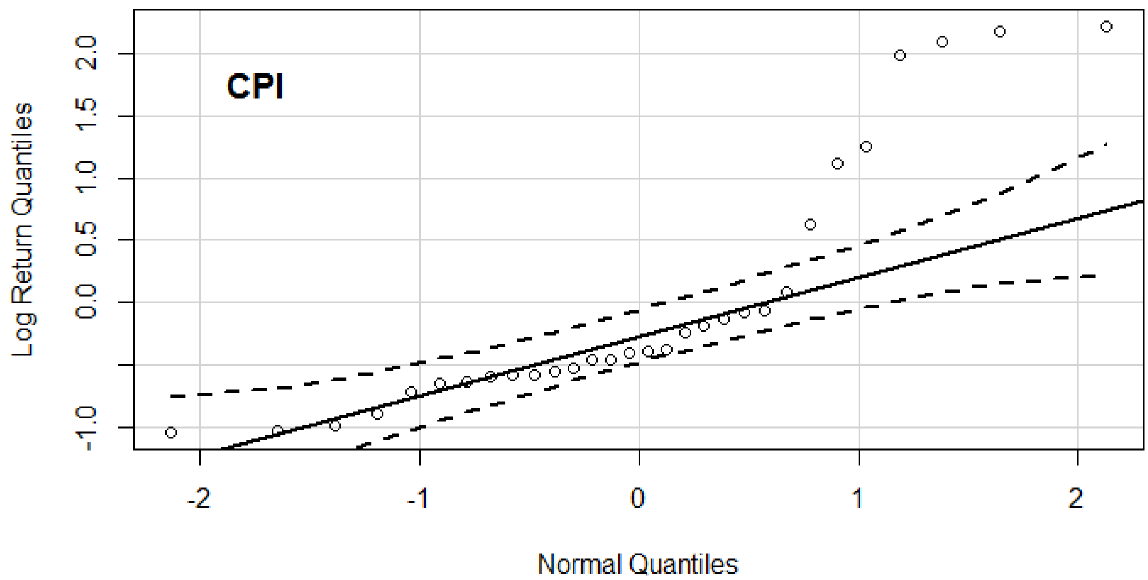

Figure C.1 – CPI log returns normal quantile-quantile plot

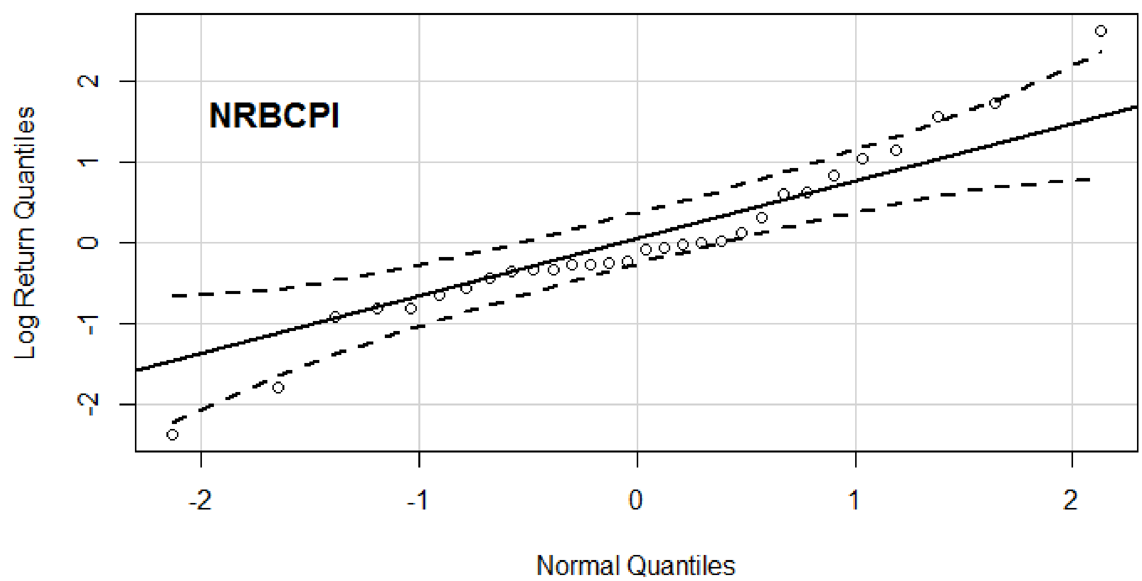

Figure C.2 – NRBCPI log returns normal quantile-quantile plot

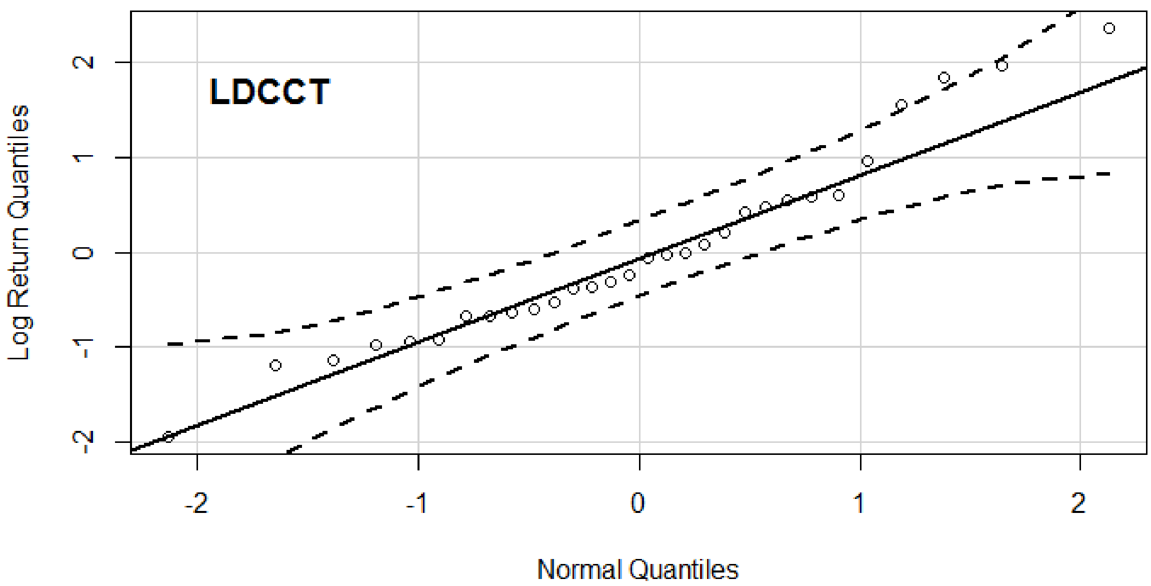

Figure C.3 – LDCCT log returns normal quantile-quantile plot

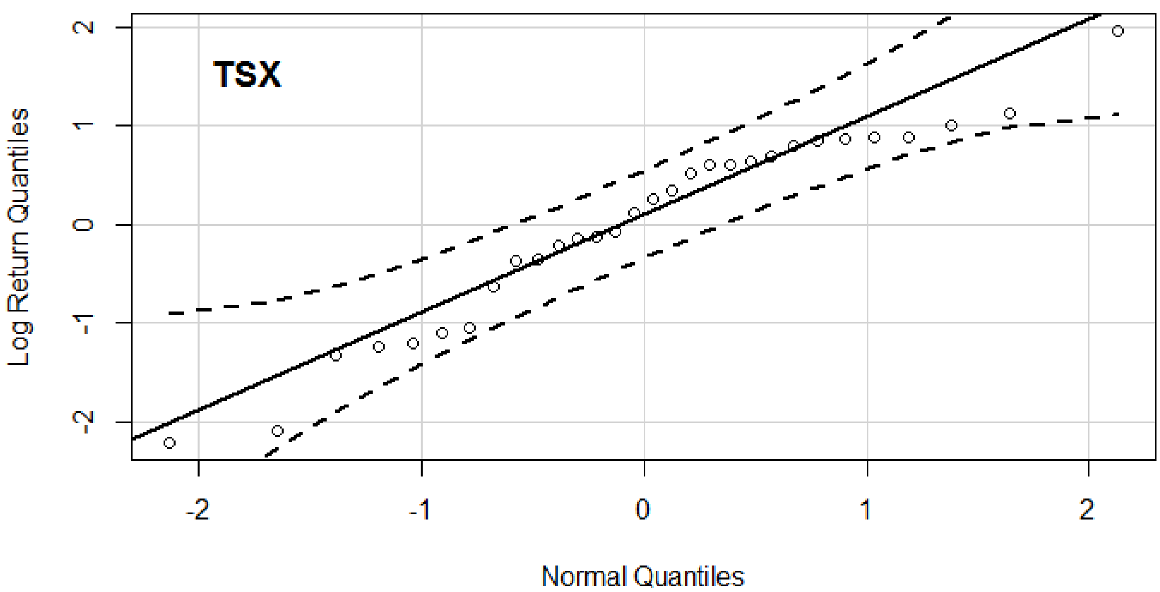

Figure C.4 – TSX composite index log returns normal quantile-quantile plot

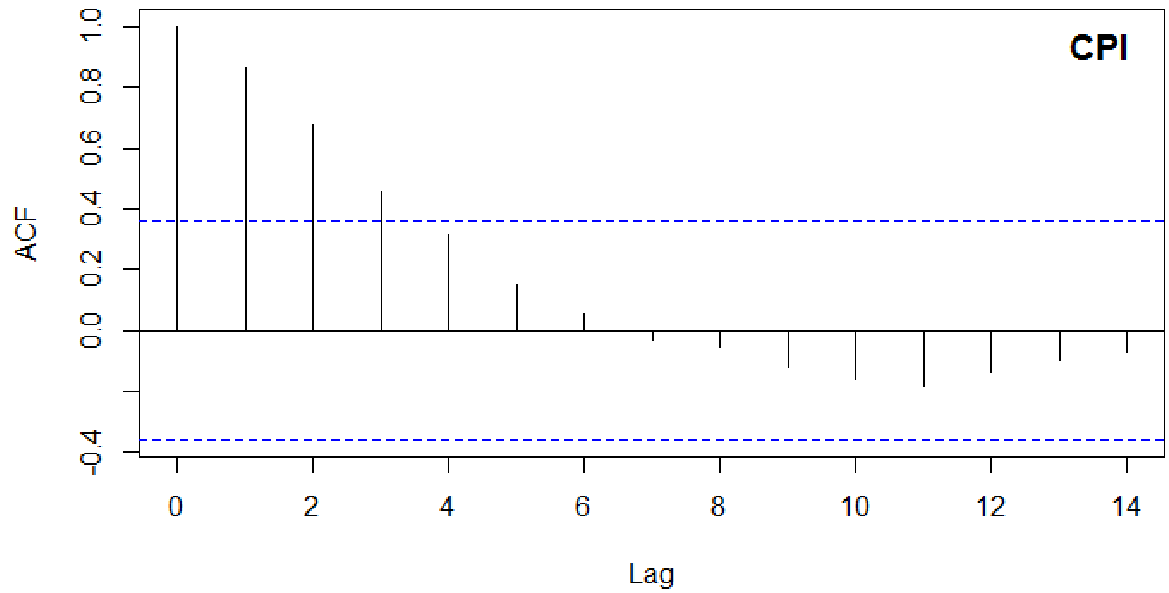

Figure C.5 – CPI log returns autocorrelation plot

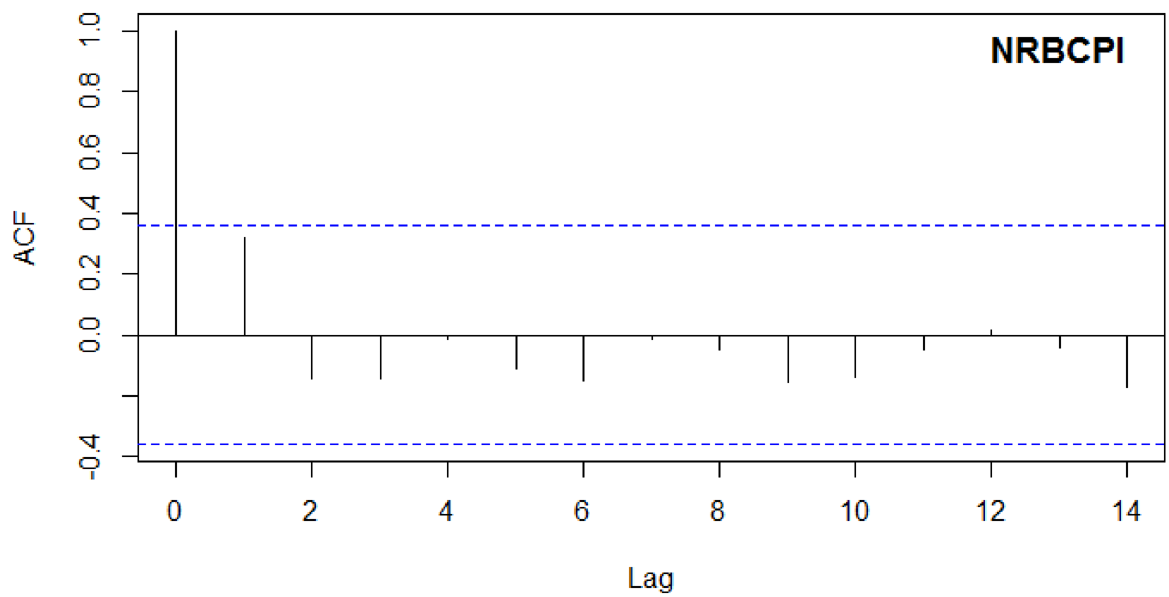

Figure C.6 – NRBCPI log returns autocorrelation plot

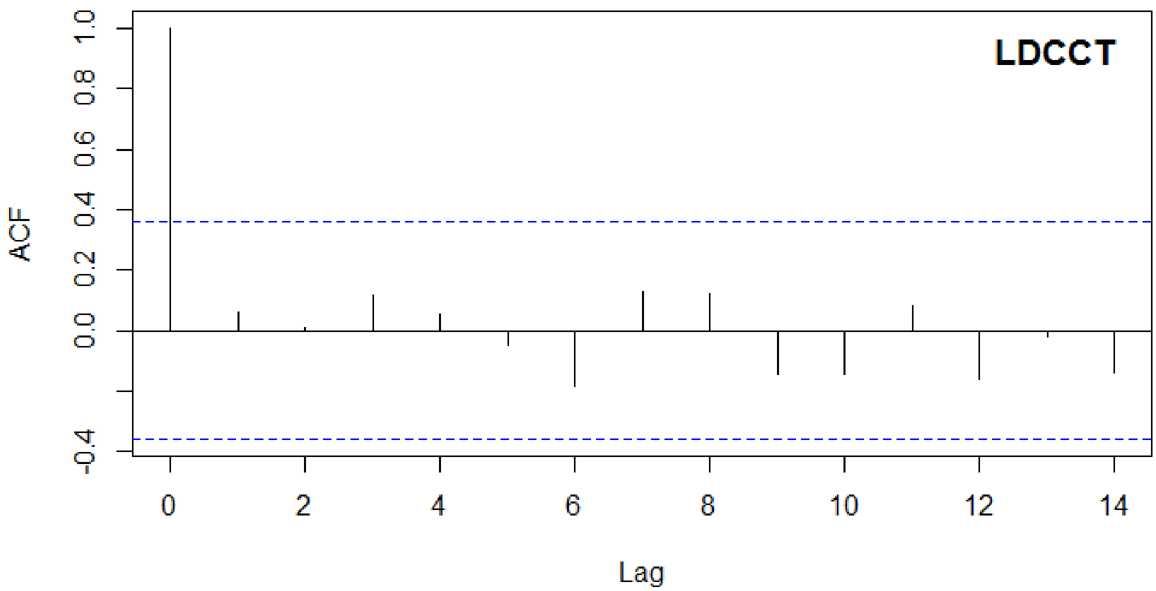

Figure C.7 – LDCCT log returns autocorrelation plot

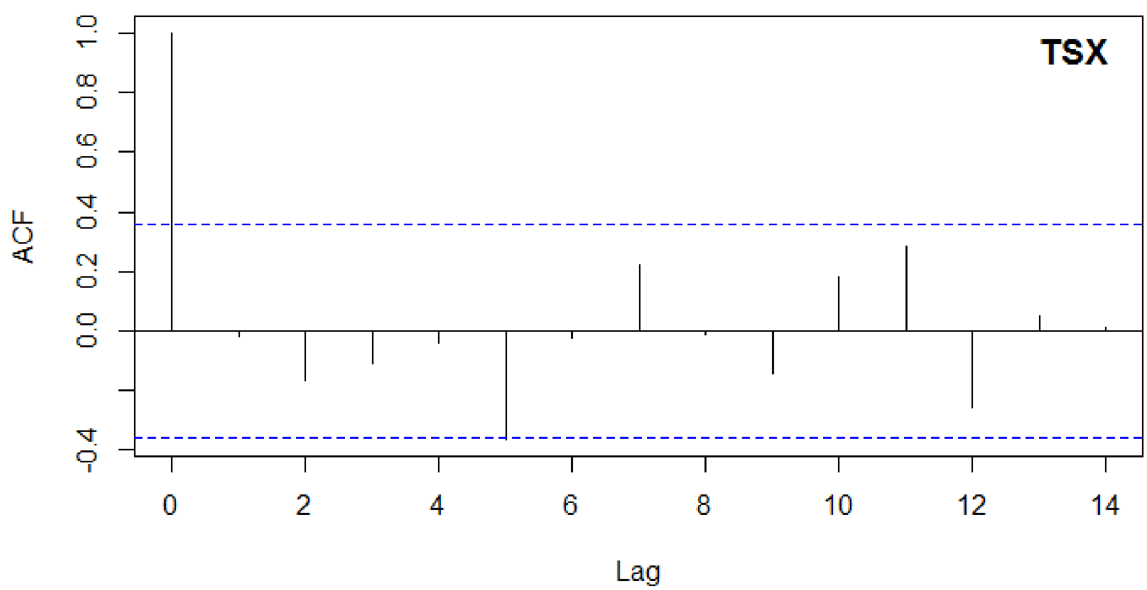

Figure C.8 – TSX composite index log returns autocorrelation plot

Appendix D

Applicability of GBM to Watermain Indices

Table D.1 – Shapiro-Wilk and Ljung-Box Test p-values for Watermain Indices

Index	Shapiro-Wilk Test (p-value)	Ljung-Box Test (p-value)
Watermain Project	0.5747	1.973×10^{-4}
Watermain Pipe	0.5978	1.473×10^{-5}
Watermain Valve	0.8741	0.2609
Watermain Hydrant	0.02731	0.01908

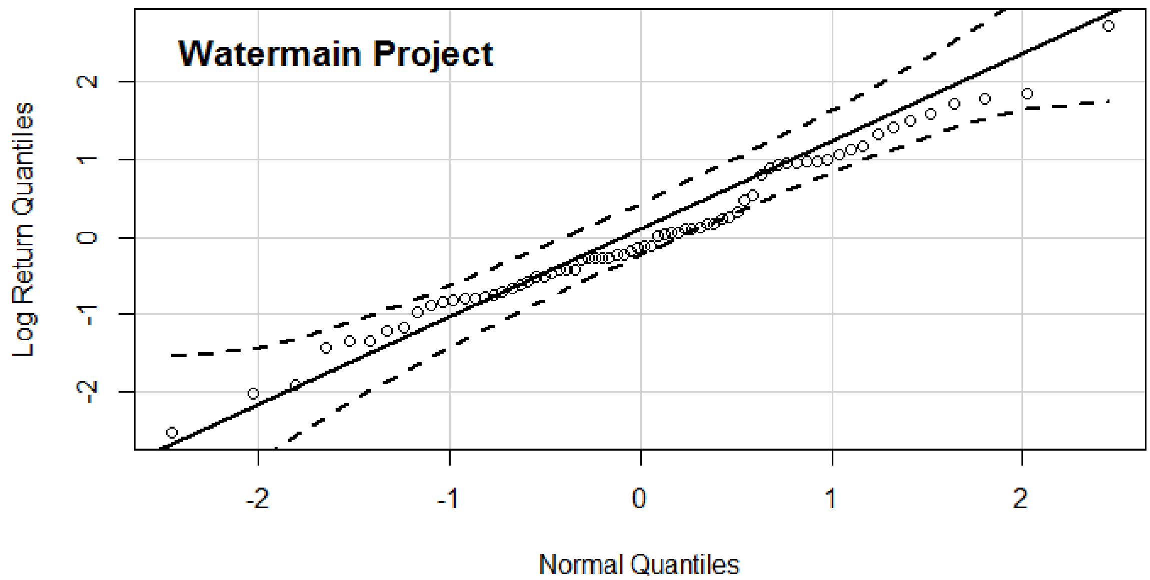

Figure D.1 – Watermain project index log returns normal quantile-quantile plot

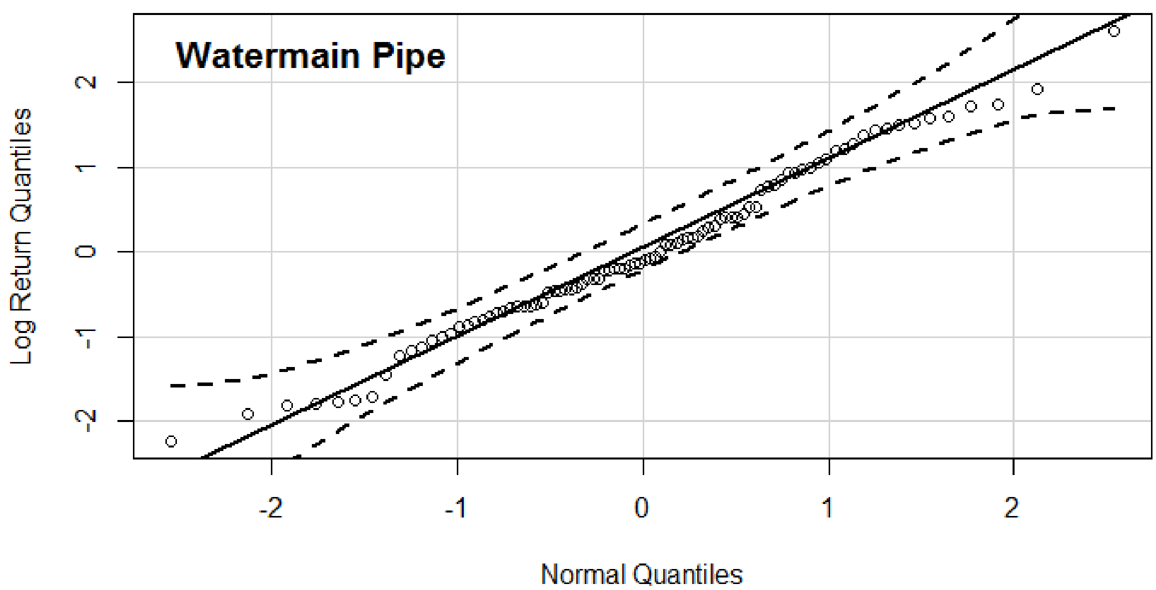

Figure D.2 – Watermain pipe index log returns normal quantile-quantile plot

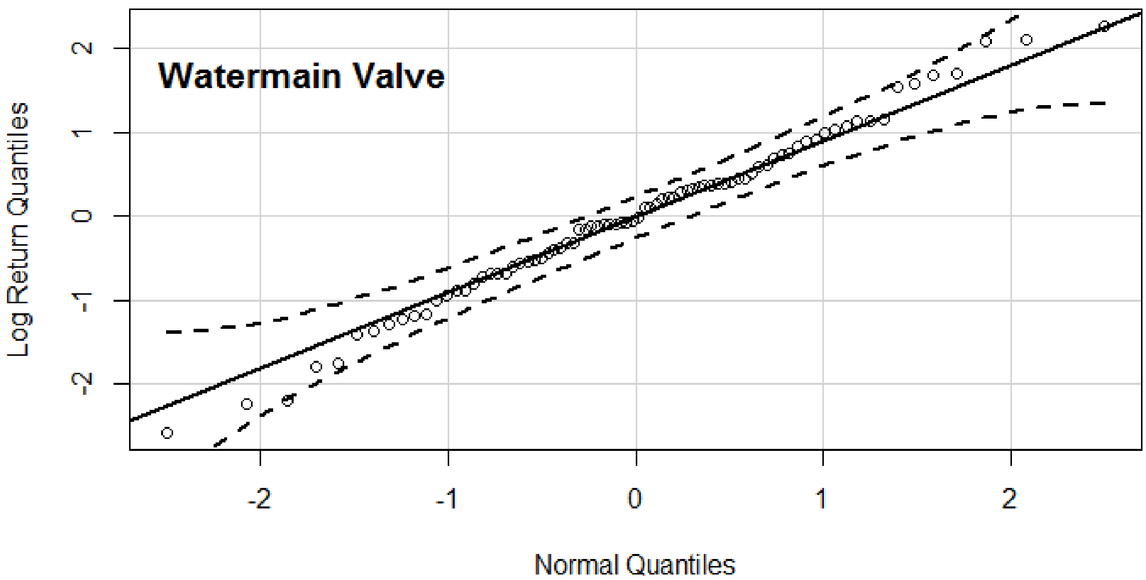

Figure D.3 – Watermain valve index log returns normal quantile-quantile plot

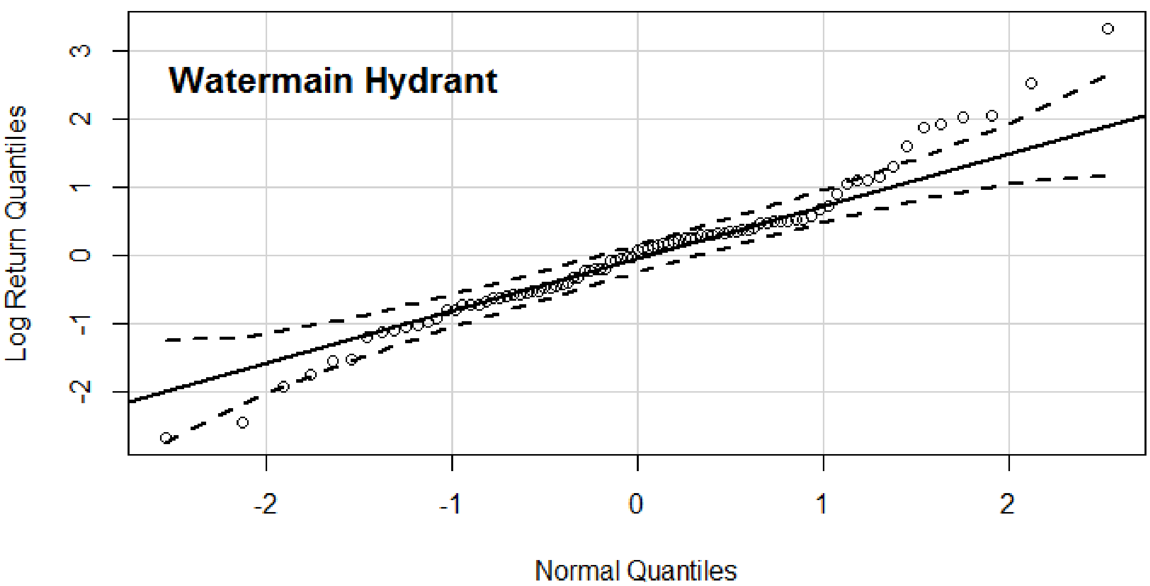

Figure D.4 – Watermain hydrant index log returns normal quantile-quantile plot

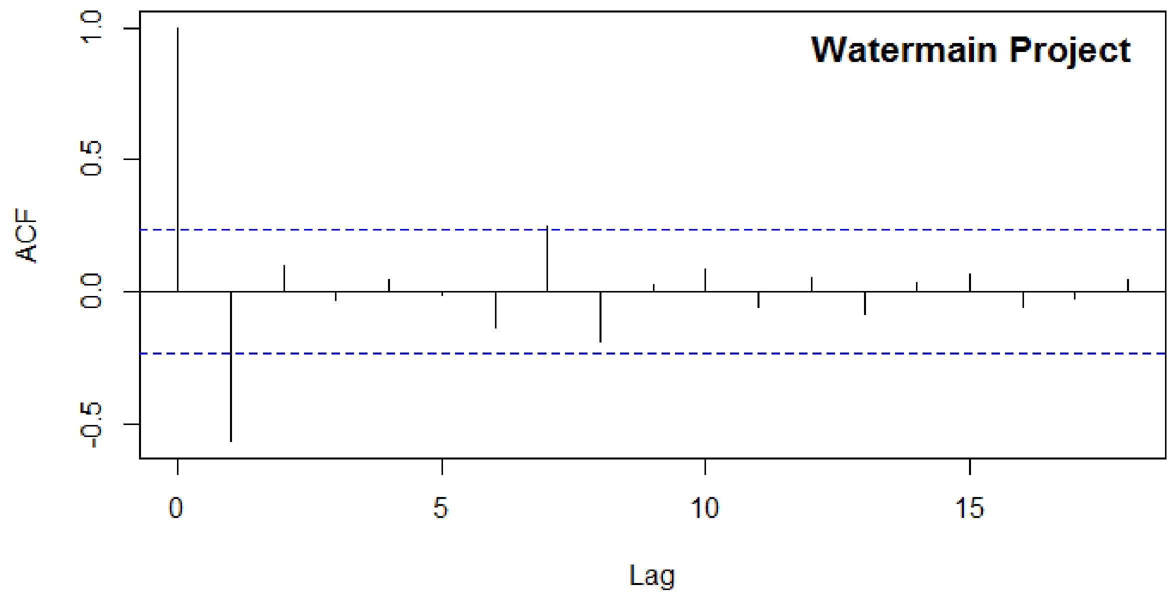

Figure D.5 – Watermain project index log returns autocorrelation plot

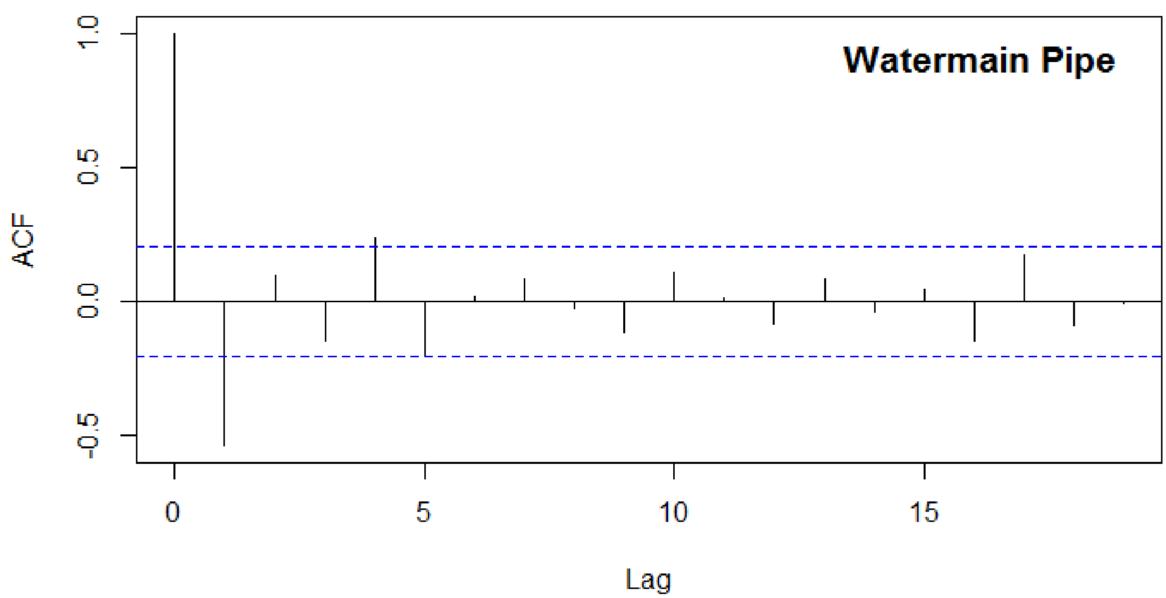

Figure D.6 – Watermain pipe index log returns autocorrelation plot

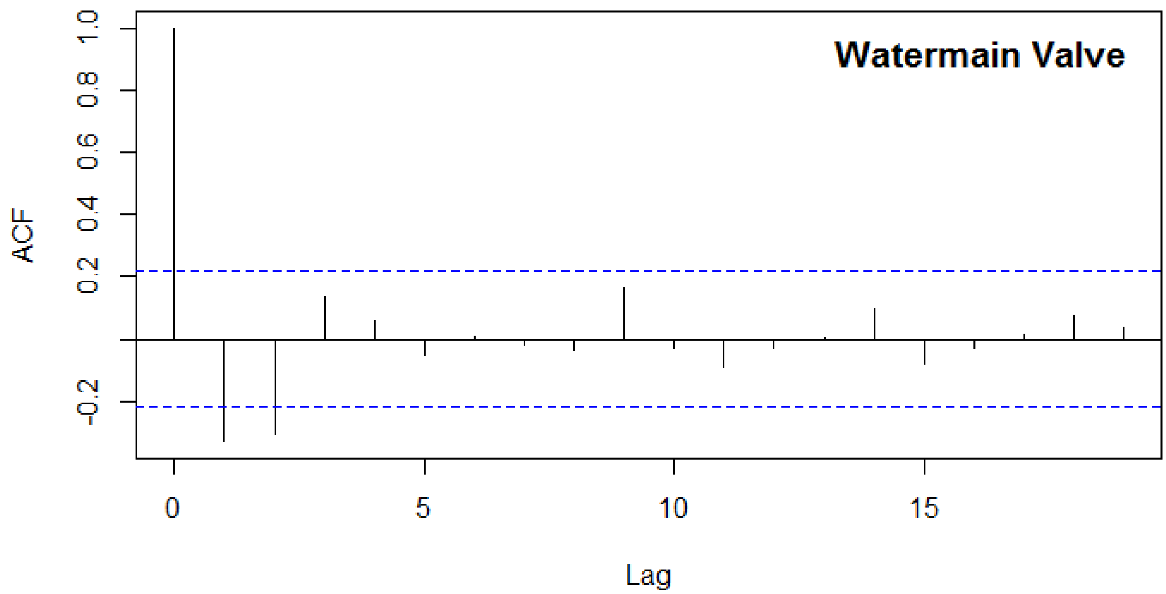

Figure D.7 – Watermain valve index log returns autocorrelation plot

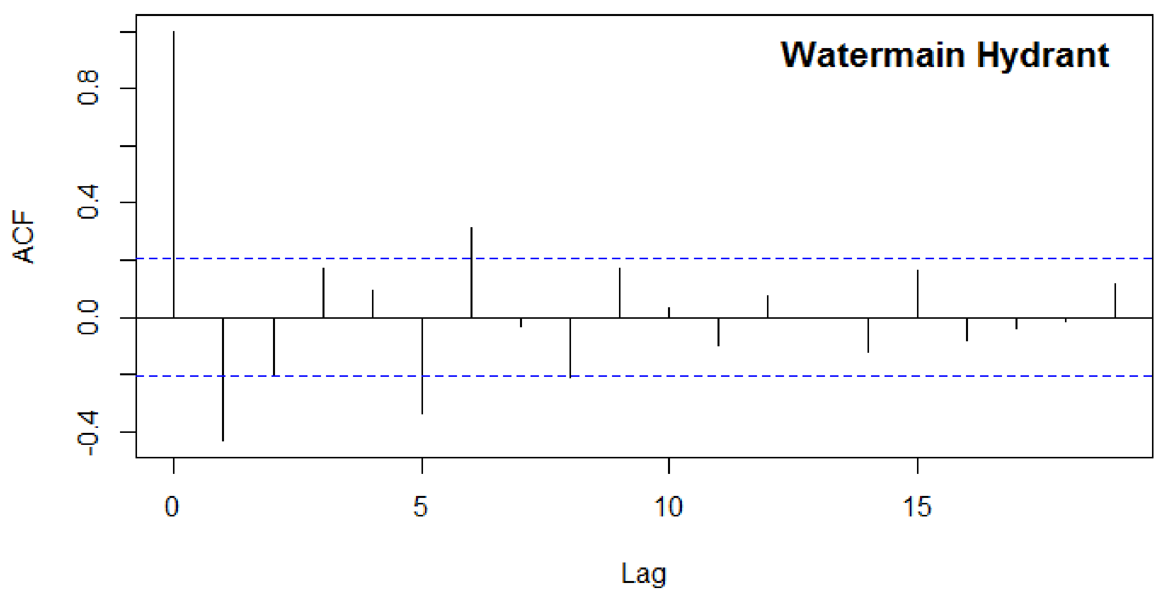

Figure D.8 – Watermain hydrant index log returns autocorrelation plot

Appendix E

Applicability of GBM to Sanitary Sewer Indices

Table E.1 – Shapiro-Wilk and Ljung-Box Test p-values for Sanitary Sewer Indices

Index	Shapiro-Wilk Test (p-value)	Ljung-Box Test (p-value)
Sanitary Sewer Project	0.3388	0.02703
Sanitary Sewer Pipe	0.9144	0.01219
Sanitary Sewer Maintenance Hole	0.3711	0.0243

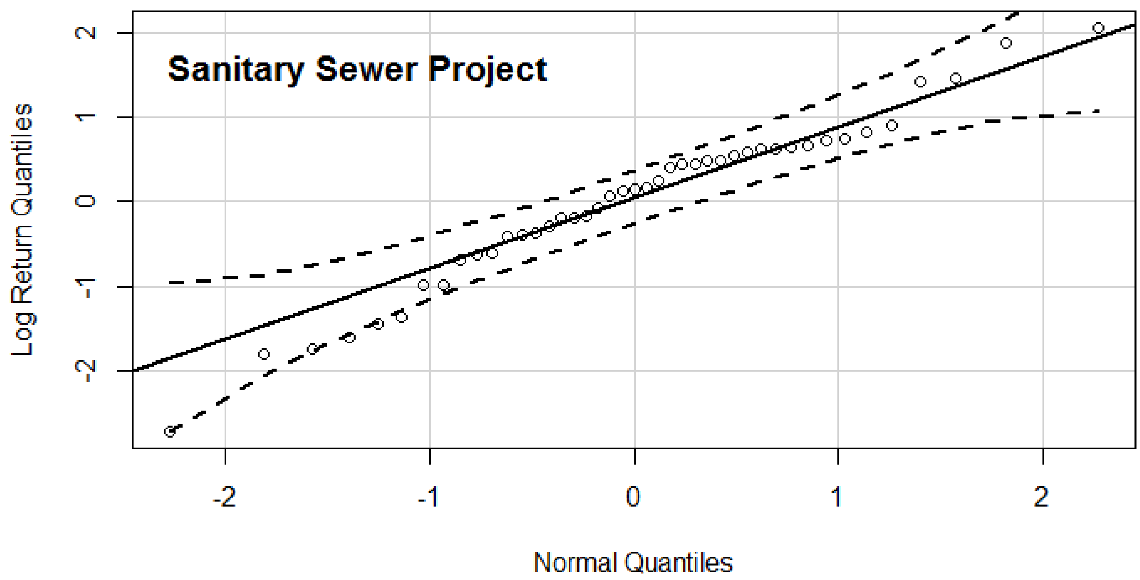

Figure E.1 – Sanitary sewer project index log returns normal quantile-quantile plot

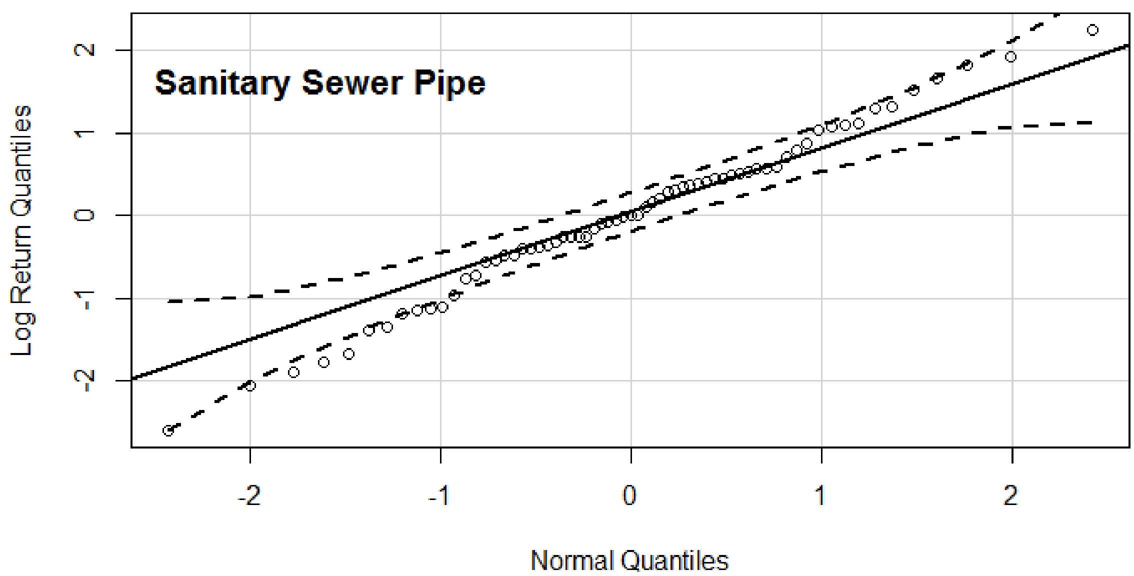

Figure E.2 – Sanitary sewer pipe index log returns normal quantile-quantile plot

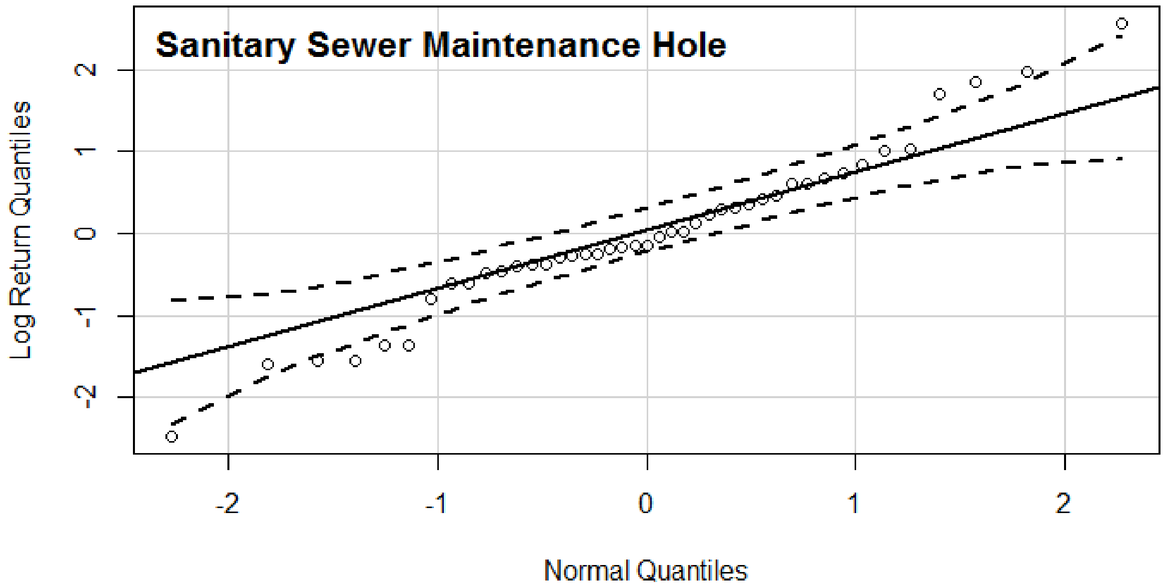

Figure E.3 – Sanitary sewer maintenance hole log returns normal quantile-quantile plot

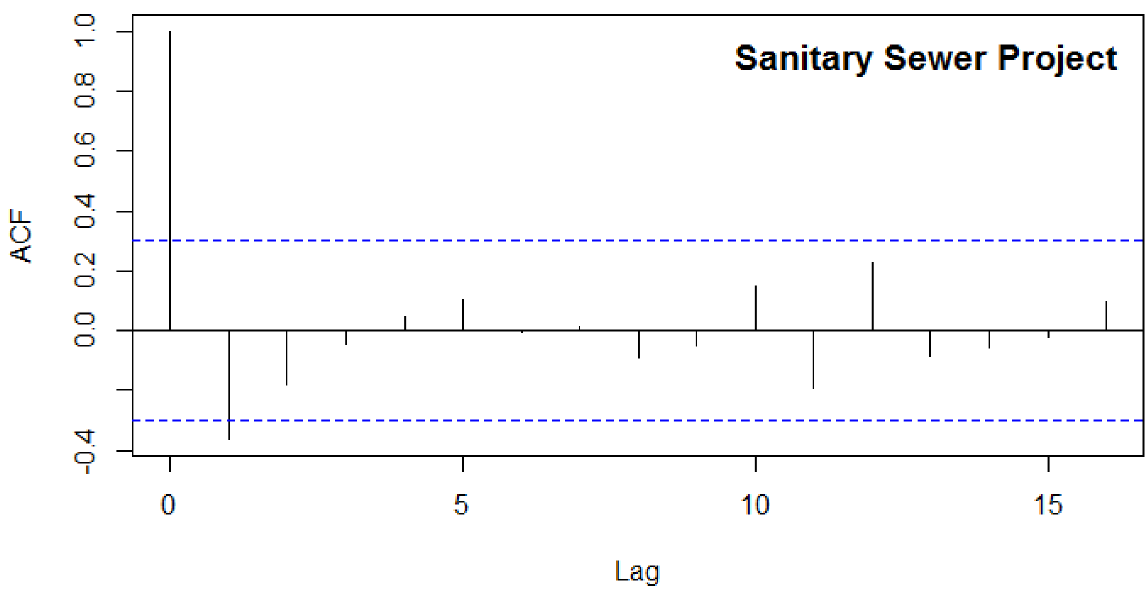

Figure E.4 – Sanitary sewer project index log returns autocorrelation plot

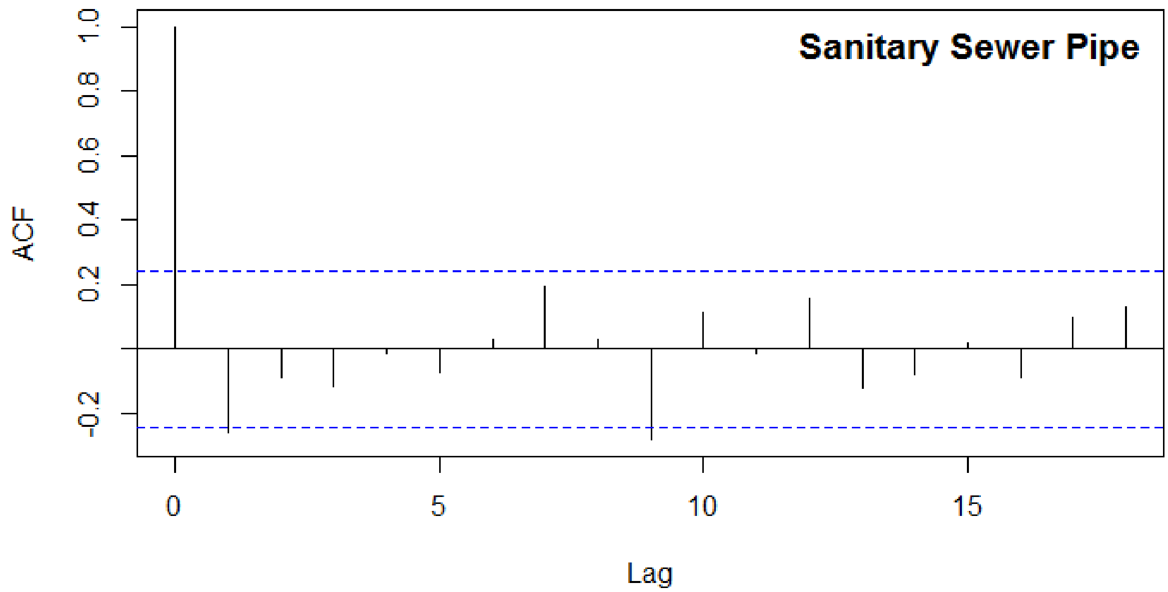

Figure E.5 – Sanitary sewer pipe index log returns autocorrelation plot

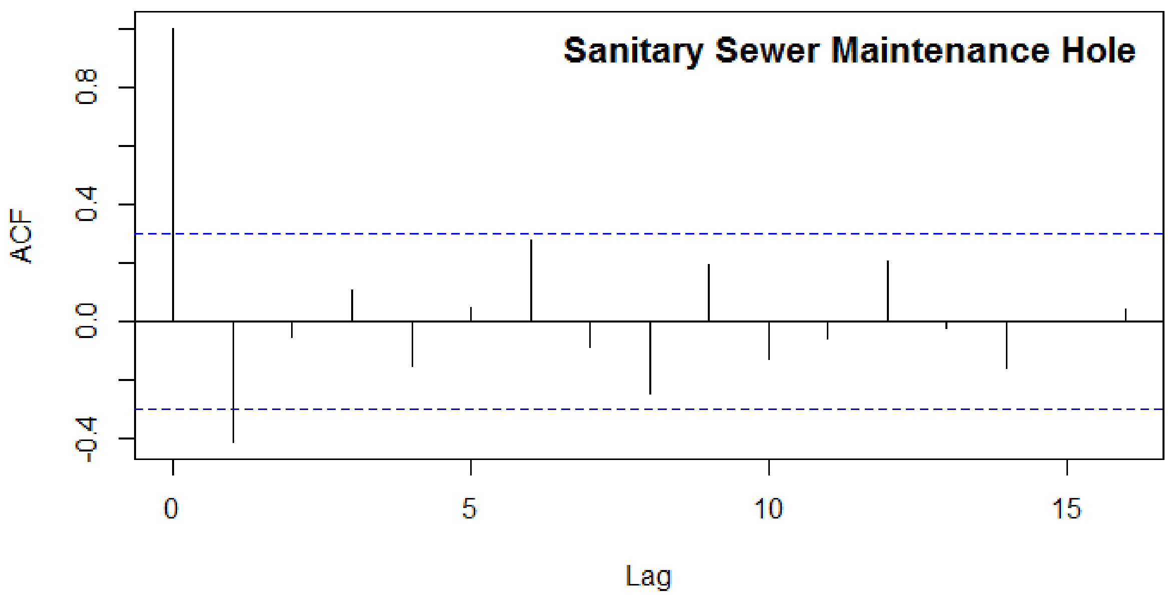

Figure E.6 – Sanitary sewer maintenance hole index log returns autocorrelation plot