DESIGNING A FRAMEWORK TO GUIDE RENEWAL ENGINEERING DECISION-MAKING FOR WATER AND WASTEWATER PIPELINES

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Thesis submitted to the faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
In
Civil Engineering

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August 11th, 2010

Blacksburg, Virginia

Keywords: Water and Wastewater Infrastructure, Renewal Engineering, Decision-Support System

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ABSTRACT

Federal, state and private organizations have an urgent need for renewal of water and wastewater pipelines. A pertinent gap remains in understanding the relationship between deteriorated host-pipe conditions and renewal products cost and performance. This work provides a framework Decision-Support System that supports water and wastewater pipeline renewal-products. Various renewal products fit utility needs, and the optimization of this process streamlines the decision-making for renewal product selection. The Thesis has classified various factors for use in the renewal product decision-making process, and it provides the justification for use of the renewal decision-making factors in recommending a product. Pipeline problem definition, system causes, system requirements and renewal product characteristics are the key decision-making areas controlling the recommendation of a renewal product. The Decision-Support System framework is developed in a user-friendly Visual Basic forms, using Microsoft tools and evaluated for vendor information. The given framework allows the user to edit product information needs, factors affecting decision-making and the classification of each factor. This allows for ease in modification, utilization and collaborative understanding. The prototype framework is an online hosting of the proposed framework will improve accessibility and validity of the renewal decision-making process.

ACKNOWLEDGEMENT

I have completed the Master's Thesis as a member of the Sustainable Water Infrastructure Management research group at Virginia Tech. Since joining the group in October 2008, I was very lucky to work with an extraordinary group of researchers who contributed to my knowledge and work. I sincerely believe these individuals deserve a special mention for their support and encouragement throughout my experience at Virginia Tech.

My heartfelt gratitude goes to my committee, for their support and encouragement, which made the completion of this Thesis possible. I have learned many lessons under the supervision of Dr Sunil K Sinha, the chairperson of my committee. I am grateful to him for investing his time in my research and in helping me grow as a civil engineering professional. I shall always remember his line – "Present it like a story, and sell the product". A summary of the list of things that I have learnt from him require a real life experience. I am glad to have a great working relationship with him.

Raj and Rahul have eagerly guided me through my assignments and projects in the SWIM lab. I will never forget the nights and weekends spent on research projects and project work with them. Manu has shared much of his time with me. Our friendship started as students in the Civil Engineering program and has a long path ahead. All the fast-food visits and long discussions on random topics were a wonderful way of spending difficult workdays. I especially remember our failed ideas on submitting a joint conference paper and the successful live demonstrations for condition assessment and rehabilitation products. The long hours in the research office along with many curricular and non-curricular activities will never repeat. Our trips to Virginia Beach, Chicago, Canada and many more have left a last impression on me. Infrastructure Asset Management is the umbrella of Rehabilitation, Condition Assessment, Inspection and not Financial Budgets. Our many debates could have easily formed the base of conference papers. I was lucky to work with members of the SWIM team and I thank them for their inputs and ideas. Park, Shaoqing Ge, Varun, Leon, Thiti, Richard and Alison are exceptional individuals who made my research more enjoyable. All the PhDs and Post-docs have a fair share of contribution to preparing me as a Research student.

My two years at Virginia Tech have exponentially increased the value of my time spent with my family. They mean a lot to me, and words will never suffice in capturing my love,

respect or dedication for them. Their efforts in molding me are priceless and unmatched. My undergraduate studies, friends and faculty have left a strong influence on my endeavors. I cherish the joyous moments that I spent with my roommates and friends. Cooking tasty Indian meals and watching Indian movies with them consumed most of my weekends. On the top of my miss-you-list are the beautiful time around New River Valley, cookouts, cricket and the three-block long downtown. The Indian Students Association (ISA), which was instrumental in organizing a good schedule of events and curricular activities, enhanced my experience in Blacksburg. The splendid group of people and the amazing activities in and around Blacksburg have helped me discover a rich American tradition. Virginia Tech with all its glory is a proud alma mater for me. Of course, I hope the Hokies get to the National Championships sooner than later.

USEPA and WERF are two organizations that have supported me throughout my graduate studies. The support provided by different technology providers in teaching and guiding me is immeasurable. Their continuous appreciation for my project results and reports has motivated me to present this thesis work. The Graduate School at Virginia Tech, Sandy Simpkins from the CEM office and Lindy Cranwell from the CEE Office are able representatives of the efforts and hard work that goes behind managing a civil engineering student. All these factors combined, I believe my time at Virginia Tech was fruitful and a learning adventure.

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LIST OF ABBREVIATIONS

AC: Asbestos Cement
AI: Artificial Intelligence
ANSI: American National Standards Institute
ASTM: American Society for Testing and Materials
AW: Annual Worth
AWWA: American Water Works Association
ASCE: American Society for Civil Engineers

BAMI-I: Buried Asset Management Institute- International
BSI: British Standards Institute

CARE: Computer Aided Rehabilitation
CEN: European Committee for Standardization
CERF: Civil Engineering Research Federation
CI: Cast Iron
CIPP: Cured In Place Pipe
CNRC: Canadian National Research COuncil
CSO: Combined Sewer Overflows

DBMS: Database Management System
DOT: Department of Transportation
DSS: Decision Support System

EPA: US Environment Protection Agency
EPCOR: Edmonton Power Corporation

FHWA: Federal Highway Administration
FRP: Fiber Reinforced Pipe
FW: Future Value

GASB: Government Accounting Standard Board
GIP: Grout In Place
GIS: Geographical Information System
GRP: Glass Reinforced Pipe
GUI: Graphical User Interface

HAZWOPER: Hazardous Waste Operations and Emergency Response
HDD: Horizontal Directional Drilling
HDPE: High Density Polyethylene

I&I: Inflow & Infiltration
ISO: International Standards Organization
ISTT: International Society for Trenchless Technology
I-WARP: Interactive Water Main Renewal Planner

KMS: Knowledge Management System

LCC: Life Cycle Costs

MIRP: Model for Infrastructure Rehabilitation Planning
MMS: Model Management System

NACWA: National Association of Clean Water Agencies
NAS: National Academy of Sciences
NASTT: North American Society for Trenchless Technology
NHPP: Non-homogenous Poisson Process
NIOSH: National Institute for Occupational Safety and Health
NPDES: National Pollutant Discharge Elimination System
NSF: National Science Foundation
NUCA: National Utility Contractor's Association

OSHA: Occupational Safety and Health Administration

PANY-NJ: Port Authority of New York and New Jersey
PCCP: Prestressed Cylinder Concrete Pipe
PU: Polyurethane
PV: Present Value
PVC: Poly Vinyl Chloride

QA/ QC: Quality Assurance/ Quality Control

RCP: Reinforced Concrete Pipe
REST: Renewal Engineering Selection Tool
RPV: Replacement Priority Value
RTDPEC: Research and Technological development Project of European Community

SDWA: Safe Drinking Water Act
SSES: Sewer Separation and Evaluation Survey
SSO: Sanitary Sewer Overflows
SWIM: Sustainable Water Infrastructure Management

TAG-R: Trenchless Assessment Guide for Rehabilitation
TTC: Trenchless Technology Center

UIM: Urban Infrastructure Management
USCG: United States Coast Guard
UV: Ultra Violet

VBA: Visual Basic for Applications

WRc: Water Research Council
WERF: Water Environment Research Foundation
WEF: Water Environment Federation

Chapter 1: INTRODUCTION

Need for Water and Wastewater Renewal

There are approximately 160,000 public water systems in the US (SDWA 1996). They distribute potable water and collect wastewater from a majority of homeowners and industries. Operation and maintenance of the $ 3.5 billion per year (EPA 2004) consumer-oriented water and wastewater service should be at-par with acceptable industry standards. Infrastructure assets typically have low failure rates, but when they fail, the consequences can be severe (Kleiner 2001).

Table **1** below highlights pipeline failure events covered by national and local newspapers.

DATE	LOCATION	ARCHIVE
November 27, 2009	Colorado Springs, Colorado	News 13 TV channel online
September 16, 2009	City of Los Angeles, California	Los Angeles times
December 23, 2008	Montgomery County, Maryland	Washington post
August 28, 2008	White Mills, Texas	Wayne independent
February 10, 2007	West New York, New Jersey	New York times

Table 1: A brief list of reported pipeline failures in the news media

Tax-paying customers endure the result of the state of our buried infrastructure. EPA's Clean Water and Drinking Water Infrastructure Gap Analysis report acknowledges, "The average pipe age in 2008 is 38 years, but by the year 2050 the average pipe age will be 50 years old, because of the boom in water pipeline installations and periodic replacement measures after World War II" (EPA 2002). The combination of age, neglect and mishaps causes at least 40,000 Sanitary Sewer Overflows (SSOs) per year and resulting illnesses and environmental degradation (EPA 2009a). While, the utility bill only covers operation, treatment and maintenance costs, and tap water costs slightly more than 2$ per 1000 gallons, an average consumer uses approximately 100 gallons per day (EPA 2010).

Table **2** reports figures estimated by agencies for the renewal of water and wastewater systems.

Table 2: Reported cost of Water and Wastewater System Renewal

PUBLISHER	VALUE	DESCRIPTION CLAUSE
EPA 2003	$183.6 billion	"Should be invested by 2023 into distribution and transmission infrastructure."
Selvakumar et. al 2002	$77 billion	"Expenditure will be dedicated to repairing and rehabilitating pipelines."
AWWA 2001	$250 billion	"Expenditures over 30 years might be required nationwide for the replacement of worn-out drinking water pipes and associated structures."
ASCE 2009	$11 billion	"To replace the aging infrastructure just to comply with existing and future federal water regulations."
EPA 2008	$390 and $274 billion	"A whopping investment respectively for wastewater and water system rehabilitation"
CNRC 2004	$15 billion	"Estimated replacement and rehabilitation cost for water main infrastructure across Canada"

One of the issues affecting present day wastewater infrastructure is Combined Sewer Overflows (CSOs). The Underground Construction Magazine et al. 2008; 2009a; 2009b has detailed editorials on EPA actions admonishing Massachusetts, New Hampshire, Ohio and Indiana to eliminate CSOs and SSOs by improving and upgrading their wastewater infrastructure. Numerous suppliers, sub-contractors and trade bodies have presented their versions of the failing water and wastewater pipeline system. The North American Society for Trenchless Technology (NASTT), International Society for Trenchless Technology (ISTT), Buried Asset Management Institute – International (BAMI-I) and Urban Infrastructure Management (UIM) are a few of them. The annual ASCE Infrastructure Report Card 2009 rates drinking water infrastructure at "D-minus", reasoning a lack of significant investment on the performance of our aging underground infrastructure. The Government Accounting Office (GAO) in a 2002 report stated that 33 percent of water utilities did not adequately maintain assets

and a further 29 percent had insufficient revenues to maintain current service levels (AWWA 2001). Government Accounting Standard Board (GASB) 34 requires utilities to consider salvage value and long-term effects, including Life Cycle Costs (GASB 2010).

The water and wastewater industry has borrowed many trenchless engineering tools from the oil and natural gas industry. Water and wastewater utilities use practical as well as theoretical models for prioritization, data collection, storage and GIS capabilities. In-house DSS are developed by the utilities include Edmonton Power Corporation (EPCOR)'s WALRUS program (Cameron and Deagle 2004). If a deteriorated facility or infrastructure service is continually used, its condition can go from bad to worse and to imminent failure. In such a case, the Present Value (PV) cost of renewing a pipeline is cheaper than Future Value (FV) cost. Condition Assessment, Inspection, Data Collection, Hydraulic Modeling and System Requirements precede Renewal Design. Condition assessment is required for product selection, preventive maintenance and infrastructure assessment (Catbas and Aktan 2002; AWWA 2004a). Replacement procedures can take many hours to complete, while repair work can be faster. Post-renewal, the main problem with water mains is the connection between mains and service lines. Renewal products suggest that it is a three-faced problem, which includes finding the connection, re-establishing the pipeline opening and connecting the pipelines (AWWA 2004a).

Aged infrastructure must be replaced with new facilities that conserve energy, provide better quality service, at lesser costs, and in less time (Miller 2002). Infrastructure renewal or Renewal engineering is not a newly coined term. Port Authority of New York and New Jersey (PANY-NJ) has commissioned a maintenance program that includes rehabilitation of structures encountering salt water. A Typical Port Asset Management Plan contains System Description, Standard of Service, Definition, Current Asset Performance, Planned Actions, Costs, Benefits and Potential Improvements (Haralambides 2002). Renewal Engineering is also an important feature of Asset Management programs practiced by Federal Highway Administration (FHWA). The 2008 Conditions and Performance Report prepared by the FHWA explains the current system conditions of federal highways and bridges (DOT 2010b). Government over-sight is easier in DOTs because their number is below the 100 mark (DOT 2010a). The growth of

renewal products for surface transport has boomed because of a clear understanding between DOTs and use of common platforms like PONTIS (Baker 2010; FHWA 2008). The Civil Engineering Research Foundation reports that reactionary engineering studies, limited databases, non-transferred research knowledge, expensive field verification and complex technologies highlight the need for Infrastructure Renewal practices in government and private clients (CERF 1996; NASTT 2008).

Decision-Support System

A web-based or computer-based Decision-Support System (DSS) can address optimization of water/ wastewater renewal products. Analytical decision-making can be achieved in six key steps, defining the goals, establishing criteria for ranking alternative actions, constructing a model to develop alternatives, ranking these alternatives, iterating and take relevant action. Decision Support Systems are defined by different sources in the business world, as given in the following Table 3.

Table 3: Various definitions of Decision-Support Systems

DEFINITION	AUTHOR
Decision-making is a process of choosing among alternative courses of action for attaining a goal or goals	Turban 1995
An interactive computer-based information system that uses data and models to help solve semi-structures or unstructured problems	Scott-Morton 1971
Software and modeling methods used to aid management decision making under uncertainty.	Swedish Morphological Society 2010
An interactive computer-based system, which generates a number of alternatives to solve an unstructured problem.	GEODISwilson 2010
Information technology and software specifically designed to help people at all levels of the company (below the executive level) make decisions. This keyword is used when a company is making creative or extensive use of DSS, above and beyond typical practice.	MIT 2010

Texas Instruments used the earliest instances of Decision Support Systems in the development of the Gate Assignment Display System (GADS) by United Airlines (Turban et al. 2008). University provided Decision-Support Systems include the University of Vermont's PROMIS system for medical decision-making and Carnegie Mellon's KMS for military decision-making.

Need for Research

Federal, state and private organizations highlight an urgent need for renewal of water main and wastewater pipe for the safe and efficient operation of the water and wastewater industry. Delay in addressing the issues on hand, will cause a cumulative increase in investment and operating costs at all the budgetary levels. A pertinent gap remains between host-pipe condition and renewal products.

Renewal Engineering is not a stand-alone event in the renewal of a candidate pipeline. It is meshed with inter-dependant and intra-dependant utility services and engineering choices. Commercial products are readily available to address pipeline renewal. a Decision-Support System can address the gap to structure known set of renewal decision-making parameters that can lead to successful choice of renewal product. Various renewal products may fit utility needs, and hence the distribution of solution on a band shall support the user in making an order of magnitude conclusion.

Problem Statement

The research aims to develop a Decision-Support System (DSS) framework that objectively supports the use of pipeline renewal products based on system renewal factors of an order of magnitude level.

Objectives of Research

The main objective of research is to develop a Decision-Support System framework that supports the use of water and wastewater renewal products based on system renewal factors of an order of magnitude level. The objective is achieved by completing the following steps of research:

- An extensive literature review of current renewal technology practices and published documents on renewal strategies
- Providing and evaluating system renewal factors based on commercial water and wastewater renewal products
- Development of a Decision-Support System framework for water and wastewater pipeline renewal products

The framework shall establish a basic layout for Renewal Engineering Selection Tool (REST) for water and wastewater pipeline renewal.

Proposed Methodology

The proposed methodology for the thesis includes identifying the decision-making factors, finding alternatives and verifying the need of the factors. The methodology explained in Figure 1 will help develop the water and wastewater renewal decision-making framework.

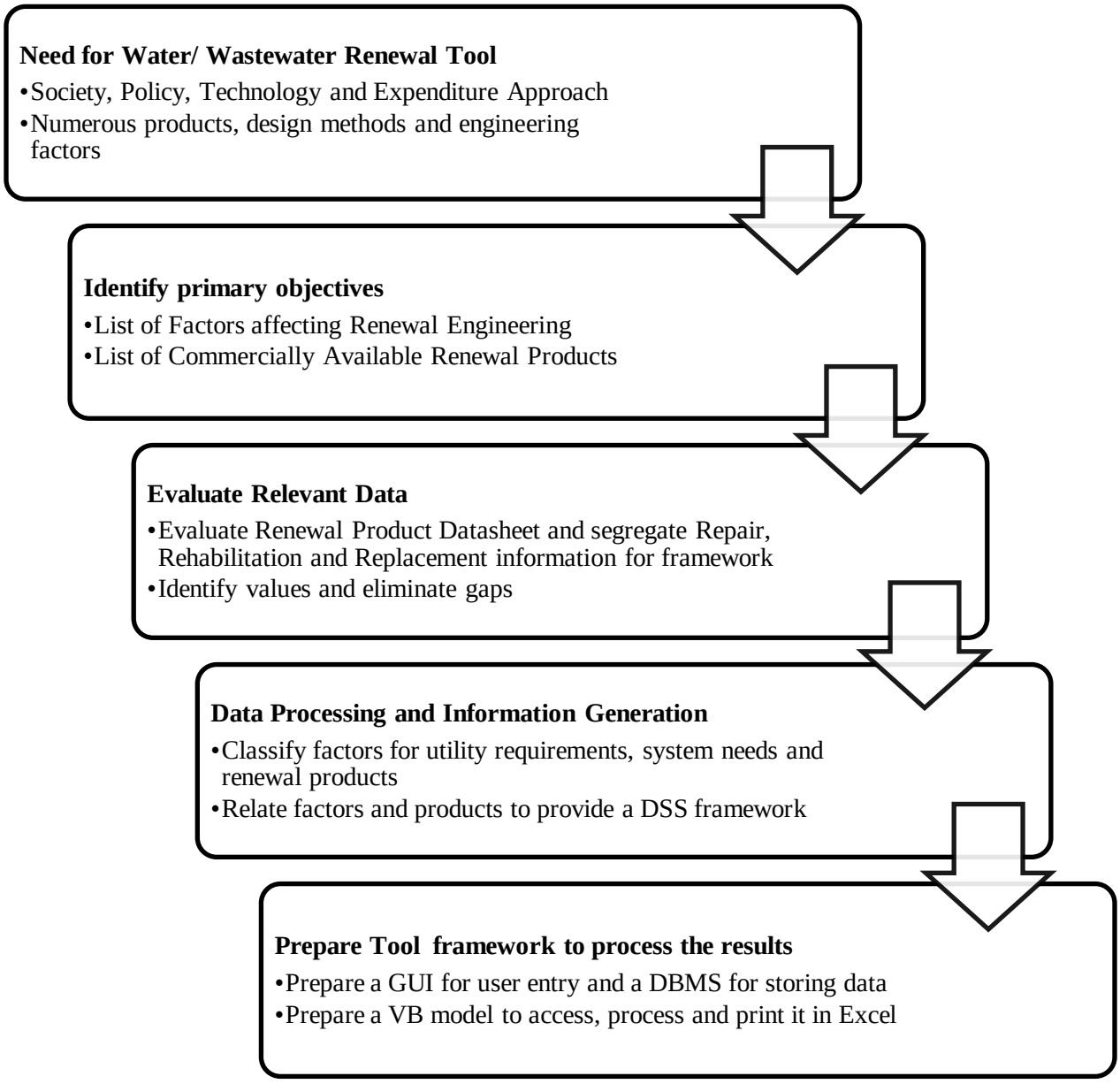

Figure 1: Proposed Research Methodology to develop a Decision-Support system

Chapter 2: LITERATURE REVIEW

Water and Wastewater Infrastructure Renewal

Europe and North America have developed separate liner classification systems. Liners that can stand alone to resist long-term internal stresses are termed "independent" under the CEN system and "full structural" under the AWWA system (Bontus and Blasczyk 2007). According to European standard EN 13566-1: Plastics piping systems for renovation of underground non-pressure drainage and sewer networks (BSI 2002), definitions for the three main groups in which wastewater rehabilitation is divided are given in Appendix A and B. The European Committee for Standardization (CEN) and International Standards Organization (ISO) provides a systematic set of definitions for trenchless construction methods (Bontus and Blasczyk 2007). The Water Research Council (WRC) Sewerage Rehabilitation Manual (WRc 1983) and the AWWA Manual of Water Supply Practice M28 (AWWA 2001b) – Rehabilitation of Water Mains provides a similar set of definitions, also mentioned in Appendix B.

Drinking Water Infrastructure System

Water Main Lines

Various water main materials are used in the system and each material can be categorized based on use and applicability. Each material can behave differently based on age, environmental conditions, and water quality (EPA 2009c). Materials like asbestos cement, cast iron, and ductile iron are commonly available in utility networks across the US. Steel followed by glass reinforced polymers and polyethylene have also been used in the market. HDPE represents 4-6% of the potable water market in the US and nearly 100% of the gas piping market (Anon 1999). Designing the pipe for adequate operating pressure, durability, ease of installation and temperature conditions is common practice. Apart from basic characteristics, a water utility manager considers the age, quality, available pipeline materials, comparison study, NSF/ANSI 61 approvals, and existing material in the system and such compatibility issues. Water mains can be categorized as either distribution piping (2" to 10") or transmission mains (12" and greater)

(AWWA 2003). Pipe diameters less than 48" do not allow man-entry and require remote inspection tools. According to AWWA's in-house resources in Water Stats:\ Survey, this covers 93% of the entire population of water main lines (AWWA 2004b).

Service Lines

An estimated 880,000 miles of piping are in service in the United States (Kirmeyer, Richards and Smith 1994) According to EES and Kennedy et al. 1989, the types of pipe in common use vary considerably. The service line typically has a diameter of ¾ inch to 1-1/2 inch. Water utilities in the United States currently replace about 0.5 percent of their pipeline assets each year, with individual programs typically ranging from zero to 1.5 percent per year (Stratus 1998). AWWA's Water:\Stats 2002 Distribution Survey (AWWA 2004b) collected data on the water distribution systems, including customer service lines, from 337 water utilities located in the US and Canada. Majority of service lines are made of copper, polyvinylchloride, polyethylene, polybutylene or reinforced plastic (Cornwell et al. 2007).

Drivers of Water Infrastructure Renewal

Infrastructure Renewal Drivers form the basic platform for deriving renewal decision-making factors. Renewal strategies drive utility operations at different steps during their service.

Inspection Methods

Numerous inspection methods are available in the industry. Condition of the host pipe can be assessed using inspection methods. Post-rehabilitation inspection is a mandatory step for pipeline renewal satisfaction. Visual Inspection, Sounding, Leak Noise Co-relaters, Acoustic leak detection, Acoustic emission monitoring and Acoustic loggers are common inspection methods. Data obtained from inspection plays an important role in rehabilitation decision-making.

Leak Detection

Visual Survey is a basic form of leak detection. Wet soils or puddles help detect surface leaks. Leak Noise Mapping, Step Testing, Noise Logger survey, Noise Logger survey and Comprehensive Survey are a few complex methods used for Leak Detection. The AWWA Manual M 36 (AWWA 2009b) provides a detailed list of Leak Detection methods. The method of surveying and documenting the leaks affects the condition assessment of a water pipeline (Fanner et al. 2007). A leakage may require a structural upgrade or a sectional upgrade.

System Redundancy

Utilities perform towards a comprehensive audit of the entire pipeline network for the purpose of asset management. Critical service providers highlight the need for redundant pipelines, along with attributes such as pipe leaks, break, fire flow availability, discolored water issues, and pressure complaints (NAS 2006). A GIS mapping system that compliments the database and has the capacity to accept pipeline attributes is an excellent tool to display pertinent pipe segment characteristics. Data-entry of maintenance activity on any pipeline is mapped. Development and maintaining data is critical to a successful program.

Criticality

Water utilities are termed as critical infrastructure and the criticality of operating it at normal operating requirements is of prime importance. A customer either has access to drinking water on a 24 x 7 basis or has a notice (AWWA 2001b). Scheduling machinery, material and work force is necessary to start and finish the job on time. Establishing bypass lines, providing water to hospitals and other emergency services and understanding the complexity of the job shall lead to completion with in designated time. Curing Time of a renewal product is important for the utility. Access to pipe, leakage or the segment that is to be renewed is a critical factor in choosing the appropriate technology. Permissions and regulatory approval for digging large areas, pavements and private properties is a complex and tedious job (Stein 2005). Improvising access to pipes can become a critical factor in pipe renewal.

Pressure Rating

Pipe are chosen to ensure that its pressure rating is adequate for handling the pressure in a specific system, Pressure ratings can be calculated using formulas and tables found in current AWWA standards (AWWA 2003). Distribution system pipe have a pressure rating of 2.5 to 4 times the normal operating pressure. AWWA has established and published specific minimum requirements to ensure adequate and consistent quality of water main lines (Kirmeyer 2000). Other agencies that have established standards for pipe include federal and state governments, UL, NSF International, American Society of Testing and Materials, and the manufacturers.

Water Audits

A water audit followed by a leak detection program can help water utilities reduce water and revenue losses and make better use of water resources. A water audit identifies how much water is lost and what that loss costs the utility (AWWA 2009b). Leak detection is a survey of the distribution system to identify leak sounds and pinpoint the exact location of hidden underground systems (Kola 2010). The overall goal of an audit is to help the utility select and implement programs on distribution system losses. The audit's total field cost depends on the number of meters in the entire system (AWWA 2009b).

Bypass Piping

For most rehabilitation techniques, keeping the customers supplied is a major consideration. Temporary pipe laid in gutters on each side of the street known as Bypass pipes supply drinking water supply (AWWA 2001b). Temporary pipes are generally 2 to 4 inches in diameter and supplied from the fire hydrant, but can range up to 12-inches. Processes and equipment used in water systems must provide assurance that the system is free of any contamination (AWWA 2007). Water mains do not have manholes like waste water systems. Hence, it is difficult to install robots and such devices without being invasive. An online robot needs to withstand high pressures.

Disinfection

Utilities flush new or repaired water pipelines for disinfection purposes. Flushing removes mud and debris left in the pipe during installation. Water utility engineers achieve a velocity of at least 2.5 feet/ sec and preferably 3.5 feet/ sec for disinfection (AWWA 2001b). Chlorine compounds are the most common chemicals used to disinfect large pipelines. Calcium hypochlorite and sodium hypochlorite solutions are disinfectants for smaller pipelines (AWWA 2007). Requirements should normally conform to the AWWA Standard C651, Disinfecting Water Mains unless there are other local, federal or state requirements overriding them (AWWA 2005).

Common Failures in Water pipelines

There is a vast array of different types of pipes, with and without corrosion protection systems, in the million miles of aging water main lines. The failure mechanism of each type of pipe is different meaning rehabilitation solutions must be tailored to match the problems experienced by a specific type of pipe material, or be flexible enough to cover a multitude of performance problems. Each failure mechanism has some indicators and data associated with the indicators. The difference through the various situations arises when the slope of the curve changes according to the cause of the failure (Griggs 2007). The occurrence of the failure and the severity of its consequence indicate the necessity of any inspection or evaluation. Common pipeline failures are listed in the EPA white paper (Royer 2005) on improvement of structural integrity monitoring for drinking water main lines.

Wastewater Infrastructure System

The U.S. sewer network totals approximately 800,000 miles in length. Force mains comprise approximately 7.5 percent of this length; thus, the force main system is approximately 60,000 miles in length and the gravity network approximately 740,000 miles. An estimated 25 percent of the gravity sewer network is more than 40 years old, 77 percent is 12 inches in

diameter or smaller, and 44 percent is clay or concrete pipe (WERF 2004). The force main network is not as old as the rest of the sewer network – just 2 percent is greater than 50 years old, while 68 percent is less than 25 years old (WERF 2007).

Gravity Sewers

Based on survey data on the types of defects observed and taking into consideration the frequency of use of the pipe materials, the priority ranking for problems affecting gravity sewers has been assessed (WERF 2004) as cracks, internal corrosion, grease build-up, root intrusion and joint misalignment or separation. These problems can cause partial blockages, leading to backing-up and overflows upstream or excessive infiltration leading to surcharge and overflows downstream.

Laterals

The omission of the laterals from Mainline Sewer rehabilitation programs results in an incomplete solution to the Inflow/ Infiltration (I&I) problem (EPA 2009e). The problem is particularly acute in conditions where the sealing of the mainline causes the groundwater table to rise sufficiently to increase the flows into the cracked and leaky laterals – thus circumventing (at least partly) the sealing of the mainline. The probable cause of low achievement of I&I reductions has been identified in many cases to be the remaining problems with the private sewer connections to the mainline sewers in the streets (WERF 2006).

Force Mains

The approximate length of the force main system in the US is 60,000 miles. The Water Environment Research Foundation (WERF) recently published a report titled "Guidelines for the Inspection of Force Mains" (WERF 2009) giving a detailed description and condition of force-mains. Ferrous materials (i.e., cast iron, ductile iron, and steel) are dominantly used in force mains (EPA 2010d). Cast iron and plastics are less widespread because of corrosive, pressure-induced properties of wastewater (AWWA 1980).

Drivers for Wastewater Rehabilitation

The main driver for wastewater rehabilitation is the system of fines and consent decrees imposed by the EPA. These generally refer to sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs), and cover both gravity sewers and force mains. The regulatory system has a variety of elements, and there is a degree of overlap among them.

National Pollutant Discharge Elimination System (NPDES)

The NPDES permit program controls water pollution by regulating point sources (e.g., collection systems and treatment plants) that discharge pollutants into open waters. The NPDES is part of the 1972 Clean Water Act intended to protect the country's waters and directs EPA to issue rules on implementation (EPA 2004; EPA 2009e). Industrial, municipal, and other facilities must obtain permits if their discharges go directly to surface waters. The permit is administered by individual states.

Sanitary Sewer Overflows (SSOs)

Wet weather demands a consistent regulatory and enforcement framework, specifically relating to SSOs. Proposals have been made by the National Association of Clean Water Agencies (NACWA) that a national SSO policy should recognize the level of risk posed by SSOs nationally and be modeled after EPA's Combined Sewer Overflow Control Policy (EPA 2009e). It shall provide the flexibility necessary to address adverse impacts when manifested at a local level and to direct resources to those areas that will have the most impact (NACWA 2007).

Combined Sewer Overflows (CSOs)

EPA's Combined Sewer Overflow Control Policy is a national framework for control of CSOs through the NPDES permitting program. The policy provides guidance to municipalities and State and Federal permitting authorities on meeting the Clean Water Act's pollution control goals. EPA estimates that the annual CSO volume is approximately 850 billion gallons, down from over 1 trillion gallons prior to issuance of the 1994 CSO Control Policy (NACWA 2007).

Government Accounting Standards Board (GASB) Statement No. 34

The Government Accounting Standards Board (GASB) defines criteria that auditors use to judge the adequacy of local and state government financial statements (GASB 2010). It has changed long-standing practices by requiring the government entities to include reporting of their capital assets in their annual balance sheet and income statement. GASB-34 highlights the costs of acquiring, owning, operating, and maintaining public-works infrastructure for government-bond holders and the public at large.

Ownership of Laterals

Ownership of sewer laterals varies significantly for various municipalities even within a single metropolitan area. The private property owner owns the lateral sewer all the way to the sewer main in the street, but there is a split as to who owns the actual connection into the main (WERF 2006). A smaller percentage of property owners own the lateral to the property line. Cleanouts help with rehabilitation and make it easier to determine whether the private or the public section of a lateral is causing the I&I problem.

Age and Location

In contrast to the nation's water supply and gravity sewer systems, the use of force mains to convey sewage is relatively recent. Sixty Eight percent of the force mains in use today have been in service for 25 years or less (EPA 2010d). This contrasts sharply with the water supply sector in which the average age of water mains in the US is now 45 years with nearly half of pipes aged more than 50 years old. Over 91% of the force main pipes are buried, so access to the exterior surface will require some form of excavation (EPA 2010d).

Redundancy

Many force mains are located at critical points in sewer systems. As a result, if they are taken out of service due to a failure, then by-pass pumping or the use of honey trucks is necessary. One way in which utilities plan for this is to install dual parallel force mains thus

providing redundancy. The advantage in having a redundant line is the ability to take one line out of service for an intrusive (internal) inspection and emergency repairs (WERF 2006).

Common Failures in Wastewater pipelines

It is important to understand the typical failure modes and mechanisms of wastewater lines to select the most appropriate repair, rehabilitation, and replacement technologies. Internal corrosion is rated as being responsible for ferrous force main failures 26.2% of the time, ahead of all other known causes, external corrosion is at 19.2% and third party damage at 19.4% are the next most common causes of failures (WERF 2010). The most common single cause of failure in gravity sewers is third party damage. It is considered that some of the structural failures reported for cementitious pipes (AC, RCP, and PCCP) are due to corrosion. Proper inspection of pipelines would allow a utility to identify signs of corrosion and leakage. For example, with information on remaining wall thickness, a utility could plan on repair, rehabilitation, or replacement before the host pipe fails.

Existing Decision Support Systems

Computer Aided Rehabilitation for Water and Sewer

CARE-W and CARE-S models are developed by The National Laboratory of Civil Engineering, Lisbon, SINTEF /NTNU, Brno University, Cemagref, Dresden University, Alborg University, WRc, Bologna University, Ferrara University and Clabsa (Baur et al. 2002; Kowalski et al. 2003). Performance Indicators like risk of infiltration and exfiltration, collapse and blockage due to pipe deterioration, hydraulic overloading resulting in flooding and/or receiving water pollution benchmarks and compares between services across Europe. Utility Operational indicators, Physical indicators, Environmental indicators, Quality of Service indicators and financial indicators are developed for a multi-criteria decision-support system, shown in Figure 2. At SINTEF, Norway a routine of two CARE-W tools, namely the RELNET for an entire network to assess the consequence of a burst and AQUAREL for the most vulnerable pipes to assess risks of failure is used (Sagrov et al. 2007). A detailed comparative analysis of CARE models and other decision support systems is explained in Figure 3 towards the end of the subsection.

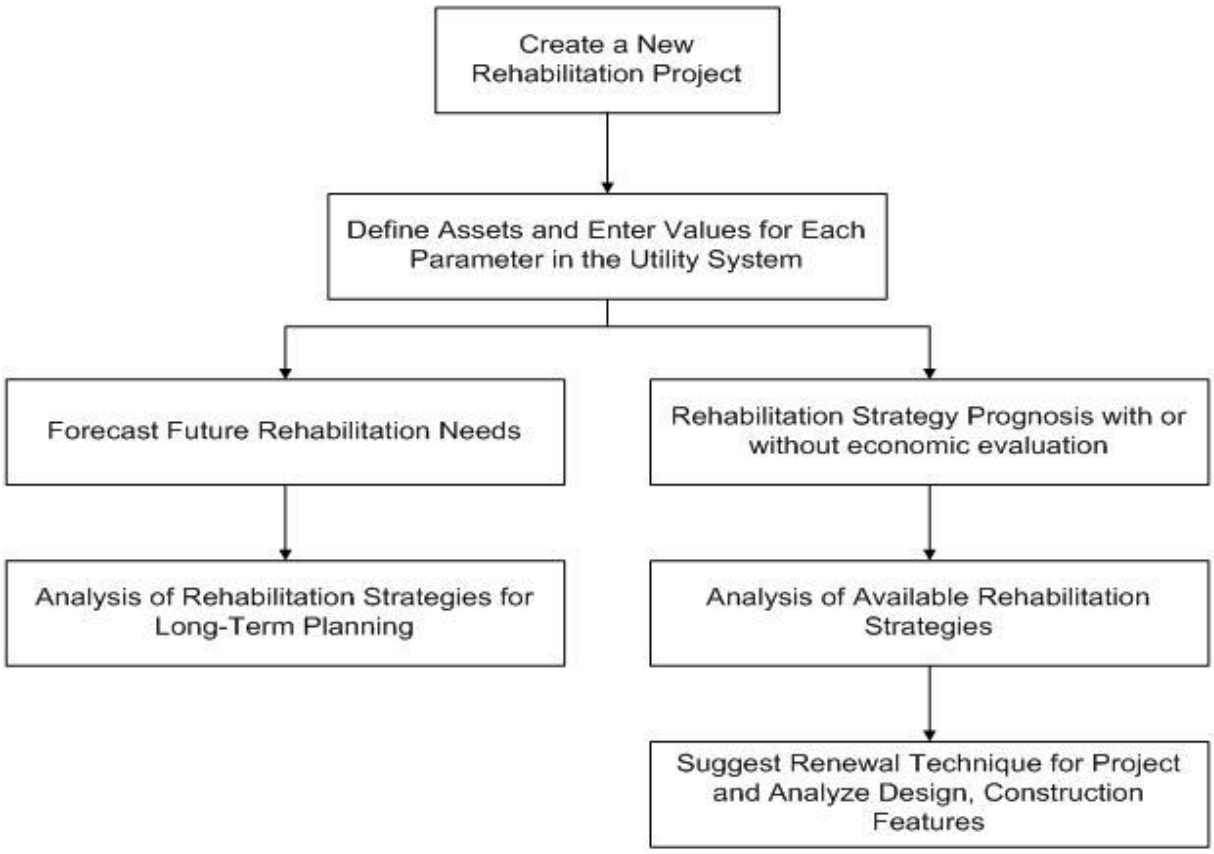

Figure 2: Working flow-chart for CARE project methodology

Trenchless Assessment Guide for Rehabilitation

The Trenchless Assessment Guide for Rehabilitation (TAG-R) project was commissioned by the National Utility Contractors Association (NUCA) Trenchless Technology Sub-Committee and is a companion to NUCA's Trenchless Construction and Rehabilitation Methods Manual. Trenchless Technology Center (TTC), Louisiana Tech developed the program as a stand-alone software to assist utility engineers in evaluating the technical feasibility of traditional open cut, trenchless construction, and inline replacement methods for a specific project (Matthews 2007). The goal of the project is to develop and codify an algorithm that accomplishes the performance of a sound technical evaluation as a screening measure to eliminate incompatible construction methods, evaluates and quantify the overall perceived risk associated with the competing alternatives and raises awareness and provides guidance to the utilization of trenchless

technology methods (Matthews 2006). It contains performance data for trenchless construction methods commonly used in utility projects. It captures candidate pipeline information and construction method requirements like diameter, depth, soil type, length, cover etc and expected trenchless technology capacity requirements (NUCA 2010).

KANEW model

The KANEW model provides a method and software for predicting deteriorating pipeline condition. The model can quantify budgetary level costs. In an AWWA review of the KANEW software, Deb et al. 1998 writes that KANEW gives utilities a tool to develop long-range pipe rehabilitation and replacement strategies. It works by importing utility data according to installation year and with respect to aging behavior. The most important criteria are age, material, diameter, and bedding quality. Considering uncertainty, the model offers pessimistic and optimistic scenarios for pipe survival. KANEW is tested and available in North America and Britain. The main advantage of KANEW is to allow the utility to use a forecasting system, enabling it to budget over the long term (Griggs 2004).

Nessie Curve

A "Nessie Curve" is a graph of estimated annual expenditure needs for replacement of water and wastewater utility pipe infrastructure. It reflects an echo of demographic waves that determines the rate at which the pipes were installed in a city. The rising shape of this graph has caused it to be named a "Nessie Curve" after the "Loch Ness Monster". In AwwaRF's Nessie Curve study, utilities polled gave an 85-year average life for pipe segments, with many water mains lasting more than 100 years. Australian utilities have graphically represented these replacement rates with a Nessie Curve (Cromwell 2010). The model will give utilities planning data that uses decay curves derived from statistical analysis of break data to forecast renewal for each class of asset. This can be projected to create the Nessie curve of future investment needs.

Non-Homogenous Poisson Process

The Non-Homogenous Poisson Process (NHPP) is a decision tool to address copper pipe pinhole leaks in domestic plumbing systems (Loganathan 2005). A causal and mechanistic corrosion model is discussed to understand the leak rates. The optimal replacement time is dictated by the arrival pattern of the leaks. The NHPP process enables the development of a minimum cost model in terms of the times at which expenditures are incurred. In the NHPP, the poisson parameter is the function of time (Law and Kelton 2000).

Individual Water Main Renewal Planner

I-WARP is a non-homogeneous Poisson approach to model breakage rates in individual water mains (Kleiner et al. 2010). The structural deterioration of water mains and their subsequent failure is affected by both static (e.g., pipe material, pipe size, age (vintage), soil type) and dynamic (e.g., climate, cathodic protection, pressure zone changes) factors. I-WARP allows for the consideration of both static and dynamic factors in the statistical analysis of historical breakage patterns. The research project was jointly funded by the National Research Council of Canada (NRC), and the Water Research foundation and supported by water utilities from USA and Canada.

EPA-NET model

EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks (Rossman 2000). A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network during a simulation period comprised of multiple time steps. EPANET is a research tool for improving common understanding of the movement and fate of drinking water constituents within distribution systems. It is used for many different kinds of applications in distribution systems analysis.

Model for Infrastructure Rehabilitation Planning (MIRP)

MIRP is a computer-based tool to help infrastructure agencies plan, select, and make decisions on infrastructure rehabilitation (Hastak et al. 2005). It can evaluate multiple types of facility for rehabilitation needs at the agency level. This evaluation depends on five factors namely technical evaluation, group member evaluation, cost evaluation, available funds and management considerations. It uses Visual Basic.net as a User Interface and Modeling component, and Microsoft Access as Database component. The decision objective is ranked on the functional or technical need for rehabilitating the infrastructure facility. An Analytic Hierarchy Process (AHP) weighs the decision-makers level of importance. The users who can control this tool include a decision-making committee, managers, field engineers and estimators. The tool captures bird-eye information about the facility like structural condition, severity, safety, mobility, community effects, environmental effects and economic development.

SIROCO

Cemgref and G2C Environment jointly developed the SIROCO project. The aim of the project is to develop a tool enabling small and medium-size water distribution companies to prioritize pipelines for rehabilitation (Renaud et al. 2009). It is useful for companies that have limited pipeline breakage data. Therefore, it uses data from several water distribution companies to provide a prioritization model. The model checks the homogeneity of the data and the performance of hydraulic models. Sixteen water utility companies were involved in providing the data and further use of the SIROCO model. The main result from the model is the average number of failures predicted for each pipeline over any given period in the future.

VOYAGE

CH2M Hill has developed the VOYAGE Decision Support Systems tool for system management of water and wastewater infrastructure systems. It is a dynamic model that supports optimization for System Management. The tool is developed in EXTEND platform in-house and can be customized for individual systems (Topping 2008). The VOYAGE system is applicable

to water systems, energy systems, environmental systems and system economics. The tool performs simulation for development of city level master plans.

Knowledge Based – Decision Support System (KB-DSS)

The Knowledge Based – Decision Support System (KB-DSS) is a composite programming tool based in an Excel spreadsheet. Knowledge Performance Indicators (KPI) forms the decision-making variable for this tool (Bohl 2007). KB-DSS is for water and wastewater market prioritization. The tool based on seven different approaches calculates Thirty-six KPIs. It is highly dynamic in nature and re-programmable for use in developing and developed countries. The focus of the tool is to provide economical decisions for the water and wastewater utility network.

Benefits and Limitations of Decision-Support Systems

The literature discusses various decision-support systems available for a utility. Research groups have developed some of these Decision Support Systems, while others are the result of commercial interest. Most of the mentioned tools use advanced mathematical models and statistical tools. Utilities and utility managers are unable to understand the limitations and loopholes in these systems. A viable approach to understanding and comparing Renewal Products is to provide the user with product-based framework. The framework should be receptive to modifications as technologies, products and understanding improves. The framework should provide a comparative study of Renewal products and not renewal technologies.

Renewal products are not a result of individual technologies, and have a high degree of constructability. Each renewal strategy changes installation, cost and project risks for the utility, engineer and contractor. When a Decision-Support System suggests the use of a renewal technology, it fails to analyze the installation and construction management metrics that affect performance and cost. The proposed Decision-Support tool should consider various factors that affect installation, application, QA/QC and cost of a renewal product.

TAG-R and KB-DSS are two tools that provide a user-friendly approach to decision-making. A framework must be supported by a database and an interactive user-interface mechanism. The framework must be easily available across different bands of users. If a framework is not made available to the utility, consultant and vendors it will not grow and adapt relative to the market conditions. It is not only difficult but also impossible to make changes to the database file for most of the above-mentioned Decision-support systems. A DSS framework with limited directory information and a closed database file will become irrelevant over a long period. As technology advances and knowledge of pipeline failure improves, the user and the developer should be able to incorporate those changes into the Decision-Support system framework.

The following Figure 3 compares theoretical decision-support systems based on different factors. They are compared on parameters like infrastructure application, utility operation, pipeline application, theory approach, set-up, availability, cost, user-friendliness and time spent in learning the systems. The proposed framework fares better than other decision-support systems. TAG-R is the other decision-support system closer to a user-friendly framework in terms of approach, application and use. The framework shall lay the needs and requirements for a Renewal Engineering Selection Tool (REST).

No.	Theoretical DSS	Level of Application	Applicability	Operational Focus	Pipeline Application	Approach	Setup	Commercialization	Start-up Costs	Level of Training	Start-up Time	User-Friendliness
1	CARE W	Utility Level	Water	Prioritization and Renewal Strategy	All	Multi-criteria and Ranking	Stand-Alone	Model and GIS based tool	High	High	High	Medium
2	CARE S	Utility Level	Wastewater	Prioritization and Renewal Strategy	All	Multi-criteria and Ranking	Stand-Alone	Model and GIS based tool	High	High	High	Medium
3	TAG-R	Candidate Pipe Level	Wastewater	Renewal Technology Selection	Gravity Sewers, Laterals, Force Mains and Water Mains	Risk-based Weighing	Online	Technology Parameters	Low	Low	Low	Medium
4	KANE-W	Utility Level	Water	Prioritization and Budget Allocation	Water Mains and Service lines	Probability function	Stand-Alone	Model Framework	Medium	High	Medium	Low
5	Nessie Curve model	Utility Level	Water	Prioritization	Water Mains and Service lines	Decay Curves	Stand-Alone	Model Framework	Medium	High	High	Low
6	NHPP	Candidate Pipe Level	Water	Corrosion Design	Copper Service Lines	Poisson Ratio	Stand-Alone	Model Framework	Medium	Medium	High	Low
7	I-WARP	Candidate Pipe Level	Water	Prediction	Ferrous Water Mains and Service lines	Poisson Ratio	Online	Dynamic Link Library Software	Low	Medium	Medium	High
8	EPANET	Water Resource Level	Water	Water Resource Planning	Water Mains	Simulation techniques	Online	Model Framework	High	High	High	Low
9	MIRP	Utility Level	Water and Wastewater	Prioritization	All	Analytic Hierarchy Process	In-house	Model Framework	High	High	High	Low
10	SIROCO	Utility Level	Water	Prioritization and Budget Allocation	Water Service Lines	Multi-criteria and KPIs	Stand-Alone	Model Framework	High	High	High	Low
11	VOYAGE	Utility Level	Water and Wastewater	Prioritization and Budget Allocation	All	Proprietary Platform with Simulation	Stand-Alone	Result sheets	High	High	Low	Low
12	KB-DSS	Utility Level	Water and Wastewater	Budgeting	All	Composite Programming	Stand-Alone	MS Excel worksheet	Low	High	Medium	Low
13	REST	Candidate Pipe Level	Water and Wastewater	Renewal Product Selection	All	Linear Distribution and Ranking	Stand-Alone	MS Excel worksheet and Access database	Low	Low	Low	High

Figure 3: Comparison between published Water/ Wastewater Decision Support Systems and REST framework

Decision Support in Utility Operations

Edmonton EPCOR

The City of Edmonton's Decision-making process is a solution to the problem created by extensive use of thin-walled CI pipes in a corrosive soil (Sergeant 2007). The whole process uses GIS based Database Management System WALRUS for evaluation (Cameron et al. 2004; Sergeant 2007). Querying, storage, processing and user interface is within the WALRUS system. EPCOR's Reactive Water Main Renewal Program is the calculated Replacement Priority Value (RPV) value of the candidate pipe. The Neighborhood Water Main Renewal Program follows it. Water Mains that have an RPV greater than three but less than five qualify for the Neighborhood Water Main Renewal program (Ancel 2007). Once the pipes under the Neighborhood Water Main Renewal program are addressed, money is allocated to the Proactive Water Main Renewal Program. If no money is left after Reactive and Neighborhood Renewal Program, then Proactive Water Main Renewal program is abandoned for that financial year. EPCOR also allocates money for Water Main lining, Cathodic Protection and Valve/ Hydrant Replacement programs. These programs have a separate budgetary allocation.

City of Atlanta

The City of Atlanta's Decision-making process is a response to the Consent decree signed by the city of Atlanta (Bechara 2007; Hunter 2007; Brown 2007). The consent decree forced the city of Atlanta to reduce combined sewer overflows (Bechara 2007; Hunter 2007). A vast repository of data was collected by using methods like CCTV, Smoke testing, Dye testing and other geo-spatial means. A thorough Sewer Separation and Evaluation Survey (SSES) were undertaken (Hunter 2007; Hunt 2007). Data in the form of costs, video interpretations and pictures was processed and warehoused into an Oracle-based Data management system. Geographical Information Systems map the existing sewer network in accordance with Town and city planning factors. Prioritization follows the database repository building process. The exact rehabilitation technology is chosen after inputting criteria in a Decision-Making tool. A qualified contractor verifies the existing pipeline, condition and shall verify the as-built plans

post-renewal. The tool provides technical and cost outputs for every change in variable. A strict quality assurance and control process was in place to check for errors in the database.

City of Wilmington, North Carolina

In coastal Wilmington, the need for sewer rehabilitation became a focus of the media and politically charged after several force main failures and system stoppages resulted in a series of sanitary sewer overflows (SSOs), one of which affected beach areas on a holiday weekend (Miles 2007). To address the importance of sewer rehabilitation, the city of Wilmington developed a technically applicable decision-making process that reflects the objectives of utility stakeholders (Miles 2007). The Decision-Making process uses a Prioritization process. A ranking system collects expensive data for factorial evaluation of each asset. A Criticality versus Condition matrix helps understand priority for failed infrastructure. The matrix prioritizes the system for short and long-term rehabilitation projects. The rehabilitation framework includes methods and technologies for collecting and coding condition assessment information needed for assigning condition level to all wastewater collection system, alternatives for delivery of the rehabilitation jobs, rehabilitation methods, resource optimization and documentation.

San Diego County Water Authority (SDCWA) Water Resources Department

San Diego‘s water resources were overhauled during World War II when President Franklin Roosevelt directed the United Sates Navy to build a pipeline from Colorado River Aqueduct to San Diego (Williams et al. 2009). It has done numerous planning studies involving system pipelines and facilities to prioritize them for renewal under the Capital Improvement Program. SDCWA serves water to 24 member district agencies across the county by way of 5 primary conveyance pipelines (or aqueducts). The pipelines carry raw water from the Metropolitan Water District of Southern California by gravity flow. SDCWA follows a development and maintenance of a Capital Improvements Project (CIP) to stay ahead of system demands. Capital projects go through several stages of conceptual planning, periodic condition assessment, long-term maintenance plans and budgetary allocation of renewal plans. This is done with a clear technical scope and detailed cost provisions.

Charleston Commissioners of Public Works (CPW)

Under the threat of privatization, CPW went through a reengineering process in August 1996 – January 1997 by modifying its operational processes and systems (Kirmeyer 2007). The objective was to bring about significant improvements in performance, production and customer service. Their reengineering started with evaluating each one of the department's processes. Based on the redefined activities, four work teams were created. These were the Maintenance Work Team, the Preventive Maintenance Work Team, the Technical Support Work Team and the New Installation Work Team. As part of the reengineering process, CPW also put together an extensive "Water Distribution Operations and Training Manual" which includes SOPs for the different utility activities including Condition Assessment, Inspection Methods and Renewal Design. For each SOP, the level of labor, equipment and materials required to execute each task were determined and then modified until all members of the team agreed on the established levels on the accuracy of the procedures and on the ease of following them.

Chapter 3: CLASSIFICATION OF RENEWAL PRODUCTS

Renewal Product characteristics help defines renewal decision-making factors. Different products are commercially available for renewing distressed water and wastewater pipelines. Renewal technologies are classified into five different categories for the purpose of this research. Cleaning products are stand-alone products or used prior to installing other renewal products in a pipeline, trench or duct. Some of these terms are inter-related and the primary aim of the technology helps classify them, as shown in Figure 4 below.

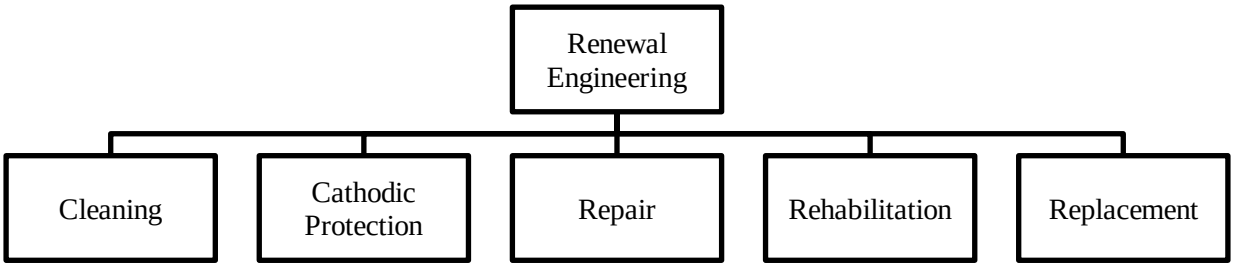

Figure 4: Classification of Renewal Technologies for the purpose of REST tool

Cleaning methods

Cleaning removes debris and waste in the wastewater pipe, but it is not the case in water main lines. In the water main lines, the main purpose of cleaning is to remove scales and corrosion by-products (EPA 2009d). PIGs, Scrapers, Chemical cleaning and hydraulic jets are commonly available cleaning methods. The framework does not compare cleaning methods alongside renewal products. It considers cleaning methods as a factor affecting the choice of one renewal product over another.

Cathodic Protection

Cathodic protection is an electrochemical method used to prevent or control corrosion of buried or submerged metallic structures. There are two principal types of cathodic protection

system: impressed current and sacrificial anode (EPA 2009d). Steel pipes are protected with a cathodic protection system because the electrical continuity of welded joints makes this a practical solution. It is more complicated for ductile iron pipe where electrical connectors need to be placed across all bell and spigot joints. Maintenance and monitoring of cathodic protection systems is seen as important by the operating utilities (Deb et al. 1998). The REST framework does not compare or recommend cathodic protection alongside renewal technologies.

Repair technologies

Repair technologies are a one-stop quick solution to water main renewal. They are used for small segments of the pipe and specifically for localized problems, poor workmanship, external damage and unexpected or rapid deterioration to unknown changes in design conditions. The focus of repair measures is to restore the water main line to operating conditions. In-house agencies and private contractors undertake repair methods shown in Figure 5. Contract formulation is on an "on-call" basis or for a group of repair works. Appendix C provides the effect of system renewal decision-making factors on various repair technologies.

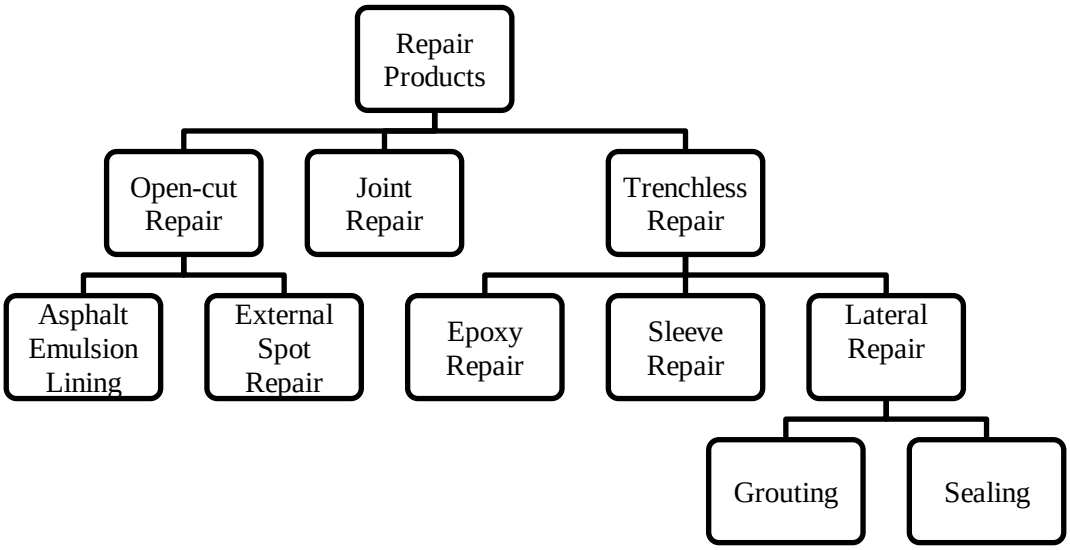

Figure 5: Classification of Water/ Wastewater Pipeline Repair Products

Open-cut Repair

Adverse situations require open-cut repairs. With numerous valves, hydrants and bends in the system, small and mid-sized utilities follow a simple process. They put into service a redundant line and shutdown supply to the distressed line in the network. The area is then dug either to provide cosmetic measures or structural provisions on the external surface of the pipe.

External Spot Repair

External Spot Repair is common for public infrastructure and industrial applications. Viscotaq® provides coating wrap for above/on ground use (Amcorr 2009). It is used to protect components or objects from adverse environmental effects.

Asphalt Emulsion Lining

Rubber based asphalt emulsion are used for pipelines to avoid interaction between soil and external wall. This lining method can be used as a secondary treatment method overlapping other products.

Joint Repairs

Joint repairs stop leaking joints by bridging the joint with a sealant (Reed et al. 2006). NPC Internal Joint Seals are designed to seal leaking pipe joints in most types of pipe (NPC 2009). Various CIP products for lateral connections are installed from a manhole to the candidate pipe for joint repair (WERF 2006).

Trenchless Repair Methods

Water utilities have to be careful while spot-repairing pressure pipes because water main lines and force-mains are prone to water pressure and water quality. Trenchless repair is carried out after detailed engineering calculations and planning. Access pits and downtime are calculated. Materials must adhere to engineering, federal, state and local standards.

Epoxy Repair

Epoxy repair is classified under repair and rehabilitation methods depending on application. The epoxy solution minimizes downtime and disruption. They can be applied in small diameter pipelines by centrifugal casting machine or by manual spray machines.

Sleeve Repairs

Steel Sleeves are used for point repairs. Stainless sleeve products can be used for repair of pin-holes, cracks and areas of corrosion, and also as stand-alone repair methods (Link-Pipe 2009). Sleeves carry their required sealant, and structurally adhere to ASTM standards.

Lateral Repair by Sealing Collar

A robotic system is introduced into the lateral that uses a silica-based resin to provide a repair of the damaged connection and form a sealing collar of material around the pipe thus stopping infiltration into the sewer system (WERF 2006; Janssen 2009).

Lateral Repair by Grouting

Grouting repair of a lateral's entire length by chemical grout is practiced to reduce I&I problems (Whitaker 1991; Lee 2008). Geotechnical methods for sealing manholes, mainlines and laterals utilize hydrostatic pressure for the injection-sealing process (WRc 2006). Proprietary chemical solutions are applied to "flood" an isolated section of sewer, which chemically reacts with the soil.

Rehabilitation technologies

The following Figure 6 summarizes the commonly used rehabilitation technologies available in the market. A choice of method will be dictated by the condition of the pipes, project objectives, and estimated costs. Determining which method is the most economical for any given situation is difficult, since it largely depends upon the perceptions of the contractors who bid the work, and,

if a method is highly specialized or proprietary; the number of bidders will be limited. The matrix of rehabilitation products presented in Appendix C explains application, installation and characteristics for each product in the research.

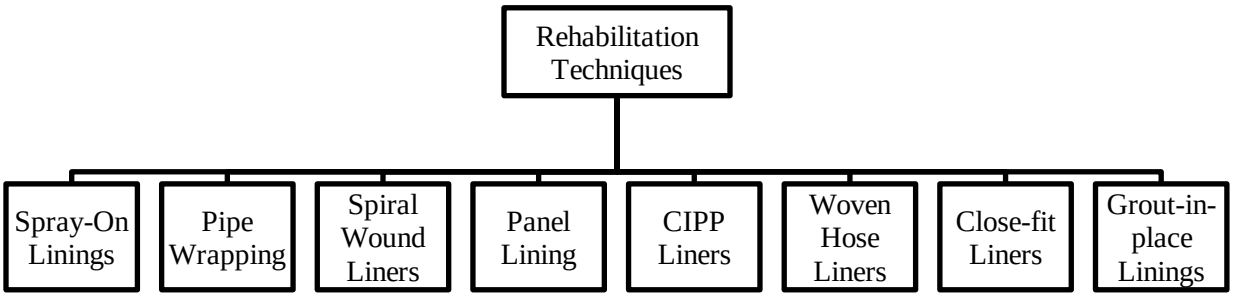

Figure 6: Classification of Rehabilitation technologies used in Water/ Wastewater Rehabilitation

Spray-On/ Spin-cast Lining

Spray-On or spin-cast lining method is a common rehabilitation technology for non-structural applications. Younger pipes having high asset value and structural strength are recommended applications. In Spin-cast method, a robotic head sprays the liner on the walls of the pipe when man-entry is not available. Spray-on method involves carrying the liquids on the back and spraying with a centrifugal spraying machine. Cement, Epoxy, Polyurethane and Polyurea are the material of choice for this method, as shown in Figure 7.

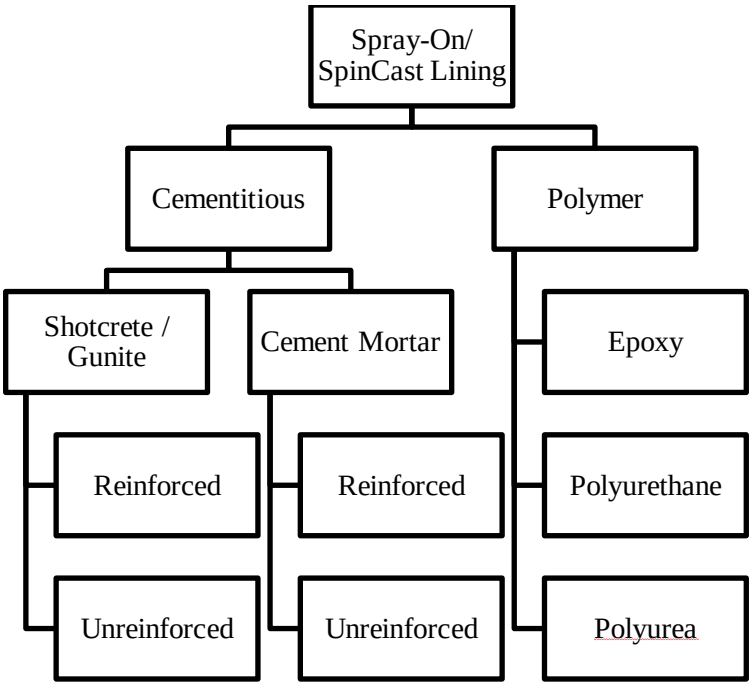

Figure 7: Classification of Spray-On/ SpinCast Lining products used in Water/ Wastewater Rehabilitation

Cementitious Linings

Cement mortar linings are frequently applied to control metal corrosion and taste problems. The corrosive environment in a sewer makes the application of ordinary cement or concrete materials in wastewater environment prone to deterioration. Guniting or Shotcreting are useful under certain conditions (EPA 2009e; Deb et al. 2002). The linings are applied by hand in a person-entry sized space or by spincast equipment in small diameter pipes. They can be used as filler material or a base structural layer that is covered by a corrosion resistant lining material.

Epoxy Spray-on Linings

Epoxy spray-on linings are widely used for water main rehabilitation and for manhole rehabilitation. They have limited application for gravity sewer main applications because of the need for a strong bond (EPA 2009e). Epoxy is a two-component materials and capable of adhering to dry and moist surfaces. Typically, utilities do not apply epoxy linings in a

sufficiently thick layer to function as a structural ring. Common products are Acuro®, Waterline Epoxy®, Belzona brand, Fast Line Plus® and Curaflo brand of products (Belzona 2009; Subterra 2009a; RLS 2009a; Hunting Specialized Products 2009).

High-strength epoxies are also available for pipeline rehabilitation. They are made from composite materials like fibers, polymer additions etc. Heitkamp Epoxy®, Raven 405®, Warren Environmental S301-14® and Powercrete PW® are examples of high-build epoxy products (RLS 2009b; Warren Environmental 2009; Berry 2009).

Polyurethane Spray-on Linings

In the water sector in the UK, polyurethanes (PU) have replaced the use of epoxy liners. The majority of water main applications are for corrosion protection and taste improvement. To overcome the inadequacies of thin polymer lining applications, high-build polyurethane applications have been developed to function as a structural liner that is less dependent on the quality of bond to the host pipe and that can bridge over holes in an internally pressurized host pipe (EPA 2009d). The 3M group and SprayRoq Inc. provide commercial polyurethane liners for medium and small diameter pipelines.

Polyurea Spray-On Linings

Polyurea linings are installed because of their fast cure times over epoxy applications. Hunting Specialized Products and Innovative Painting & Waterproofing produce polyurea-based spray products for the pipeline renewal industry.

Pipe Wrapping

Wrapping a pipe on the internal face (i.e. wet) can be used to repair segments in large diameter pipelines. The technologies are generally a sandwich of an adhesive-bonding material and a wrapping-material. The wrapping coat comes in direct contact with potable water and needs NSF 61 approval. Wrapping requires the main to go off service and involves man-entry in

the pipe (Fyfe 2009). One can pre-cut the wrapping rolls to desired lengths after calculating pipeline diameter, overlapping length and understanding the factor of safety. Various pipe-wrapping technologies are available in the market like FibrWrap®, CarbonWrap®, A+Wrap® and FreyCWrap®.

Spiral Wound Liners

Spiral-wound linings are used as grout-in-place linings. They can be used as stand-alone liners that provide support to the host pipe and help seal against infiltration into the sewer mainline. In the simplest version, a spiral-winding machine is set up and narrow PVC strips are fed into the machine and press-sealed together to form a continuous spiral-wound pipe (Gumbel 1998). As the spiral pipe is produced, it extends along the pipe to be lined. Openings for laterals are not marked by dimples as in most CIPP installations and hence must be cut based on recorded position or some other form of marking. In larger diameters where additional liner stiffness is required, steel inserts in the PVC liner strips can be used. Sekisui, Inc produces a range of spiral winding products for the pipeline renewal market (Sekisui 2009).

Panel Lining

Panel linings have many similarities to the grout-in-place liners but rather than being anchored by the annular grouting process, the panels are adhered to the wall of the host pipe (EPA 2010d). They have an interlocking and sealing capability between the panel edges. Panel linings are practical in person-entry diameters. A special termination strip is used to protect the lower edge of the liner Panel Lining products.

CIPP Liners

It is estimated that worldwide about 40,000 miles of CIPP liners have been installed and it is by far the leading method for the rehabilitation of gravity sewers (Heavans 2002). The major generic technology variants for CIPP rehabilitation are described in terms of the tube

construction, installation method, cure method, and resins used. The basic CIPP product is a felt tube, impregnated with polyester resin, inverted into a pipeline through a manhole and cured using hot water. Figure 8 explains classification of CIPP products, which are available in the market.

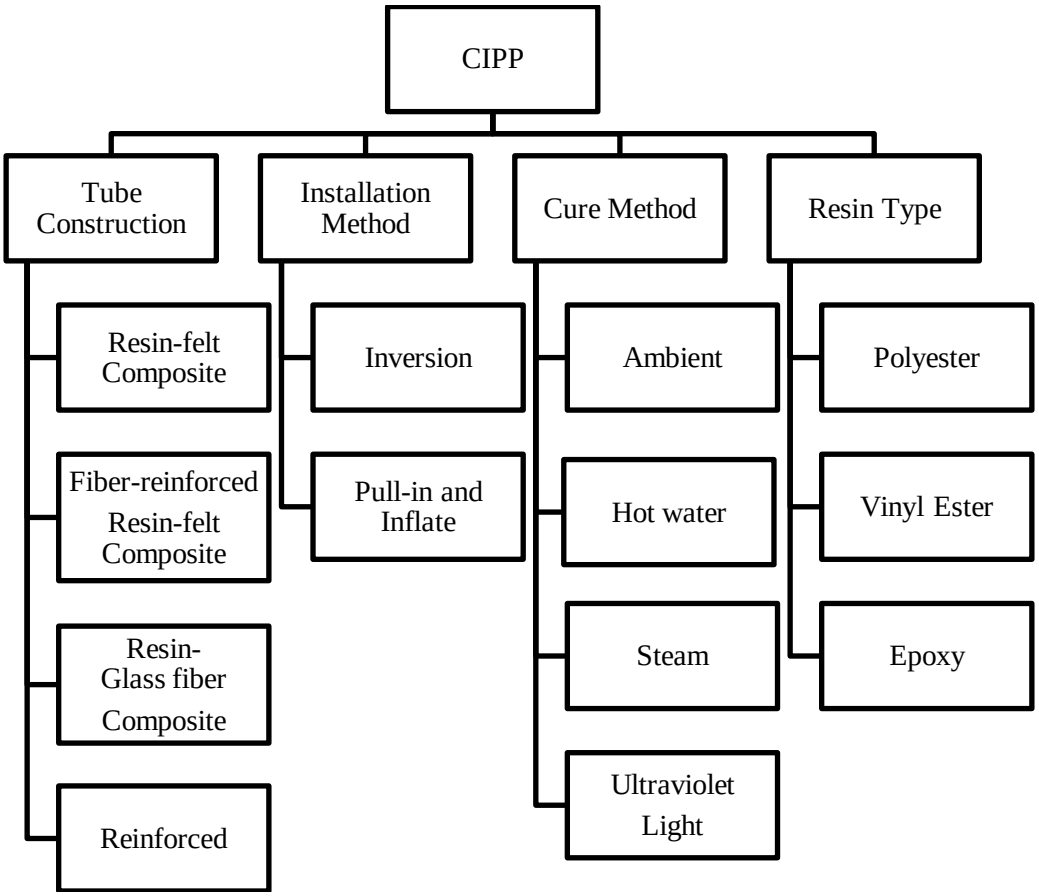

Figure 8: Classification of factors affecting CIPP product installation

CIPP inversion method installs the impregnated but uncured liner forced by water or air pressure to turn itself inside out along the host pipe section (IAMPO 2008). A secondary installation method is to pull the uncured liner into position without inversion (AWWA 2001b). For example, a polyethylene tube is first inverted into the host pipe, and then the liner is inverted inside the first tube. Ambient curing of a liner is possible but seldom used because it reduces productivity. Steam curing offers a faster cure but has some operational and safety drawbacks. Lateral liners (3" to 4" diameter) are frequently impregnated by hand on site. Large diameter

liners are wet out on site using special wet out facilities due to the high weight of the impregnated liner for transportation (McSweeney et al. 2000). Polyester resin proves economic and efficient for corrosion resistance to normal sewage conditions. Vinyl ester resins and epoxy resins are used to provide greater chemical resistance when needed but increase cost.

Woven hose Liners

Woven hose linings differ from ordinary CIPP products by the construction of the tube reinforcement (Meeuwissen 1988; Orlando 2005). Woven-hose liners are manufactured from polyester, glass, or aramid fibers woven into a hose-type configuration, similar to the type of construction used for fire hoses. Hose liners are pull-in-place rather than installed by inversion, due to the structural strength and thickness of the products.

Close-fit Liners

The use of close fit liners is often called modified sliplining. Classification of close fit liners is shown in Figure 9. It involves the use of a thin walled PE liner with an outside diameter that is similar to the inside diameter of the host pipe. The key to installing the liner is temporary reduction in the liner diameter to facilitate its insertion into the host pipe (Elzink 2001). Once the liner is in place, it is reverted back to its original outside diameter forming a close fit to the host pipe. The reinstatement of connections and fittings often requires special techniques and fittings.

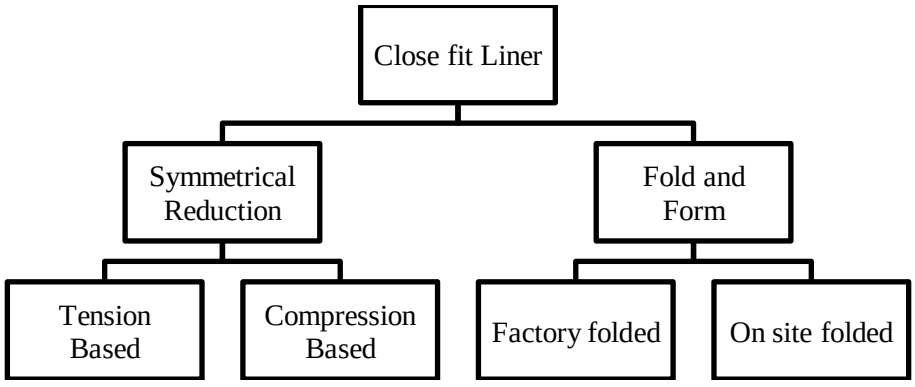

Figure 9: Classification of Close-fit Liners for Water/ Wastewater Rehabilitation

Close fit liners are thin walled to maximize retention of cross-section. There is a range of products from which to choose including thin semi-structural liners to thicker structural liners.

Fold-and-Form – Factory folded PVC

PVC based fold and form liners are folded to a smaller cross-section at the factory. The material is high abrasion and once installed it is expanded using air pressure or hot water. The design of the liner is based on ASTM F1216. For installation, access is required at both ends.

Fold-and-Form – On site PE

Close fit PE liner is folded into "C" or heart shape to facilitate insertion of the liner into the host pipe. Once inside, it is reverted to its original round shape by the use of heat and/or pressure to form a close fit. Once inserted, the PE liner is inflated with water to break the temporary bands and revert the pipe to its original diameter (Insituform 2009). InsituGuard® Folded and Subline® are examples of this method.

Fold-and-Form – Factory Folded PE

Fold and Form liners pass through the folding mold in a factory and are transported in the same manner. The folded PE pipes require more effort in folding and reverting than PVC based products.

Fold-and-Form – PRP

Thermopipe is a thin reinforced polyethylene liner that is supplied as a factory-folded "C" shape liner. The liner is winched into the host pipe from a reel and reverted with air and steam.

Symmetrical Reduction Close Fit Lining – Tension Based

In this process, the diameter of the PE pipe is reduced by pulling the pipe through a static die or simultaneously pushing it through a series of concentric rollers. The liner pipe is pulled into the existing pipe at one time without stoppage or release of tension. If the pipe reverts during installation, there is no way to move it.

Symmetrical Reduction Close Fit Lining – Compression Based

In a compression-based system, the PE pipe is pushed through a die consisting of a series of concentric concave rollers. The diameter reduction is associated with a thickening of the pipe wall rather than an increase in length.

Grout-in-place Linings

Grout-in-place linings are installed with an annular space that is grouted to complete the installation. Once grouted, the liner functions as a composite liner with each element providing its own contribution to the overall performance (Mainsaver 2009). The interior liner element is anchored into the grout once the grout has cured following installation.

Replacement technologies

Replacement involves the installation of a new structural pipe to take over the functions of the deteriorated main. There are several technologies available for online and offline replacement. The most common method of renewal has been offline replacement. The effect of renewal factors on replacement products is provided in Appendix C. Emerging replacement methods have yielded methods that now limit the amount of excavation to a minimum. These methods fall into both online and offline methods. Online is where the new pipe is laid to the same line and grade as the deteriorated pipe being replaced. Offline replacement consists of

installing a new pipe in a different line. Figure 10 classifies water and wastewater replacement products based on installation methodology and use of equipment.

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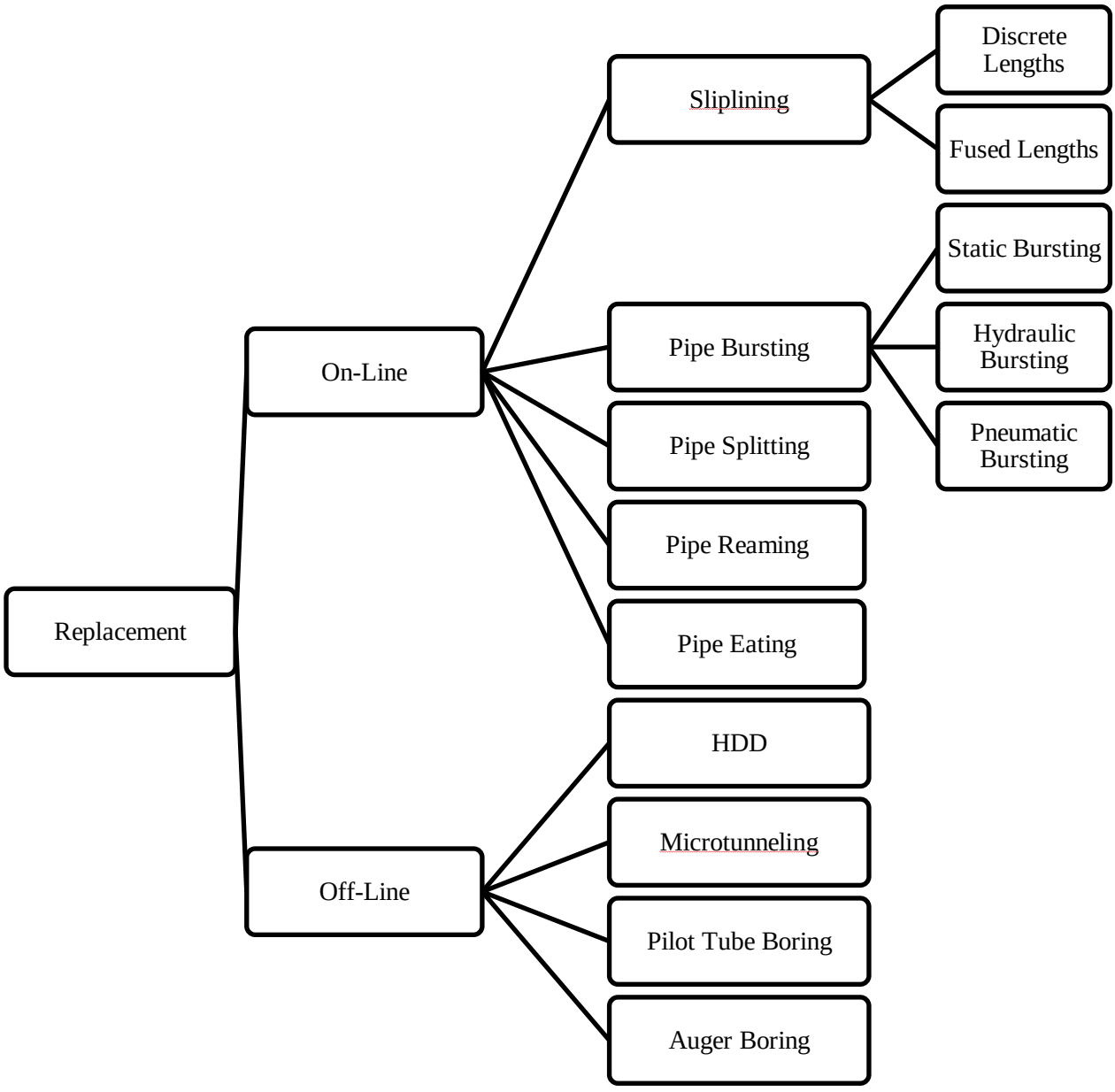


Figure 10: Classification of Water/ Wastewater pipeline replacement products

Sliplining

Sliplining is used for replacing large diameter pipes. It involves the insertion of a new pipe with a smaller outside diameter than the inside diameter of the pipe to be rehabilitated. The most common pipe material used for pressure sliplining has been PE (Zhao 2003). In large diameters, steel, ductile iron, and glass or fiber-reinforced plastic (GRP/FRP) pipes have can be used. The new pipe can either be pulled or pushed into the existing pipe. The annulus between the two pipes is often filled with a low-density grout. It can be done by Discrete pipe lengths or Fused pipe lengths. The PVC based piping system can handle a wide range of system operating pressures and can restore the flow capacity of the host pipe. They are used in renewal applications that require more than 2000 feet replacement. These pipelines are extruded from a specific formulation of PVC resin, that allows the joints to be butt fused together.

Pipe Bursting

Pipe bursting involves the breaking up of the old pipe and pushing it into the surrounding soil by passing a bursting or splitting device through it while pulling a replacement pipe in behind the bursting head (Simicevic 2001). The replacement pipe is usually HDPE, PVC, or ductile iron. In some cases, the process can be used to expand the void with the insertion of a larger diameter. The bursting method works best on friable pipes, including cast iron, asbestos-cement, non-reinforced concrete, PVC, and clay pipes. Bursting is impossible in encased pipes, while shallow buried pipes risk surface displacement. Since the original pipe is destroyed, the new pipe is designed for external loads and hydraulic pressure. After insertion of the new pipe behind the bursting head, the soil will tend to close back on the pipe providing support.

<u>Static Pipe Bursting</u>

Static bursting was original developed by British Gas to replace cast iron gas mains. It works with cast iron and asbestos cement pipes.

Pneumatic Pipe Bursting

With pneumatic bursting, an air operated hammer shatters the old pipe as the bursting head is pulled through the line. A rear expander pushes broken pieces outward, which can also upsize the resulting void.

Hydraulic Pipe Bursting

Hydraulic pressure is primarily used to expand the candidate pipe, which breaks the old pipe and pushes the pieces into the surrounding soil. An expansion cone can be accommodated for upsizing.

Pipe Splitting

Pipe slitting is a variation of the static method incorporating cutting wheels preceeding the bursting head (Chapman et al. 2003). The cutting wheel slits the ductile pipe, such as ductile iron or steel, allowing the bursting head to open the slit pipe.

Pipe Reaming

A Horizontal Directional Drill (HDD) provides tensile pull and rotational torque capability for the Pipe Reaming process (Simicevic 2001). A drilled entry path is needed for the drill rod entry. The drill rod is pushed along the existing pipe to the insertion pit and is connected to a reaming head with cutting teeth. The replacement pipe is attached to the rear of the reaming head and then the HDD rig is used to ream out the existing pipe as the drill rods are retracted.

Pipe Eating

The pipe "eating" process uses excavation heads that can cut through and fragment the existing pipe material (Simicevic 2001). In this case, a microtunneling-style excavation head is jacked along the existing pipe alignment. This system has seldom been used in North America, if at all.

Directional Drilling

Directional drilling starts by drilling a small-diameter pilot hole along the designed directional path. The drill head can be steered horizontally and vertically. The pilot hole is enlarged and finally the replacement pipe is pulled in to the reamed hole. Typical pipes that can be pulled into the diameter are steel, HDPE, PVC, and ductile iron. Steel pipe would have welded joints, or mechanically locked joints. In 2005, American Society of Civil Engineers (ASCE) released a Manual of Practice #108 for Pipeline Design for Installation by Horizontal Directional Drilling (ASCE 2005).

Microtunneling

Microtunneling involves the installation of a new pipe behind a tunneling shield or tunnel boring machine (TBM). On short to medium length drives, the pipe string and shield are driven forward by hydraulic jacks operating from a drive shaft, while on long drives, intermediate jacking stations are installed at intervals along the pipe string. Once the TBM reaches the reception pit, it is removed. The jacked pipes can be the replacement pipes themselves, or they can serve as a casing for subsequent installation of the replacement pipes by sliplining. The selection of the right jacking pipe is paramount. Typical pipes that have been used for jacking of pressure pipes are GRP, polymer concrete, reinforced concrete, steel, and ductile iron (Chung et al. 2004).

Auger Boring

Auger boring is a pipe jacking method where the ground is excavated by a cutter head (Carnes 2003). Rotating the auger simultaneously excavates the ground and moves the excavated spoil towards the launching pit. The method has limited steering capability and cannot operate in poor ground conditions or below the water table.

Pilot tube method

The pilot tube method is a hybrid installation approach that uses the slanted head steering capability from HDD soil drilling to create an accurate, straight alignment (Deb et al. 2002; EPA 2010d). The final installation may be completed by microtunneling, auger boring or even pipe ramming. The pilot tube can easily be retracted if an obstacle is encountered and the probability of installation success is increased once a pilot tube connection is made between the launching and reception shafts.

Chapter 4: CLASSIFICATION OF RENEWAL FACTORS

Candidate Pipeline Problem Definition

Pipeline Application

Renewal products are designed for specific application: water or wastewater. Force mains have similar design characteristics to water mains. Both carry working and surge pressures of the system, are generally buried 4 to 8 ft and subjected to live loads in addition to trench loads. Water mains carry potable water so their influence on water quality is important, which is not the case with sewer force mains. However, the effluent carried in a force main is far more corrosive than potable or raw water, especially where gas pockets develop. Consequently, some technologies that are suitable for sewer force mains, providing they also meet ANSI/NSF 61 standards, would also be applicable for a water main. A classification of pipeline applications is shown in Figure 11 below.

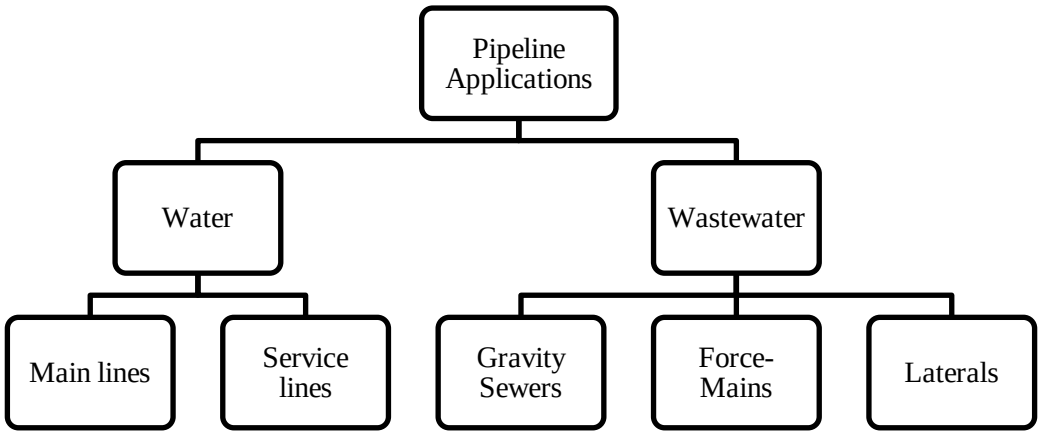


Figure 11: Classification of Water and Wastewater pipelines based on application

Pipeline Diameter

Water mains, wastewater pipes and force-mains are available in various diameters. The pipeline diameter is classified based on pipeline material, manufacturer and continuous

operations. Polymer-based pipes use Dimension Ratio as an indicator of pipe diameter. Dimension Ratio is obtained by dividing the diameter of the pipe with its thickness. Standard Dimension Ratio (SDR) and Nominal Pipe Size (NPS) are another set of pipe dimensioning standards used for pressure pipes. From literature, we know that different types and sizes of pipes are available for different applications. A common range of pipes was required to relate renewal products with the pipeline application. This was developed by plotting different ranges in a graph. The overlapping ranges were identified and a common set of five ranges were developed, as shown in Figure 12.

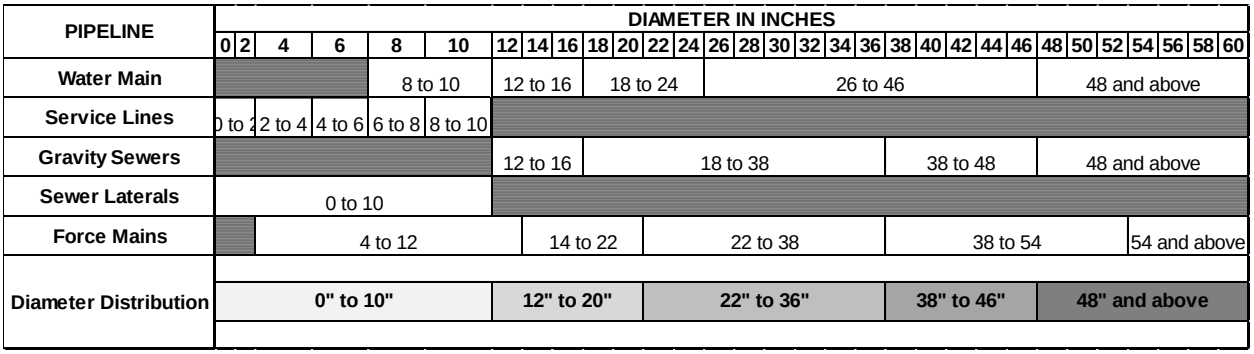


Figure 12: Development of a common Pipeline Diameter Range for REST tool

Pipeline Problems

Capacity Problems

The capacity available in portions of the sewer network, in individual lines or in treatment plant capacity affect pipeline renewal options. The need to upsize capacity while renewing the host pipe will eliminate relining options leaving upsizing using pipe bursting or open cut replacement as principal renewal optionsThis is especially true in large diameter pipelines. Flow can be calculated based on the Manning's equation for normal flow conditions.

Structural Problems

Assuming minor loss of flow capacity is acceptable, the first thing a designer has to consider is the structural condition of the pipeline. ASTM Standard of Practice F-1216 has categorized the condition of existing pipes into either partially deteriorated or fully deteriorated conditions. A partially deteriorated pipe can support soil and surcharge loads, while a fully deteriorated pipeline is not structurally sound and cannot support soil and live loads or is expected to reach this condition over the design life of the rehabilitated pipe. There is no consideration given to the existing pipe's ability to safely carry the internal working pressure or surge pressure. The following Table 4 shows the classification differences in structural problems.

Table 4: Comparative Cases for Pipeline structural problems

ID	CASES	ASTM F1216 CLASSIFICATION	COMMON ENGINEERING CLASSIFICATION
1	A ferrous pipe has lost 40% of its wall thickness and is still handling the internal working pressure with reasonable factors of safety on hoop tensile stress	Partially Deteriorated Pipe	Partially Deteriorated Pipe
2	A ferrous pipe that has lost 80% of its wall thickness, but it can support the overburden soil and live loads, yet does not have an acceptable factor of safety	Partially Deteriorated Pipe	Fully Deteriorated Pipe

Water Quality Problems

Water Quality monitoring is fundamental to operation and installation of pipelines. The primary goal of such a system is to test for chemical, physical, microbiological and aesthetic parameters. A potable water monitoring system provides water quality at representation points, identifies deteriorated water quality and the source of complaints. Similarly, wastewater systems are monitored for increasing hydrogen sulfide presence, corrosivity of effluents and presence toxic chemicals like mercury, cadmium, lead and chromides. OSHA, EPA, USCG and NIOSH regulate the quality operations in the wastewater system by the HAZWOPER regulations. A

typical quality plan can include ambient quality, seasonal variations, and type of treatment, size and condition of distribution system, configuration, compliances, complaints, lab facilities, emergency protocols and system water goals.

Joint Problems

Local leaks in gravity lines lead to puddle formation and soil displacement. Minor joint leaks in pressure lines can magnify over time due to hammer effect and surge pressure causing brittle pipe failures. Water-tightness is another issue confronting installed rehabilitation products. CIPP from time to time has faced joint leakage problems. Joints in mashine-installed thermoplastic panel systems have reported leaks. Recent inspection systems provide an effective means of finding and quantifying leaks. FELL system is an example of such methods.

Local Problems

Changes in load patterns are the prime reason for sectional problems in pressure pipelines. Soil settlement, improper bedding construction, root intrusion and poor workmanship can also cause problems in a specific section of the pipeline segment.

I/I Problems

The cost effectiveness of rehabilitation to reduce I/I within a system can look different depending on whether the system has excess treatment capacity or it exceeds its capacity during rainfall events. Dislocated joints are a key issue for Inflow and Outflow problems.

Flow Problems

. Capacity and flow conditions affect the cost of the work significantly when a bypass is needed to carry out the work. Debris and roots in the pipeline will affect the flow in a gravity sewer. Clogging and root intrusion will lead to structural problems in the pipe barrel. Impeded

flow can cause faulty measurement of flow and can largely reduce sewer capacity during storm events.

Utility System Needs

Host Pipe Material

For the purpose of this research, host pipe materials can be categorized into iron-based materials i.e. ferrous and non-ferrous materials. The key problem with use of unlined ferrous materials is corrosion. Non-ferrous materials like lead and asbestos cement are directly chosen for replacement because of their toxic nature. Concrete-based pipelines include different kinds of PCCP and RCP. PCCP is commonly used in pressure applications and is addressed for renewal because of failing tension strands. RCP is a material of choice in non-pressure pipes of medium and large diameter and the chemically corrosive waste eats away the concrete cover thereby causing structural problems for the pipe. Vitrified clay and clay-lined pipes are common for old sewer systems. Local failures and long-term protection are the key design requirements for renewing these pipelines. Polymer-based pipes form a small part of utility networks, and are relatively new. Material classification is shown in Table 5.

Table 5: Pipeline defects for different pipeline materials and their application

MATERIAL	POTENTIAL PROBLEM/DEFECT	APPLICATION
Vitrified Clay	Cracks/broken pipe, Root intrusion	Wastewater
PVC	Excessive deflection, Grease build-up	Water and Wastewater
Concrete	Internal or external corrosion of concrete and/or reinforcement, Cracks and fractures	Water and Wastewater
Cast Iron/Ductile Iron	Internal corrosion, External (pit) corrosion	Water and Wastewater
Concrete with Liner	External corrosion of concrete and/or reinforcement, Liner failure or separation	Water and Wastewater
Prestressed Concrete Cylinder Pipe	Corrosion of prestressing wires , Grease build-up	Water and Wastewater
Polyethylene	Excessive deflection, Grease build-up	Water and Wastewater

Steel	Internal corrosion, Weld failure	Water and Wastewater
Brick	Missing bricks, Soft mortar	Wastewater
Asbestos-Cement	Internal corrosion, Cracks	Water and Wastewater
Fiberglass	Grease build-up, Excessive deflection	Water and Wastewater
Copper	Not Available	Water
Lined Ductile Iron	Not Available	Water
Polybutylene	Not Available	Water
Fiber Reinforced Pipe	Not Available	Water and Wastewater

As-Built Pipe depth

Depth of a pipeline affects the range of renewal products that can be installed. A classification of pipe-depths commonly used across utilities is shown in Table 6. While, water mains lie at the same depth in a given service area, gravity sewers can be at significantly different depths in the service area. Large diameter pipelines are preferably laid at or near the surface because of their importance. The effect of grade is considered constant for the tool.

Table 6: Renewal products and description for classifying As-built Pipe depth

ID	DEPTH	DESCRIPTION	PRODUCTS
1	Surface/Shallow	0 to 3 feet	Danby Panel Lok, Hydro-Seal
2	Medium	4-8 feet	Fusible C900, Carbon Wrap
3	Deep	9 feet and below	Impactor Pipe Bursting, Jabar

Candidate Pipe Profile

Pipelines can be circular, non-circular or with no distinct geometric shape as shown in Table 7. Severely deteriorated pipelines operating at optimum capacity can be deformed due to corrosion or tuberculation. Deformations due to traffic loads, soil displacement, manufacturing defects go unnoticed until the pipelines are inspected. Dye-manufactured products are commonly designed for circular applications i.e. fold and form, woven hose techniques etc. It is impossible to install them in non-circular or deteriorated pipelines is nearly impossible.

Table 7: Renewal products and description for classifying pipeline profile

ID	PIPE PROFILE	DESCRIPTION	PRODUCTS
1	Circular	Most pipelines	Paraliner PW, RollDown
2	Non-circular	Brick lined, Culverts or Tuberculated pipe	Seaboard EM 12, Trolining GIP

Geographic Pipe Location

Several utilities can be located in close distance of one another. This is common for densely populated areas. The location of a water or wastewater pipe affects the choice of renewal product. Climate, hours of operation and statutory laws affect the location of a buried pipelines. It is virtually impossible to excavate for large diameter pipes in dense residential or commercial areas, similarly it is cost-effective to excavate in farm areas. Water bodies, marshes, places of historic importance and location of emergency services can affect renewal product decision-making. Table 8 shows a practical approach to classifying pipe locations.

Table 8: Renewal products and description for classifying pipeline location

ID	PIPE LOCATION	DESCRIPTION	PRODUCTS
1	Uninhabited Lands	Ease in installation, no effects to human settlement	MCS Inliner, Nowak InneReam
2	Town side	Low density	Waterline Epoxy
3	Suburban Areas	Medium density	-
4	Dense Residences	High density population	Titeliner, Subline
5	Commercial Areas	Immediate effects on trade and commerce	U-Liner, Subcoil

Excavation space

Pipelines are laid before and after people move into the area. Some pipelines are moved to adjacent areas to build foundations, while others are left alone before new development is

undertaken. Trenchless technologies do not require excavation across the whole length of pipeline, but some renewal products require space to place equipments and tools. Joint Replacement, lateral rehabilitation, cross-piping, offsets and 90° turns in a pipeline also warrant the need for excavation space. For the purpose of this study, excavation requirements are explained in Table 9.

Table 9: Renewal products and description for classifying site excavation requirements

ID	EXCAVATION	DESCRIPTION	PRODUCTS
1	Available Excavation Space	Open grounds, Parks, Public owned area	EX Pipe, Grouting Sleeve
2	Limited Excavation Space	Road side, Residential Backyards, Rail lines, Industries	Jabar, Grundotugger
3	Excavation Space is not Available	Water bodies, Structures, Traffic	-

Extended Pipe Age

Age of the pipeline facilitates the understanding of remaining age. Although, it is difficult to assess the remaining life of a pipeline, softwares are available to provide estimates. They must account manufacturing and operating conditions of the candidate pipeline. Remaining life is used to calculate the appropriate renewal product, shown in Table 10. Repair technologies are a short-term solution, and will not be recommended for 50+ year old pipelines if they service high priority areas. Similarly, replacement is an expensive option for young pipelines.

Table 10: Renewal products and description for classifying pipeline age

ID	SYSTEM RENEWAL	PIPE AGE RANGE	PRODUCTS
1	Repair	Less than 30 years	Acuro system, Grouting Sleeve
2	Rehabilitation	31 to 69 years	Nordipipe, Primus Line
3	Replacement	70 years and above	Herrenknecht Crush-Liner, Grundocrack

Operating Pressure

Pressure pipelines include Service lines, Water Mains and Force Mains. Service mains form a large percent of the water distribution network, and the operating pressure in service mains differs based on layout, consumer requirements, pipeline diameter and other factors. Utilities maintain a standard operating pressure for their large diameter water mains and force-mains. Both the pipelines form a small percent of a utility's network. Water mains are commonly designed to carry water safely at 150 psi, while wastewater pipelines are not designed for pressure applications. Wastewater lines that also carry storm water discharge require different pressure ratings.

Operating Temperature

Pressure pipelines perform at varying temperature. Renewal products that come in contact with water mains are rated for NSF Cold (73.4°F) temperature use, while commercial lines, force-mains and industrial pressure lines use products rated for NSF Hot (180°F) temperature use. NSF certification for temperature use is not compulsory pipelines that do not carry potable water. Utility service providers maintain maximum operating temperature across their infrastructure to help in engineering design and maintenance operations.

Required Thickness

The minimum thickness required for structurally upgrading the pipeline is calculated in the renewal design process. Thickness of the renewal product is inversely proportional to hydraulic flow. Thicker the product, lesser the hydraulic flow in the pipe cross-section. Nascent pipeline materials have standard charts for thickness versus diameter, but it is not true for proprietary renewal products. AWWA Class IV products are structurally independent and comparatively thickest among renewal products. Epoxies and Polyuera based spray-on coatings stand at the other end of the thickness scale for renewal products. The thickness of the renewed

pipeline is a sum of existing thickness and the thickness of the renewal product. The total thickness of the renewed pipeline should be used to estimate the hydraulic flow.

Section Renewal Length

Rehabilitation products can address longer renewal lengths than repair products. A large percent of repair products can address up to 50 feet. Such products are effective for fissures, cracks, joint repairs and local leakage problems. Rehabilitation products using Fold and Form technology or Cured-In-Place-Pipe technology are not recommended for shorter segments. The basic product is manufactured in longer lengths and its use is justified in renewing above 1000 feet pipeline sections. For shorter rehabilitation solutions, Pipe wrapping, Panel lining and Spiral winding are a technically sound alternative. These products are composed of segments or strips joined by interlocking mechanisms or adhesive mixtures respectively. Replacement technologies like sliplining and tunneling are used in longer renewal segments to offset the costs of mobilization, excavation, welding and heavy equipments.

Renewal Engineeering Needs

Corrosion Protection

Corrosion in water mains can go unnoticed and reduce the life of a pipe at a fast rate. Renewal design of moderately or lightly corroded pipes can be complex. Consideration must be given to pipe's resistance to both internal and external corrosion. Pipe materials will also be damaged by corrosive soil unless special coatings are applied to the pipe exterior. Reducing ph Levels in water, spray-on products and CIPP products can contain the level of corrosion in structurally sound pipelines. Lined ductile iron pipes are in production.

According to the National Science Foundation (NSF 2005), minerals in water can react with galvanizing material and form scale, which builds up over time and will eventually clog the

service line. In addition, iron oxide can build up over time, especially in small diameter pipes, causing the water to become rust colored in the first flush.

Cleaning

PIGs and metal scrappers are commonly used to clean pipes. Power boring equipments can be used in heavily tuberculated pipes. Renewal products require cleaning prior and post installation. It allows the renewal product to form an adhesive bond with the host pipe or to avoid interaction between the newly installed product and foreign material. Cleaning methods have been classified into five different categories, shown in Table 11, based on the need for installation of renewal products.

Table 11: Renewal products and description for pipeline cleaning requirements categories

ID	SYSTEM RENEWAL	PURPOSE	PRODUCTS
1	Jet Spray	Basic cleaning to maintain adhesion between product and pipeline	IPEX M34, Grundoburst
2	Flushing	Removal of small debris	Insitform RPP, Aquapipe
3	Pigging	Salt Scales, Root intrusion	Heitkamp Epoxy, Fast Line Plus
4	Scrapping	Heavy tuberculation, Large Debris	-
5	Chemical	Reduce toxicity, remove foreign materials	-

Access Pits

The size of an access pits should not be confused with the amount of excavation. Access pits are required for man-entry, movement of material and entry of the actual rehabilitation product. Access Pits are dug vertically downwards to expand an existing man-hole or valve station. Staging areas are setup in and around the access pit to maintain smooth operations. Access pits are always required for pipeline renewal, which is not true in the case of excavation. Road Space is sometimes used for access pits, thereby leading to lane closure. Penalties are

specified on contractors for lane closure beyond contract time (Downey 2009). They are classified for the purpose of risk into Small pits, Medium Pits and Large Pits.

Down Time

Downtime is confused with flushing time, cleaning time and installation time. Essentially downtime is the amount of time lost by keeping a given pipeline out of service. Simple installation methods can account for lesser down-times, as shown in Table 12. Downtime includes the time lost while draining excess water, cleaning, installation, inspection, flushing and return to service (Rockaway and Ball 2007).

Cleaning gravity sewers takes more time due to sedimentation and encrustation problems, while EPA laws mandate flushing a potable water main or service main. Utilities have parallel lines and resilient systems to counter downtime for system maintenance. This factor is accounted for prioritizing candidate pipeline renewal. A utility may install a new pipeline before renewing an existing line to maintain service standards.

Table 12: Renewal products for pipeline service down-time categories

ID	DOWN-TIME	PRODUCTS
1	More than 24 hours	Hobas FRP Panel, FibrWrap
2	3 to 24 hours	Phoenix, MainSaver
3	Less than 3 hours	Hydro Seal, NPC Internal Joint Seal

Service Connections

Service connections create the need for dig-outs. The insertion of a pipe or liner within the old main generally obscures the service line. In the wastewater industry, where laterals are large, a dimple indicates its presence. In water main lines, the small diameter service lines become invisible post-renewal. Table 13 explains the classification of renewal products based on their effect on existing service connections.

Table 13: Renewal products and description for categorized effects on service connections

ID	SERVICE CONNECTIONS	DESCRIPTION	PRODUCTS
1	No effect on Connections (Clean the connections)	Post-lining, the service connections are visible and can be re-instated into service without acoustic emissions	KA-TE Robotic System, Perma-Liner Point Repair System
2	Limited Connections	Post-lining, the service connections are not visible and need robotic devices to find and make cut-outs in the renewal product	Sure Grip Liner, TRIC Sewer Lateral Pipe Liner
3	Replace Connections (Not Recommended)	Post-lining, the service connections may or may not be visible, but need to be replaced because they will not form a joint with the renewal product	Waterline Epoxy, PolySpray

Annular Space

Most utilities choose an interactive liner that does not leave an annulus between the liner and the host pipe. This can be difficult for pipes needing high structural strength. Thicker builds can be achieved by pressure grouting the annular spaces. Table 14 classifies renewal products for different kinds of annular space between candidate pipe and renewal product.

Table 14: Renewal products and description for classified annular space post-renewal

ID	ANNULAR SPACE	DESCRIPTION	PRODUCTS
1	No Annular Space	Interactive renewal product leaves no annual space between product and host pipe	AM-Liner II, Duraliner
2	Adhesive	Annular Space is filled with adhesive. Commonly applied to the face of renewal product before installation	CarbonWrap, Channeline SL
3	Grouting	Annular Space is filled with grouts. Grouts are injected post-renewal and require inspection of renewal products	Sanipor, LogiBall Test & Seal

Bends

Bends, valves and pumps reduce hydraulic capacity and a majority of renewal equipment cannot handle bends. They are reinstalled with complementing materials post-renewal. Bends can worsen the situation if the pipe diameter is reduced drastically post-renewal. A classification for the effect of bends in a candidate pipe is shown in Table 15.

Table 15: Renewal products and description for classified System Bends

ID	SYSTEM BENDS	DESCRIPTION	PRODUCTS
1	No Bends	Renewal section has no bends	Jabar, Consplit
2	Horizontal Bends	Renewal section has only horizontal bends	Insituform RPP, LMK T-Liner
3	Vertical Bends	Renewal section has only vertical bends	Top Hat, Viscotaq Coat Wrap

Subsurface Features

Replacing utilities can be expensive change orders in infrastructure development. Electrical lines, communication lines, gas lines are some utilities that share buried space with the water and wastewater network. Their location, size, importance and future developments affect renewal design, shown in Table 16. Pipe bursting and modified pipe bursting are generally avoided in such cases to avoid the pipe shrapnels from affecting nearby utilities. Many utilities may collaborate in renewal projects to avoid digging twice.

Table 16: Renewal products and description for classified Subsurface Features

ID	SUBSURFACE FEATURE	DESCRIPTION	PRODUCTS
1	Rare	Utilities are more than 15 feet away	Grundotugger, Nowak InneReam
2	Moderate	Other utilities lie within 15 feet	InsituGuard Flexed, Avanti Ultrafine
3	Dense	Utilities within the ROW of pipeline	Frey C Wrap, Nordipipe

External Loads

Depending on the state of deterioration of the existing main, the renewal liner can be designed for corrosion protection or replacement. Design requirements are classified for renewal products in Table 17. Factors that enter load-design are corrosion, temperature, fatigue and erosion/abrasion considerations.

The pressure rating of most thermoplastics and reinforced thermosetting resin pipes are based on long-term pressure regression testing at ambient temperature. Due to the presence of solids, force mains are far more abrasive environments than potable water mains. The design of a renewal liner for pressure mains must take the potential for erosion. Unibell PVC Pipe Association has published a design guideline for the use of PVC pipe in sewer force mains.

Table 17: Renewal products and description for classified external loads

ID	EXTERNAL LOAD	DESCRIPTION	PRODUCTS
1	Not Required	No load calculations are required. Hydraulic Calculations may still be required.	Grouting Sleeve, Fast Line Plus
2	Limited Design required	Pressure applications requiring internal load-based design calculations	Hobas FRP Panel, FibrWrap
3	Full Design required	Traffic, soil bearing, ground water, structures require detailed design calculations	Subcoil, Thermopipe

Ground Water level

Ground water can enter the annular space. Higher Groundwater level requires continuous dewatering during product installation. It will also cause increased humidity in the pipe, leading to longer waiting times. Groundwater classification is provided in Table 18.

Table 18: Renewal products and description for classified groundwater levels

ID	GROUNDWATER LEVEL	DESCRIPTION	PRODUCTS
1	Below Bedding Level	Groundwater does not affect product installation or operation	Heitkamp Epoxy, Curaflow Spincast
2	Around Pipe Level	Groundwater affects pipeline structure, product installation and product operation	Linabond Simulform Panel, Acuro System
3	Above Crown Level	Groundwater affects pipeline design, product design, installation and product operation	EX Pipe, Insituguard Flexed

Renewal Product Characteristics

ANSI/NSF 61 requirements

NSF/ANSI Standard 61 Drinking Water System Components establishes minimum health effects requirements for the chemical contaminants and impurities that are indirectly imparted to drinking water (NSF 2005). The standard provides the criteria used to evaluate the public health safety of materials, components, products, or systems that contact drinking water, drinking water chemicals, or both.

Product Status

The amount of time spent by a commercial product in the market improves technical understanding and reduces the cost of installing them. Conventional Renewal Products have been in the market for more than 30 years and the market is growing everyday with upcoming innovative products. A classification of products is presented in Table 19.

Table 19: Renewal products and description for classified Product Status

ID	PRODUCT STATUS	DESCRIPTION	PRODUCTS
1	Conventional Product	Products that are commonly understood by different stakeholders in trenchless engineering	Subline, RollDown
2	Emerging Product	Products are known among certain sections of trenchless engineering	Thermopipe, Top Hat
3	Innovational Product	Products that are unknown to different stakeholders in trenchless engineering	A+Wrap, InnerSeal Lo Mod

Environmental Impact

Trenchless renewal affects the environment on a smaller scale then Open-cut method. Smaller number of excavation pits, localized use of machinery and controlled disposal of hazardous wastes are synonymous with trenchless renewal products. Renewal products can different levels of impact based on their installation method. A classification of environmental impacts is provided in Table 20 based on standard installation methods.

Table 20: Renewal products and description for environmental impact categories

ID	ENVIRONMENTAL IMPACT	DESCRIPTION	PRODUCTS
1	Limited Effect	Products do not disturb soil, are below 90 db, do not cause vibration and do not require disposal	PolySpray, SprayWall
2	Moderate Effects	Products affect 200lbs soil, noise between 91 and 124 db, vibration and hazardous materials Class 1	Aquapipe, Avanti Ultrafine
3	Severe Effects	Products that comparatively require more than 200lbs of soil displacement, cause noise above 125db and disposal of Class 2 hazardous materials	ConSplit, Impactor Pipe Bursting

Codes and Specifications

Various product standards are available in the market. Both vendors and utilities commonly practice British, European and American standards. These product standards need to be refined with increase in the rehabilitation market. A classification of codes is given in Table 21.

Table 21: Renewal products and description for different categories of codes

ID	CODES	DESCRIPTION	PRODUCTS
1	Not Available	Products that are not approved for or tested under American Standards, International Standards or Industry codes	SubCoil, Nuflow Process
2	Design Codes	Products tested under American Standards or International Standards, but do not conform to Industry codes	Linkpipe Insta-Liner, National Liner
3	Specialty Codes	Products not tested under American Standards, but are supported by Industry codes	U-Liner, Starline HPL-W
4	Design & Specialty Codes	Products approved by Industry generated specialty codes, American Standards and International Standards	Sekisui Spiral Wound GIP, Powercrete PE

Installation Method

Installation methods vary largely across pipeline renewal practices. Use of equipment, curing methods, layers and materials affect renewal products within the same renewal technology domain. Utility crews use certain installation methods repeatedly because of their ease in installation. For effective use of the renewal product, various utilities and contractors have developed Standard Operating Procedures. They are the result of repeated use and known shortcomings in application. A classification of installation methods is provided for the tool in Table 22.

Table 22: Renewal products and description for different categories of installation methods

ID	INSTALLATION METHODS	DESCRIPTION	PRODUCTS
1	Common Method	Products used across different engineering applications with limited steps and no use of heavy equipment	AM-Liner II, Aquapipe
2	Moderate Method without Curing	Products used in Buried Infrastructure with no curing, limited use of equipments and well-documented operating procedures	Fusible C900, Grouting Sleeve
3	Moderate Method with Curing	Products used in Buried Infrastructure with curing, limited use of equipments and well-documented operating procedures.	Insituform PPL, Masterliner CIPP
	Complex Method	Products requiring equipment, proprietary operating procedures and specialized personnel for installation, repair and maintenance procedures	FibrWrap, MainSaver

Historical Utilization

Periodic and regular use of a product induces a level of confidence. Maintenance programs become effective if the materials in their system are common throughout. Long-term use of a renewal product translates to long-term performance and increased utility control over their systems. Products that have been in the market for long period are potential winners over competing brands. A classification of renewal product use is provided in Table 23.

Table 23: Renewal products and description for different categories of utilization

ID	UTILIZATION	PRODUCTS
1	Not Applicable	National Liner, Phoenix Process
2	Less than 50 miles	Paraliner, MCS Inliner
3	51 to 99 miles	Primus Line, Nordipipe
4	100 miles or more	Grundoburst, Grundomat

References

Published literature and case studies allow new clients to understand the properties of the product. Independent reviewers make a strong case for the use and specific application of a renewal product. The following Table 24 provides a classification of available references for renewal products.

Table 24: Renewal products and description for different categories of references

ID	REFERENCES	DESCRIPTION	PRODUCTS
1	Limited Information	Information available on brochures, website or at trade shows	Insitumain, Nuflow Process
2	Vendor information	Test reports, performance results and vendor published material	Viscotaq, Warren Environmental S301-14
3	Independent Reviews	Case-studies, Utility usage, test reports and vendor published materials	Top Hat, Trolining GIP

Practitioners

Utilities in similar geographical areas have matching practices and materials. Information sharing between utilities can increase the probability of using one product over another. Table 25 highlights a classification of renewal products based on the number of practitioners in the market.

Table 25: Renewal products and description for different categories of practioners

ID	PRACTITIONERS	PRODUCTS
1	Not Available	PerpetuWall, Phoenix
2	Less than 3 users	Hobas CCFRPM, Inliner
3	4 or more users	Nowak Reaming, Perma Lateral Lining System

Quality Control

Quality control of epoxy resins assures its use in water pipe rehabilitation measures. All epoxy resin material used in situ lining of potable water main lines must be solvent and benzyl alcohol free, high-build, slump resistant, rapid curing and moisture tolerant (AWWA, 2002). Depending upon the technology, a level of rehabilitation system's qualification testing varies greatly. For instance, the evaluation and testing of materials for CIPP are given by requirements of the ASTM Standard D5813. A classification is used for the purpose of this study, as shown in Table 26.

Table 26: Renewal products and description for different categories of QA/QC

ID	SYSTEM RENEWAL	DESCRIPTION	PRODUCTS
1	Factory-Built Material	Products manufactured in a factory environment and installed in the same physical and chemical state.	Danby Panel Lok, NPC Internal Joint Seal
2	Site-Built Material	Products manufactured in factory environment and maybe chemically or physically modified.	Saertex Liner, Sanipor, Scotchkote 269

Known Costs

If the equipment and crew size remain same, the number of segments that can be completed in a day has a strong impact on the unit cost of the work. Technology providers have worked to reduce their required time on site and increase productivity. Examples include preheated water for CIPP curing and reuse of the heated water for additional segments, use of steam and UV curing for CIPP, and rapid-curing polymers for sprayed liner applications. Known cost of renewal products are classified for the purpose of selection. The classification of products is shown in Table 27.

Table 27: Description for different categories of costs in REST tool

ID	SYSTEM RENEWAL	DESCRIPTION
1	Not Available	No figures are available at the time of database creation
2	Manufacturing costs	Cost of manufacturing the basic renewal product per linear foot, per gallon or container
3	Tendered Costs	Estimated cost of installing a renewal product with given specifications and performance
4	Project Costs	Actual costs borne by the contractor and paid for the owner for installing a renewal product on a specific project

Chapter 5: DEVELOPMENT OF REST TOOL FRAMEWORK

Introduction

The Decision-Support System framework explained in this chapter accounts for repair, rehabilitation and replacement products across the length of commercially available renewal practices. Data for these products is sourced from vendors. The REST tool framework employs factors classified and categorized in Chapter 4. Renewal products are recommended upon comparing the factors and user requirements. A graphical and tabular recommendation list of seven renewal products is provided in the output sheet. The final decision to use one particular product is made by the user. The user should obtain further information about the renewal product prior to making final decision. The user can understand the four basic parts of this REST decision-support by clicking on the boxes shown in Figure 13.

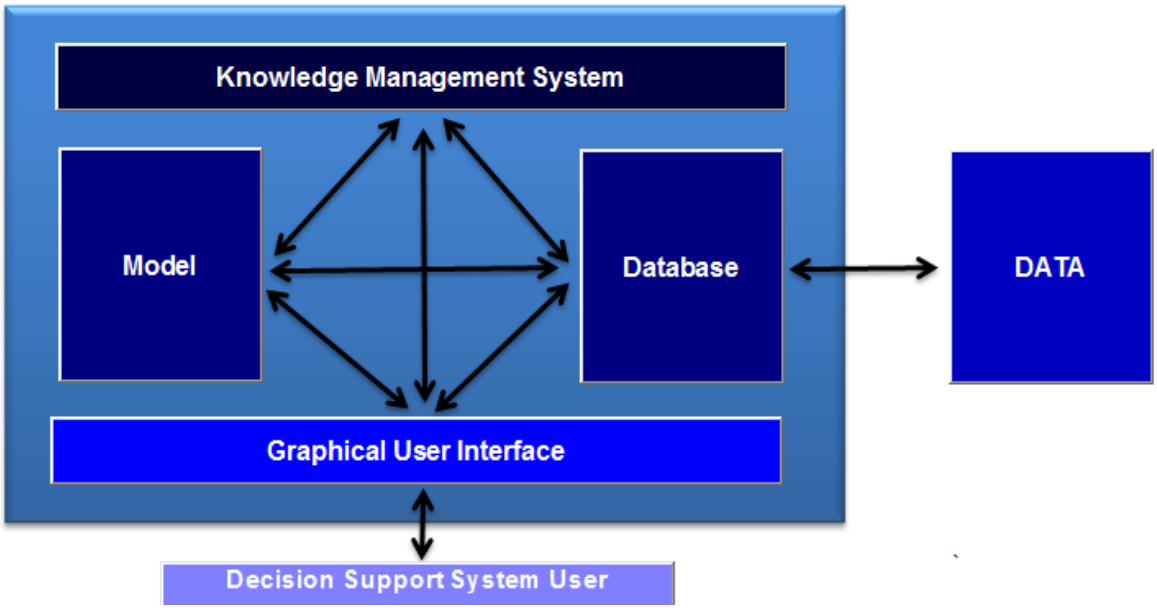


Figure 13: Research Methodology for set-up of REST tool

Graphical User Interface System

Microsoft Excel is the choice for DSS generator because it is widely available and can integrate with Microsoft Access (Database), Word (Reports), PowerPoint (presentations) and Internet Explorer (www). Its capabilities are extended by the Visual Basic for Applications (VBA) and several add-ons in the market. Microsoft Excel allows the design and development of a GUI. A user enters the required data in a Graphical User Interface System. The GUI is framed keeping the user's experience and the Decision-Support tools' objectives in mind. It has to be easy-to-operate, visually effortless and efficient in relating with other management systems in the DSS.

Basic Platform

The User form forms the platform for Graphic User Interface. A typical user form allows text and numerical entries. The Toolbox, shown in Figure 14 allows for insertion of different objects in the userform. Objects like Combo boxes, List boxes, Textboxes etc control the input and output functions on the userform.

Figure 14: Toolbox available for user-form design in Visual Basic

The user form can be initiated either when the excel program starts or through a button on the worksheet. In this program, it starts with the command button on the excel page as shown in Figure 15.

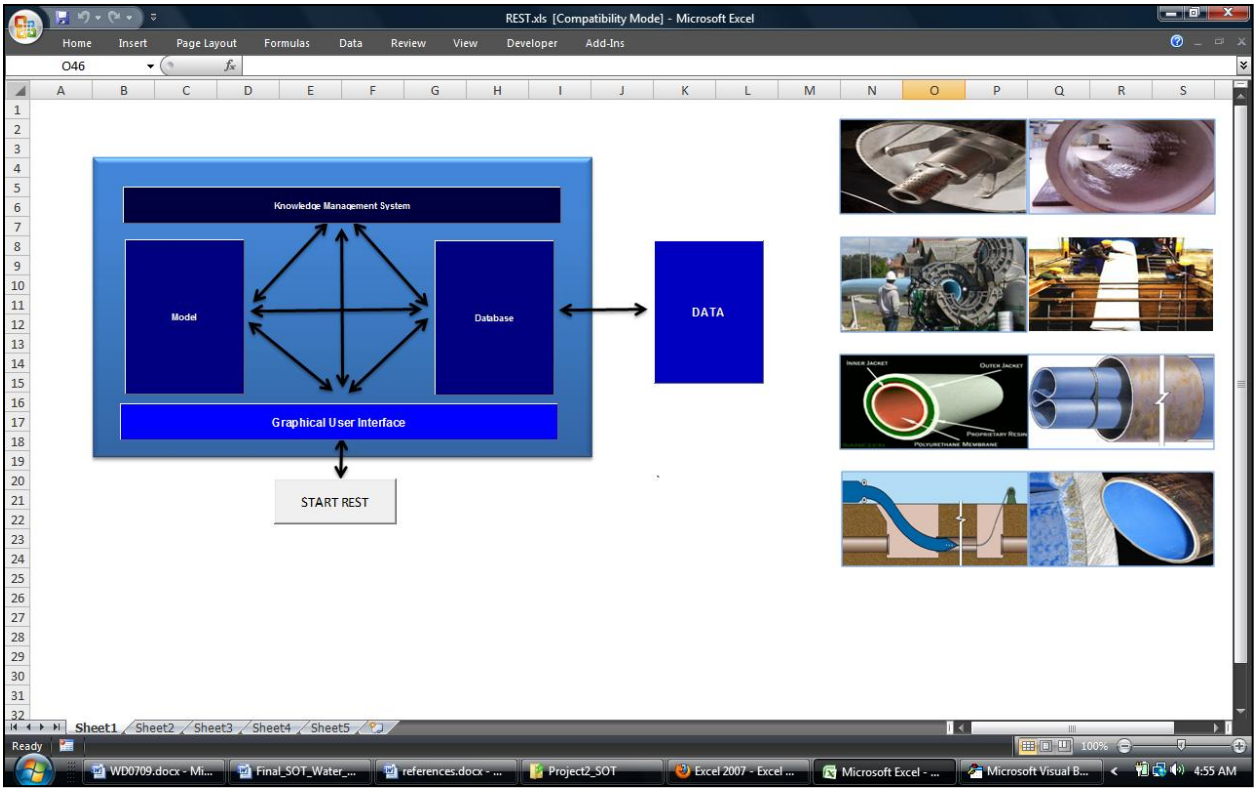


Figure 15: View of Excel worksheet at the start of REST tool

The REST model's GUI is based on a multipage object, as shown in Figure 16. It allows the developer to design different pages for data-entry. The pages are used for presenting the different steps in the model.

Operability

The first page of user-form has a command button to start the process. By clicking command button, the user agrees to provide complete data for the REST tool. Command button is disabled upon starting the process and can be enabled only after restarting the process from scratch. Apart from the first page, all succeeding pages have a "Previous" command button,

while all the pages have a "Next" command button. The "Previous" button and "Next" button allow the user to go one-step back or forth respectively. The last page has a "Calculate" button to calculate and print the results. Every page of the user-form has a "Help" button. It takes the user to a help file that explains the functioning of the Decision Support tool.

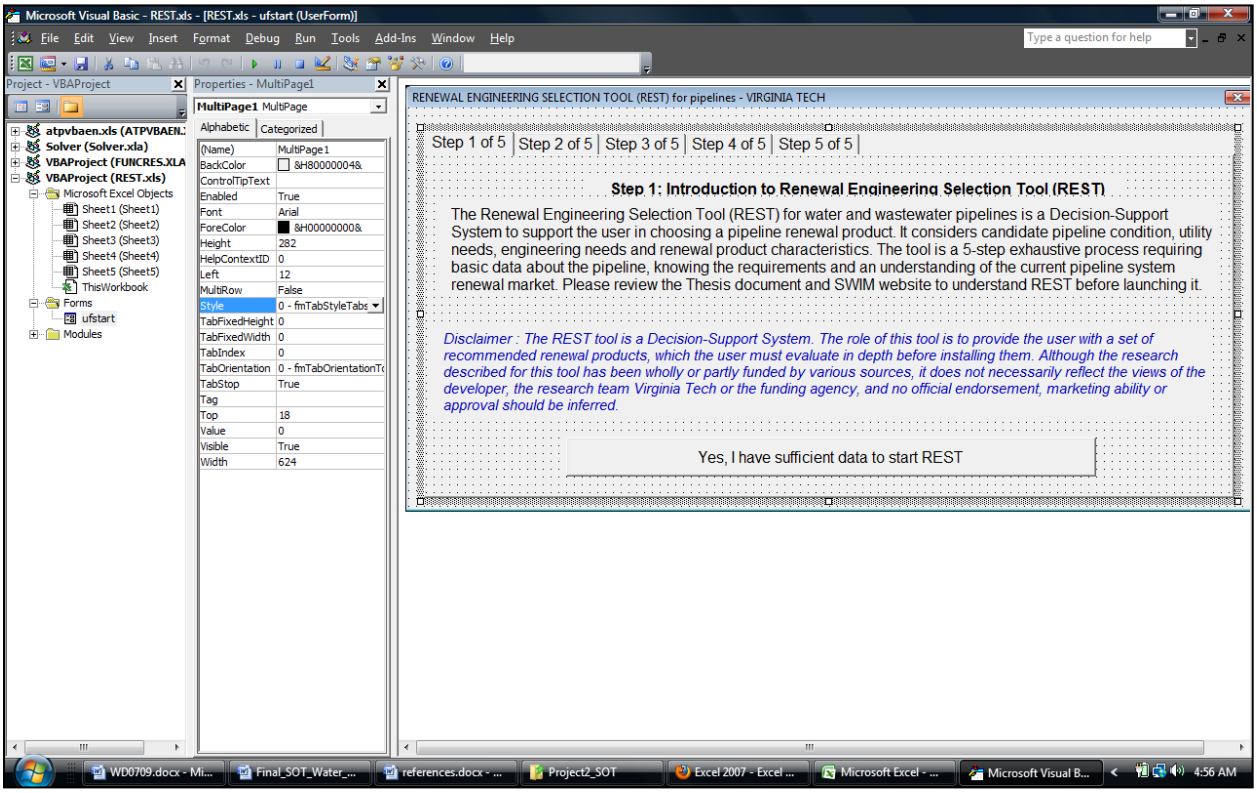


Figure 16: Step 1 of User-form with five different steps shown on top of the user form

A "Restart" button on the last page of the user form allows the user to close the existing process and restart it. The "Close" button on the top left corner of the user form can be used on any page to close the REST tool. Neither the "Close" button nor "Restart" button will publish any results.

Use and Application

The user form has textboxes, radio buttons, combo boxes, command buttons, labels and frames. It does not use several other objects like list boxes, scroll buttons and picture controls

etc. Certain objects cannot be modified, while others are open for data-entry. Message boxes that pop up for warning, information or error are also a part of the GUI.

Model Management System

The model management system connects the user interface with the database system. It begins with the button on "Sheet 1". The code behind the button loads the user form. The model is designed static by nature. The user cannot change factors, weights, mathematical operations and formats without opening the Visual Basic component. A developer or experienced professional can make changes to the model.

The model follows the Ranking method. Once the user selects the categories for each factor, the worksheet is sorted to provide the product with the lowest score. Each Recommended product has different values in each step. The values are color-coded in Red, Yellow and Green to cognitively understand "the distance of the product" from user requirements. The Decision-Making factors used in the model are explained thoroughly in Chapter 4 and Renewal technologies classification is provided in Chapter 3.

Performance Indicators

The renewal products are evaluated based on the number of matching criteria and on three performance indicators explained in

Figure **17**. The Performance Indicators help identify the acceptance, knowledge and use of the renewal product across stakeholders.

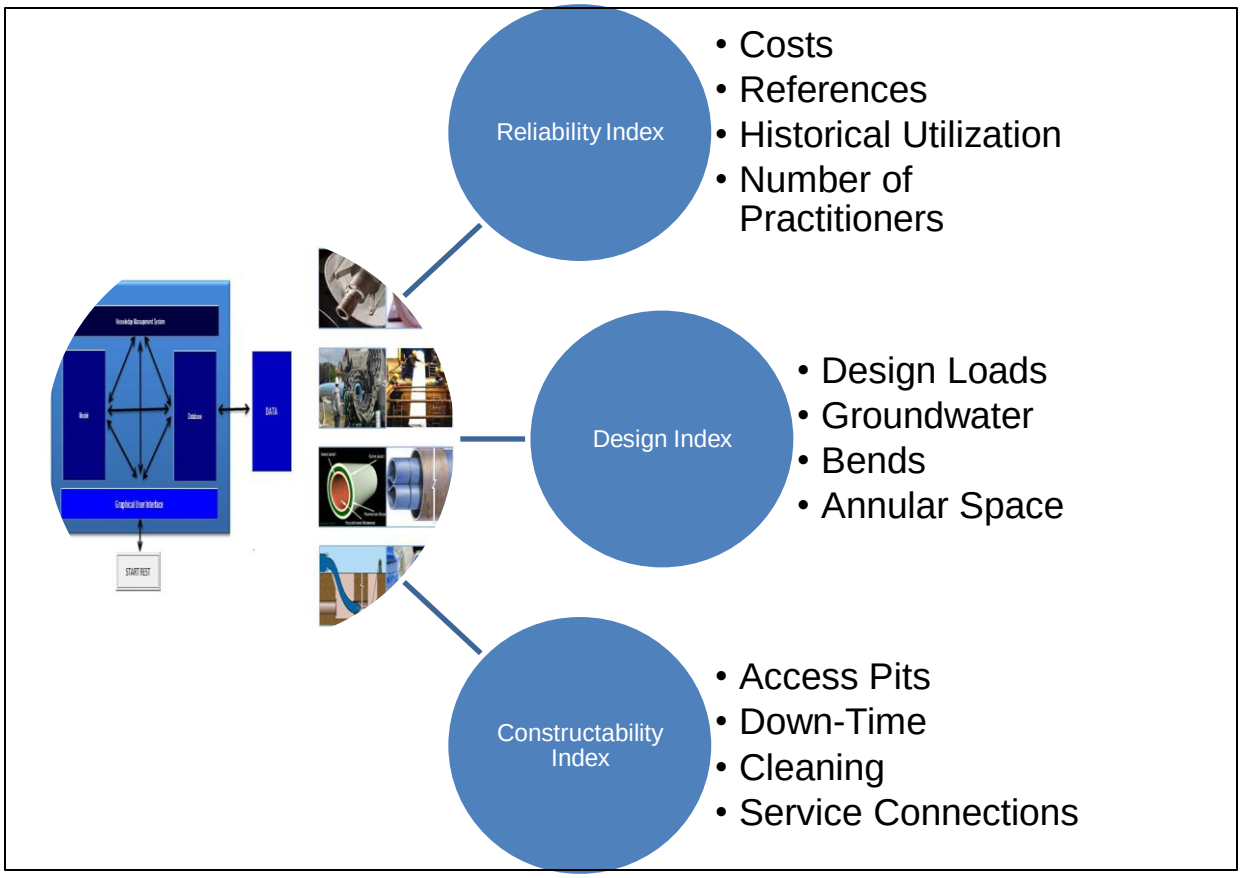


Figure 17: Classification of the three indices for Renewal Product Confidence

Reliability Index (*Ri*)

Reliability Index supports further investigation of a recommended renewal product for the end-user. The model compares user requirements with database values. The database values need to be tested for reliability. The vendors validate quality of data and the source of data, but some information is missing and assumed. Certain information can make the product a preferred choice. Knowledge on cost, references, utilization and the number of practitioners improves the reliability of a recommended product. The Reliability Index of a recommended product indicates if the user can obtain more information about the product from reliable sources.

Design Index (*Di*)

The Design Index provides a degree of engineering design required before installing a recommended renewal product. A Renewal product's effect of design loads, groundwater, bends and annular space on a pipeline improves design calculations. Extreme load conditions, ground water forces, multiple bends and an interactive material increase complexity in design. The action of multiple forces and unpredictable behavior of interactive pipelines increases the design process and warrants the use of a higher safety factor. Designers, Consultants and Third party testing facilities can sufficiently predict behavior and performance of renewal products with a lower Design Index.

Constructability Index (*Ci*)

The Constructability Index is useful for attributing construction risk to the installation of a renewal product. Access Pits, Cleaning, Service Connections and QA/QC primarily affect project risk. Large Access pits, heavy cleaning machinery, digging up for reconnection and site manufacturing will increase the risks associated with the project. Project costs are directly proportional to the risk. Hence, a smaller Constructability Index value translates to higher degree of constructability for the installer. Construction Managers, Clients and Financiers should consider products that have a lower Constructability Index score.

Database System

The current database is limited. Some renewal products are common across the sub-steps, for example, they can be used for water and wastewater application. It is housed in a Microsoft Access named Renewal Products. SQL statements are used to process information in the database. It is a string value and requires connecting the database, opening the record set and closing the record set. The following is the code to connect the visual basic with the access. Then an SQL statement is generated by defining a mathematical operation into an SQL query format. As the mathematical operation changes, so does the query. The SQL query statement accesses the products based on user information and stores them in the record set for further processing.

The database is dynamic in nature. New products entered in the database will participate in the REST tool. The Warning messages will automatically consider changes in the range of database values.

Renewal products data was collected from vendor websites as shown in Appendix G. A further list of products was accessed from EPA's State Of Technology Reports. The data was entered into a technical sheet format to avoid assumptions and reduce probability. Each technical sheet represents different renewal products used in the water and wastewater pipeline industry. The developed framework was run with the renewal products data to understand scope, limitation and application of the REST tool framework.

Knowledge Management System

The Knowledge Management System in this tool is not developed. This feature can be accessed at the SWIM website. The website has a large set of renewal products, features and case studies. The website shall host information on condition assessment tools and techniques along with predictability and preventability matrices. A message box, shown in Figure 18, will direct you to the website.

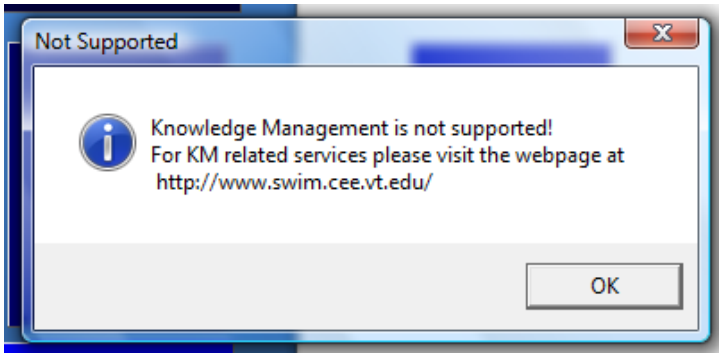


Figure 18: View of Message Box indicating website link for Knowledge Management

Chapter 6: CODING FOR REST TOOL FRAMEWORK

Step 1: Introduction to the Tool

The first step, shown in Figure 19 of REST tool framework provides introductory information. A successful running requires data pertaining to system requirements, system causes and renewal product characteristics. It highlights an important fact that it is a not a fail-safe framework. The developed code is available for understanding purposes in Appendix H.

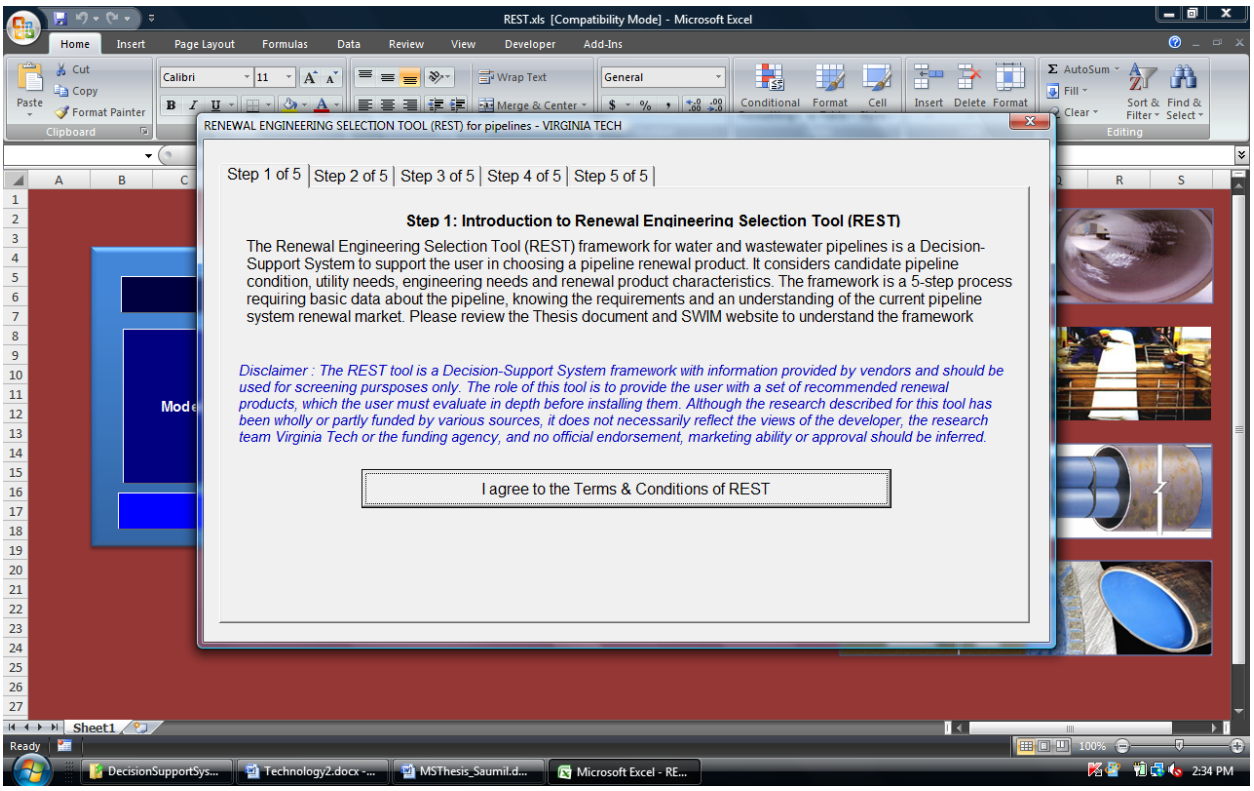


Figure 19: Step 1 with command button, description and disclaimer

The first click on command button "Yes, I have sufficient data to start REST" disables it from further use during a given process. The "AddItem" property will populate the combo boxes for the succeeding steps. A user can restart the tool by clicking on the close button at the top left corner of the user-form. The "ListIndex" property shown in Figure 20 is entered behind this button to have default values selected in the combo boxes. This will make sure that the user does

not leave the combo boxes empty. Populating is disabled using the “Enable” property, once the command button has populated the combo boxes.

```
Private Sub cmdpopulate_Click()
   With cbxmaterial
   .AddItem "Ductile Iron"
   .AddItem "Cast Iron"
   .AddItem "Asbestos Cement"
   .AddItem "Polyethylene"
   .AddItem "Poly Vinyl Chloride"
   .AddItem "Reinforced Concrete"
   .AddItem "Prestressed Concrete"
   .AddItem "Vitrified Clay"
End With

cmdpopulate.Enabled = False

cbxmaterial.ListIndex = 0
cbxdepth.ListIndex = 0
```

Figure 20: Visual basic code to populate and arrange default values for combo boxes

Step 2: Problem Definition

The user has to define the candidate pipeline problem in this step. The pipeline problem is divided into three parts and five sub-parts, as shown in Figure 21. Radio-buttons are placed in a frame object for each part and each radio button represents the sub-parts. The user can select one sub-part out of five in each frame. The steps and sub-steps are given in the following chart.

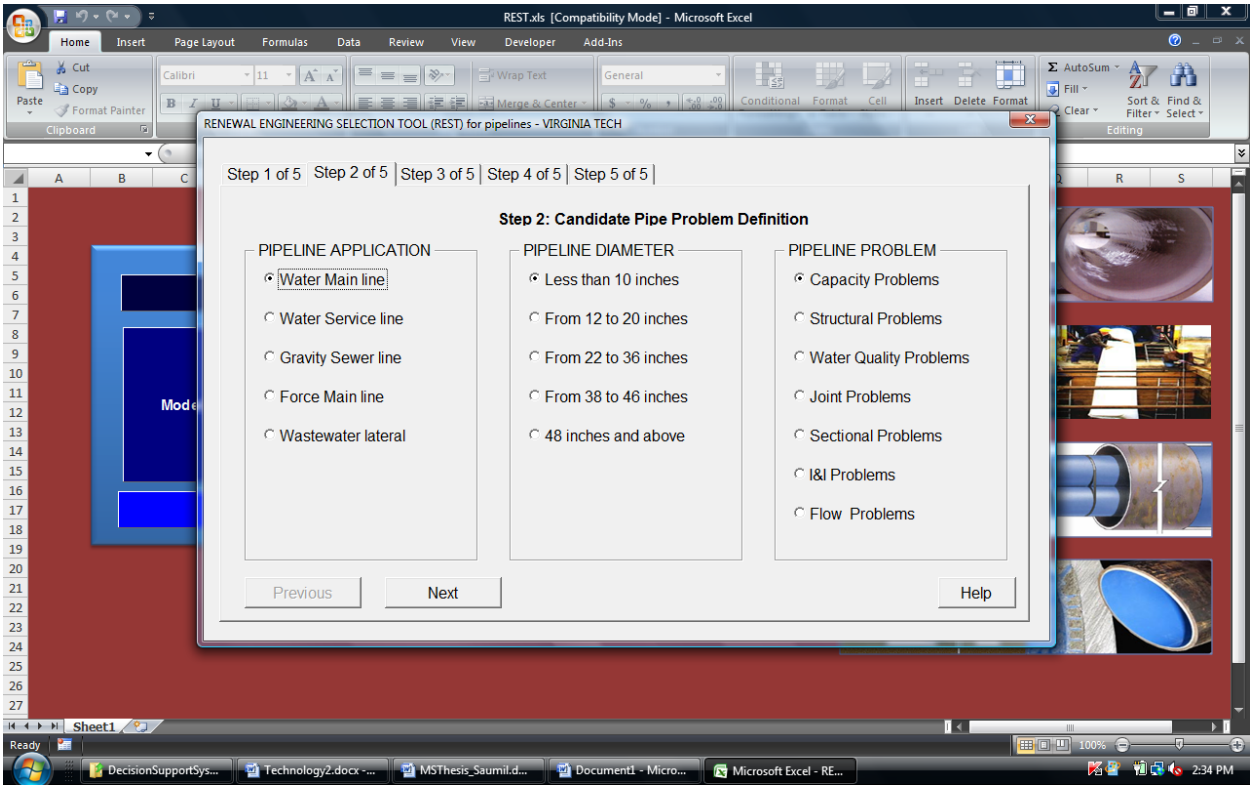


Figure 21: Step 2 with Radio buttons, Command boxes and Frame

The user selection must accurately match with product database for all three parts for the successful recommendation of the renewal product. The radio-buttons are connected to the database file via visual basic code. Any changes in the radio-button or the database will be reflected in subsequent processes. Upon selection of the radio-button, it is stored in a SQL statement. An "If…Then" statement is used in the model for identifying and assigning a value to the selection, as shown in Figure 22. The renewal products are not distributed equally across the pipeline problems. Hence, certain scenarios may have a small or null set of recommended products.

The "Previous" button on this page is disabled. The button would have otherwise taken the user to Step 1 with no further action possible. The "Next" button on this page will take the user to Step 3 via the following code. The "Multipage.Value" property is repeated in all enabled

"Next" buttons, taking the user to the succeeding page and simultaneously processing the entered values.

```
Private Sub cmdnext1_Click()

ufstart.MultiPage1.Value = 2
StrSQL1 = "Select * From RenewalProduct Where 1 = 1 "

If optwater = True Then StrSQL1 = StrSQL1 & "and water_main = 1 "
…
If optvelocity = True Then StrSQL1 = StrSQL1 & "and velocity = 1 "

End Sub
```

Figure 22: SQL Query to process user selection for radio-buttons

Step 3: System Causes

Step 3 of REST tool collects basic data and system information on the candidate pipe, as shown in Figure 23. It consists of labels, combo boxes, text boxes and command buttons. On the left side of the page are combo boxes, where a drop-down list allows the user to choose for each factor. Pipeline Material selection should accurately match the renewal product, but this is not the case with other factors like Temperature, Pressure, Age, Length and Thickness.

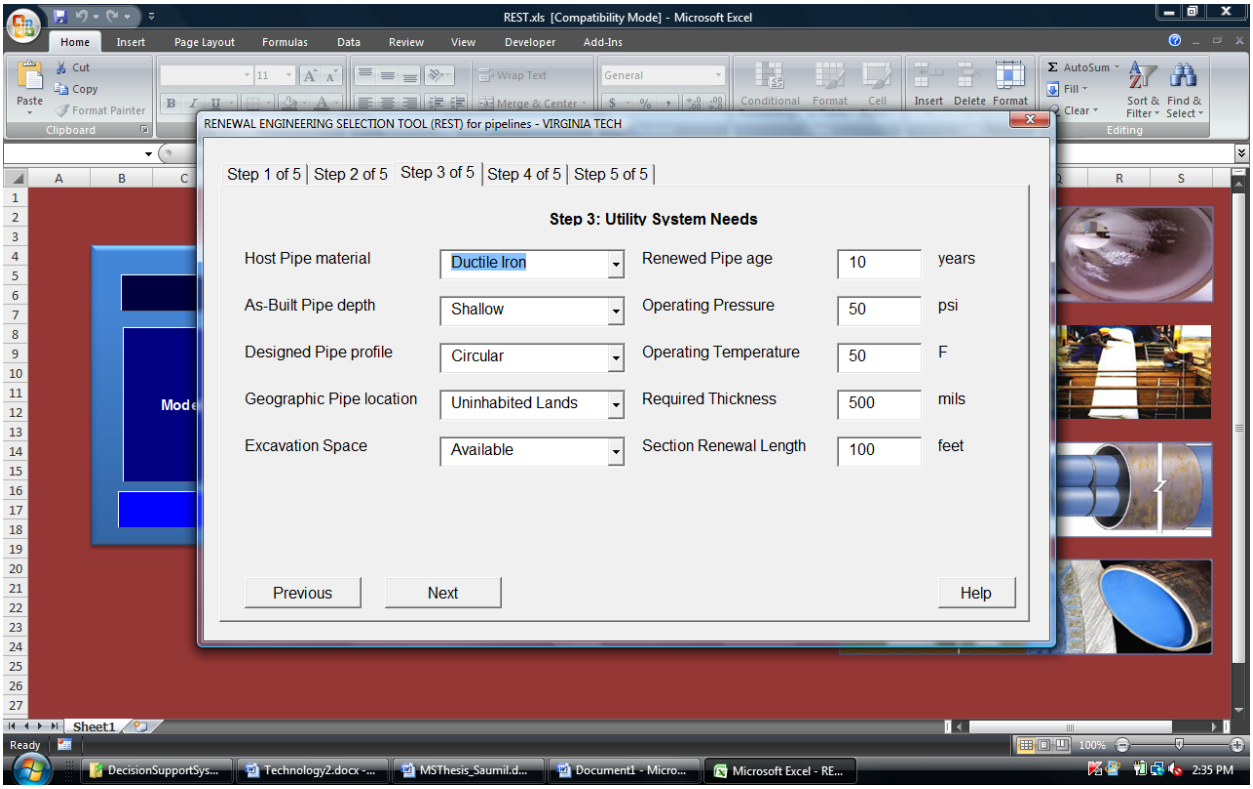


Figure 23: View of Step 3 with Combo boxes and Command boxes

Pipe depth, profile, location and excavation space need not match exactly with the renewal product. The factors are classified in to value-attributed categories. The first category in each factor has a value of zero, with +1 for each succeeding category. For example, the value of "Medium-Pipe Depth" is one and the value of "Commercially-located Pipe Location" is four. On the right side of the page are text boxes for entering numerical values. The numerical values have default values to help the user identify the data entry format. The numerical value entered in these boxes is compared with the maximum or minimum value for the renewal product. The user-required values have to be lesser than the renewal product values for it being considered. The tool will provide a product, which is thicker than user requirement. It is opposite for the other physical parameters.

The “Next” button primarily does mathematical operations. For each combo-box, the user required category is compared with the renewal product category, as shown in Figure 24. If the selected category has a higher value than the product category value, then the factor gets a positive score. A negative score is given to the factor, if the product category value is below the user-required value. A zero value is attached to the factor, if the requirements and product parameters match. The positive score for each factor is calculated and stored in the variable “p_score” and the negative score is calculated and stored in the variable “n_score”. For this step, the scores are stored in the first column of the multi-dimensional array. This mathematical operation is repeated for each product in the database by the “Do While… Loop” formula. The “cbxdepth.ListIndex + 1” has a +1 because the first category in the factor has a default value of 0, while the values in the database start at 1. It is necessary to match the category value in the database and the GUI.

```
Do While (Not rs1.EOF)

        If rs1("depth").Value > cbxdepth.ListIndex + 1 Then
    p_score(1, rs1("id").Value) = p_score(1, rs1("id").Value) + rs1("depth").Value -
(cbxdepth.ListIndex + 1)
    Else
    n_score(1, rs1("id").Value) = n_score(1, rs1("id").Value) + (1 + cbxdepth.ListIndex) -
rs1("depth").Value
    End If

...
      If rs1("location").Value > cbxlocation.ListIndex + 1 Then
    p_score(1, rs1("id").Value) = p_score(1, rs1("id").Value) + rs1("location").Value -
(cbxlocation.ListIndex + 1)
    Else
    n_score(1, rs1("id").Value) = n_score(1, rs1("id").Value) + (cbxlocation.ListIndex +
1) - rs1("location").Value
    End If

    rs1.MoveNext


  Loop
```

Figure 24: Visual Basic Code to generate score for Renewal Products exceeding and failing criteria

The “Previous” button and “Next” button on this page are different from other instances of the buttons. The “Previous” button on this page will take you to Step 2, while the “Next” button will take you to Step 4. Due to the cyclic nature of “Previous” and “Next” buttons, the model is designed to check the state of the record set. The Record set stores information processed after the user has entered data. It is an object within the ADO library. Once a “Previous” button is clicked, the model will come back to a preceding page while the Record Set is open. To avoid opening the same record set again, the code in Figure 25 checks the status of this record set.

```
If TypeName(rs1) = "Recordset" Then
    If rs1.State <> adStateClosed Then
       rs1.Close
    End If
  End If
```

Figure 25: Visual Basic Code to close record set

It has a secondary objective as well. Warning messages are coded in the button. The text boxes are checked for three different issues: Numerical entry, Empty box and Values beyond database range. If the text box is left empty, a warning message box will prompt the user to enter values for each factor. Values beyond the database range will also activate a message box prompting the user that no product addresses these requirements. A warning message, shown in Figure 26 will prompt the user to enter numerical users, if attempts are made to enter text. Towards of the end of this step, a message box prompting the list of renewal products available for given selection will also pop up.

```
If txtage = vbNullString Or _
   txtthickness = vbNullString Or _
   txttemperature = vbNullString Or _
   txtlength = vbNullString Or _
   txtpressure = vbNullString Then
MsgBox "Please enter all values to continue!"
cmdprevious3_Click
Exit Sub
End If

strConnect = "Provider=Microsoft.Jet.OLEDB.4.0; Data Source=" & ThisWorkbook.Path
& "\database.mdb"
strSQL = "Select Max(maxage) AS MaxAge From RenewalProduct"
rs.Open strSQL, strConnect, adOpenStatic
If rs("MaxAge").Value < CDec(txtage) Then
MsgBox "Current products support age below " & rs("MaxAge").Value & " years ",
vbExclamation, "Error"
rs.Close
cmdprevious3_Click
Exit Sub
Else
rs.Close
End If

Private Sub txtage_Change()
    If txtage = vbNullString Then Exit Sub
    If Not IsNumeric(txtage) Then
        MsgBox "Pipe Age must have numerical value!"
       txtage = vbNullString
    End If
End Sub
```

Figure 26: Visual Basic Code to check textboxes for entering values, values between range and for numerical values

Step 4: System Requirements

Step 4 of REST tool requires the user to provide data about construction management methods, site specifications and utility standard installation procedures. A condensed list of

factors is shown in Figure 27. These factors affect a majority of renewal-making decisions, but project specific factors exist.

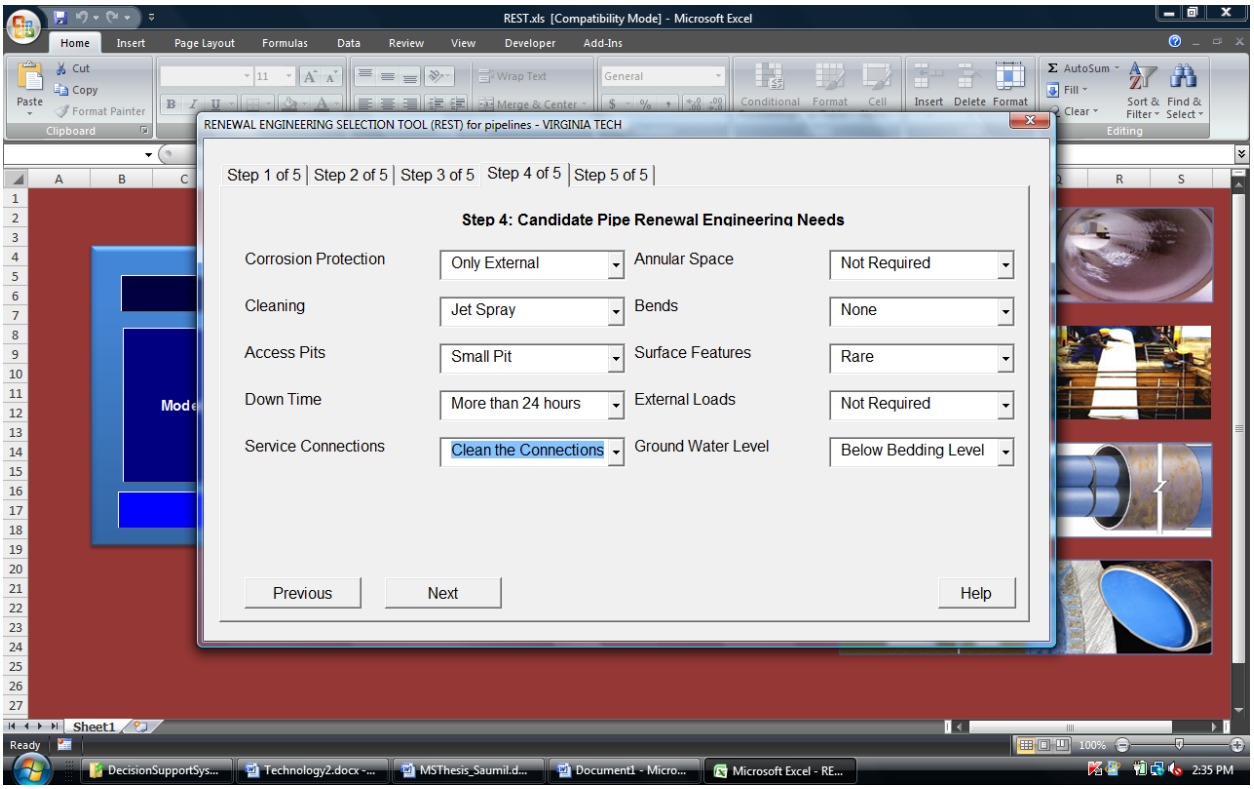


Figure 27: View of Step 4 with Combo boxes and Command boxes

A text box at the bottom of the page provides information about the factors. Similar to Step 3, there are two command boxes at the bottom of the page. The "Previous" button on this page has different functionality than earlier instances. Once a "Previous" button is clicked, the increased number of "Next" button clicks will duplicate information in the record sheet. To avoid duplication, the code in the previous button resets mathematical operators to zero and avoids duplication when the "Next" button is clicked on the previous page. The visual basic code is shown in Figure 28.

```
Private Sub cmdprevious3_Click()
   ufstart.MultiPage1.Value = 2

i = 0
Do While (i < 95)

n_score(1, i) = 0
p_score(1, i) = 0
i = i + 1

Loop

End Sub
```

Figure 28: Visual Basic Code to reset the values for renewal products exceeding or failing criteria to zero

The "Next" button on Step 4 does not have any warning codes. It follows mathematical operations for combo boxes, similar to "Next" button from the previous step. For this step, the scores are stored in the second column of the multi-dimensional array.

Step 5: Renewal Product

Step 5, as shown in Figure 29 is dedicated to renewal product characteristics and is the last step of the decision-making process. Renewal products have been in the market for not more than 30-40 years. Some techniques are still emerging, while others are undergoing field trials and third party approvals. The last step of the user form looks and functions similar to the earlier step.

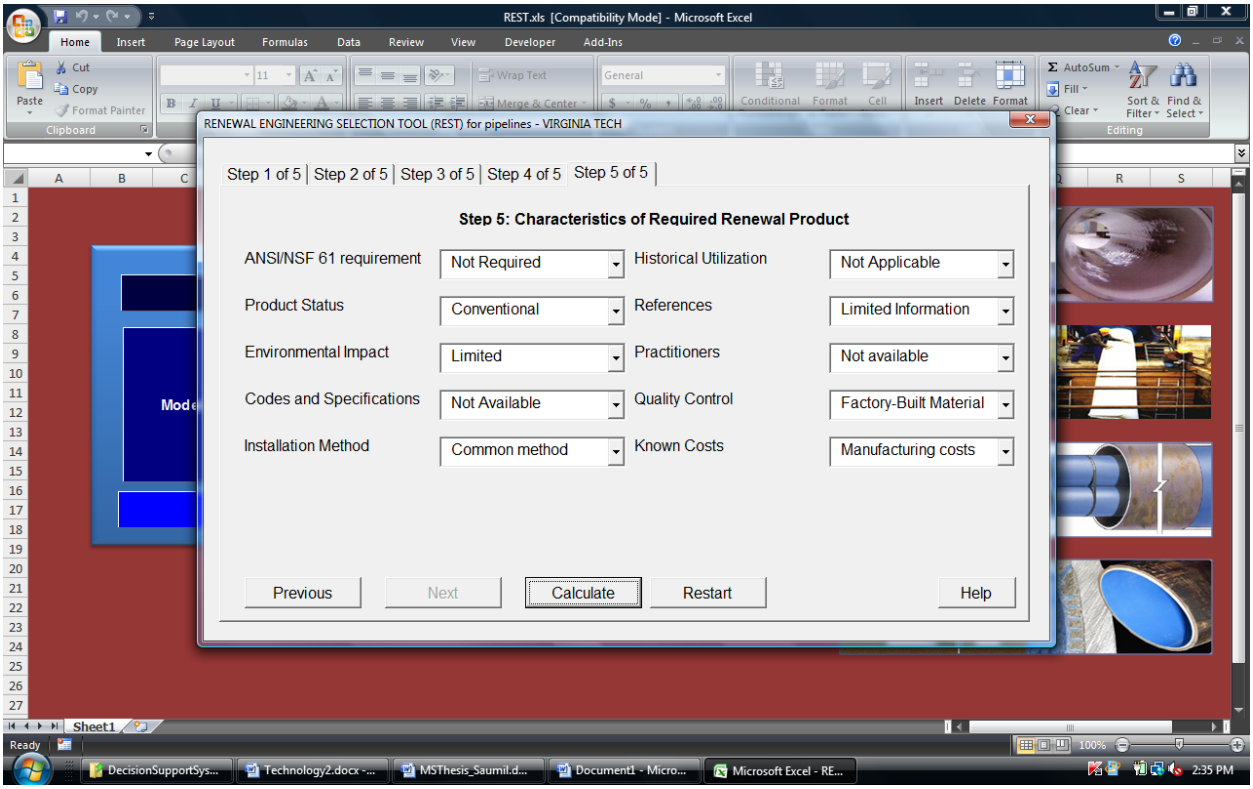


Figure 29: View of Step 5 with Combo boxes and Command boxes

The "Previous" button functions same as the button from Step 4. It uses the "Calculate"button to perform mathematical operations, while the "Next" button is disabled. It follows mathematical operations for combo boxes, similar to "Next" button from the previous step. For this step, the scores are stored in the third column of the multi-dimensional array, as shown in Figure 30. The "Calculate" button also performs function to print the results.

```
    If rs1("nsf61").Value > 1 + cbxnsf61.ListIndex Then
    p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("nsf61").Value - (1 +
cbxnsf61.ListIndex)
    Else
    n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxnsf61.ListIndex) -
rs1("nsf61").Value
    End If
```

Figure 30: Visual Basic Code to calculate and save scores in third row for last step

Output Sheet

Statically, the column headings are entered in the excel sheet. The recommended products follow the Column Headings. Their values are obtained by performing a "Do While… Loop" on the record set, as shown in Figure 31. In the previous set of operations, the recommended products and the row of information from the database file were saved in the record set. Numerical and String values are obtained from the record set. The recommended product list is truncated to seven top ranked products. The value for Exceeding and Failing criteria are added, the criteria score for each step is totaled and the index values are added in this stage.

```
    reccount = rs1.RecordCount
    Sheets.Add After:=Sheets(Sheets.Count)
    Range("A1").Value = "Exceeding Criteria"
    Range("B1").Value = "Failing Criteria"
...
    Range("M1").Value = "Constructability Index"
    Range("N1").Value = "Design Index"

irow = 1
      Do While (Not rs1.EOF And irow <> 8)

      irow = irow + 1

      Range("A" & irow).Value = p_score(1, rs1("id").Value) + p_score(2,
rs1("id").Value) + p_score(3, rs1("id").Value)
      Range("B" & irow).Value = n_score(1, rs1("id").Value) + n_score(2,
rs1("id").Value) + n_score(3, rs1("id").Value)

      Range("C" & irow).Value = rs1("ID").Value
...
      Range("H" & irow).Value = rs1("costs").Value

      Range("I" & irow).Value = p_score(1, rs1("id").Value) - n_score(1, rs1("id").Value)
...
      Range("N" & irow).Value = rs1("loads").Value + rs1("water").Value +
rs1("bends").Value + rs1("space").Value
```

Figure 31: Visual Basic Code to print results and corresponding values on output sheet

Once the values are entered in the cells, they are color coded for cognitive understanding as shown in Figure 32. Three colors, namely red (code: 255), yellow (code: 65535) and green (code: 5296274) are used to explain the distribution of values. Red indicates the product is far from matching the criteria. Such products do not match criteria on more than five counts on either side of the mean value. Scores between two and five or between negative two and negative five are neither too far from the requirements nor near them. Cell ranges are coded yellow. Green color is shaded in cells that range between negative two and two, effectively being away from user requirements on two or less criteria.

```
If Range("I" & irow).Value < -5 Then
Range("I" & irow).Interior.Color = 255
End If

If Range("I" & irow).Value >= -5 And Range("I" & irow).Value < -2 Then
Range("I" & irow).Interior.Color = 65535
End If

If Range("I" & irow).Value >= -2 And Range("I" & irow).Value <= 2 Then
Range("I" & irow).Interior.Color = 5296274
End If

If Range("I" & irow).Value > 2 And Range("I" & irow).Value <= 5 Then
Range("I" & irow).Interior.Color = 65535
End If

If Range("I" & irow).Value > 5 Then
Range("I" & irow).Interior.Color = 255
End If
```

Figure 32: Visual Basic Code to color code cells in the output sheet

Once the calculated values are entered into the output sheet, visual basic ranks them by code shown in Figure 33. The seven recommended products are ranked first by exceeding criteria in “Column A” and then by failing criteria in “Column B”. The product that is closest to the user’s requirements on the exceeding side is ranked first. The rest of the values for the product are sorted according to product ranking.

```
ActiveWorkbook.Worksheets(sheet_name).Sort.SortFields.Add Key:=Range("A1"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
ActiveWorkbook.Worksheets(sheet_name).Sort.SortFields.Add Key:=Range("B1"), _
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
With ActiveWorkbook.Worksheets(sheet_name).Sort
    .SetRange Range("A2:N" & irow)
    .Header = xlNo
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply
```

Figure 33: Visual Basic Code to sort values for recommended renewal products

Renewal Product Confidence

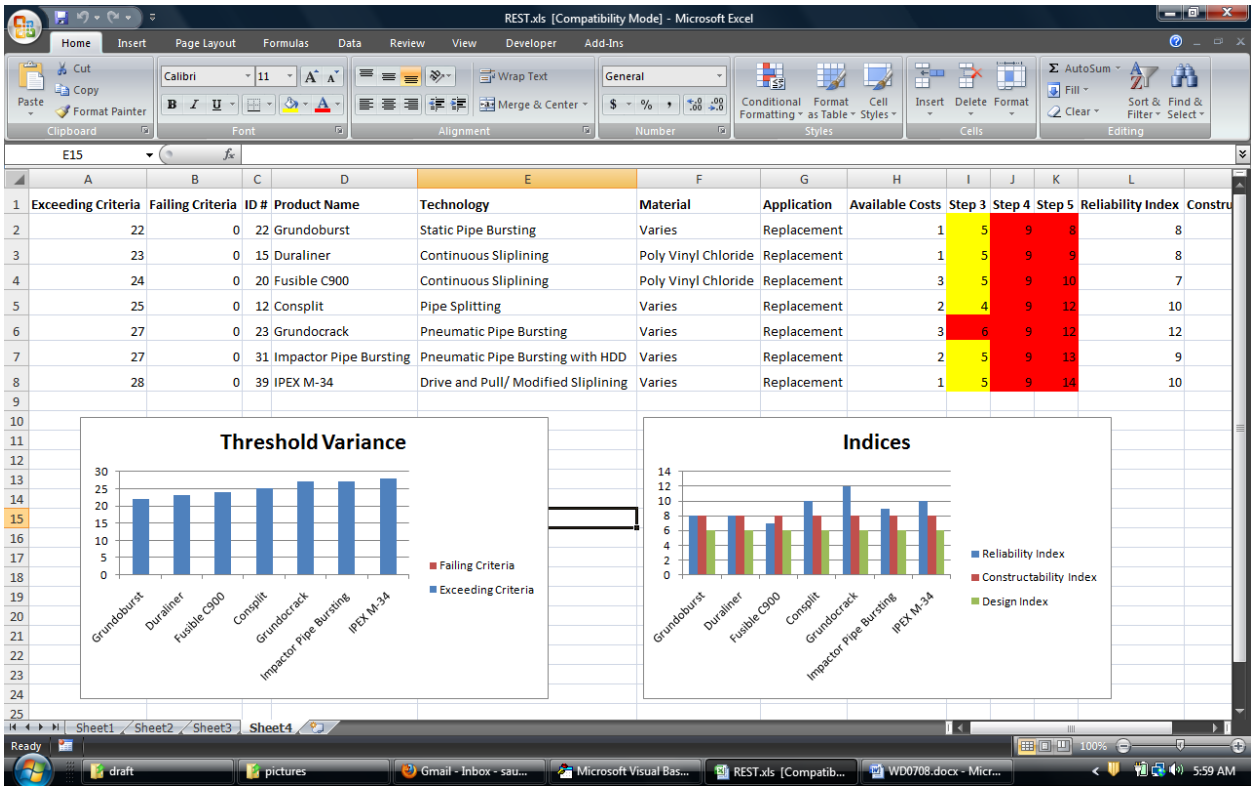
The values are used to generate two different kinds of charts. The first chart is a Column Clustered chart for Reliability Index, Constructability Index and Design Index. Chart legend and the three bars are graphically represented for each product. The visual basic codes in Figure 34 automatically pick up values and legend names for the chart.

```
    Set chartobj = ActiveSheet.Shapes.AddChart(Left:=Range("A10:E10").Width + 5,
Top:=Range("A1:A9").Height + 5)
    chartobj.Chart.SetSourceData Source:=Range("'" & sheet_name & "'!$L$2:$N$8")
    chartobj.Chart.ChartType = xlColumnClustered
    chartobj.Chart.SeriesCollection(1).XValues = ("'" & sheet_name & "'!$D$2:$D$8")
    chartobj.Chart.SetElement (msoElementChartTitleAboveChart)
    chartobj.Chart.ChartTitle.Text = "Indices"
    ActiveSheet.ChartObjects("Chart 1").Activate
    ActiveChart.SeriesCollection(1).Name = "='" & sheet_name & "'!$L$1"
    ActiveChart.SeriesCollection(2).Name = "='" & sheet_name & "'!$M$1"
    ActiveChart.SeriesCollection(3).Name = "='" & sheet_name & "'!$N$1"

    Set chartobj = ActiveSheet.Shapes.AddChart(Left:=40, Top:=Range("A1:A9").Height
+ 5)
    chartobj.Chart.SetSourceData Source:=Range("'" & sheet_name & "'!$A$2:$B$8")
    chartobj.Chart.ChartType = xlColumnStacked
    chartobj.Chart.SeriesCollection(1).XValues = ("'" & sheet_name & "'!$D$2:$D$8")
    chartobj.Chart.SetElement (msoElementChartTitleAboveChart)
    chartobj.Chart.ChartTitle.Text = "Threshold Variance"
    ActiveSheet.ChartObjects("Chart 2").Activate
    ActiveChart.SeriesCollection(1).Name = "='" & sheet_name & "'!$A$1"
    ActiveChart.SeriesCollection(2).Name = "='" & sheet_name & "'!$B$1"
```

Figure 34: Visual Basic Code to develop charts for values and indices

The Reliability Index is a blue-colored bar, Constructability Index is red and the Design Index is green. Similarly, Exceeding Criteria and Failing Criteria for each product is represented in a Column Stacked chart. Exceeding Criteria is marked blue and Failing Criteria is marked red for each product. A single bar denotes each product. The chart title, axis and series are formatted automatically by the Visual basic codes. A typical output sheet is shown in Figure 35 on the next page.



Exceeding Criteria	Failing Criteria	ID #	Product Name	Technology	Material	Application	Available Costs	Step 3	Step 4	Step 5	Reliability Index	Constru
22	0	22	Grundoburst	Static Pipe Bursting	Varies	Replacement	1	5	9	8	8	
23	0	15	Duraliner	Continuous Sliplining	Poly Vinyl Chloride	Replacement	1	5	9	9	8	
24	0	20	Fusible C900	Continuous Sliplining	Poly Vinyl Chloride	Replacement	3	5	9	10	7	
25	0	12	Consplit	Pipe Splitting	Varies	Replacement	2	4	9	12	10	
27	0	23	Grundocrack	Pneumatic Pipe Bursting	Varies	Replacement	3	6	9	12	12	
27	0	31	Impactor Pipe Bursting	Pneumatic Pipe Bursting with HDD	Varies	Replacement	2	5	9	13	9	
28	0	39	IPEX M-34	Drive and Pull/ Modified Sliplining	Varies	Replacement	1	5	9	14	10	

Figure 35: View of Output worksheet with graphs, values and color-coding

Chapter 7: TRIAL RESULTS

Trial 1

In this trial, we study the renewal of a ductile iron water main line having diameter less than 10 inches and capacity related problems. Numerical values for temperature, age, pressure, thickness and renewal length consider a young and short pipe. The water main line was studied for the lowest limit of category selection wherever possible. The trial was studied to understand the recommendation set of renewal products, if the user did not make changes to the default selections. Appendix D provides the selected categories for each factor and the output sheet.

Replacement products using bursting, sliplining and splitting technology form the top of the list. The result of the REST tool was top seven products having the least "Exceeding Criteria" among the set of products. None of the seven products fail given criteria. From the results in Step 3, Step 4 and Step 5, it is clear that none of these products are close to the requirements. As the database of products increases, the loophole will be closed. The Reliability Index for one of the products is far higher than others meaning various secondary sources of information are available. The Constructability and Design Indices do not help among the products.

Trial 2

In this trial, a reinforced concrete water service line having diameter between 12 and 20 inches and structural problems was chosen for renewal. Numerical values for temperature, age, pressure, thickness and renewal length were assumed for extreme conditions. The water main line was analyzed for the highest limit of category selection wherever possible. The trial was designed to understand the recommendation set of renewal products, if the user chose a very conservative approach to renewal product selection. Appendix E provides the selected categories for each factor and the output sheet.

A polymer resin based lining is the only rehabilitation product recommended for this trial. The products fails given criteria on 31 counts and does not exceed requirements for any category. From the results in Step 4 and Step 5, it is clear that the products is far from requirements. As the database of products increases, the loophole will be closed. The Reliability, Constructability and Design Indices do not clearly recommend the use of given product.

Trial 3

In this trial, a prestressed concrete gravity sewer line having diameter more than 48 inches and flow quality related problems was chosen for renewal. The pipe is hypothetically placed in a town needing moderate engineering control and use of an innovative renewal product. Operating characteristics of a town's wastewater system were mirrored for this trial. Appendix provides the selected categories for each factor and the output sheet. System requirements, causes and renewal product characteristics were designed to recommend a set of products that match or slightly exceed needs. The recommended product set would match utility needs, consumer concerns and expenditure. Appendix F provides the selected categories for each factor and the output sheet.

CIPP products close fit liner, pipe wrapping and pipe bursting products formed the set of renewal products. The result of the REST tool was five products that exceed and fail renewal criteria. Step 5: Renewal Product Characteristics for the recommended renewal products shows that most of the products are far from meeting user requirements. It is important to note that the calculation of values for these cells is an addition of exceeding and failing factors. Thus a product indicating red-coded values suggests that it should not be considered. The Index values for each product are within close proximity of each other, and a decision cannot be supported by those values. Masterliner CIPP and Grundocrack Pipe Bursting are two products that should be researched by the user for given case.

Chapter 8: CONCLUSION

Benefits of REST tool framework

The REST tool framework provides its users with products in a real-time situation. Depending on selection of factors, the tool will provide with products that closely match user requirements. It provides the results based on construction management related factors, thereby reducing the level of risk in installing the products. It recommends a set of seven products that support the user's requirements. The user can investigate and request information from vendors before making the final choice. In the ensuing process, the user will not have to depend on previous cases and make the final decision after processing results. It eliminates the need for studying renewal products from multiple literature sources.

The tool recommends renewal products and not renewal technologies. It catalogues each product as a separate entity with specific values for each renewal decision-making factor. The addition of new renewal product and renewal factors becomes easier due to the cataloging process. Changes in the product set can be done without affecting other products or factors. Renewal products are identified by renewal technologies as well in the database file. A flexible database file allows the user to import and remove renewal products. A trained developer can also change factors and categories for each factor without many restrictions.

Microsoft Excel forms an excellent backbone for the tool. Like other stand-alone tools, the user does not have to install the programs. Excel is a standard program that does not require any extra training. The help manual, presentation files, access database and excel file are created in basic Microsoft products for user friendliness. Microsoft Office 2003 serves the purpose for each of the files. Each step in the tool is clearly laid out for the user to understand the process. The whole process can be understood by clicking on the model management tab before starting the Decision Support tool. The explanation for renewal factors and classification is explained for user's understanding.

Limitations of REST tool framework

A single technology does not govern the design of Renewal Products. Pipeline condition, cleaning and method of installation affects the performance and cost of using a recommended renewal product. Renewal products have repeatedly used certain technologies, but these products differ on grounds like diameter application, engineering code adherence and mode of installation. Warranties and level of expertise are two key factors that play an important role in the operation of renewed pipelines.

The current framework is built with real and validated database. Vendors have provided information about their products. The information provided by vendors cannot be 100% accurate and complete. The developer has assumed some information, while the vendor could inflate some information for marketability. Independent verification of the information must be done before choosing a renewal product. Field trials, testing reports and consultant reviews are available from the vendor upon request.

The tool has lower and upper functional limits. Renewal product factors are classified into various categories for recommending the set of products. As new products are entered in the database, the categories may change. The lower and upper limits will also change and may require modifications to the entire set of products. Due to the limits, it also means the user cannot obtain a product that is significantly away from either of the limits. A selection of the lowest limit for each factor will recommend a set of renewal products and a null case will never exist.

Future Work

The framework is an evolving decision support system. As new products come in the market, the database and model can be updated. Laboratory testing and long-term performance reports shall also reason changes in existing values for renewal products. With increasing factors, the database can be moved to stronger and faster database systems like Oracle. Further pages can be added to the model to improve the decision-making process. Such pages can discuss

construction management services, project delivery methods and project cost breakdown structures. Knowledge Management System is missing in the current decision support system. Once the number of cycles in the DSS increases, a relevant Knowledge Management System can be developed. The data from repeated use will help the developer generate thumb-rule assumptions and understand relationship metrics between particular user requirements and renewal product performance. Cost and Performance information from numerous sources can make the framework robust in the end.

The current mathematical model is based on linear distribution and ranking. Optimization and Artificial Intelligence methods can be applied as the database expands. Product optimization will provide the user with renewal products based on multiple mathematical requirements, while AI will add constants to the equation in known scenarios. The mathematical operators can improve technical understanding of renewal projects.

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APPENDIX

Appendix A: Basic Technical Information Sheet

I. Technology Background	
Technology/Method	
Status	
Date of Introduction	
Utilization Rates	
Vendor Name(s)	
Practitioner(s)	
Description of Features	
Main Benefits Claimed	
Main Limitations Cited	
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Oil, Gas and Industrial pipelines
II. Technology Parameters	
Service Application	
Service Connections	
Structural Rating Claimed	
Materials of Composition	
Diameter Range, inches	
Thickness Range, inches	
Pressure Capacity, psi	
Temperature Range, ^{o}F	
Renewal Length, feet	
Other Notes	
III. Technology Design, Installation, and QA/QC Information	
Product Standards	
Design Standards	
Design Life Range	
Installation Standards	
Installation Methodology	
QA/QC	
IV. Operation and Maintenance Requirements	
O&M Needs	
Repair Requirements for Rehabilitated Sections	
V. Costs	
Key Cost Factors	
Case Study Costs	
VI. Data Sources	
References	

Appendix B: Definitions for Water and Wastewater Infrastructure classification by known international organization

PUBLICATIONS	DESCRIPTION
EPA	1. Repair: A repair technique is used when the existing pipe is structurally sound, provides acceptable flow capacity, and can serve as the support or host of the repair method. 2. Rehabilitation: Rehabilitation systems can provide improved hydraulic conditions and structural integrity better than the original pipe. 3. Replacement: When the existing pipe is severely deteriorated, collapsed, or increased flow capacity is needed, it is usually replaced.
WRc	1. Repair: Rectification of damage to the structural fabric of the sewer and the reconstruction of short lengths, but not the reconstruction of the whole pipeline. 2. Renovation: methods by which the performance of a length of sewer is improved by incorporating the original sewer fabric, but excluding maintenance operations such as root or silt removal 3. Replacement: Construction of a new sewer on or offline of an existing sewer. The function of the new sewer will incorporate that of the old, but may also include improvement or development work.
CEN	1. Rehabilitation: All measures for restoring or upgrading the performance of an existing pipeline system. 2. Renovation: Work incorporating all or part of the original fabric of the pipeline by means of which its current performance is improved. 3. Repair: Rectification of local damage. 4. Replacement: Rehabilitation of an existing pipeline system by installation of a new pipeline system, without incorporating the original fabric.
AWWA	1. Class 1: Primarily protect inner surface of the pipe from corrosion, with minimal ability to bridge discontinuities such as holes or gaps. 2. Class 2: Long term internal burst strength (tested independently of host pipe) is less than maximum allowable operating pressure (MAOP) of the host pipe; designed to bridge specified size holes and gaps; depend entirely on adhesion to

	the host pipe wall to prevent collapse if the pipe is depressurized. 3. Class 3: Long term internal burst strength (tested independently of host pipe) is less than the MAOP of the host pipe; designed to bridge specified size holes and gaps; sufficient inherent ring stiffness to be self-supporting in event of depressurization of the pipe ; may also be designed to withstand specified external hydrostatic or vacuum forces. 4. Class 4: Long term internal burst strength (tested independently of host pipe) is greater than the MAOP of the host pipe to be renovated; the liner if close-fitting must also be capable of surviving possible future failure of the host pipe.
European standard EN 13566-1	1. Repair: rectification of local damage. 2. Renovation: work incorporating all or part of the original fabric of the pipeline by means of which its current performance is improved. 3. Replacement: rehabilitation of existing pipeline by the installation of a new pipeline without incorporating the original fabric.

Appendix C: Developed Matrix for REST tool

ID	product	material	technology
1	A+Wrap	Glass-Fiber Composite	Composite Wrapping
2	Acuro System	Polymer	Polymer Resin Lining
3	AM-Liner II	Poly Vinyl Chloride	Close-fit On-site Thermo-formed Fold-and Form
4	Aqualiner	Glass Reinforced Polymer	Close-fit Thermo-formed CIP
5	Aquapipe	Woven Hose	Woven hose liner with Epoxy coating
6	Avanti Ultrafine	Cement	Cementitous Grouting
7	Belzona	Epoxy	Spray-On Epoxy Lining
8	Berolina Liner	Fiber-Polyester composite	Fiber-composite CIPP with UV curing
9	Blue-Tek	Fiber-Polyester composite	Fiber-composite CIPP with UV curing
10	CarbonWrap	Glass-Fiber Composite	Composite Wrapping
11	Channeline SL	Glass-Fiber Composite	Segmental Composite Panel Lining
12	Consplit	Varies	Pipe Splitting
13	Curaflo Spincast	Epoxy	Spray-On Epoxy Lining
14	Danby Panel Lok	PVC	Segmental Rigid Lining
15	Duraliner	Poly Vinyl Chloride	Continuous Sliplining
16	EX Pipe	Poly Vinyl Chloride	Close-fit On-site Thermo-formed Fold-and Form
17	Fast Line Plus	Epoxy	Spray-On Epoxy Lining
18	FibrWrap	Glass-Fiber Composite	Composite Wrapping
19	Frey C Wrap	Glass-Fiber Composite	Composite Wrapping
20	Fusible C900	Poly Vinyl Chloride	Continuous Sliplining
21	Grouting Sleeve	Stainless Steel	Sleeve Repair
22	Grundoburst	Varies	Static Pipe Bursting
23	Grundocrack	Varies	Pneumatic Pipe Bursting
24	Grundomat	Varies	Pipe Extraction and Replacement
25	Grundotugger	Varies	Lateral Pipe Bursting
26	Heitkamp Epoxy	Epoxy	Spray-On Epoxy Lining
27	Herrenknecht Crush-Liner	Varies	Pipe Eating
28	Hobas CCFRPM	Fiber-Composite	CCFRPM sliplining
29	Hobas FRP Panel	Glass-Fiber Composite	Segmental Lining
30	Hydro-Seal	Stainless Steel	Sleeve Repair

ID	product	material	technology
31	Impactor Pipe Bursting	Varies	Pneumatic Pipe Bursting with HDD
32	Inliner CIPP	Polyester	Polyester CIPP and Pull-In-Place
33	Inner Seal Lo-Mod	PolyUrea	Spray-On PolyUrea Lining
34	Insituform PPL	Fiber-Polyester composite	Fiber-composite CIPP
35	Insituform RPP	Fiber-Polyester composite	Fiber-composite CIPP
36	InsituGuard Flexed	Polyethylene	Close-fit On-site Symmetrical Compression
37	InsituGuard Folded	Polyethylene	Close-fit On-site Fold and Form
38	Insitumain	Fiber-Polyester composite	Fiber-composite CIPP and Pull-In-Place
39	IPEX M-34	Varies	Drive and Pull/ Modified Sliplining
40	Jabar	Varies	Pneumatic Pipe Bursting
41	Janssen Process	Silica Gel	Sealing Collar
42	KA-TE Robotic System	Epoxy	Sealing Collar
43	Linabond Simulform Panel	PVC	Segmental Rigid Lining
44	Linkpipe Insta-Liner	Stainless Steel	Segmental Stainless Steel Lining
45	LMK CIPP Liner	Polyester	Sectional Polyester CIPP
46	LMK T-Liner	Polyester	Lateral Polyester CIPP
47	Logiball Push Packer	Chemical	Lateral Chemical Grouting
48	Logiball Test & Seal	Chemical	Lateral Chemical Grouting
49	MainSaver	Polymer	Close-fit Grout-In-Place liner
50	Masterliner CIPP	Polyester	Polyester CIPP
51	MCS Inliner	Glass-Fiber Composite	Reaming and GRP lining
52	National Liner	Polyester	Polyester CIPP and Pull-In-Place
53	Neopoxy NPR 2000	Epoxy	Epoxy Repair
54	Nordipipe	Woven Hose	Woven Hose liner with Epoxy coating
55	Nowak InneReam	Varies	Pipe Reaming
56	NPC Internal Joint Seal	Rubber and SS	Rubber Seal Joint Repair
57	NuFlow	Polymer	Domestic Line Repair
58	Paraliner PW	Fiber-Polyester composite	Fiber-composite CIPP
59	Perma Lateral Lining System	Polyester	Lateral Polyester CIPP
60	PermaLiner InnerSeal	Polyester	Lateral Polyester CIPP
61	Perma-Liner Point Repair System	Fiber-Polyester composite	Sectional Fiber-composite CIPP
62	PerpetuWall	Glass-Fiber Composite	Woven Hose Liner with Fiber
63	Phoenix	Polyester	Polyester CIPP
64	PolySpray	PolyUrea	Spray-On PolyUrea Lining

ID	product	material	technology
65	Powercrete PW	Epoxy	Spray-On Epoxy Lining
66	Primus Line	Woven Hose	Woven Hose liner with PE
67	Raven 405	Epoxy	Spray-On Epoxy Lining
68	Roll Down	Polyethylene	Close-fit On-site Symmetrical Compression
69	Saertex Liner	Fiber-Polyester composite	Fiber-composite CIPP with UV/Steam curing
70	Sanipor	Chemical	Chemical Flood Grouting
71	Scotchkote 169HB	Polyurethane	Spray-On Polyurethane Lining
72	Scotchkote 269	Polyurethane	Spray-On Polyurethane Lining
73	Seaboard EM 12	Asphalt	Spray-On Asphalt Emulsion Lining
74	Sekisui Rib Loc Spiral EX/ ROTALOC	PVC	Spiral Winding
75	Sekisui Rib Loc SPR PE/ SPR ST	Steel Composite	Spiral Winding
76	Sekisui SPR Spiral Wound GIP	GIP	Spiral Winding
77	Shotcrete Cementitious Lining	Cement Concrete	Spray-On Concrete Lining
78	SprayShield Green #2	Polyurethane	Spray-On Polyurethane Lining
79	SprayWall	Polyurethane	Spray-On Polyurethane Lining
80	Starline HPL - W	Woven Hose	Woven Hose liner with Epoxy coating
81	SubCoil	Polyethylene	Close-fit Factory folded Fold and Form
82	Subline	Polyethylene	Close-fit On-site Fold and Form
83	Sure Grip Liner	Polymer	Close-fit Grout-In-Place liner
84	Swagelining	Polyethylene	Close-fit On-site Symmetrical Tension
85	Thermopipe	Reinforced Polymer	Close-fit Factory folded Fold and Form
86	Tite Liner	Polyethylene	Close-fit On-site Symmetrical Tension
87	Top Hat	FRP Composite	Lateral CIPP Joint Repair
88	TRIC Sewer Lateral Pipe Liner	Varies	Lateral Pipe Bursting
89	TroLining GIP	Polymer	Close-fit Grout-In-Place liner
90	U-Liner	Polyethylene	Close-fit Factory folded Fold and Form
91	Ultraliner Pipeliner	Poly Vinyl Chloride	Close-fit Factory Thermo-formed Fold-and Form
92	Viscotaq Coat Wrap	Neoprene Composite	External surface Repair
93	Warren Environmental S301-14	Epoxy	Spray-On Epoxy Lining
94	Waterline Epoxy	Epoxy	Spray-On High-build Epoxy Lining

ID	product	Applicability	water_main	service_line	gravity_sewer	force_main	lateral
1	A+Wrap	Rehabilitation	No	No	No	Yes	No
2	Acuro System	Rehabilitation	Yes	Yes	No	No	No
3	AM-Liner II	Rehabilitation	No	No	Yes	Yes	No
4	Aqualiner	Rehabilitation	Yes	No	No	Yes	No
5	Aquapipe	Rehabilitation	Yes	No	No	Yes	No
6	Avanti Ultrafine	Repair	No	No	Yes	No	Yes
7	Belzona	Rehabilitation	Yes	Yes	Yes	Yes	Yes
8	Berolina Liner	Rehabilitation	No	No	Yes	Yes	No
9	Blue-Tek	Rehabilitation	No	No	Yes	Yes	No
10	CarbonWrap	Rehabilitaiton	Yes	No	Yes	No	No
11	Channeline SL	Rehabilitation	No	No	Yes	No	No
12	Consplit	Replacement	Yes	No	Yes	Yes	Yes
13	Curaflo Spincast	Rehabilitation	Yes	No	Yes	No	No
14	Danby Panel Lok	Rehabilitation	Yes	No	Yes	No	No
15	Duraliner	Replacement	Yes	Yes	No	Yes	Yes
16	EX Pipe	Rehabilitation	No	No	Yes	Yes	No
17	Fast Line Plus	Rehabilitation	Yes	No	No	No	No
18	FibrWrap	Rehabilitation	Yes	No	Yes	No	No
19	Frey C Wrap	Rehabilitation	Yes	No	Yes	No	No
20	Fusible C900	Replacement	Yes	No	No	Yes	No
21	Grouting Sleeve	Repair	No	No	Yes	No	No
22	Grundoburst	Replacement	Yes	No	Yes	Yes	No
23	Grundocrack	Replacement	Yes	No	Yes	Yes	No
24	Grundomat	Replacement	No	Yes	Yes	No	Yes
25	Grundotugger	Replacement	No	No	No	No	Yes
26	Heitkamp Epoxy	Rehabilitation	Yes	No	Yes	No	No
27	Herrenknecht Crush-Liner	Replacement	No	No	Yes	Yes	No
28	Hobas CCFRPM	Replacement	No	No	Yes	No	No
29	Hobas FRP Panel	Rehabilitation	No	No	Yes	No	No
30	Hydro-Seal	Repair	Yes	No	No	No	No

ID	product	Applicability	water_main	service_line	gravity_sewer	force_main	lateral
31	Impactor Pipe Bursting	Replacement	Yes	No	Yes	Yes	No
32	Inliner CIPP	Rehabilitation	No	No	Yes	Yes	Yes
33	Inner Seal Lo-Mod	Rehabilitation	No	No	Yes	No	No
34	Insituform PPL	Rehabilitation	Yes	No	No	Yes	No
35	Insituform RPP	Rehabilitation	No	No	No	Yes	No
36	InsituGuard Flexed	Rehabilitation	Yes	No	No	Yes	No
37	InsituGuard Folded	Rehabilitation	Yes	No	No	Yes	No
38	Insitumain	Rehabilitation	Yes	No	No	Yes	No
39	IPEX M-34	Replacement	Yes	No	Yes	No	Yes
40	Jabar	Replacement	Yes	No	Yes	No	No
41	Janssen Process	Repair	No	No	No	No	Yes
42	KA-TE Robotic System	Repair	No	No	No	No	Yes
43	Linabond Simulform Panel	Rehabilitation	Yes	No	Yes	No	No
44	Linkpipe Insta-Liner	Rehabilitation	No	Yes	Yes	No	No
45	LMK CIPP Liner	Rehabilitation	No	No	Yes	No	No
46	LMK T-Liner	Rehabilitation	No	No	No	No	Yes
47	Logiball Push Packer	Repair	No	No	No	No	Yes
48	Logiball Test & Seal	Repair	No	No	No	No	Yes
49	MainSaver	Rehabilitation	Yes	No	No	Yes	No
50	Masterliner CIPP	Rehabilitation	No	No	Yes	No	Yes
51	MCS Inliner	Replacement	No	No	Yes	No	No
52	National Liner	Rehabilitation	No	No	Yes	Yes	Yes
53	Neopoxy NPR 2000	Repair	Yes	No	No	No	No
54	Nordipipe	Rehabilitation	Yes	No	Yes	Yes	No
55	Nowak InneReam	Replacement	No	No	Yes	No	No
56	NPC Internal Joint Seal	Repair	Yes	No	Yes	Yes	Yes
57	NuFlow	Repair	Yes	No	Yes	No	Yes
58	Paraliner PW	Rehabilitation	Yes	No	Yes	Yes	Yes
59	Perma Lateral Lining System	Rehabilitation	No	No	No	No	Yes
60	PermaLiner InnerSeal	Rehabilitation	No	Yes	Yes	Yes	Yes
61	Perma-Liner Point Repair System	Rehabilitation	Yes	No	Yes	Yes	No
62	PerpetuWall	Rehabilitation	No	Yes	No	No	No
63	Phoenix	Rehabilitation	Yes	No	Yes	No	No
64	PolySpray	Rehabilitation	No	No	Yes	No	Yes

ID	product	Applicability	water_main	service_line	gravity_sewer	force_main	lateral
65	Powercrete PW	Rehabilitation	Yes	No	Yes	No	No
66	Primus Line	Rehabilitation	Yes	No	No	No	Yes
67	Raven 405	Rehabilitation	No	No	Yes	Yes	No
68	Roll Down	Rehabilitation	Yes	No	No	No	Yes
69	Saertex Liner	Rehabilitation	No	No	Yes	Yes	No
70	Sanipor	Repair	No	No	Yes	No	Yes
71	Scotchkote 169HB	Rehabilitation	Yes	No	Yes	No	Yes
72	Scotchkote 269	Rehabilitation	Yes	No	Yes	No	Yes
73	Seaboard EM 12	Rehabilitation	Yes	No	No	No	No
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Rehabilitation	No	No	Yes	No	No
75	Sekisui Rib Loc SPR PE/ SPR ST	Rehabilitation	No	No	Yes	No	No
76	Sekisui SPR Spiral Wound GIP	Rehabilitation	Yes	Yes	Yes	Yes	No
77	Shotcrete Cementitious Lining	Rehabilitation	No	No	Yes	No	No
78	SprayShield Green #2	Rehabilitation	No	No	Yes	No	No
79	SprayWall	Rehabilitation	Yes	No	Yes	Yes	No
80	Starline HPL - W	Rehabilitation	Yes	No	No	Yes	No
81	SubCoil	Rehabilitation	Yes	No	No	No	No
82	Subline	Rehabilitation	Yes	No	No	No	No
83	Sure Grip Liner	Rehabilitation	Yes	No	Yes	Yes	No
84	Swagelining	Rehabilitation	Yes	No	No	Yes	No
85	Thermopipe	Rehabilitation	Yes	No	No	Yes	No
86	Tite Liner	Rehabilitation	Yes	No	No	Yes	No
87	Top Hat	Repair	No	No	No	No	Yes
88	TRIC Sewer Lateral Pipe Liner	Replacement	Yes	No	Yes	No	Yes
89	TroLining GIP	Rehabilitation	Yes	No	Yes	Yes	No
90	U-Liner	Rehabilitation	Yes	No	Yes	Yes	No
91	Ultraliner Pipeliner	Rehabilitation	No	No	Yes	Yes	No
92	Viscotaq Coat Wrap	Repair	Yes	Yes	Yes	Yes	Yes
93	Warren Environmental S301-14	Rehabilitation	No	No	Yes	No	No
94	Waterline Epoxy	Rehabilitation	Yes	No	No	Yes	No

ID	product	below 10	below 20	below 36	below 46	above 48	capacity	joint	structure	velocity	section
1	A+Wrap	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
2	Acuro System	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
3	AM-Liner II	Yes	Yes	No	No	No	No	No	Yes	Yes	No
4	Aqualiner	Yes	Yes	No	No	No	No	No	Yes	Yes	No
5	Aquapipe	Yes	Yes	No	No	No	No	No	Yes	Yes	No
6	Avanti Ultrafine	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
7	Belzona	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
8	Berolina Liner	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
9	Blue-Tek	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
10	CarbonWrap	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
11	Channeline SL	No	No	No	No	Yes	No	No	Yes	Yes	Yes
12	Consplit	Yes	No	No	No	No	Yes	No	No	Yes	No
13	Curaflo Spincast	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes
14	Danby Panel Lok	No	No	No	No	Yes	No	No	Yes	Yes	Yes
15	Duraliner	Yes	Yes	No	No	No	Yes	No	No	Yes	No
16	EX Pipe	Yes	Yes	No	No	No	No	No	Yes	Yes	No
17	Fast Line Plus	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
18	FibrWrap	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
19	Frey C Wrap	No	No	No	No	Yes	No	No	Yes	Yes	Yes
20	Fusible C900	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No
21	Grouting Sleeve	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes
22	Grundoburst	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No
23	Grundocrack	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No
24	Grundomat	Yes	No	No	No	No	Yes	No	No	Yes	No
25	Grundotugger	Yes	No	No	No	No	Yes	No	No	Yes	No
26	Heitkamp Epoxy	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
27	Herrenknecht Crush-Liner	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No
28	Hobas CCFRPM	Yes	No	No	No	No	Yes	No	No	Yes	No
29	Hobas FRP Panel	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
30	Hydro-Seal	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes

ID	product	below10	below20	below36	below46	above48	capacity	joint	structure	velocity	section
31	Impactor Pipe Bursting	Yes	Yes	No	No	No	Yes	No	No	Yes	No
32	Inliner CIPP	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
33	Inner Seal Lo-Mod	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
34	Insituform PPL	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
35	Insituform RPP	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
36	InsituGuard Flexed	Yes	No	No	No	No	No	No	Yes	Yes	No
37	InsituGuard Folded	No	Yes	Yes	Yes	No	No	No	Yes	Yes	No
38	Insitumain	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
39	IPEX M-34	Yes	Yes	No	No	No	Yes	No	No	Yes	No
40	Jabar	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No
41	Janssen Process	Yes	Yes	No	No	No	No	Yes	No	No	Yes
42	KA-TE Robotic System	Yes	Yes	No	No	No	No	Yes	No	No	Yes
43	Linabond Simulform Panel	No	No	No	No	Yes	No	No	Yes	Yes	Yes
44	Linkpipe Insta-Liner	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
45	LMK CIPP Liner	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
46	LMK T-Liner	Yes	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes
47	Logiball Push Packer	Yes	No	No	No	No	No	No	Yes	Yes	Yes
48	Logiball Test & Seal	Yes	No	No	No	No	No	No	Yes	Yes	Yes
49	MainSaver	Yes	Yes	No	No	No	No	No	Yes	Yes	No
50	Masterliner CIPP	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
51	MCS Inliner	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No
52	National Liner	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
53	Neopoxy NPR 2000	Yes	Yes	No	No	No	No	Yes	No	No	Yes
54	Nordipipe	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
55	Nowak InneReam	Yes	Yes	Yes	No	No	Yes	No	No	Yes	No
56	NPC Internal Joint Seal	No	No	No	No	Yes	No	Yes	No	No	Yes
57	NuFlow	Yes	No	No	No	No	No	Yes	No	No	Yes
58	Paraliner PW	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
59	Perma Lateral Lining System	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
60	PermaLiner InnerSeal	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes
61	Perma-Liner Point Repair System	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
62	PerpetuWall	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
63	Phoenix	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
64	PolySpray	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes

ID	product	below10	below20	below36	below46	above48	capacity	joint	structure	velocity	section
65	Powercrete PW	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
66	Primus Line	Yes	Yes	No	No	No	No	No	Yes	Yes	No
67	Raven 405	Yes	Yes	Yes	No	No	No	No	Yes	Yes	Yes
68	Roll Down	Yes	Yes	No	No	No	No	No	Yes	Yes	No
69	Saertex Liner	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
70	Sanipor	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
71	Scotchkote 169HB	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
72	Scotchkote 269	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes
73	Seaboard EM 12	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes
75	Sekisui Rib Loc SPR PE/ SPR ST	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
76	Sekisui SPR Spiral Wound GIP	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
77	Shotcrete Cementitious Lining	No	No	No	No	Yes	No	No	Yes	Yes	Yes
78	SprayShield Green #2	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
79	SprayWall	No	No	No	Yes	Yes	No	No	Yes	Yes	Yes
80	Starline HPL - W	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
81	SubCoil	Yes	Yes	No	No	No	No	No	Yes	Yes	No
82	Subline	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
83	Sure Grip Liner	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No
84	Swagelining	Yes	Yes	Yes	Yes	No	No	No	Yes	Yes	No
85	Thermopipe	Yes	Yes	No	No	No	No	No	Yes	Yes	No
86	Tite Liner	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
87	Top Hat	Yes	No	No	No	No	No	Yes	No	No	Yes
88	TRIC Sewer Lateral Pipe Liner	Yes	Yes	No	No	No	Yes	No	No	Yes	No
89	TroLining GIP	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No
90	U-Liner	Yes	Yes	No	No	No	No	No	Yes	Yes	No
91	Ultraliner Pipeliner	Yes	Yes	Yes	No	No	No	No	Yes	Yes	No
92	Viscotaq Coat Wrap	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes
93	Warren Environmental S301-14	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes
94	Waterline Epoxy	Yes	Yes	No	No	No	No	No	Yes	Yes	Yes

ID	product	ductile	cast	AC	HDPE	PVC	RCP	PCCP	clay	depth
1	A+Wrap	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
2	Acuro System	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
3	AM-Liner II	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Medium
4	Aqualiner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
5	Aquapipe	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
6	Avanti Ultrafine	No	No	No	No	No	Yes	Yes	Yes	Deep
7	Belzona	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
8	Berolina Liner	No	No	No	No	No	Yes	No	Yes	Medium
9	Blue-Tek	No	No	No	No	No	Yes	No	Yes	Medium
10	CarbonWrap	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
11	Channeline SL	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Shallow
12	Consplit	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
13	Curaflo Spincast	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
14	Danby Panel Lok	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Shallow
15	Duraliner	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Medium
16	EX Pipe	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Medium
17	Fast Line Plus	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
18	FibrWrap	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
19	Frey C Wrap	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
20	Fusible C900	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Medium
21	Grouting Sleeve	No	No	No	Yes	No	Yes	Yes	No	Shallow
22	Grundoburst	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
23	Grundocrack	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
24	Grundomat	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
25	Grundotugger	No	No	Yes	Yes	Yes	No	No	No	Medium
26	Heitkamp Epoxy	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
27	Herrenknecht Crush-Liner	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Medium
28	Hobas CCFRPM	No	No	Yes	Yes	No	Yes	Yes	Yes	Medium
29	Hobas FRP Panel	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Shallow
30	Hydro-Seal	Yes	Yes	No	Yes	No	No	Yes	No	Shallow

ID	product	ductile	cast	AC	HDPE	PVC	RCP	PCCP	clay	depth
31	Impactor Pipe Bursting	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
32	Inliner CIPP	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
33	Inner Seal Lo-Mod	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
34	Insituform PPL	Yes	Yes	No	Yes	Yes	No	Yes	No	Deep
35	Insituform RPP	Yes	Yes	No	Yes	Yes	No	Yes	No	Deep
36	InsituGuard Flexed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
37	InsituGuard Folded	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
38	Insitumain	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
39	IPEX M-34	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Medium
40	Jabar	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
41	Janssen Process	No	No	No	Yes	No	No	Yes	No	Medium
42	KA-TE Robotic System	No	No	No	Yes	No	No	Yes	No	Medium
43	Linabond Simulform Panel	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Shallow
44	Linkpipe Insta-Liner	No	No	No	Yes	Yes	Yes	No	Yes	Shallow
45	LMK CIPP Liner	No	No	No	Yes	Yes	Yes	Yes	Yes	Medium
46	LMK T-Liner	No	No	No	No	Yes	Yes	No	Yes	Medium
47	Logiball Push Packer	No	No	No	No	No	Yes	Yes	Yes	Medium
48	Logiball Test & Seal	No	No	No	No	No	Yes	Yes	Yes	Medium
49	MainSaver	No	No	Yes	No	No	Yes	Yes	Yes	Medium
50	Masterliner CIPP	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Medium
51	MCS Inliner	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Medium
52	National Liner	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
53	Neopoxy NPR 2000	Yes	Yes	No	Yes	No	No	No	Yes	Shallow
54	Nordipipe	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
55	Nowak InneReam	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Medium
56	NPC Internal Joint Seal	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Shallow
57	NuFlow	Yes	Yes	No	No	No	Yes	No	No	Medium
58	Paraliner PW	Yes	Yes	No	Yes	Yes	No	Yes	No	Deep
59	Perma Lateral Lining System	No	No	No	No	Yes	Yes	No	Yes	Medium
60	PermaLiner InnerSeal	No	No	No	No	Yes	Yes	No	Yes	Medium
61	Perma-Liner Point Repair System	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Medium
62	PerpetuWall	Yes	Yes	No	Yes	Yes	No	Yes	No	Deep
63	Phoenix	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
64	PolySpray	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep

ID	product	ductile	cast	AC	HDPE	PVC	RCP	PCCP	clay	depth
65	Powercrete PW	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
66	Primus Line	Yes	Yes	No	Yes	Yes	No	Yes	No	Deep
67	Raven 405	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
68	Roll Down	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
69	Saertex Liner	No	No	No	No	No	Yes	No	Yes	Deep
70	Sanipor	No	No	No	No	No	Yes	Yes	Yes	Medium
71	Scotchkote 169HB	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
72	Scotchkote 269	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
73	Seaboard EM 12	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Yes	Yes	No	No	No	Yes	No	Yes	Medium
75	Sekisui Rib Loc SPR PE/ SPR ST	Yes	Yes	No	No	No	Yes	No	Yes	Medium
76	Sekisui SPR Spiral Wound GIP	Yes	Yes	No	No	No	Yes	No	Yes	Medium
77	Shotcrete Cementitious Lining	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
78	SprayShield Green #2	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
79	SprayWall	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep
80	Starline HPL - W	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Deep
81	SubCoil	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
82	Subline	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
83	Sure Grip Liner	No	No	Yes	No	No	Yes	Yes	Yes	Medium
84	Swagelining	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
85	Thermopipe	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
86	Tite Liner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Medium
87	Top Hat	No	No	No	No	No	No	No	No	Medium
88	TRIC Sewer Lateral Pipe Liner	No	No	Yes	Yes	Yes	No	No	No	Medium
89	TroLining GIP	No	No	Yes	No	No	Yes	Yes	Yes	Medium
90	U-Liner	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Deep
91	Ultraliner Pipeliner	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Medium
92	Viscotaq Coat Wrap	Yes	Yes	No	Yes	No	Yes	Yes	Yes	Shallow
93	Warren Environmental S301-14	Yes	Yes	No	No	No	Yes	Yes	Yes	Medium
94	Waterline Epoxy	Yes	Yes	No	No	No	Yes	Yes	Yes	Deep

ID	product	profile	location	excavation
1	A+Wrap	Non-circular	Dense Residences	Limited
2	Acuro System	Circular	Dense Residences	Limited
3	AM-Liner II	Circular	Dense Residences	Available
4	Aqualiner	Circular	Townside	Available
5	Aquapipe	Circular	Dense Residences	Limited
6	Avanti Ultrafine	Non-circular	Dense Residences	Limited
7	Belzona	Circular	Dense Residences	Limited
8	Berolina Liner	Circular	Dense Residences	Limited
9	Blue-Tek	Circular	Dense Residences	Limited
10	CarbonWrap	Non-circular	Dense Residences	Limited
11	Channeline SL	Circular	Townside	Limited
12	Consplit	Circular	Townside	Limited
13	Curaflo Spincast	Circular	Dense Residences	Limited
14	Danby Panel Lok	Circular	Townside	Limited
15	Duraliner	Circular	Dense Residences	Limited
16	EX Pipe	Circular	Dense Residences	Available
17	Fast Line Plus	Non-circular	Townside	Limited
18	FibrWrap	Non-circular	Dense Residences	Limited
19	Frey C Wrap	Non-circular	Dense Residences	Limited
20	Fusible C900	Circular	Dense Residences	Limited
21	Grouting Sleeve	Circular	Uninhabitated Lands	Available
22	Grundoburst	Non-circular	Townside	Limited
23	Grundocrack	Non-circular	Townside	Limited
24	Grundomat	Non-circular	Uninhabitated Lands	Limited
25	Grundotugger	Non-circular	Townside	Limited
26	Heitkamp Epoxy	Non-circular	Townside	Limited
27	Herrenknecht Crush-Liner	Non-circular	Townside	Limited
28	Hobas CCFRPM	Circular	Dense Residences	Limited
29	Hobas FRP Panel	Circular	Townside	Limited
30	Hydro-Seal	Circular	Uninhabitated Lands	Available

ID	product	profile	location	excavation
31	Impactor Pipe Bursting	Circular	Townside	Limited
32	Inliner CIPP	Circular	Townside	Limited
33	Inner Seal Lo-Mod	Non-circular	Townside	Limited
34	Insituform PPL	Circular	Dense Residences	Limited
35	Insituform RPP	Circular	Dense Residences	Limited
36	InsituGuard Flexed	Circular	Dense Residences	Available
37	InsituGuard Folded	Circular	Dense Residences	Available
38	Insitumain	Circular	Dense Residences	Limited
39	IPEX M-34	Circular	Dense Residences	Limited
40	Jabar	Circular	Townside	Limited
41	Janssen Process	Circular	Townside	Available
42	KA-TE Robotic System	Circular	Townside	Available
43	Linabond Simulform Panel	Circular	Townside	Limited
44	Linkpipe Insta-Liner	Circular	Townside	Limited
45	LMK CIPP Liner	Circular	Townside	Limited
46	LMK T-Liner	Circular	Townside	Limited
47	Logiball Push Packer	Circular	Townside	Limited
48	Logiball Test & Seal	Circular	Townside	Limited
49	MainSaver	Non-circular	Townside	Available
50	Masterliner CIPP	Circular	Townside	Limited
51	MCS Inliner	Circular	Uninhabitated Lands	Limited
52	National Liner	Circular	Townside	Limited
53	Neopoxy NPR 2000	Non-circular	Dense Residences	Available
54	Nordipipe	Circular	Dense Residences	Limited
55	Nowak InneReam	Non-circular	Uninhabitated Lands	Limited
56	NPC Internal Joint Seal	Circular	Townside	Available
57	NuFlow	Circular	Dense Residences	Available
58	Paraliner PW	Circular	Dense Residences	Limited
59	Perma Lateral Lining System	Circular	Townside	Limited
60	PermaLiner InnerSeal	Circular	Townside	Limited
61	Perma-Liner Point Repair System	Circular	Townside	Limited
62	PerpetuWall	Circular	Dense Residences	Limited
63	Phoenix	Circular	Townside	Limited
64	PolySpray	Non-circular	Townside	Limited

ID	product	profile	location	excavation
65	Powercrete PW	Non-circular	Townside	Limited
66	Primus Line	Circular	Dense Residences	Limited
67	Raven 405	Non-circular	Townside	Limited
68	Roll Down	Circular	Dense Residences	Available
69	Saertex Liner	Circular	Dense Residences	Limited
70	Sanipor	Circular	Townside	Limited
71	Scotchkote 169HB	Non-circular	Townside	Limited
72	Scotchkote 269	Non-circular	Townside	Limited
73	Seaboard EM 12	Non-circular	Townside	Limited
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Non-circular	Townside	Limited
75	Sekisui Rib Loc SPR PE/ SPR ST	Non-circular	Townside	Limited
76	Sekisui SPR Spiral Wound GIP	Non-circular	Townside	Limited
77	Shotcrete Cementitious Lining	Non-circular	Townside	Limited
78	SprayShield Green #2	Non-circular	Townside	Limited
79	SprayWall	Circular	Dense Residences	Limited
80	Starline HPL - W	Circular	Dense Residences	Limited
81	SubCoil	Circular	Commercial Areas	Available
82	Subline	Circular	Dense Residences	Available
83	Sure Grip Liner	Non-circular	Townside	Available
84	Swagelining	Circular	Dense Residences	Available
85	Thermopipe	Circular	Commercial Areas	Available
86	Tite Liner	Circular	Dense Residences	Available
87	Top Hat	Circular	Townside	Available
88	TRIC Sewer Lateral Pipe Liner	Circular	Townside	Limited
89	TroLining GIP	Non-circular	Townside	Available
90	U-Liner	Circular	Commercial Areas	Available
91	Ultraliner Pipeliner	Circular	Commercial Areas	Available
92	Viscotaq Coat Wrap	Non-circular	Townside	Available
93	Warren Environmental S301-14	Non-circular	Townside	Limited
94	Waterline Epoxy	Non-circular	Townside	Limited

ID	product	minthick	maxtemp	maxpressure	maxrenew	maxage	corrosion
1	A+Wrap	20	74	900	500	30	Internal
2	Acuro System	120	74	150	650	25	Limited Internal
3	AM-Liner II	185	74	150	1000	50	Internal
4	Aqualiner	120	104	145	500	50	Internal
5	Aquapipe	120	100	150	500	50	Internal
6	Avanti Ultrafine	50	74	75	250	15	Limited Internal
7	Belzona	10	74	75	500	25	Internal
8	Berolina Liner	80	122	45	1200	30	Internal
9	Blue-Tek	140	74	75	1000	30	Internal
10	CarbonWrap	125	74	75	2000	30	Internal
11	Channeline SL	1000	150	10	1500	30	Internal
12	Consplit	400	74	75	400	75	External & Internal
13	Curaflo Spincast	200	74	150	500	25	Internal
14	Danby Panel Lok	1000	74	150	500	30	Internal
15	Duraliner	200	74	150	500	75	External & Internal
16	EX Pipe	200	140	150	600	50	Internal
17	Fast Line Plus	100	74	75	500	25	Internal
18	FibrWrap	1000	220	350	1200	30	Internal
19	Frey C Wrap	27	74	290	500	30	Internal
20	Fusible C900	200	140	305	3500	75	External & Internal
21	Grouting Sleeve	400	74	150	36	10	Internal
22	Grundoburst	200	74	150	750	75	External & Internal
23	Grundocrack	200	74	150	2000	75	External & Internal
24	Grundomat	400	74	150	150	75	External & Internal
25	Grundotugger	100	74	150	150	75	External & Internal
26	Heitkamp Epoxy	40	95	75	500	25	Limited Internal
27	Herrenknecht Crush-Liner	400	74	150	750	75	External & Internal
28	Hobas CCFRPM	380	120	200	10000	75	External & Internal
29	Hobas FRP Panel	1000	74	150	5000	30	Internal
30	Hydro-Seal	375	74	560	36	10	Limited Internal

ID	product	minthick	maxtemp	maxpressure	maxrenew	maxage	corrosion
31	Impactor Pipe Bursting	200	74	150	750	75	External & Internal
32	Inliner CIPP	120	140	60	2400	30	Internal
33	Inner Seal Lo-Mod	1000	74	150	3000	25	Limited Internal
34	Insituform PPL	300	120	200	1000	30	Internal
35	Insituform RPP	200	120	80	1000	30	Internal
36	InsituGuard Flexed	150	140	150	2000	50	Internal
37	InsituGuard Folded	400	140	150	2000	50	Internal
38	Insitumain	100	120	150	500	30	Internal
39	IPEX M-34	196	140	150	500	75	External & Internal
40	Jabar	200	74	150	750	75	External & Internal
41	Janssen Process	100	100	75	24	10	Limited Internal
42	KA-TE Robotic System	100	74	75	4	10	Limited Internal
43	Linabond Simulform Panel	800	74	150	500	30	Internal
44	Linkpipe Insta-Liner	500	74	150	500	30	Limited Internal
45	LMK CIPP Liner	1000	90	75	50	30	Limited Internal
46	LMK T-Liner	3000	200	75	200	30	Internal
47	Logiball Push Packer	50	74	75	75	15	Limited Internal
48	Logiball Test & Seal	50	74	75	30	15	Limited Internal
49	MainSaver	120	74	300	500	50	Internal
50	Masterliner CIPP	100	74	150	3000	30	Internal
51	MCS Inliner	400	74	75	500	75	External & Internal
52	National Liner	4500	200	50	2000	30	Internal
53	Neopoxy NPR 2000	50	74	75	500	10	Limited Internal
54	Nordipipe	180	160	250	600	50	Internal
55	Nowak InneReam	400	74	150	1500	75	External & Internal
56	NPC Internal Joint Seal	150	74	30	500	10	Internal
57	NuFlow	50	74	75	1000	10	Limited Internal
58	Paraliner PW	180	220	230	1000	30	Internal
59	Perma Lateral Lining System	3000	150	75	150	30	Internal
60	PermaLiner InnerSeal	3000	150	75	75	30	Internal
61	Perma-Liner Point Repair System	3000	150	75	30	30	Internal
62	PerpetuWall	125	74	150	3000	50	Internal
63	Phoenix	100	74	75	1640	30	Internal
64	PolySpray	500	74	75	500	25	Limited Internal

ID	product	mint hick	maxte mp	maxpr essure	maxre new	maxa ge	corrosion
65	Powercrete PW	100	131	75	500	25	Limited Internal
66	Primus Line	240	140	500	6000	50	Internal
67	Raven 405	250	200	75	1000	25	Internal
68	Roll Down	150	74	150	5000	50	Internal
69	Saertex Liner	118	74	150	1640	30	Internal
70	Sanipor	50	90	75	250	15	Limited Internal
71	Scotchkote 169HB	200	74	145	575	25	Internal
72	Scotchkote 269	140	74	75	500	25	Limited Internal
73	Seaboard EM 12	30	74	75	500	25	Internal
74	Sekisui Rib Loc Spiral EX/ ROTALOC	1450	74	150	430	30	Internal
75	Sekisui Rib Loc SPR PE/ SPR ST	1500	74	150	440	30	Internal
76	Sekisui SPR Spiral Wound GIP	1500	74	150	1000	30	Internal
77	Shotcrete Cementitious Lining	400	74	75	500	25	Internal
78	SprayShield Green #2	1000	140	75	720	25	Limited Internal
79	SprayWall	500	140	75	500	25	Internal
80	Starline HPL - W	1500	74	450	500	50	Internal
81	SubCoil	400	74	150	3280	50	Internal
82	Subline	400	74	150	3280	50	Internal
83	Sure Grip Liner	82	74	150	3000	50	Internal
84	Swagelining	400	74	150	3000	50	Internal
85	Thermopipe	80	140	170	1600	50	Internal
86	Tite Liner	400	74	150	2600	50	Internal
87	Top Hat	120	74	75	18	10	Internal
88	TRIC Sewer Lateral Pipe Liner	100	140	160	1400	75	External & Internal
89	TroLining GIP	78	120	120	600	50	Internal
90	U-Liner	400	74	145	600	50	Internal
91	Ultraliner Pipeliner	650	120	80	1000	50	Internal
92	Viscotaq Coat Wrap	50	185	75	100	10	Only External
93	Warren Environmental S301-14	1000	74	75	500	25	Internal
94	Waterline Epoxy	40	74	75	500	25	Limited Internal

ID	product	cleaning	accesspits	downtime	connections
1	A+Wrap	Pigging	Small Pit	More than 24 hours	Limited re-connection
2	Acuro System	Pigging	Small Pit	3 to 24 hours	Not recommended
3	AM-Liner II	Flushing	Medium Pit	3 to 24 hours	Limited re-connection
4	Aqualiner	Pigging	Large Pit	3 to 24 hours	Clean the connection
5	Aquapipe	Flushing	Small Pit	3 to 24 hours	Limited re-connection
6	Avanti Ultrafine	Flushing	Small Pit	3 to 24 hours	Clean the connection
7	Belzona	Pigging	Small Pit	3 to 24 hours	Not recommended
8	Berolina Liner	Flushing	Small Pit	3 to 24 hours	Limited re-connection
9	Blue-Tek	Flushing	Small Pit	3 to 24 hours	Limited re-connection
10	CarbonWrap	Pigging	Small Pit	More than 24 hours	Limited re-connection
11	Channeline SL	Pigging	Small Pit	More than 24 hours	Clean the connection
12	Consplit	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
13	Curaflo Spincast	Pigging	Small Pit	3 to 24 hours	Not recommended
14	Danby Panel Lok	Pigging	Small Pit	More than 24 hours	Clean the connection
15	Duraliner	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
16	EX Pipe	Flushing	Medium Pit	3 to 24 hours	Limited re-connection
17	Fast Line Plus	Pigging	Small Pit	3 to 24 hours	Not recommended
18	FibrWrap	Pigging	Small Pit	More than 24 hours	Limited re-connection
19	Frey C Wrap	Pigging	Small Pit	More than 24 hours	Limited re-connection
20	Fusible C900	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
21	Grouting Sleeve	Jet Spray	Large Pit	Less than 3 hours	Clean the connection
22	Grundoburst	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
23	Grundocrack	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
24	Grundomat	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
25	Grundotugger	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
26	Heitkamp Epoxy	Pigging	Small Pit	3 to 24 hours	Not recommended
27	Herrenknecht Crush-Liner	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
28	Hobas CCFRPM	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
29	Hobas FRP Panel	Pigging	Small Pit	More than 24 hours	Clean the connection
30	Hydro-Seal	Jet Spray	Large Pit	Less than 3 hours	Clean the connection

ID	product	cleaning	accesspits	downtime	connections
31	Impactor Pipe Bursting	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
32	Inliner CIPP	Flushing	Small Pit	3 to 24 hours	Limited re-connection
33	Inner Seal Lo-Mod	Pigging	Small Pit	3 to 24 hours	Not recommended
34	Insituform PPL	Flushing	Small Pit	3 to 24 hours	Limited re-connection
35	Insituform RPP	Flushing	Small Pit	3 to 24 hours	Limited re-connection
36	InsituGuard Flexed	Flushing	Large Pit	3 to 24 hours	Clean the connection
37	InsituGuard Folded	Flushing	Medium Pit	3 to 24 hours	Clean the connection
38	Insitumain	Flushing	Small Pit	3 to 24 hours	Limited re-connection
39	IPEX M-34	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
40	Jabar	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
41	Janssen Process	Jet Spray	Large Pit	3 to 24 hours	Clean the connection
42	KA-TE Robotic System	Jet Spray	Large Pit	3 to 24 hours	Clean the connection
43	Linabond Simulform Panel	Pigging	Small Pit	More than 24 hours	Clean the connection
44	Linkpipe Insta-Liner	Pigging	Small Pit	More than 24 hours	Clean the connection
45	LMK CIPP Liner	Flushing	Small Pit	3 to 24 hours	Clean the connection
46	LMK T-Liner	Flushing	Small Pit	3 to 24 hours	Not recommended
47	Logiball Push Packer	Flushing	Small Pit	3 to 24 hours	Clean the connection
48	Logiball Test & Seal	Flushing	Small Pit	3 to 24 hours	Clean the connection
49	MainSaver	Pigging	Large Pit	3 to 24 hours	Limited re-connection
50	Masterliner CIPP	Flushing	Small Pit	3 to 24 hours	Limited re-connection
51	MCS Inliner	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
52	National Liner	Flushing	Small Pit	3 to 24 hours	Limited re-connection
53	Neopoxy NPR 2000	Flushing	Medium Pit	3 to 24 hours	Clean the connection
54	Nordipipe	Flushing	Small Pit	3 to 24 hours	Limited re-connection
55	Nowak InneReam	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
56	NPC Internal Joint Seal	Jet Spray	Large Pit	Less than 3 hours	Clean the connection
57	NuFlow	Flushing	Medium Pit	3 to 24 hours	Clean the connection
58	Paraliner PW	Flushing	Small Pit	3 to 24 hours	Limited re-connection
59	Perma Lateral Lining System	Flushing	Small Pit	3 to 24 hours	Not recommended
60	PermaLiner InnerSeal	Flushing	Small Pit	3 to 24 hours	Not recommended
61	Perma-Liner Point Repair System	Flushing	Small Pit	3 to 24 hours	Clean the connection
62	PerpetuWall	Flushing	Small Pit	3 to 24 hours	Limited re-connection
63	Phoenix	Flushing	Small Pit	3 to 24 hours	Limited re-connection
64	PolySpray	Pigging	Small Pit	3 to 24 hours	Not recommended

ID	product	cleaning	accesspits	downtime	connections
65	Powercrete PW	Pigging	Small Pit	3 to 24 hours	Not recommended
66	Primus Line	Flushing	Small Pit	3 to 24 hours	Limited re-connection
67	Raven 405	Pigging	Small Pit	3 to 24 hours	Not recommended
68	Roll Down	Flushing	Large Pit	3 to 24 hours	Clean the connection
69	Saertex Liner	Flushing	Small Pit	3 to 24 hours	Limited re-connection
70	Sanipor	Flushing	Small Pit	3 to 24 hours	Clean the connection
71	Scotchkote 169HB	Pigging	Small Pit	3 to 24 hours	Not recommended
72	Scotchkote 269	Pigging	Small Pit	3 to 24 hours	Clean the connection
73	Seaboard EM 12	Pigging	Small Pit	3 to 24 hours	Clean the connection
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Flushing	Small Pit	3 to 24 hours	Not recommended
75	Sekisui Rib Loc SPR PE/ SPR ST	Flushing	Small Pit	3 to 24 hours	Clean the connection
76	Sekisui SPR Spiral Wound GIP	Flushing	Small Pit	3 to 24 hours	Clean the connection
77	Shotcrete Cementitious Lining	Pigging	Small Pit	3 to 24 hours	Not recommended
78	SprayShield Green #2	Pigging	Small Pit	3 to 24 hours	Not recommended
79	SprayWall	Pigging	Small Pit	3 to 24 hours	Not recommended
80	Starline HPL - W	Flushing	Small Pit	3 to 24 hours	Limited re-connection
81	SubCoil	Flushing	Medium Pit	3 to 24 hours	Clean the connection
82	Subline	Flushing	Medium Pit	3 to 24 hours	Clean the connection
83	Sure Grip Liner	Pigging	Large Pit	3 to 24 hours	Limited re-connection
84	Swagelining	Flushing	Large Pit	3 to 24 hours	Clean the connection
85	Thermopipe	Flushing	Medium Pit	3 to 24 hours	Clean the connection
86	Tite Liner	Flushing	Large Pit	3 to 24 hours	Clean the connection
87	Top Hat	Jet Spray	Large Pit	3 to 24 hours	Not recommended
88	TRIC Sewer Lateral Pipe Liner	Jet Spray	Large Pit	3 to 24 hours	Limited re-connection
89	TroLining GIP	Pigging	Large Pit	3 to 24 hours	Limited re-connection
90	U-Liner	Flushing	Medium Pit	3 to 24 hours	Clean the connection
91	Ultraliner Pipeliner	Flushing	Medium Pit	3 to 24 hours	Limited re-connection
92	Viscotaq Coat Wrap	Jet Spray	Large Pit	Less than 3 hours	Clean the connection
93	Warren Environmental S301-14	Pigging	Small Pit	3 to 24 hours	Not recommended
94	Waterline Epoxy	Pigging	Small Pit	3 to 24 hours	Not recommended

ID	product	space	bends	surface	loads
1	A+Wrap	Adhesive	Vertical	Dense	Limited Design
2	Acuro System	Not Required	Horizontal	Dense	Not Required
3	AM-Liner II	Not Required	None	Moderate	Full Design
4	Aqualiner	Adhesive	None	Dense	Full Design
5	Aquapipe	Adhesive	Horizontal	Moderate	Limited Design
6	Avanti Ultrafine	Grouting	Vertical	Moderate	Not Required
7	Belzona	Not Required	Horizontal	Dense	Not Required
8	Berolina Liner	Adhesive	Horizontal	Dense	Not Required
9	Blue-Tek	Adhesive	Horizontal	Dense	Not Required
10	CarbonWrap	Adhesive	Vertical	Dense	Limited Design
11	Channeline SL	Adhesive	Vertical	Dense	Limited Design
12	Consplit	Not Required	None	Rare	Full Design
13	Curaflo Spincast	Not Required	Horizontal	Dense	Not Required
14	Danby Panel Lok	Adhesive	Vertical	Dense	Limited Design
15	Duraliner	Not Required	None	Rare	Full Design
16	EX Pipe	Not Required	None	Moderate	Full Design
17	Fast Line Plus	Not Required	Horizontal	Dense	Not Required
18	FibrWrap	Adhesive	Vertical	Dense	Limited Design
19	Frey C Wrap	Adhesive	Vertical	Dense	Limited Design
20	Fusible C900	Not Required	None	Rare	Full Design
21	Grouting Sleeve	Adhesive	Vertical	Rare	Not Required
22	Grundoburst	Not Required	None	Rare	Full Design
23	Grundocrack	Not Required	None	Rare	Full Design
24	Grundomat	Not Required	None	Rare	Full Design
25	Grundotugger	Not Required	None	Rare	Full Design
26	Heitkamp Epoxy	Not Required	Horizontal	Dense	Not Required
27	Herrenknecht Crush-Liner	Not Required	None	Rare	Full Design
28	Hobas CCFRPM	Not Required	None	Rare	Full Design
29	Hobas FRP Panel	Adhesive	Vertical	Dense	Limited Design
30	Hydro-Seal	Adhesive	Vertical	Rare	Not Required

ID	product	space	bends	surface	loads
31	Impactor Pipe Bursting	Not Required	None	Rare	Full Design
32	Inliner CIPP	Adhesive	Horizontal	Dense	Not Required
33	Inner Seal Lo-Mod	Not Required	Horizontal	Dense	Not Required
34	Insituform PPL	Adhesive	Horizontal	Dense	Not Required
35	Insituform RPP	Adhesive	Horizontal	Dense	Not Required
36	InsituGuard Flexed	Not Required	None	Moderate	Full Design
37	InsituGuard Folded	Not Required	None	Dense	Full Design
38	Insitumain	Adhesive	Horizontal	Dense	Not Required
39	IPEX M-34	Not Required	None	Rare	Full Design
40	Jabar	Not Required	None	Rare	Full Design
41	Janssen Process	Adhesive	Vertical	Rare	Not Required
42	KA-TE Robotic System	Adhesive	Vertical	Rare	Not Required
43	Linabond Simulform Panel	Adhesive	Vertical	Dense	Limited Design
44	Linkpipe Insta-Liner	Adhesive	Vertical	Dense	Full Design
45	LMK CIPP Liner	Adhesive	None	Dense	Not Required
46	LMK T-Liner	Adhesive	Horizontal	Dense	Not Required
47	Logiball Push Packer	Grouting	Vertical	Moderate	Not Required
48	Logiball Test & Seal	Grouting	Vertical	Moderate	Not Required
49	MainSaver	Adhesive	None	Dense	Limited Design
50	Masterliner CIPP	Adhesive	Horizontal	Dense	Not Required
51	MCS Inliner	Not Required	None	Rare	Full Design
52	National Liner	Adhesive	Horizontal	Dense	Not Required
53	Neopoxy NPR 2000	Not Required	Vertical	Rare	Not Required
54	Nordipipe	Adhesive	Horizontal	Dense	Limited Design
55	Nowak InneReam	Not Required	None	Rare	Full Design
56	NPC Internal Joint Seal	Adhesive	Vertical	Rare	Not Required
57	NuFlow	Not Required	Vertical	Rare	Not Required
58	Paraliner PW	Adhesive	Horizontal	Dense	Not Required
59	Perma Lateral Lining System	Adhesive	Horizontal	Dense	Not Required
60	PermaLiner InnerSeal	Adhesive	Horizontal	Dense	Not Required
61	Perma-Liner Point Repair System	Adhesive	None	Dense	Not Required
62	PerpetuWall	Adhesive	Horizontal	Dense	Limited Design
63	Phoenix	Adhesive	Horizontal	Dense	Not Required
64	PolySpray	Not Required	Horizontal	Dense	Not Required

ID	product	space	bends	surface	loads
65	Powercrete PW	Not Required	Horizontal	Dense	Not Required
66	Primus Line	Adhesive	Horizontal	Dense	Limited Design
67	Raven 405	Not Required	Horizontal	Dense	Not Required
68	Roll Down	Not Required	None	Moderate	Full Design
69	Saertex Liner	Adhesive	Horizontal	Dense	Not Required
70	Sanipor	Grouting	Vertical	Moderate	Not Required
71	Scotchkote 169HB	Not Required	Horizontal	Dense	Not Required
72	Scotchkote 269	Not Required	Horizontal	Dense	Not Required
73	Seaboard EM 12	Not Required	Horizontal	Dense	Not Required
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Adhesive	Vertical	Dense	Limited Design
75	Sekisui Rib Loc SPR PE/ SPR ST	Adhesive	Vertical	Dense	Limited Design
76	Sekisui SPR Spiral Wound GIP	Adhesive	Vertical	Dense	Limited Design
77	Shotcrete Cementitious Lining	Not Required	Horizontal	Dense	Not Required
78	SprayShield Green #2	Not Required	Horizontal	Dense	Not Required
79	SprayWall	Not Required	Horizontal	Dense	Not Required
80	Starline HPL - W	Adhesive	Horizontal	Dense	Limited Design
81	SubCoil	Not Required	None	Dense	Full Design
82	Subline	Not Required	None	Dense	Full Design
83	Sure Grip Liner	Adhesive	None	Dense	Limited Design
84	Swagelining	Not Required	None	Moderate	Full Design
85	Thermopipe	Not Required	None	Dense	Full Design
86	Tite Liner	Not Required	None	Moderate	Full Design
87	Top Hat	Adhesive	Vertical	Rare	Not Required
88	TRIC Sewer Lateral Pipe Liner	Not Required	None	Rare	Full Design
89	TroLining GIP	Adhesive	None	Dense	Limited Design
90	U-Liner	Not Required	None	Dense	Full Design
91	Ultraliner Pipeliner	Not Required	None	Moderate	Full Design
92	Viscotaq Coat Wrap	Adhesive	Vertical	Rare	Not Required
93	Warren Environmental S301-14	Not Required	Horizontal	Dense	Not Required
94	Waterline Epoxy	Not Required	Horizontal	Dense	Not Required

ID	product	water	nsf61	status	environment
1	A+Wrap	Around Pipe Level	Not required	Innovative	Limited
2	Acuro System	Around Pipe Level	Required	Conventional	Limited
3	AM-Liner II	Above Crown Level	Not required	Conventional	Limited
4	Aqualiner	Above Crown Level	Not required	Emerging	Limited
5	Aquapipe	Around Pipe Level	Required	Conventional	Moderate
6	Avanti Ultrafine	Below Bedding Level	Not required	Conventional	Moderate
7	Belzona	Below Bedding Level	Required	Conventional	Limited
8	Berolina Liner	Around Pipe Level	Not required	Emerging	Moderate
9	Blue-Tek	Around Pipe Level	Not required	Emerging	Moderate
10	CarbonWrap	Around Pipe Level	Required	Innovative	Limited
11	Channeline SL	Around Pipe Level	Not required	Conventional	Limited
12	Consplit	Below Bedding Level	Required	Conventional	Severe
13	Curaflo Spincast	Below Bedding Level	Not required	Conventional	Limited
14	Danby Panel Lok	Around Pipe Level	Not required	Conventional	Limited
15	Duraliner	Below Bedding Level	Required	Conventional	Moderate
16	EX Pipe	Above Crown Level	Not required	Conventional	Limited
17	Fast Line Plus	Below Bedding Level	Required	Innovative	Limited
18	FibrWrap	Around Pipe Level	Required	Innovative	Limited
19	Frey C Wrap	Around Pipe Level	Required	Innovative	Limited
20	Fusible C900	Below Bedding Level	Required	Innovative	Moderate
21	Grouting Sleeve	Below Bedding Level	Not required	Innovative	Moderate
22	Grundoburst	Below Bedding Level	Required	Conventional	Severe
23	Grundocrack	Below Bedding Level	Required	Conventional	Severe
24	Grundomat	Below Bedding Level	Required	Innovative	Severe
25	Grundotugger	Below Bedding Level	Not required	Conventional	Severe
26	Heitkamp Epoxy	Below Bedding Level	Not required	Conventional	Limited
27	Herrenknecht Crush-Liner	Below Bedding Level	Required	Conventional	Severe
28	Hobas CCFRPM	Below Bedding Level	Not required	Conventional	Moderate
29	Hobas FRP Panel	Around Pipe Level	Not required	Conventional	Limited
30	Hydro-Seal	Below Bedding Level	Required	Conventional	Moderate

ID	product	water	nsf61	status	environment
31	Impactor Pipe Bursting	Below Bedding Level	Required	Conventional	Severe
32	Inliner CIPP	Around Pipe Level	Not required	Conventional	Moderate
33	Inner Seal Lo-Mod	Around Pipe Level	Not required	Innovative	Limited
34	Insituform PPL	Around Pipe Level	Required	Emerging	Moderate
35	Insituform RPP	Around Pipe Level	Not required	Emerging	Moderate
36	InsituGuard Flexed	Above Crown Level	Required	Conventional	Limited
37	InsituGuard Folded	Above Crown Level	Required	Conventional	Limited
38	Insitumain	Around Pipe Level	Not required	Emerging	Moderate
39	IPEX M-34	Below Bedding Level	Required	Emerging	Moderate
40	Jabar	Below Bedding Level	Required	Conventional	Severe
41	Janssen Process	Below Bedding Level	Not required	Innovative	Limited
42	KA-TE Robotic System	Below Bedding Level	Not required	Innovative	Limited
43	Linabond Simulform Panel	Around Pipe Level	Not required	Conventional	Limited
44	Linkpipe Insta-Liner	Above Crown Level	Not required	Conventional	Limited
45	LMK CIPP Liner	Around Pipe Level	Not required	Conventional	Moderate
46	LMK T-Liner	Around Pipe Level	Not required	Innovative	Moderate
47	Logiball Push Packer	Below Bedding Level	Not required	Conventional	Moderate
48	Logiball Test & Seal	Below Bedding Level	Not required	Conventional	Moderate
49	MainSaver	Above Crown Level	Required	Innovative	Limited
50	Masterliner CIPP	Around Pipe Level	Not required	Conventional	Moderate
51	MCS Inliner	Below Bedding Level	Not required	Conventional	Severe
52	National Liner	Around Pipe Level	Not required	Conventional	Moderate
53	Neopoxy NPR 2000	Below Bedding Level	Required	Conventional	Limited
54	Nordipipe	Around Pipe Level	Required	Conventional	Moderate
55	Nowak InneReam	Below Bedding Level	Required	Conventional	Severe
56	NPC Internal Joint Seal	Below Bedding Level	Not required	Innovative	Moderate
57	NuFlow	Below Bedding Level	Required	Conventional	Limited
58	Paraliner PW	Around Pipe Level	Required	Emerging	Moderate
59	Perma Lateral Lining System	Around Pipe Level	Not required	Innovative	Moderate
60	PermaLiner InnerSeal	Around Pipe Level	Not required	Innovative	Moderate
61	Perma-Liner Point Repair System	Around Pipe Level	Not required	Innovative	Moderate
62	PerpetuWall	Around Pipe Level	Not required	Innovative	Moderate
63	Phoenix	Around Pipe Level	Not required	Conventional	Moderate
64	PolySpray	Around Pipe Level	Not required	Innovative	Limited

ID	product	water	nsf61	status	environment
65	Powercrete PW	Below Bedding Level	Required	Conventional	Limited
66	Primus Line	Around Pipe Level	Not required	Emerging	Moderate
67	Raven 405	Below Bedding Level	Not required	Conventional	Limited
68	Roll Down	Above Crown Level	Required	Conventional	Limited
69	Saertex Liner	Around Pipe Level	Not required	Emerging	Moderate
70	Sanipor	Below Bedding Level	Not required	Innovative	Moderate
71	Scotchkote 169HB	Around Pipe Level	Required	Conventional	Limited
72	Scotchkote 269	Around Pipe Level	Required	Emerging	Limited
73	Seaboard EM 12	Below Bedding Level	Not required	Conventional	Moderate
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Around Pipe Level	Not required	Conventional	Limited
75	Sekisui Rib Loc SPR PE/ SPR ST	Around Pipe Level	Not required	Conventional	Limited
76	Sekisui SPR Spiral Wound GIP	Around Pipe Level	Not required	Conventional	Limited
77	Shotcrete Cementitious Lining	Below Bedding Level	Not required	Conventional	Limited
78	SprayShield Green #2	Around Pipe Level	Not required	Innovative	Limited
79	SprayWall	Around Pipe Level	Required	Conventional	Limited
80	Starline HPL - W	Around Pipe Level	Required	Conventional	Moderate
81	SubCoil	Above Crown Level	Not required	Conventional	Limited
82	Subline	Above Crown Level	Required	Conventional	Limited
83	Sure Grip Liner	Above Crown Level	Not required	Conventional	Limited
84	Swagelining	Above Crown Level	Required	Conventional	Limited
85	Thermopipe	Above Crown Level	Required	Emerging	Limited
86	Tite Liner	Above Crown Level	Required	Conventional	Limited
87	Top Hat	Below Bedding Level	Not required	Emerging	Limited
88	TRIC Sewer Lateral Pipe Liner	Below Bedding Level	Not required	Innovative	Severe
89	TroLining GIP	Above Crown Level	Not required	Conventional	Limited
90	U-Liner	Above Crown Level	Not required	Conventional	Limited
91	Ultraliner Pipeliner	Above Crown Level	Not required	Conventional	Limited
92	Viscotaq Coat Wrap	Below Bedding Level	Not required	Conventional	Severe
93	Warren Environmental S301-14	Below Bedding Level	Not required	Emerging	Limited
94	Waterline Epoxy	Below Bedding Level	Required	Conventional	Limited

ID	product	codes	installation
1	A+Wrap	Design Codes	Complex method
2	Acuro System	Design and Specialty codes	Common Method
3	AM-Liner II	Design Codes	Complex method
4	Aqualiner	Design Codes	Complex method
5	Aquapipe	Design and Specialty codes	Common Method
6	Avanti Ultrafine	Not Available	Common Method
7	Belzona	Not Available	Common Method
8	Berolina Liner	Design and Specialty codes	Moderate with curing
9	Blue-Tek	Design Codes	Moderate with curing
10	CarbonWrap	Design Codes	Complex method
11	Channeline SL	Design and Specialty codes	Moderate without curing
12	Consplit	Design and Specialty codes	Common Method
13	Curaflo Spincast	Not Available	Common Method
14	Danby Panel Lok	Design Codes	Moderate without curing
15	Duraliner	Specialty Codes	Moderate without curing
16	EX Pipe	Design Codes	Complex method
17	Fast Line Plus	Specialty Codes	Common Method
18	FibrWrap	Design Codes	Complex method
19	Frey C Wrap	Design Codes	Complex method
20	Fusible C900	Design and Specialty codes	Moderate without curing
21	Grouting Sleeve	Design and Specialty codes	Moderate without curing
22	Grundoburst	Design Codes	Common Method
23	Grundocrack	Design Codes	Common Method
24	Grundomat	Design Codes	Common Method
25	Grundotugger	Design Codes	Common Method
26	Heitkamp Epoxy	Not Available	Common Method
27	Herrenknecht Crush-Liner	Design Codes	Common Method
28	Hobas CCFRPM	Design Codes	Moderate without curing
29	Hobas FRP Panel	Not Available	Moderate without curing
30	Hydro-Seal	Specialty Codes	Moderate without curing

ID	product	codes	installation
31	Impactor Pipe Bursting	Design and Specialty codes	Moderate with curing
32	Inliner CIPP	Design Codes	Moderate with curing
33	Inner Seal Lo-Mod	Design Codes	Common Method
34	Insituform PPL	Design Codes	Moderate with curing
35	Insituform RPP	Design Codes	Moderate with curing
36	InsituGuard Flexed	Design and Specialty codes	Moderate without curing
37	InsituGuard Folded	Design and Specialty codes	Moderate without curing
38	Insitumain	Not Available	Moderate with curing
39	IPEX M-34	Design and Specialty codes	Moderate without curing
40	Jabar	Design and Specialty codes	Common Method
41	Janssen Process	Not Available	Common Method
42	KA-TE Robotic System	Design and Specialty codes	Common Method
43	Linabond Simulform Panel	Not Available	Moderate without curing
44	Linkpipe Insta-Liner	Design Codes	Moderate without curing
45	LMK CIPP Liner	Design Codes	Moderate with curing
46	LMK T-Liner	Design Codes	Moderate with curing
47	Logiball Push Packer	Design and Specialty codes	Moderate without curing
48	Logiball Test & Seal	Design and Specialty codes	Moderate without curing
49	MainSaver	Design and Specialty codes	Complex method
50	Masterliner CIPP	Not Available	Moderate with curing
51	MCS Inliner	Design Codes	Common Method
52	National Liner	Design Codes	Moderate with curing
53	Neopoxy NPR 2000	Design and Specialty codes	Common Method
54	Nordipipe	Design and Specialty codes	Common Method
55	Nowak InneReam	Design Codes	Common Method
56	NPC Internal Joint Seal	Design Codes	Common Method
57	NuFlow	Not Available	Moderate without curing
58	Paraliner PW	Design Codes	Moderate with curing
59	Perma Lateral Lining System	Design and Specialty codes	Complex method
60	PermaLiner InnerSeal	Design and Specialty codes	Complex method
61	Perma-Liner Point Repair System	Design and Specialty codes	Moderate with curing
62	PerpetuWall	Design Codes	Common Method
63	Phoenix	Not Available	Moderate with curing
64	PolySpray	Design Codes	Common Method

ID	product	codes	installation
65	Powercrete PW	Design and Specialty codes	Common Method
66	Primus Line	Specialty Codes	Common Method
67	Raven 405	Design and Specialty codes	Common Method
68	Roll Down	Design and Specialty codes	Moderate without curing
69	Saertex Liner	Design Codes	Moderate with curing
70	Sanipor	Design and Specialty codes	Common Method
71	Scotchkote 169HB	Design and Specialty codes	Common Method
72	Scotchkote 269	Design Codes	Common Method
73	Seaboard EM 12	Design and Specialty codes	Common Method
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Design and Specialty codes	Moderate without curing
75	Sekisui Rib Loc SPR PE/ SPR ST	Design and Specialty codes	Moderate without curing
76	Sekisui SPR Spiral Wound GIP	Design and Specialty codes	Moderate without curing
77	Shotcrete Cementitious Lining	Not Available	Common Method
78	SprayShield Green #2	Design Codes	Common Method
79	SprayWall	Design Codes	Common Method
80	Starline HPL - W	Specialty Codes	Common Method
81	SubCoil	Not Available	Common Method
82	Subline	Design and Specialty codes	Moderate without curing
83	Sure Grip Liner	Not Available	Complex method
84	Swagelining	Design and Specialty codes	Moderate without curing
85	Thermopipe	Specialty Codes	Common Method
86	Tite Liner	Not Available	Moderate without curing
87	Top Hat	Design and Specialty codes	Moderate without curing
88	TRIC Sewer Lateral Pipe Liner	Design and Specialty codes	Common Method
89	TroLining GIP	Design Codes	Complex method
90	U-Liner	Specialty Codes	Common Method
91	Ultraliner Pipeliner	Design Codes	Common Method
92	Viscotaq Coat Wrap	Design and Specialty codes	Common Method
93	Warren Environmental S301-14	Design Codes	Common Method
94	Waterline Epoxy	Design Codes	Common Method

ID	product	historical	references	practitioners
1	A+Wrap	51 to 99 miles	Vendor Articles	Not Available
2	Acuro System	Not Applicable	Vendor Articles	Less than 3 users
3	AM-Liner II	Less than 50 miles	Vendor Articles	Not Available
4	Aqualiner	More than 100 miles	Limited Information	Less than 3 users
5	Aquapipe	Less than 50 miles	Vendor Articles	Less than 3 users
6	Avanti Ultrafine	Not Applicable	Vendor Articles	Not Available
7	Belzona	More than 100 miles	Vendor Articles	More than 4 users
8	Berolina Liner	Not Applicable	Independent Reviews	More than 4 users
9	Blue-Tek	Not Applicable	Vendor Articles	Less than 3 users
10	CarbonWrap	Not Applicable	Vendor Articles	Not Available
11	Channeline SL	Not Applicable	Vendor Articles	Less than 3 users
12	Consplit	51 to 99 miles	Independent Reviews	Less than 3 users
13	Curaflo Spincast	Not Applicable	Vendor Articles	Less than 3 users
14	Danby Panel Lok	More than 100 miles	Vendor Articles	Not Available
15	Duraliner	More than 100 miles	Vendor Articles	Not Available
16	EX Pipe	Less than 50 miles	Vendor Articles	Less than 3 users
17	Fast Line Plus	More than 100 miles	Vendor Articles	More than 4 users
18	FibrWrap	Not Applicable	Independent Reviews	More than 4 users
19	Frey C Wrap	More than 100 miles	Vendor Articles	Less than 3 users
20	Fusible C900	Not Applicable	Vendor Articles	Not Available
21	Grouting Sleeve	More than 100 miles	Vendor Articles	Not Available
22	Grundoburst	More than 100 miles	Limited Information	Less than 3 users
23	Grundocrack	More than 100 miles	Independent Reviews	Less than 3 users
24	Grundomat	More than 100 miles	Independent Reviews	Less than 3 users
25	Grundotugger	More than 100 miles	Independent Reviews	More than 4 users
26	Heitkamp Epoxy	More than 100 miles	Vendor Articles	More than 4 users
27	Herrenknecht Crush-Liner	More than 100 miles	Independent Reviews	Not Available
28	Hobas CCFRPM	Not Applicable	Vendor Articles	Less than 3 users
29	Hobas FRP Panel	Not Applicable	Vendor Articles	Not Available
30	Hydro-Seal	More than 100 miles	Vendor Articles	Not Available

id	product	historical	references	practitioners
31	Impactor Pipe Bursting	Less than 50 miles	Independent Reviews	Less than 3 users
32	Inliner CIPP	Not Applicable	Independent Reviews	Less than 3 users
33	Inner Seal Lo-Mod	More than 100 miles	Limited Information	Not Available
34	Insituform PPL	Less than 50 miles	Vendor Articles	Less than 3 users
35	Insituform RPP	Less than 50 miles	Vendor Articles	Less than 3 users
36	InsituGuard Flexed	Not Applicable	Vendor Articles	Not Available
37	InsituGuard Folded	Not Applicable	Vendor Articles	Less than 3 users
38	Insitumain	More than 100 miles	Limited Information	Not Available
39	IPEX M-34	More than 100 miles	Independent Reviews	Less than 3 users
40	Jabar	More than 100 miles	Independent Reviews	Less than 3 users
41	Janssen Process	Not Applicable	Independent Reviews	More than 4 users
42	KA-TE Robotic System	Not Applicable	Independent Reviews	Not Available
43	Linabond Simulform Panel	More than 100 miles	Vendor Articles	Not Available
44	Linkpipe Insta-Liner	More than 100 miles	Vendor Articles	Not Available
45	LMK CIPP Liner	Less than 50 miles	Vendor Articles	More than 4 users
46	LMK T-Liner	More than 100 miles	Independent Reviews	More than 4 users
47	Logiball Push Packer	Not Applicable	Independent Reviews	More than 4 users
48	Logiball Test & Seal	Not Applicable	Independent Reviews	More than 4 users
49	MainSaver	Less than 50 miles	Vendor Articles	Less than 3 users
50	Masterliner CIPP	More than 100 miles	Independent Reviews	Not Available
51	MCS Inliner	Less than 50 miles	Vendor Articles	Not Available
52	National Liner	Not Applicable	Vendor Articles	Not Available
53	Neopoxy NPR 2000	More than 100 miles	Vendor Articles	Not Available
54	Nordipipe	51 to 99 miles	Vendor Articles	Less than 3 users
55	Nowak InneReam	51 to 99 miles	Independent Reviews	More than 4 users
56	NPC Internal Joint Seal	More than 100 miles	Limited Information	Less than 3 users
57	NuFlow	More than 100 miles	Limited Information	Not Available
58	Paraliner PW	Less than 50 miles	Vendor Articles	Less than 3 users
59	Perma Lateral Lining System	Not Applicable	Independent Reviews	More than 4 users
60	PermaLiner InnerSeal	Less than 50 miles	Independent Reviews	More than 4 users
61	Perma-Liner Point Repair	Not Applicable	Independent Reviews	Not Available
62	PerpetuWall	More than 100 miles	Vendor Articles	Not Available
63	Phoenix	Not Applicable	Vendor Articles	Not Available
64	PolySpray	More than 100 miles	Vendor Articles	Not Available

ID	product	historical	references	practitioners
65	Powercrete PW	More than 100 miles	Vendor Articles	Not Available
66	Primus Line	51 to 99 miles	Independent Reviews	Less than 3 users
67	Raven 405	Not Applicable	Independent Reviews	More than 4 users
68	Roll Down	More than 100 miles	Limited Information	Less than 3 users
69	Saertex Liner	Less than 50 miles	Independent Reviews	Less than 3 users
70	Sanipor	Not Applicable	Independent Reviews	More than 4 users
71	Scotchkote 169HB	Not Applicable	Independent Reviews	Less than 3 users
72	Scotchkote 269	More than 100 miles	Vendor Articles	Not Available
73	Seaboard EM 12	More than 100 miles	Vendor Articles	More than 4 users
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Less than 50 miles	Vendor Articles	More than 4 users
75	Sekisui Rib Loc SPR PE/ SPR ST	51 to 99 miles	Vendor Articles	More than 4 users
76	Sekisui SPR Spiral Wound GIP	Less than 50 miles	Vendor Articles	More than 4 users
77	Shotcrete Cementitious Lining	Not Applicable	Vendor Articles	Less than 3 users
78	SprayShield Green #2	51 to 99 miles	Vendor Articles	Not Available
79	SprayWall	Not Applicable	Vendor Articles	Less than 3 users
80	Starline HPL - W	More than 100 miles	Limited Information	Not Available
81	SubCoil	More than 100 miles	Limited Information	Not Available
82	Subline	More than 100 miles	Limited Information	Less than 3 users
83	Sure Grip Liner	More than 100 miles	Limited Information	Not Available
84	Swagelining	Not Applicable	Vendor Articles	Less than 3 users
85	Thermopipe	Not Applicable	Vendor Articles	Less than 3 users
86	Tite Liner	Not Applicable	Limited Information	Not Available
87	Top Hat	Not Applicable	Independent Reviews	More than 4 users
88	TRIC Sewer Lateral Pipe Liner	Not Applicable	Independent Reviews	More than 4 users
89	TroLining GIP	Not Applicable	Independent Reviews	Less than 3 users
90	U-Liner	Not Applicable	Limited Information	Not Available
91	Ultraliner Pipeliner	Not Applicable	Independent Reviews	Less than 3 users
92	Viscotaq Coat Wrap	More than 100 miles	Vendor Articles	Less than 3 users
93	Warren Environmental S301-14	Not Applicable	Vendor Articles	More than 4 users
94	Waterline Epoxy	More than 100 miles	Vendor Articles	Not Available

ID	product	quality	costs
1	A+Wrap	Site-built material	Manufacturing Costs
2	Acuro System	Site-built material	Manufacturing Costs
3	AM-Liner II	Site-built material	Manufacturing Costs
4	Aqualiner	Site-built material	Tendered Costs
5	Aquapipe	Factory-built material	Project Costs
6	Avanti Ultrafine	Site-built material	Manufacturing Costs
7	Belzona	Site-built material	Project Costs
8	Berolina Liner	Site-built material	Manufacturing Costs
9	Blue-Tek	Site-built material	Manufacturing Costs
10	CarbonWrap	Site-built material	Tendered Costs
11	Channeline SL	Factory-built material	Project Costs
12	Consplit	Factory-built material	Tendered Costs
13	Curaflo Spincast	Site-built material	Project Costs
14	Danby Panel Lok	Factory-built material	Manufacturing Costs
15	Duraliner	Factory-built material	Manufacturing Costs
16	EX Pipe	Site-built material	Tendered Costs
17	Fast Line Plus	Site-built material	Project Costs
18	FibrWrap	Site-built material	Project Costs
19	Frey C Wrap	Site-built material	Manufacturing Costs
20	Fusible C900	Factory-built material	Project Costs
21	Grouting Sleeve	Site-built material	Manufacturing Costs
22	Grundoburst	Factory-built material	Manufacturing Costs
23	Grundocrack	Factory-built material	Project Costs
24	Grundomat	Factory-built material	Manufacturing Costs
25	Grundotugger	Factory-built material	Manufacturing Costs
26	Heitkamp Epoxy	Site-built material	Project Costs
27	Herrenknecht Crush-Liner	Factory-built material	Manufacturing Costs
28	Hobas CCFRPM	Factory-built material	Tendered Costs
29	Hobas FRP Panel	Factory-built material	Manufacturing Costs
30	Hydro-Seal	Site-built material	Manufacturing Costs

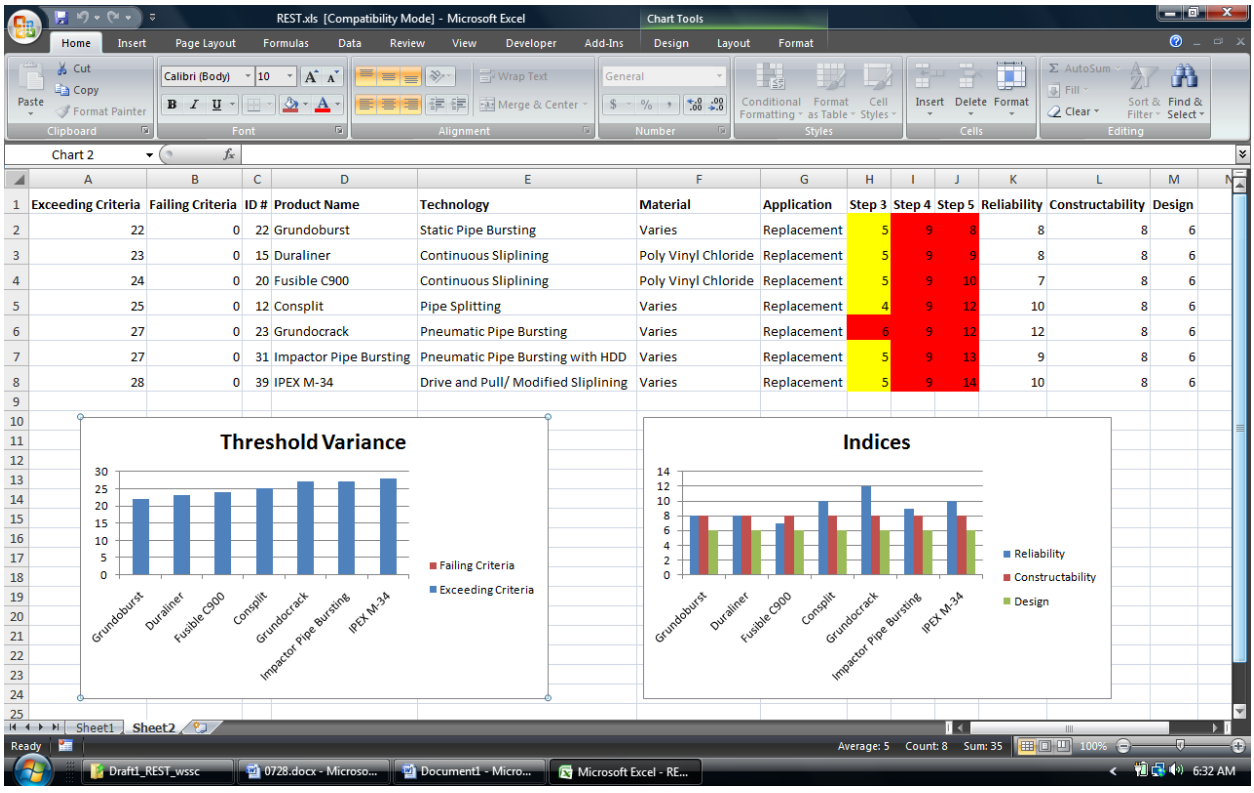
ID	product	quality	costs
31	Impactor Pipe Bursting	Factory-built material	Tendered Costs
32	Inliner CIPP	Site-built material	Manufacturing Costs
33	Inner Seal Lo-Mod	Site-built material	Manufacturing Costs
34	Insituform PPL	Site-built material	Manufacturing Costs
35	Insituform RPP	Site-built material	Manufacturing Costs
36	InsituGuard Flexed	Site-built material	Manufacturing Costs
37	InsituGuard Folded	Factory-built material	Manufacturing Costs
38	Insitumain	Site-built material	Manufacturing Costs
39	IPEX M-34	Factory-built material	Manufacturing Costs
40	Jabar	Factory-built material	Manufacturing Costs
41	Janssen Process	Site-built material	Tendered Costs
42	KA-TE Robotic System	Site-built material	Tendered Costs
43	Linabond Simulform Panel	Factory-built material	Manufacturing Costs
44	Linkpipe Insta-Liner	Factory-built material	Manufacturing Costs
45	LMK CIPP Liner	Site-built material	Manufacturing Costs
46	LMK T-Liner	Site-built material	Project Costs
47	Logiball Push Packer	Factory-built material	Tendered Costs
48	Logiball Test & Seal	Factory-built material	Project Costs
49	MainSaver	Site-built material	Manufacturing Costs
50	Masterliner CIPP	Site-built material	Manufacturing Costs
51	MCS Inliner	Factory-built material	Manufacturing Costs
52	National Liner	Site-built material	Manufacturing Costs
53	Neopoxy NPR 2000	Site-built material	Manufacturing Costs
54	Nordipipe	Factory-built material	Manufacturing Costs
55	Nowak InneReam	Factory-built material	Tendered Costs
56	NPC Internal Joint Seal	Factory-built material	Manufacturing Costs
57	NuFlow	Site-built material	Manufacturing Costs
58	Paraliner PW	Site-built material	Manufacturing Costs
59	Perma Lateral Lining System	Site-built material	Project Costs
60	PermaLiner InnerSeal	Site-built material	Manufacturing Costs
61	Perma-Liner Point Repair System	Site-built material	Tendered Costs
62	PerpetuWall	Factory-built material	Manufacturing Costs
63	Phoenix	Site-built material	Manufacturing Costs
64	PolySpray	Site-built material	Manufacturing Costs

ID	product	quality	costs
65	Powercrete PW	Site-built material	Manufacturing Costs
66	Primus Line	Factory-built material	Manufacturing Costs
67	Raven 405	Site-built material	Project Costs
68	Roll Down	Site-built material	Manufacturing Costs
69	Saertex Liner	Site-built material	Project Costs
70	Sanipor	Site-built material	Project Costs
71	Scotchkote 169HB	Site-built material	Tendered Costs
72	Scotchkote 269	Site-built material	Manufacturing Costs
73	Seaboard EM 12	Site-built material	Project Costs
74	Sekisui Rib Loc Spiral EX/ ROTALOC	Factory-built material	Manufacturing Costs
75	Sekisui Rib Loc SPR PE/ SPR ST	Factory-built material	Manufacturing Costs
76	Sekisui SPR Spiral Wound GIP	Factory-built material	Manufacturing Costs
77	Shotcrete Cementitious Lining	Site-built material	Manufacturing Costs
78	SprayShield Green #2	Site-built material	Manufacturing Costs
79	SprayWall	Site-built material	Project Costs
80	Starline HPL - W	Factory-built material	Manufacturing Costs
81	SubCoil	Factory-built material	Manufacturing Costs
82	Subline	Factory-built material	Manufacturing Costs
83	Sure Grip Liner	Site-built material	Manufacturing Costs
84	Swagelining	Site-built material	Manufacturing Costs
85	Thermopipe	Factory-built material	Manufacturing Costs
86	Tite Liner	Site-built material	Manufacturing Costs
87	Top Hat	Site-built material	Project Costs
88	TRIC Sewer Lateral Pipe Liner	Factory-built material	Project Costs
89	TroLining GIP	Site-built material	Manufacturing Costs
90	U-Liner	Factory-built material	Manufacturing Costs
91	Ultraliner Pipeliner	Site-built material	Project Costs
92	Viscotaq Coat Wrap	Factory-built material	Manufacturing Costs
93	Warren Environmental S301-14	Site-built material	Project Costs
94	Waterline Epoxy	Site-built material	Manufacturing Costs

Appendix D: Trial 1 Sheets

STEP NO.	CLASSIFICATION	CATEGORY SELECTION
2	Pipeline Application	Water Main line
2	Pipeline Diameter	Less than 10 inches
2	Pipeline Problem	Capacity Problems
3	Host Pipe material	Ductile Iron
3	As-Built pipe depth	Shallow
3	Designed Pipe profile	Circular
3	Geographic Pipe Location	Uninhabited Lands
3	Excavation Space	Available
3	Known Pipe Age	10
3	Operating Pressure	50
3	Operating Temperature	50
3	Required Thickness	500
3	Section Renewal Length	100
4	Corrosion Protection	Only External
4	Cleaning	Jet Spray
4	Access Pits	Small Pit
4	Down Time	More than 24 hours
4	Service Connections	Clean the connections
4	Annular Space	Not Required
4	Bends	None
4	Subsurface Features	Rare
4	External Loads	Not Required
4	Groundwater Level	Below Bedding Level

5	ANSI/ NSF 61 requirement	Not Required
5	Product Status	Conventional
5	Environmental Impact	Limited
5	Codes and Specifications	Not Available
5	Installation Method	Common method
5	Historical Utilization	Not Applicable
5	References	Limited Information
5	Practitioners	Not Available
5	Quality Controls	Factory-Built material
5	Known Costs	Manufacturing costs

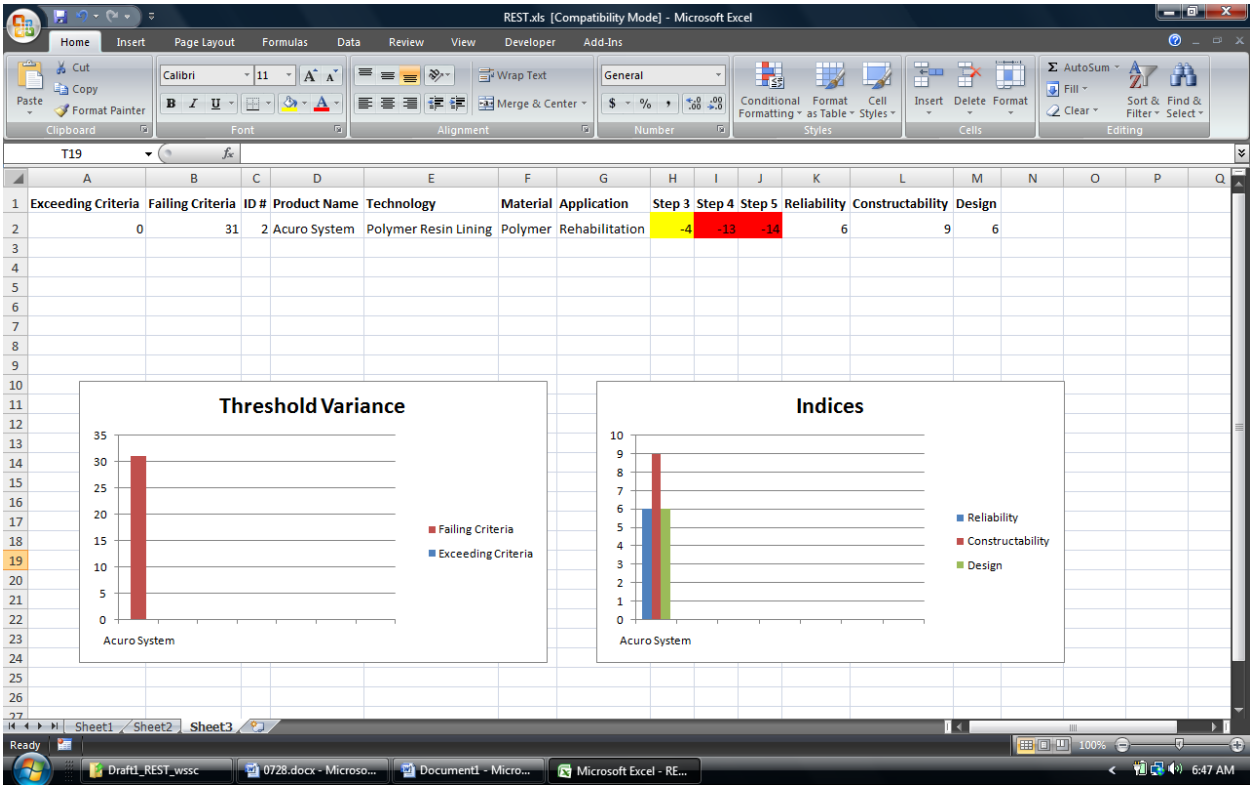


Exceeding Criteria	Failing Criteria	ID #	Product Name	Technology	Material	Application	Step 3	Step 4	Step 5	Reliability	Constructability	Design
22	0	22	Grundoburst	Static Pipe Bursting	Varies	Replacement	5	9	8	8	8	6
23	0	15	Duraliner	Continuous Sliplining	Poly Vinyl Chloride	Replacement	5	9	9	8	8	6
24	0	20	Fusible C900	Continuous Sliplining	Poly Vinyl Chloride	Replacement	5	9	10	7	8	6
25	0	12	Consplit	Pipe Splitting	Varies	Replacement	4	9	12	10	8	6
27	0	23	Grundocrack	Pneumatic Pipe Bursting	Varies	Replacement	6	9	12	12	8	6
27	0	31	Impactor Pipe Bursting	Pneumatic Pipe Bursting with HDD	Varies	Replacement	5	9	13	9	8	6
28	0	39	IPEX M-34	Drive and Pull/ Modified Sliplining	Varies	Replacement	5	9	14	10	8	6

Appendix E: Trial 2 Sheets

STEP NO.	CLASSIFICATION	CATEGORY SELECTION
2	Pipeline Application	Water Service Line
2	Pipeline Diameter	From 12 to 20 inches
2	Pipeline Problem	Structural Problems
3	Host Pipe material	Reinforced Concrete
3	As-Built pipe depth	Deep
3	Designed Pipe profile	Non-circular
3	Geographic Pipe Location	Commercial Areas
3	Excavation Space	Not Available
3	Known Pipe Age	20
3	Operating Pressure	75
3	Operating Temperature	70
3	Required Thickness	500
3	Section Renewal Length	600
4	Corrosion Protection	External & Internal
4	Cleaning	Chemical
4	Access Pits	Large Pit
4	Down Time	Less than 3 hours
4	Service Connections	Not Recommended
4	Annular Space	Grouting
4	Bends	Vertical
4	Subsurface Features	Dense
4	External Loads	Full Design
4	Groundwater Level	Above Crown Level

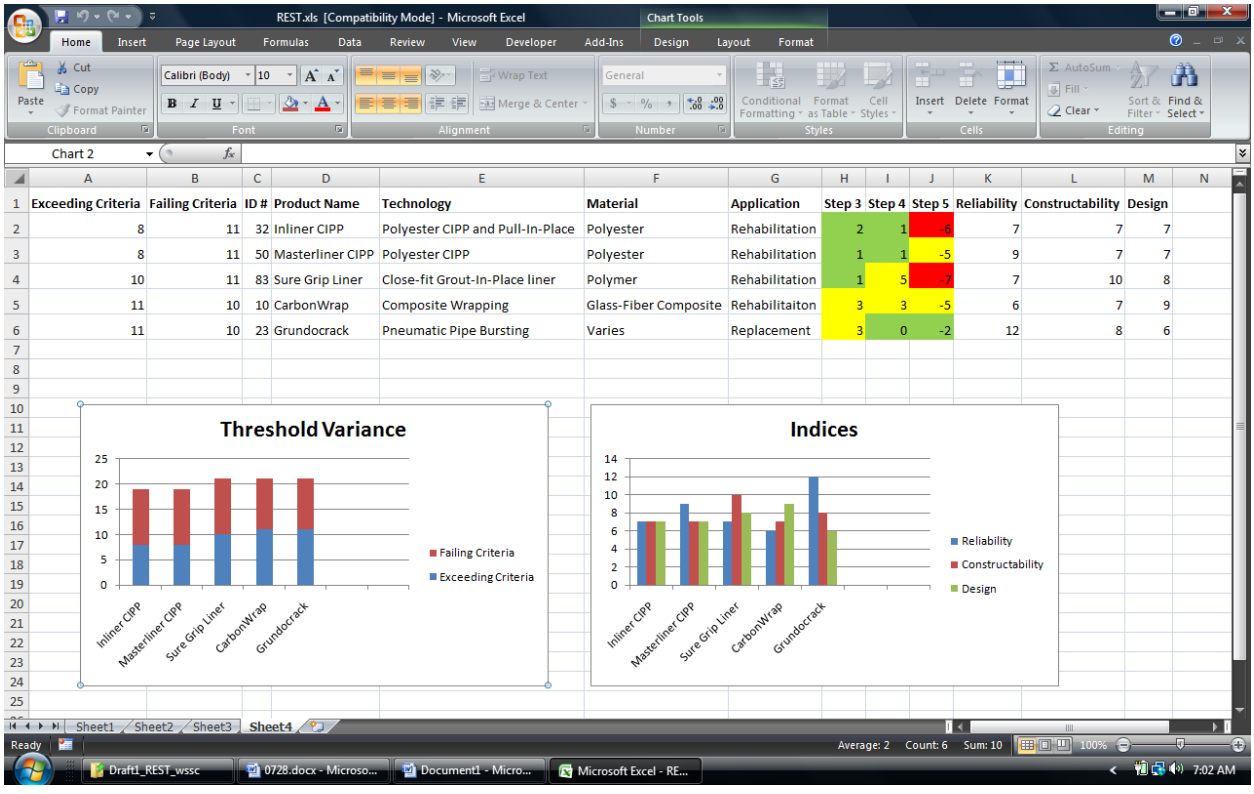
5	ANSI/ NSF 61 requirement	Required
5	Product Status	Emerging
5	Environmental Impact	Severe
5	Codes and Specifications	Design & Specialty codes
5	Installation Method	Complex method
5	Historical Utilization	More than 100 miles
5	References	Independent Reviews
5	Practitioners	4 or more users
5	Quality Controls	Site-built material
5	Known Costs	Project Costs



Appendix F: Trial 3 Sheets

STEP NO.	CLASSIFICATION	CATEGORY SELECTION
2	Pipeline Application	Gravity Sewer
2	Pipeline Diameter	48 inches and above
2	Pipeline Problem	Flow Quality problems
3	Host Pipe material	Prestressed Concrete
3	As-Built pipe depth	Shallow
3	Designed Pipe profile	Circular
3	Geographic Pipe Location	Suburban Areas
3	Excavation Space	Limited
3	Known Pipe Age	15
3	Operating Pressure	10
3	Operating Temperature	65
3	Required Thickness	500
3	Section Renewal Length	1000
4	Corrosion Protection	Internal
4	Cleaning	Scrapping
4	Access Pits	Medium Pit
4	Down Time	3 to 24 hours
4	Service Connections	Clean the connections
4	Annular Space	Not Required
4	Bends	None
4	Subsurface Features	Moderate
4	External Loads	Limited Design
4	Groundwater Level	Below Bedding Level

5	ANSI/ NSF 61 requirement	Not Required
5	Product Status	Innovative
5	Environmental Impact	Limited
5	Codes and Specifications	Design & Specialty codes
5	Installation Method	Moderate with curing
5	Historical Utilization	51 to 99 miles
5	References	Independent Reviews
5	Practitioners	Less than 3 users
5	Quality Controls	Site-built material
5	Known Costs	Project Costs



Exceeding Criteria	Failing Criteria	ID #	Product Name	Technology	Material	Application	Step 3	Step 4	Step 5	Reliability	Constructability	Design
8	11	32	Inliner CIPP	Polyester CIPP and Pull-In-Place	Polyester	Rehabilitation	2	1	-6	7	7	7
8	11	50	Masterliner CIPP	Polyester CIPP	Polyester	Rehabilitation	1	1	-5	9	7	7
10	11	83	Sure Grip Liner	Close-fit Grout-In-Place liner	Polymer	Rehabilitation	1	5	-7	7	10	8
11	10	10	CarbonWrap	Composite Wrapping	Glass-Fiber Composite	Rehabilitaiton	3	3	-5	6	7	9
11	10	23	Grundocrack	Pneumatic Pipe Bursting	Varies	Replacement	3	0	-2	12	8	6

Appendix G: Renewal Product Technical Sheets

Technology/Method	Spray-on Polyurethane Lining
Status	Innovative
Date of Introduction	3M Scotchkote Spray in Place Pipe 269 was released in the US in June 2009.
Utilization Rates	Not Applicable
Vendor Name(s)	3M Scotchkote 269 3M Corrosion Protection Products Division Austin, Texas Phone 512-984-5515 Fax: 512-984-4871 Mobile: 512-789-9060 Web: http://www.3m.com/ Email: gsnatwig@mmm.com
Practitioner(s)	Not Applicable
Description of Main Features	3M™ Scotchkote™ Spray In Place Pipe 269 Coating offers a sustainable, cost-effective alternative to traditional potable water pipe infrastructure rehabilitation methods. 3M™ Scotchkote™ Spray In Place Pipe 269 Coating has been specifically developed to rehabilitate potable water pipe infrastructure to extend service life, reduce leaks and improve water quality.
Main Benefits Claimed	• Contains no VOCs per EPA method 8260 • Quick cure allows CCTV inspection immediately after application • Same day return to service possible, permitting the elimination of bypass piping • Recommended for application in pipes with diameters of 4 in (10 cm) to 12 in (30 cm). • May work for larger diameter pipes • Typically will not plug service connections • Adds structural integrity and service life to the pipeline • Application method incorporates trenchless technology
Main Limitations Cited	Not recommended for pipe with residual asset life less than 30 years
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:
II. Technology Parameters	
Service Application	Rehabilitation by Spray lining
Service Connections	Does not plug the service connections.
Structural Rating Claimed	ASTM D638
Materials of Composition	Polyurea, Based on two-part poly-urea chemistry
Diameter Range, inches	4” to 12” pipes
Thickness Range, inches	140 mils or 3.5mm

Pressure Capacity, psi	Capacity changes with material thickness and pipe diameter
Temperature Range, °F	NSF 61 approved for 73.4°F when in contact with water
Renewal Length, feet	Not Available
Other Notes	Representative Coverage Rate for 8" diameter pipe is 0.2 gallons/ft
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI/ NSF 61 approved
Design Standards	ASTM D7028, ASTM D696, ASTM D2794, ASTM D790 and ASTM D638
Design Life Range	Not Applicable
Installation Standards	Number of Coats: 1 Maximum Field Use Dry Film Thickness (in mils): 276 Final Cure Time and Temperature: 1 hour at 3°C Special Comments: Mix ratio of Part A:Part B is 1:1 by volume;
Installation Methodology	• Linings of 1mm – 5mm thickness may be applied in a single pass of the application head. • Cleaning, Drying and Joint-filling are required. • 1 excavation required for every 100-150m approximately. • Same day return to service for every 100-150m renewal length. • Disruption for around 8 hours. • Recommended Deflection in pipe of upto 12 degrees. • CCTV inspection of the coating may be carried out after a minimum cure period of 10 minutes from completion of lining. • The coating shall be allowed to cure for a minimum period of 60 minutes after completion of lining before the commencement of disinfection and flushing procedures.
QA/QC	Disinfect with 50 ppm chlorine and then flush for 1 hour at 5 gallons/minute.
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements	Not Available
V. Costs	
Key Cost Factors	Lesser storage space required, reduced number of pit excavation, single item product, universal item product and does not vary for different pipe diameters, all soil to be treated as contaminated waste, allows use of existing pipe rather than exhuming it, smaller carbon footprint, does not affect external pipe condition, small number of resources amounting to reduced contractor risk, lesser time for installation site, tarmac coating required at excavation pits. Contribution to material costs includes the lining material, part of equipment and use of pipe.
Case Study Costs	Not Applicable
VI. Data Sources	
References	1. http://www.3mwaterinfrastructure.com/Resources/Images/306.pdf

	2. http://www.3mwaterinfrastructure.com/ 3. Email correspondence with Mr. Gary Natwig

Technology/Method	Woven-Hose liner with PE/ Epoxy coating
Status	Innovative
Date of Introduction	2000 in Canada and 2005 in USA
Utilization Rates	With the help of its licensees, over 800,000 feet (250,000 meters) of Aqua-Pipe ® have been installed over the past eight years throughout Eastern Canada and the United States .
Vendor Name(s)	Aqua-Pipe® Sanexen Environmental Services Inc. 1471 Lionel-Boulet boulevard Suite 32 Varennes (Quebec) Canada J3X 1P7 Web: http://www.aqua-pipe.com Email: aqua-pipe@sanexen.com Phone: 1 800 263-07870 1 450 652-9990
Practitioner(s)	John Vose, City of Naperville (630) 420-6741 1200 W Ogden Naperville, IL 60563 USA Kevin Bainbridge City of Hamilton (905) 546-2424 x 5677 320-77 James Street North, Hamilton, ON L8R 2K3 Canada Kamran Sarrami City of Toronto (416) 395-6370 ksarrami@toronto.ca North York Civic Center, 2nd Floor Toronto Ontario M2N 5V7 Canada
Description of Main Features	Sanexen, in collaboration with the National Research Council Canada (NRC) developed a new structural liner for the structural rehabilitation of drinking water main lines. Aqua-Pipe® is an economical and viable alternative to the water main problems where, in the past, dig and replace was the only choice. Aqua-Pipe® is a class IV structural liner that is designed and manufactured with mechanical properties exceeding all

	specifications and meeting drinking water requirements
Main Benefits Claimed	• Rapid installation of ± 2500 feet (800 meters) per week and negotiates bends less than 90^0. • Added life for water main because of corrosion resistance and no effect on water quality. • Economic considerations include low Carbon Dioxide costs.
Main Limitations Cited	Cannot negotiate 90^0 bends
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation and Replacement
Service Connections	The service connections are reinstated from within using a remote controlled mechanical robot. A closed circuit television system is used for monitoring the operation. Water tightness is preserved by the resin that surrounds the threaded cavities of the service connections and ensures a tight bond with AQUA-PIPE®.
Structural Rating Claimed	Class IV (AWWA M28 Manual) fully structural independent liner
Materials of Composition	• Composite of woven seamless textile jacket with resin and polymeric membrane • Aqua-Pipe ® is composed of two concentric, tubular, plain woven polyester jackets with a polymeric membrane bonded to the interior to ensure water tightness. • The liner is impregnated with a specific thermoset epoxy resin that allows a tight bond between the liner and the host pipe.
Diameter Range, inches	6” to 12”
Thickness Range, inches	3 to 6 mm
Pressure Capacity, psi	Maximum operating pressures up to 150 psi
Temperature Range, ^{o}F	35^0 F to 100^0 F
Renewal Length, feet	Up to 500 feet (150 meters) between access pits. The distance between access pits determines the length of the segment.
Other Notes	Hazen-Williams coefficient > 120
III. Technology Design, Installation, and QA/QC Information	
Product Standards	AQUA-PIPE® is certified by NSF to NSF/ANSI 61 and under BNQ Standard 3660-950.
Design Standards	The mechanical properties of AQUA-PIPE® exceed ASTM F1216 and ASTM F1743 recommendations.
Design Life Range	50+ years
Installation Standards	AQUA-PIPE® is precisely aligned with the host pipe's point of entry and pulled through to the exit point.
Installation Methodology	The shaping of AQUA-PIPE® is achieved by pushing a pig through the hose using water pressure. Circulating hot water ensures the curing process. Pulled-in-Place Piping (PIPP) method.

	This product requires the following cure time, temperature, and flush: Day 1: Cure 1.5 hours at 65° C and 25 psi water pressure, then cure for 12 hours at ambient temperature and 50 psi water pressure Day 2: Flush at 2.8 liters per minute for 24 hours at ambient temperature Day 3: Cure for 24 hours at ambient temperature This product requires a 1 hour flush with potable water prior to being placed into service.
QA/QC	No special procedures beyond standard manufacturer's recommendations
IV. Operation and Maintenance Requirements	
O&M Needs	No particular maintenance needs for rehabilitated pipe; Pressure or dry taps for future service connections can be easily carried out with no special equipment
Repair Requirements for Rehabilitated Sections	Typically need to cut out defective pipe section and replace with new pipe;
V. Costs	
Key Cost Factors	List of parameters or key drivers for the costs. Set-up cost: mobilization, temporary by-pass installation, pit excavation & backfill, pipe cleaning & inspection, service plugging & reinstatement, lining, testing, disinfection & site restoration Material costs: liner, resin, new pipe & fittings including valves and hydrants
Case Study Costs	Hamilton =133$/ft (35% savings); Toronto =137$/ft (50% savings); Naperville= 186$/ft (see case study)
VI. Data Sources	
References	http://www.sanexen.com/en/aquapipe/index.htm http://www.sanexen.com/en/aquapipe/tech_info_product.htm

Technology/Method	Continuous Sliplining
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Duraliner™ expandable PVC pipe Underground Solutions, Inc. 229 Howes Run Road Sarver, PA 16055 Phone: 724-353-3000 Fax: 724-353-3020 Email: info@undergroundsolutions.com Web: www.undergroundsolutions.com
Practitioner(s)	Not Available
Description of Main Features	Duraliner™ is a patented, fully structural pipe rehabilitation system. The piping system can handle a wide range of system operating pressures and restore or improve the flow capacity of the host pipe. Duraliner™ PVC provides a design-life of 100+ years. The end result is a brand new pipe within the existing pipe.
Main Benefits Claimed	• It meets System Operating Pressures. • Fully Structural "Stand Alone" System. • It is resistant to water disinfectant induced oxidation and resistant to hydrocarbon permeation.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Fire protection systems , Industrial water lines
II. Technology Parameters	
Service Application	Rehabilitation and Replacement
Service Connections	• Duraliner™ is tapped with standard fittings and procedures. • Duraliner™ easily connects with standard fittings and valves. • Most common applications have Duraliner™ expanded to ductile iron (DI) outside diameters (OD), making standard PVC gasketed fittings compatible. Connect to MJ • Duraliner™ may be tapped with the same tapping saddles used on conventional PVC. • When tapping Duraliner™ one should refer to the Uni-Bell PVC Pipe Association's guidance for tapping PVC.
Structural Rating Claimed	Not Available
Materials of Composition	PVC
Diameter Range, inches	4" to 16"
Thickness Range, inches	Not Available
Pressure Capacity, psi	150psi+

Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Not Available
Other Notes	The improved coefficient of friction offsets the reduction in internal area to maintain or improve flow.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF-61 Certified Products meet all of the same current performance standards and health/safety issues as AWWA C900 and C905 PVC pipe
Design Standards	It conforms to cell classification 12454 as defined in ASTM D1784, meets ANSI/AWWA C900 or ANSI/AWWA C905
Design Life Range	100 Year Design Life
Installation Standards	Not Available
Installation Methodology	1. Minimal excavations are performed. 2. Duraliner™ is fused to length for the project. 3. DuralinerTM is expanded tightly against the interior walls of the host pipe. 4. Exposed ends of the Duraliner™ are expanded to standard fitting sizes. 5. The new Duraliner is cut to length and reconnected to system. 6. Fused Duraliner™ is inserted into cleaned, inspected host pipe.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	As Duraliner™ is expanded molecular reorientation increases its hydrostatic design basis. This works toward offsetting the DR increase from expansion in the pressure rating.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	Website for Underground Solutions Inc.

Technology/Method	Structural CIPP
Status	Emerging
Date of Introduction	Introduced in the US in early 2009
Utilization Rates	Not Applicable
Vendor Name(s)	InsituMain™ Insituform Technologies, Inc 17999 Edison Avenue Chesterfield, MO 63005 Phone: 636-530-8000 Fax: 636-519-8744 Web: http://www.insituform.com
Practitioner(s)	Not Applicable
Description of Main Features	• An AWWA Class IV fully structural pressure rated cured in place technology. • The InsituMain™ system is an ideal solution for the renewal of both distribution and transmission water. • No risk of disrupting or damaging nearby utilities or other underground infrastructure systems.
Main Benefits Claimed	• The system has a polyethylene layer on the inside pipe surface which increases the pipe's smoothness, reduces the surface friction and provides an additional corrosion barrier for the pipe. • It can withstand internal pressure and external load requirements. • Eliminates leakage and corrosion. • Adheres to the existing host pipe. • No need for specialty fittings.
Main Limitations Cited	Bypass required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Industrial Pressure, Fire
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	No specialty fittings required. In 6" and larger pipes service connections can be made by robotic remote access using mechanical sealing apparatus.
Structural Rating Claimed	Exceeds ASTM F1216 and ASTM F1743 standards
Materials of Composition	Epoxy composite layer which is reinforced with glass and polyester fiber materials
Diameter Range, inches	Nominal diameter range from 6 to 36 inches
Thickness Range, inches	Not Available
Pressure Capacity, psi	150 psi+ applications
Temperature Range, ^{o}F	120 ^{o}F
Renewal Length, feet	Not Available

Other Notes	Suitable for Cast/ Ductile Iron, Steel, Asbestos cement, RCP and Thermoplastic. Can do bends up to 45 degrees Include specific notes here such as Water Quality, I/I control, other
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Certified to ANSI/ NSF 61 standards
Design Standards	Not Available
Design Life Range	50 years Design Life
Installation Standards	In accordance with manufacturer's operation manual.
Installation Methodology	1. The composite materials are saturated with a thermosetting epoxy resin system either on the job-site or in an authorized Insituform wet out facility. 2. Using water or air pressure, the tube is then inserted into the host pipe by either a pull-in or inversion method. 3. Following installation, hot water or steam is used to cure the thermosetting resin. 4. The pipe is cooled, the ends are cut and the pipe is returned to service. Lined sections are re-established to the existing system using standard pipe fittings.
QA/QC	Inspection of main prior to installation. Followed by post-installation inspection, pressure testing (at twice the operating pressure).
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before pressing it in to service.
Repair Requirements for Rehabilitated Sections	Excavate, remove the damaged portion of the pipe, install end couplers and bridge the previously damaged location with new pipe and couplers.
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Applicable
VI. Data Sources	
References	http://www.insituform.com/mm/files/InsituMain%20Brochure.pdf

Technology/Method	Compression-based Symmetrical Reduction
Status	Emerging
Date of Introduction	Date of introduction in US is 2001
Utilization Rates	Total HDPE experience worldwide - over 8000 miles.
Vendor Name(s)	InsituGuard™ Flexed HDPE Insituform Technologies, Inc 17999 Edison Avenue Chesterfield, MO 63005 PH: 636-530-8000 FAX: 636-519-8744 Product inquiries to 800-234-2992. http://www.insituform.com/
Practitioner(s)	Not Available
Description of Main Features	Inserted into a new or existing pipeline, the polyethylene liner is continuous, and installed with a close-fit against the inner wall of the host pipe. The polyethylene liner isolates the flow stream from the host pipe wall, eliminating internal corrosion. InsituGuard stops leaks, and can provide a fully structural solution in some cases. InsituGuard typically increases flow capacity.
Main Benefits Claimed	• Rapid installation • Drinking water approved • Negotiates sweeping bends • Utilizes PE 80 (3408) and high-performance PE 100 (4710) • Minimizes disruption
Main Limitations Cited	• Cannot do factory bends • Bypass required
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manhole Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Service Connections have to be excavated.
Structural Rating Claimed	Class 3 or 4 depending upon diameter, pressure and host pipe condition.
Materials of Composition	4710 (PE 100) is preferred.
Diameter Range, inches	6 inches to 10 inches
Thickness Range, inches	DR 17 or thinner
Pressure Capacity, psi	Pressure rating to 150+ psi for Class 3. Class 4 dependent upon DR.
Temperature Range, °F	140°F
Renewal Length, feet	2000+ ft depending on winching capacity.
Other Notes	Pipes may be cleaned, as needed, with high-pressure water jet cleaners, mechanically powered equipment, and winch cable attached devices or fluid-propelled pig devices.

III. Technology Design, Installation, and QA/QC Information	
Product Standards	HDPE is certified as complying with ANSI NSF Standard 61.
Design Standards	Class 4 design based on AWWA/PPI design standards. Class 3 interactive design based on industry accepted design methodology.
Design Life Range	50 years
Installation Methololology	1. Excavations are required for installation and to remove any existing fittings. 2. The PE pipe selected for the project is welded into lengths suitable for installation; this can be the entire length, or shorter segments to accommodate available work space. If shorter segments are used, they will be fused together prior to entering the folding machine. 3. The welded pipe is pushed through the roller box, which alters the shape of the pipe, resulting in a diameter reduction of up to 20% of the cross-sectional area. 4. The liner is inserted into the host pipe. 5. Once the liner is in place, it is cut to length, end fittings are attached and liner is pressurized to snap the bands. 6. Intermediate fittings are installed, service connections are excavated and reconnected, and the completed line is pressure tested, disinfected and returned to service. Access points are backfilled and reinstated.
QA/QC	• Prior to installation of InsituGuard, CCTV inspection of the main is needed to locate any obstructions, protrusion, changes in diameter or in-line valves that could affect the InsituGuard. • After installation, InsituGuard is inspected again visually with CCTV, and any abnormalities are noted. • For the post-installation pressure test, InsituGuard is subjected to an internal pressure equal to twice the known operating pressure, or operating pressure plus 50 psi, whichever is less. • After a stabilization period, the test period is one hour. Limit on make-up water to maintain pressure is 20 gallons per inch diameter per mile of pipe per day.
IV. Operation and Maintenance Requirements	
O&M Needs	Before returning the InsituGuard to service, for potable water, the system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Excavate, remove the damaged portion of InsituGuard and host pipe (if necessary), install end couplers and bridge the previously damaged location with new pipe and couplers as required.
V. Costs	

Key Cost Factors	The most costly material is the pipe.
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.insituform.com/default.aspx http://www.insituform.com/content/309/insituguard---pressure-pipe.aspx http://www.insituform.com/content/312/polyflex_installation.aspx

Technology/Method	On-site Close-Fitted PE liner
Status	Emerging
Date of Introduction	Date of introduction in US is 2001
Utilization Rates	Total HDPE experience worldwide - over 8000 miles. Folded HDPE worldwide experience – approximately 6 miles.
Vendor Name(s)	**InsituGuard™ Folded HDPE** **Insituform Technologies, Inc** 17999 Edison Avenue Chesterfield, MO 63005 PH: 636-530-8000 FAX: 636-519-8744 Product inquiries to 800-234-2992. http://www.insituform.com/
Practitioner(s)	1,000 ft of 19" - 24" Steven Tusler City of Colorado Springs 121 S. Tejon Colorado Springs, CO 80947 (719) 668-8537 19,000 ft of 30" Mr. Dick Fett IMC Agrico Company Mulberry, Florida (863) 648-9990 3,700 ft of 36" Mr. Howard Wellspring City of Baytown, TX 2123 Market St Baytown, TX 77522 713-424-5508
Description of Main Features	Inserted into a new or existing pipeline, the polyethylene liner is continuous, and installed with a close-fit against the inner wall of the host pipe. The polyethylene liner isolates the flow stream from the host pipe wall, eliminating internal corrosion. InsituGuard stops leaks, and can provide a fully structural solution in some cases. InsituGuard typically increases flow capacity.
Main Benefits Claimed	• Rapid installation • Drinking water approved • Negotiates sweeping bends • Utilizes PE 80 (3408) and high-performance PE 100 (4710) • Minimizes disruption

Main Limitations Cited	Cannot do factory bends; Bypass required; Wall thickness limitation dependent upon diameter.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Service Connections have to be excavated.
Structural Rating Claimed	Class 3 or 4 depending upon diameter, pressure and host pipe condition.
Materials of Composition	4710 (PE 100) is preferred.
Diameter Range, inches	12 inches to 48 inches
Thickness Range, inches	DR 17 or thinner
Pressure Capacity, psi	Pressure rating to 150+ psi for Class 3. Class 4 dependent upon DR.
Temperature Range, ^{o}F	140°F
Renewal Length, feet	2000+ ft depending on winching capacity.
Other Notes	Pipes may be cleaned, as needed, with high-pressure water jet cleaners, mechanically powered equipment, and winch cable attached devices or fluid-propelled pig devices.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	HDPE is certified as complying with ANSI NSF Standard 61.
Design Standards	Class 4 design based on AWWA/PPI design standards. Class 3 interactive design based on industry accepted design methodology.
Design Life Range	50 years
Installation Methology	1. Excavations are required for installation and to remove any existing fittings. 2. The PE pipe selected for the project is welded into lengths suitable for installation; this can be the entire length, or shorter segments to accommodate available work space. If shorter segments are used, they will be fused together prior to entering the folding machine. 3. The welded pipe is pushed through the folding machine, which alters the shape of the pipe, resulting in a diameter reduction of up to 40% of the cross-sectional area. The shape is maintained by banding the folded pipe. 4. The liner is inserted into the host pipe. 5. Once the liner is in place, it is cut to length, end fittings are attached and liner is pressurized to snap the bands.

	6. Intermediate fittings are installed, service connections are excavated and reconnected, and the completed line is pressure tested, disinfected and returned to service. Access points are backfilled and reinstated.
QA/QC	Prior to installation of InsituGuard, CCTV inspection of the main is needed to locate any obstructions, protrusion, changes in diameter or in-line valves that could affect the InsituGuard. After installation, InsituGuard is inspected again visually with CCTV, and any abnormalities are noted. For the post-installation pressure test, InsituGuard is subjected to an internal pressure equal to twice the known operating pressure, or operating pressure plus 50 psi, whichever is less. After a stabilization period, the test period is one hour. Limit on make-up water to maintain pressure is 20 gallons per inch diameter per mile of pipe per day.
IV. Operation and Maintenance Requirements	
O&M Needs	Before returning the InsituGuard to service, for potable water, the system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Excavate, remove the damaged portion of InsituGuard and host pipe (if necessary), install end couplers and bridge the previously damaged location with new pipe and couplers as required.
V. Costs	
Key Cost Factors	The most costly material is the pipe.
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.insituform.com/default.aspx

Technology/Method	PolyUrea spray-on Lining
Status	Innovative
Date of Introduction	July 2006
Utilization Rates	Not Available
Vendor Name(s)	PolySpray Hunting Specialized Products 1210 Glendale-Milford Road, Cincinnati, Ohio 45215 US Phone: 513-771-9319 Web: http://www.huntingsp.com/index.html Email: info@huntingsp.com
Practitioner(s)	Not Available
Description of Main Features	• PolySpray is a spray-applied structural lining system that has extraordinary toughness and flexibility. • When applied to the interior of a deteriorated pipeline, PolySpray literally builds a new pipe inside the existing pipeline. This Built-in-Place Pipe (BIPP) trench-less technology is unique. • PolySpray can be applied to large concrete or metal structures, sealing leaks and protecting the structure against corrosion. • The chemistry of polyurea provides polyspray with performance characteristics that cannot be achieved with conventional coating systems. Primary advantages of polyurea include rapid cure, high film build, abrasion resistance and high elongation.
Main Benefits Claimed	1. A Fully Structural Lining - Restores and enhances structural integrity of the system. 2. High Flexibility and Toughness - New lining is not brittle; resists fracture if subjected impact or load. 3. Flexible and Waterproof - Provides a leak tight seal. 4. Good Chemical Resistance - Resists most corrosive effluents. 5. Excellent Abrasion Resistance - Excellent wear resistance; extends life of lined pipe.
Main Limitations Cited	The extremely-short time available for the material to be adequately mixed, passed through the application head, and sprayed onto pipe before it turns solid requires special installation procedures.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storm-water lines
II. Technology Parameters	
Service Application	Rehabilitation, Repair, and Replacement

Service Connections	When the machine is used, service connections need to be covered, for big diameter pipes when a human being is using a machine to spray the polyurea it is easier to handle service connections.
Structural Rating Claimed	PolySpray has been independently tested for structural properties such as; flexural modulus, tensile modulus and elongation so that the correct lining thickness can be recommended depending upon pipe diameter and pipe depth underground. Flexural modulus and tensile strength exceeds those required by ASTM F-1216
Materials of Composition	PolyUrea
Diameter Range, inches	>= 6 inches
Thickness Range, inches	The liner is: tough and flexible, has outstanding corrosion resistance and can be applied in thicknesses from 0.002 up to 0.5 inches
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Recommended for use in cold water installations.
Renewal Length, feet	Not Available
Other Notes	Include specific notes here such as Water Quality, I/I control, other
III. Technology Design, Installation, and QA/QC Information	
Product Standards	No NSF 61 listing
Design Standards	PolySpray meets or exceeds the minimum requirements of ASTM F-1216 Standard Practice for Rehabilitation of Pipelines by Inversion & Curing of Resin Impregnated Tube (CIPP).
Design Life Range	Not Available
Installation Standards	Special equipment developed to install PolySpray is contained in a 36-foot trailer.
Installation Methodology	• The material is mixed as it is applied from the application head by high pressure impingement. • The mixed material is injected into a rotating cone which then centrifugally applies the lining, still in a liquid state, at this stage, onto the pipe wall. • Extremely fast, 2½ -second cure time. • Computer monitored for all the essential parameters such as temperature, rate of material flow, spray head pressure and lining speed • Once pipes have been prepared, the lining hoses will be pulled through the pipe for the required lining length. • The application head then is connected, and the lining started with the hoses being pulled back through the pipe at a controlled rate to provide the specified lining thickness. • As soon as the lining process has been completed, a further

	CCTV survey can be conducted to monitor lining quality and then the pipe can be re-commissioned. •
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	ucononline.com Underground Construction, page 35 http://www.huntingsp.com/productsPolySpray.php NSF/ANSI 61 website

Technology/Method	Woven Hose epoxy coating liner
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Starline HPL-W Starline trenchless technology, LLC 1700 South Mount Prospect Road Des Plaines, IL 60018-1804 USA Phone: 847/768-0889 Cell Phone: 847/387-0455 Mail: edward.johnston@gastechnology.org
Practitioner(s)	Not Available
Description of Main Features	For use in rehabilitation of drinking water main lines
Main Benefits Claimed	Not Available
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Need to be addressed separately. Can be identified externally via digging or internally via robot.
Structural Rating Claimed	Not Available
Materials of Composition	Polyester Woven liner, adhesive and epoxy coatings
Diameter Range, inches	3" to 24"
Thickness Range, inches	Not Available
Pressure Capacity, psi	Up to 450 psi
Temperature Range, ^{o}F	Recommended for use up to 78F
Renewal Length, feet	Not Available
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	All requirements for the technology's application in drinking water pipes in Germany, the KTW recommendations for application of plastics in drinking water pipes and the DVGW W270 Recommended Practice (German Association of Gas and Water), have been complied with. The relevant U.S. certificate, NSF61 (National Sanitation Foundation), has been applied for and will be issued shortly.
Design Standards	Not Available
Design Life Range	Not Available
Installation Standards	Not Available
Installation Methodology	The liner has to be pressed through calibrated rollers before it

	is pushed into the pipe. Liner is then wound on a pressure drum and bolted into an inversion cone which it then attached to the host pipe. The liner is then forced to invert inside the host pipe and the process ends when the liner reaches the catch basket
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.starlinett.com/index.htm

Technology/Method	Close-fit type Tension based Symmetrical Reduction lining
Status	Conventional
Date of Introduction	Late 1980s
Utilization Rates	Over 1,000 miles (1,600km) of Swagelining have been installed to date.
Vendor Name(s)	Swagelining Suite 100 600 Bent Creek Boulevard Mechanicsburg, PA 17050 Telephone: +1 717-724-1900 Fax: +1 717-724-1901 Web: http://www.gl-group.com Email: info.us@advanticagroup.com
Practitioner(s)	Licenser: Murphy Pipeline Contractors, Inc Contact: Andy Mayer 11243-4 St. Johns Industrial Parkway South Jacksonville, FL 32246 Tel: +1 904 620 9702 Fax: +1 904 620 9703 e-mail: andym@murphypipelines.com
Description of Main Features	• The Swagelining system uses Polyethylene pipe which has an outside diameter slightly larger than the inside diameter of the pipe to be lined. After sections of PE are fused together to form a continuous pipe, the PE pipe is pulled through a reduction die, which temporarily reduces its diameter. • This allows the PE pipe to be pulled through the existing pipeline. After the PE pipe has been pulled completely through the pipe, the pulling force is removed and the PE pipe returns toward its original diameter until it presses tightly against the inside wall of the host pipe. The tight fitting PE liner results in a flow capacity close to the original pipeline design. • Swagelining is suitable for the rehabilitation of all types of pressure pipe.
Main Benefits Claimed	• It is not necessary for the PE liner to depend upon the original pipe for strength, unless the new PE pipe is being used to replace the old pipe. • When the host pipe is structurally sound, the wall thickness of the liner may be reduced. • Since sections of PE pipe are butt fused together, there are no joints where leaks could develop in the future.

	• Compact, lightweight equipment requires very little setup time resulting in less disruption, faster installation, and less expense. • It is capable of installing the full range of PE pipe quickly and easily in cast iron, ductile iron, steel, concrete and asbestos cement pipelines. • There is no shrinkage or curing, and no field chemistry or heating is required. Polyethylene is flexible, leak tight, and highly resistant to chemical attack.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Water Main Forced Sewer Other: Gas, Water Injection Lines, Mining Slurry and any other services using metallic pipe.
II. Technology Parameters	
Service Application	Rehabilitation and Replacement
Service Connections	Standard fittings are available to allow sections of PE-lined pipe to be easily and securely reconnected to the rest of your water transmission or distribution system. Wide variety of PE pipes and a full complement of tapping, branching, and connection methods have been developed to provide a total renewal system.
Structural Rating Claimed	This depends on the PE pipe rating as well as whether or not the PE is to be used as a liner or a replacement for the existing pipe.
Materials of Composition	Polyethylene
Diameter Range, inches	4" to 48"
Thickness Range, inches	Any thickness of PE and host pipe
Pressure Capacity, psi	This depends on the PE pipe rating as well as whether or not the PE is to be used as a liner or a replacement for the existing pipe.
Temperature Range, ^{o}F	This depends on the PE pipe rating as well as whether or not the PE is to be used as a liner or a replacement for the existing pipe.
Renewal Length, feet	Up to 3,000’ between excavations.
Other Notes	Not Applicable
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NOT approved under NSF 61 Listing (PE pipe is approved for potable water service in most countries, and can be specified to withstand a wide range of internal pressures and burial depths.)
Design Standards	PE pipes used in the Swagelining process are manufactured to ISO, AGA, ASTIVI, and API standards, so lines renewed by this process have known physical properties and an established service life.
Design Life Range	As per specification of PE pipe used.
Installation Standards	As per client specifications.
Installation Methodology	As per sliplining, but the PE pipe is pulled through a die prior to being pulled through the host pipe.
QA/QC	-N/A-
IV. Operation and Maintenance Requirements	

O&M Needs	Resistant to corrosion, abrasion, and ground movement. Yes, as PE pipe is used.
Repair Requirements for Rehabilitated Sections	Standard as PE pipe is used.
V. Costs	
Key Cost Factors	Social & economic cost of open cut replacement versus trenchless rehabilitation of existing pipe lines Labour, transport, PE prices & delivery, joints (price & delivery), mobilization, pit excavation, cleaning, inspection, gauging, lining, testing, re-connection, site restoration.
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.gl-group.com/en/is/8816.php http://www.gl-group.com/pdf/Swagelining_DS.pdf

Technology/Method	Close-fit PRP Liner
Status	Emerging
Date of Introduction	Introduced in the US in 1997
Utilization Rates	Over 800,000 ft. installed worldwide
Vendor Name(s)	Thermopipe Insituform Technologies, Inc 17999 Edison Avenue Chesterfield, MO 63005 Phone: 636-530-8000 Fax: 636-519-8744 Web: http://www.insituform.com
Practitioner(s)	1550 ft of 12” water main Dennis Pay City of South Salt Lake 195 W. Oakland Avenue South Salt Lake UT 84115 801-483-6038 1400 ft of 8" Terry Hodnik NIES Engineering Hammond , IN 219-844-8680 1000 ft of 8" George Fanous City of Grand Prairie, TX 972-237-8143
Description of Main Features	• Thermopipe® is a thin reinforced polyethylene liner that is ideally suited for rehabilitation of distribution water main lines and other pressurized piping systems. • Supplied as a factory-folded “C” shape liner, the Thermopipe® polyethylene liner is winched into the host pipe from a reel and reverted with air and steam. • Once inflated and heated, the liner forms a close-fit within the host pipe, creating a jointless, leak-free lining system able to independently carry the full system internal design pressure up to 230 psi. • The installation process is simple and can usually be completed within an 8-hour time period.
Main Benefits Claimed	• The fully structural polyethylene liner stops leakage by bridging and sealing holes and faulty joints with the liner. • Improves quality of water within the water main. • Reduces social cost of water main repair because of low foot

	print and minimal downtime. • Extends life of water infrastructure
Main Limitations Cited	Bypass required, will collapse under external loads
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Industrial Fire applications, Fire applications
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	In pipe 6" in diameter and greater, service reconnections up to 10" diameter can be made to the lined pipe by remote internal connection of a mechanical sealing apparatus
Structural Rating Claimed	Independent structural lining, AWWA Class 4
Materials of Composition	Polyester Reinforced Polyethylene
Diameter Range, inches	2.75" to 12"
Thickness Range, inches	0.08" to 0.20"
Pressure Capacity, psi	pressure rating of 170 psi (230 psi available for 4" through 8")
Temperature Range, ^{o}F	140°F
Renewal Length, feet	1600 ft for 4"-8" and 700 ft for 10"-12"
Other Notes	Can do bends up to 45 degrees.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Thermopipe is certified as complying with ANSI/NSF Standard 61
Design Standards	Manufacturer supplied internal pressure rating
Design Life Range	50 year design life
Installation Standards	In accordance with manufacturer's recommendations
Installation Methodology	Installation of Thermopipe a. The existing pipe shall be dewatered and reasonably free of incoming water. If water is present, measures shall be taken to minimize the possibility of trapping water between the Thermopipe and the existing pipe. b. The Thermopipe shall be installed through an appropriate pipe opening by means of hand or powered pulling device. Inflation and Steam Forming a. The Thermopipe shall be inflated using compressed air. b. The Thermopipe shall be formed by softening and pressurizing with steam. Steam forming shall apply sufficient heat and pressure to completely erase the folded memory of the PRP and create a tight fit to the host pipe Cooling Adequate air pressure shall be maintained continuously during the cooling process to ensure a tight fit between the PRP and the host

	pipe when pressure is removed. <u>Finished Thermopipe</u> The finished Thermopipe shall be continuous and as free as commercially possible from visual defects such as foreign inclusions, pinholes, twists and blistering. The Contractor shall correct defects that will cause operational problems in a mutually acceptable manner and without cost to the Client. <u>End Couplers</u> After installation, the Thermopipe shall be cut to appropriate length to allow fitting of End Couplers. End Couplers shall be capable of maintaining a leak proof seal at the system design pressure.
QA/QC	• Prior to installation of Thermopipe, CCTV inspection of the main is needed to locate any obstructions, protrusion, changes in diameter or in-line valves that could affect the Thermopipe. • After installation, Thermopipe is inspected again visually with CCTV, and any abnormalities are noted. • Pressure testing is carried out after Thermopipe has cooled to the original ambient ground temperature. The Thermopipe is subjected to an internal pressure equal to twice the known operating pressure, or operating pressure plus 50 psi, whichever is less. • After a stabilization period, the test period is one hour. Limit on make-up water to maintain pressure is 20 gallons per inch diameter per mile of pipe per day.
IV. Operation and Maintenance Requirements	
O&M Needs	Before returning the Thermopipe to service, for potable water, the system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Excavate, remove the damaged portion of Thermopipe and host pipe (if necessary), install end couplers and bridge the previously damaged location with new pipe and couplers as required.
V. Costs	
Key Cost Factors	In order, most costly materials are fittings and Thermopipe.
Case Study Costs	Not Available
VI. Data Sources	
References	Insituform Website and Thermopipe brochure

Technology/Method	Spray Epoxy coating
Status	Conventional
Date of Introduction	-N/A-
Utilization Rates	-N/A-
Vendor Name(s)	Belzona® 5811 Belzona, Inc. 2000 N.W. 88th Court Miami, Florida U.S.A. 33172 Phone: (800) 238-3280 Web: http://www.belzona.com/ E-mail: belzona@belzona.com
Practitioner(s)	-N/A-
Description of Main Features	Belzona® 5811 is a two-component system applied by brush or spray for protection of metallic and non-metallic surfaces operating under immersion conditions in contact with aqueous solutions and aggressive chemicals.
Main Benefits Claimed	Belzona® 5811 provides protection from the effects of salt water, acid, alkali, alcohol, hydrocarbon and the environment. It is advertised as long lasting and economically sound system. Main advantages of Belzona are: 1. Repair and protect weld seams 2. Repair and seal pipe expansion bellows 3. Repair existing linings 4. Repair leaking pipes 5. Repair steam cut or wire drawn flanges 6. Re-form/reseat distorted or corroded flange faces
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Pipe surfaces in contact with aqueous solutions and aggressive chemicals.
II. Technology Parameters	
Service Application	Rehabilitation/ Repair
Service Connections	Spray application hence connections may have to be plugged or handled separately.
Structural Rating Claimed	Not Available
Materials of Composition	Epoxy
Diameter Range, inches	For pipe sizes larger than 16”
Thickness Range, inches	10 mils
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Not Available
Other Notes	Final Curing Time is 5 days and at 68°F temperature. A re-coat Cure

	Time is for 6-8 hours at 68°F temperature for a maximum of 72 hours.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI /NSF 61 approved
Design Standards	Not Available
Design Life Range	Not Available
Installation Standards	Not Available
Installation Methodology	The epoxy system is achieved by spraying 2 coats. Each coat having a mix ratio of Part A to Part B at 3 to 1 by volume.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.belzona.com/prod5k.aspx http://www.nsf.org/Certified/PwsComponents/Listings.asp?Company=05720&Standard=061 Product Flyer – Belzona 5811

Technology/Method	Pipe Wrapping
Status	Conventional
Date of Introduction	Invented and introduced in 1989 at The Arizona State University, U.S. Developed and largely used in the South-Western states.
Utilization Rates	Over 100,000 linear feet have been wrapped by the CarbonWrap family of products across the country
Vendor Name(s)	CarbonWrap CarbonWrap™ Solutions LLC 3843 N. Oracle Rd. Tucson, Arizona 85705 USA Fax: (520) 408-5274 Toll Free: (866) 380-1269 Phone: (520) 292-3109 E-mail: info@carbonwrapsolutions.com Web: http://www.carbonwrapsolutions.com
Practitioner(s)	Not Available
Description of Main Features	• One of the most effective and economical applications of CarbonWrap™ is in strengthening of buried pipes. • Concrete and steel pipes can be strengthened to take pressures even greater than that of their original design value at a fraction of the cost and time of alternatives.
Main Benefits Claimed	• Requires no excavation Increases pipe strength to even higher than its original pressure rating • Access is made only through manholes • Creates a very smooth surface and improves pipe flow significantly • Requires no heavy equipment for installation • Costs far less than the alternatives and results in speedy construction
Main Limitations Cited	Cannot be used if the temperature is above 200F
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Repair
Service Connections	This repair technique is only good for the pipe barrel?
Structural Rating Claimed	Structural material
Materials of Composition	Epoxy and carbon
Diameter Range, inches	Works for 3 feet and larger diameter pipe
Thickness Range, inches	one-eighth of an inch thick
Pressure Capacity, psi	10 times the pipe
Temperature Range, ^{o}F	Application in humid temperature is not recommended.
Renewal Length, feet	No limitation-1000/2000feet shorter lengths

Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 compliant
Design Standards	ACI 440
Design Life Range	Minimum 25 years
Installation Standards	As per manufacturer guidelines
Installation Methodology	• In the case of 3 foot and larger diameter pipes, simple access is made through the manholes and all operations are conducted internally. • If the pipe can be accessed from the outside, the wrapping can be performed on the outside face of the pipe; resulting in the same benefits. It is generally applied in the following format: Epoxy-fiber-epoxy-fiber.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Regular cleaning is required. Maintenance strategies should include condition assessment measures.
Repair Requirements for Rehabilitated Sections	Re-lining may be done
V. Costs	
Key Cost Factors	The composite material is generally the key governing cost in the contracts. It may vary from job to job depending on site accessibility and pipe condition.
Case Study Costs	Material cost at 10-15$/ sq.ft
VI. Data Sources	
References	http://www.carbonwrapsolutions.com/PDFinfo/Brochure.pdf

Technology/Method	Asphalt-Emulsion Spray coating
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	EM-12 Seaboard Asphalt Products Company 3601 Fairfield Road Baltimore, MD 21226 Toll Free: (800) 536-0332 Voice: (410) 355-0330 Fax: (410) 355-5864 Email: sales@seaboardasphalt.com Web: http://www.seaboardasphalt.com/
Practitioner(s)	Not Available
Description of Main Features	Clippership EM-12 Pipe Coat is a single component non-flammable highly rubberized asphalt emulsion modified with polymers and plasticizers.
Main Benefits Claimed	Clippership EM-12 Pipe Coat is a sprayable coating designed to protect from corrosion, waterproofing, environmental elements and achieves excellent durability and flexibility.
Main Limitations Cited	Material should not be allowed to freeze. Thinning should not be done.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: None
II. Technology Parameters	
Service Application	Repair and Rehabilitation
Service Connections	Service connections are plugged and coated at a later stage of required.
Structural Rating Claimed	Not Available
Materials of Composition	Asphalt emulsion
Diameter Range, inches	For pipes larger than 3”
Thickness Range, inches	Maximum dry field thickness of 3 mils
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Approved for operating temperature of 73.4^{o}F
Renewal Length, feet	Not Available
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI/NSF 61 Approved
Design Standards	ASTM D997-73, ASTM-D-562, ASTM-D-36, ASTM-D-5
Design Life Range	Not Available
Installation Standards	AASHTO M140-70

Installation Methodology	Clippership EM-12 Pipe Coat must be applied to a surface that is free from all foreign matter. This material should remain dry until it has cured. This material should be mixed before using. Curing time is less than 1 hour.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Seaboard Gilsonite Paint should be kept in a warm area before usage during cold seasons, but this material can be used year round and the only protection would be from weathering on the container.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.seaboardasphalt.com/EM-12_Data.htm

Technology/Method	Pipe Wrapping
Status	Conventional
Date of Introduction	US Patent 5931198 - Introduced in 1988 in the US market
Utilization Rates	Not Available
Vendor Name(s)	Fyfe Co. LLC The FibrWrap Company Nancy Ridge Technology Center 6310 Nancy Ridge Drive, Suite 103 San Diego, CA 92121-3209 Phone: 858.642.0694, 858.642.0947 Email: info@fyfeco.com Web: http://www.fyfeco.com
Practitioner(s)	1. Gary Schult Project Sponsor Kiewit Western Company For 60" through 96" PCCP pipes Phone: 602-437-7841 2. John Galleher Senior Engineer San Diego County Water Authority For Pipeline 5: 2 sections of 24' for 96" pipe 610 W 5th Avenue Escondido, CA 92025 Phone: 760-488-1991 Cell: 760-233-3206 3. Don Lieu and Robert Diaz Chief and Engineering Project Manager Utility Design Division Department of Public Works Bureau of Engineering Howard County, MD Cell for Mr. Lieu: 410-313-6121 Cell for Mr. Diaz: 410-313-6125
Description of Main Features	The Tyfo® Fibrwrap® Pipe Rehabilitation System is a Fiber-Reinforced Polymer (FRP) based trenchless technology method for the repair, strengthening and retrofit of corrosion-damaged and distressed large diameter PCCP, RCCP, and Steel pressure pipelines used in municipal, industrial and other applications.
Main Benefits Claimed	• Restoration of Pipelines to Original Hydrostatic Pressure Capacity • Accommodation of Increased Internal Pressure Requirements • Re-establishment of Flexural Loading Capabilities

	• Restoration of Original External Load Bearing Capacity • Upgrade Load Bearing Capacity Due to Higher Traffic Requirements • Non-metallic material ensures that corrosion-related damages do not recur in rehabilitated pipe segments.
Main Limitations Cited	Limited to Sectional Repairs. Requires Highly Trained Technicians and Extensive Polymer Durability Studies to Predict Lifecycle.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Tunnel
II. Technology Parameters	
Service Application	Repair
Service Connections	Repaired dependent on size.
Structural Rating Claimed	Fully structural rehabilitation of only distressed pipe segments
Materials of Composition	Layers of FRPs (carbon fibers and glass fibers)
Diameter Range, inches	30" through 201" and above
Thickness Range, inches	0.25" to 1"
Pressure Capacity, psi	100 Psi to 350 Psi.
Temperature Range, ^{o}F	220°F
Renewal Length, feet	16 ft sections – 1200 ft lengths typically
Other Notes	Care should be taken during installation to prepare the surface for bonding and the humidity must be maintained. It is non-Corrosive in nature, rapid installation schedule, long term durability, leaves the internal diameter of the pipe unchanged, has reduced surface co-efficient of friction and negligible loss of pipe volume
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI/NSF 61 approved
Design Standards	Full scale testing, weather ability studies and in-field service life have proven the durability of FRP-based systems (50-75) years ASTM G 53, Biological Growth Support Potential Test (BGSP) cleared Long Term Durability Testing by Metropolitan Water District of Southern California. External loading from soils to pipe should be considered and designed accordingly. ACI 503R-93, ACI 546R-96, ACI D 3039-93 and ACI D 695-02a.
Design Life Range	Minimum 50-year service life
Installation Standards	ICC Pmg Report and Fyfe Co. QA/QC
Installation Methodology	By bonding layers of FRPs to the internal surface of a pipeline, advantage is taken of the inherent strength of these FRP systems which in turn contribute to significantly increasing both the hoop and axial strengths of a distressed pipe segment. Application of the layers of fiber composites virtually leaves the internal diameter of the pipe unchanged and results in a rapid installation process that is both economical and, most importantly, fully structural. When necessary, protective coatings can be applied for aggressive

	chemical or environmental exposures. Speed of completion is 48 to 72 hours
QA/QC	As per Manufacturer provided manual, which includes responsibility sharing on site and in lab, manufacturing specifications, installation controls, storage, testing, certifications, calibrations, complaints and inspection.
IV. Operation and Maintenance Requirements	
O&M Needs	Indicated and provided by Manufacturer.
Repair Requirements for Rehabilitated Sections	Periodic Visual Inspections. Top coat renewal.
V. Costs	
Key Cost Factors	Exact pricing will depend on: 1) Distance from repair location to surface access. 2) Quantity of lineal feet contracted 3) Lead time for crews mobilization 4) Allotted time for onsite completion of project 5) Project Service Life of repair
Case Study Costs	$1000/ LF - $6000/ LF this varies based on design requirements and project conditions. Typically, a 54” pipe operating at 150psi with 12’ of cover would be $3000 lf.
VI. Data Sources	
References	http://www.fibrwrapconstruction.com/pipe.htm http://www.fibrwrapconstruction.com/pipe/pipebrochure.pdf www.fyfeco.com

Technology/Method	Pipe Wrapping
Status	Innovative
Date of Introduction	Product is ready to be commercialized, but not used in the market as of March, 2009
Utilization Rates	Not Applicable
Vendor Name(s)	Foreva[R] Frey-C-Wrap system Frey-CWrap B500 polymer, Resin 382 and Resin 385 FREYSSINET L.L.C. 44880 Falcon Place, Suite 100 Sterling, VA, 20166 Phone: (703) 378-2500 Fax: (703) 378-2700 Web: http://www.freyssinetusa.com/ Email: freyssinet@freyssinetusa.com
Practitioner(s)	1. 24'5" diameter pipe repair by additional post-tensioning - Phoenix, AZ 2. 96" diameter pipe repair by additional post-tensioning - Potomac, MD 3. 84" diameter pipe repair by additional post-tensioning - Tucson, AZ
Description of Main Features	Reinforcement by Carbon Fiber Reinforced Polymer (CFRP) lining is a promising technology for pipe repair and to meet this growing demand for the technology, Freyssinet has developed FREY-CWRAP®: a carbon fiber/epoxy resin composite specifically designed for application on PCCP surfaces.
Main Benefits Claimed	This technology will make sure that there is no delamination due to internal pressure. Complete water tightness is guaranteed. It is a primary solution to corrosion in PCCP pipes. It can also handle premature failing due to hydrogen brittleness, corrosion of the liner initiating from inside the pipe and leakage due to defects or differential settlement. It uses a Foreva[R] Frey C-wrap robot making it an industrialized and automated pipe relining.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Mainly PCCP pipes
II. Technology Parameters	
Service Application	Repair
Service Connections	Need to be plugged. Joints can be bridged by NSF approved glass-fiber based products.
Structural Rating Claimed	Not Available
Materials of Composition	Carbon Fiber Reinforced Polymer
Diameter Range, inches	59” and larger diameter pipes

Thickness Range, inches	20-27 mils
Pressure Capacity, psi	290 psi
Temperature Range, ^{o}F	3^{o}C above dew-point, generally ambient temperature is acceptable.
Renewal Length, feet	Not Available
Other Notes	Eponal 387 - Mix ratio of A:B is 100:27; Eponal 385 - Mix ratio of A:B is 100:20; Eponal 382 - Mix ratio of A:B is 100:34. Polymer Product comes in standard size of 24" width.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 approved
Design Standards	Meets and adheres to ASTM D 3039
Design Life Range	50-year design life
Installation Standards	As per manufacturer's installation manual
Installation Methodology	1. Pipeline is dewatered. 2. Defects and delaminated concrete surfaces are repaired with Foreva solutions 3. Inner surface is dried. 4. The robot is introduced in the pipeline through existing manholes or normal entry points. 5. It is assembled and loaded with carbon fabric rolls and resin barrels. 6. Initially a layer of Epanol Resin 385 is coated followed by 11 coats of Resin 382 and Resin 385 such that the last coat is Resin 385, which seals the edges. 7. Curing time and recoating is done at ambient temperature within 0-2 hours. 8. Final coat has a cure time of 15 days at ambient temperature. If a second coat is applied, it shall be cured for 7 days.
QA/QC	Bond tests are performed to check the bond strength of 2MPa. Ensure a minimum overlapping of 600m.
IV. Operation and Maintenance Requirements	
O&M Needs	Freyssinet took the technique one step further by developing the FREY-CWRAP® robot, automated equipment capable of repairing pipes between 60" and 120" in diameter at high speeds.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	It less expensive to replacing or tubing of damaged pipe sections.
VI. Data Sources	
References	http://www.freyssinetusa.com/tech_sheets/structural_repairs/Durable%20PCCP%20repair%20tech.pdf http://www.freyssinetusa.com/activity_pipe_repairs.html Brochure provided by Freyssinet USA

Technology/Method	Stainless Steel Sleeve
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Hydro-Seal™ LINK-PIPE Inc. 27 West Beaver Creek Road - Unit #2 Richmond Hill, ON Canada L4B 1M8 North American Calls: 800-265-5696 Overseas Calls: 905-886-0335 Fax: 905-886-7323 E-mail: info@linkpipe.com Web: http://www.linkpipe.com/applications.htm
Practitioner(s)	Not Available
Description of Main Features	Hydro-Seal™ is an internal repair method, designed for joint rehabilitation of water main lines, repair of pin-holes, cracks and areas of corrosion.
Main Benefits Claimed	Hydro-Seal™ provides long-term seal of leaks using mechanically locked stainless steel sleeves and aquatic resin sealers. - Seals leaking, separated, misaligned and offset joints and seals pinholes
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Repair
Service Connections	Need to address separately. Punching holes in the sleeve is not recommended.
Structural Rating Claimed	Not Available
Materials of Composition	The sleeve core is made of stainless steel SST-316 with internal locking mechanism. Outside gasket is saturated with resin that is mechanically pressed against the host pipe when sleeve is expanded and locked in place. The resin is ambient temperature cured and seals the sleeve in place and mechanically bonds to the host pipe, thus sealing the joints, pin holes and cracks in the pipe.
Diameter Range, inches	4" to 54"
Thickness Range, inches	Less than 3/8”
Pressure Capacity, psi	Hydro-Seal™ is tested up to 560 psi. (37 bar) for ultimate pressure over a 3/8-inch (10mm) wide open joint. Maximum recommended working pressure in the pipe is 150 psi
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Standard lengths of 12", 18", 24" and 36" are available.
Other Notes	Not Available

III. Technology Design, Installation, and QA/QC Information	
Product Standards	All components of the product have NSF or FDA approval. Customization is available on request.
Design Standards	Not Available
Design Life Range	Not Available
Installation Standards	Not Available
Installation Methodology	Including curing method and reinstatement of service method: • Sleeves in diameters 4"-24" can also be supplied with Ratchet Lock mechanism. • The Ratchet Lock mechanism was designed for the purpose of creating dimensional compatibility in host pipe. • Old cast iron mains may have unpredictable variations in manufacturing tolerances, roundness and joint offsets to which the sleeve must conform. • Sleeves Dia. 25"-54" come designed with single fixed diameters allowing customization at time of ordering if requested by the customer.
QA/QC	Link-Pipe HydroSeal™ is manufactured at the Link-Pipe factory under ISO-9001:2000 certified quality control conditions.
IV. Operation and Maintenance Requirements	
O&M Needs	Regular inspection and cleaning is required.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Cost of stainless steel is key. Variations in product size can also affect the size.
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.linkpipe.com/applications.htm

Technology/Method	Pipe wrapping
Status	Innovative
Date of Introduction	Largely used in the oil and gas market
Utilization Rates	Not Available
Vendor Name(s)	A+ Wrap™ Pipe Wrap P.O. Box 270190 Houston, TX 77277 **Phone:** 713.365.0881 **Fax:** 713.463.4459 Web: http://www.piperepair.net/index.html E-mail: info@piperepair.net Toll free: 877-PIPE-FIX
Practitioner(s)	Not Available
Description of Main Features	The A+ Wrap Repair System is a pliable water-activated high strength composite sleeving system used to permanently repair external defects associated with general corrosion up to 80% wall loss, blunt dents and gouges. The system is comprised of a high compressive strength putty, an Epoxy Coating, Smart Pig Detector Tabs (as applicable) and the load carrying composite wrap. A+ Wrap (PWAP) is used to rehabilitate D.O.T. regulated pipeline.
Main Benefits Claimed	• It is a high strength piping remediation wrap consisting of proprietary glass fiber reinforcement fabric that is factory impregnated with durable, moisture cured polyurethane (MCU) resins. • It offers complete non-intrusive piping remediation, repair, reinforcement, and/or complete hoop strength replacement to any size piping, constructed of any material, in any shape or configuration including elbows, manifolds, tees, reducers or bends. • It is an efficient, economical, simple to use alternative to sleeves, welding or pipe replacement. • It is chemically resistant, nonconductive and temperature resistant.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Oil and Gas lines
II. Technology Parameters	
Service Application	Repair and rehabilitation
Service Connections	Service connections have to be plugged and done separately if required.
Structural Rating Claimed	Shear Modulus 185,000 psi as per ASTM D5379 Tensile Modulus 3.01 x 10^6psi as per ASTM D3039

	Tensile Strength 51,800 psi as per ASTM D3039 Flexural Modulus 1.9 x 10^6 psi as per ASTM D790 Thermal Expansion 10.2 (um/m/C^o) as per ASTM E831
Materials of Composition	Resin Impregnated Woven fiberglass
Diameter Range, inches	Not Available
Thickness Range, inches	Ply Thickness 0.022"
Pressure Capacity, psi	Recommended for 900 psi
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Not Available
Other Notes	Natural color is transparent Creme gloss. Setting Time of 1 hour and a curing time of 24 hours to achieve 100% operational use.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Allowed for D.O.T. pipeline repairs under 49 CFR, Parts 192 and 195, as well as being validated and certified for use under the ASME PCC-2 Article for B31.3, B31.4 and B31.8, ISO 24817. No NSF/ ANSI 61 listing available
Design Standards	Not Available
Design Life Range	20 years+ life
Installation Standards	Not Available
Installation Methodology	1. Preparation Prepare pipe by abrasive blast to produce a uniform 2.5 to 4 mil profile. Disk grinding or wire wheel can be used as alternatives in some situations. 2. Installation Apply accompanying undercoating, according to directions, over prepared area. Wrap with PWAP tightly over the coating. Wrap a layer, spray with water and repeat until area is covered. Wrap Constrictor Wrap, perforate, remove when cured.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.piperepair.net/apluswrap.html

Technology/Method	Polyurethane Spray-applied coating
Status	Conventional
Date of Introduction	Introduced on 1st January 1990 in the US and is developed by Sprayroq Inc.
Utilization Rates	Over 150,000+ Structures repaired/rehabilitated to date
Vendor Name(s)	SprayWall® Sprayroq, Inc. World Headquarters 4707 Alton Court PO Box 101707 Birmingham, AL 35210 USA Phone: 800-634-0504 | 205-957-0020 Fax: 205-957-0021 Email: info@sprayroq.com Web: http://www.sprayroq.net/index.php
Practitioner(s)	1. Wayne Schutz Assistant Manager Derry Township, PA E-mail: wschutz@dtma.com Office: 717-566-3237, X 312, Cell: 717-497-8026 2. Rodney Jones Construction Program Manager County of Sarasota, FL E-mail: rjones@scgov.net Cell: 941-232-8295
Description of Main Features	SprayWall® is a naturally golden colored, durable, spray-applied 100% VOC-free polyurethane coating.
Main Benefits Claimed	SprayWall® is fast and easy to install with a superior corrosion resistance. It provides both structural enhancement and chemical resistance against all elements that eat away at underground structures.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Manholes Appurtenances Water Main Other: Tanks, Wet wells, Lift stations, Clarifiers, Digesters, Flow Channels, i.e. any exposed walls or surfaces.
II. Technology Parameters	
Service Application	Repair and Rehabilitation
Service Connections	Connections need to be plugged or bypassed if in pipe/structures during installation
Structural Rating Claimed	• Tensile Strength 7450 psi • Compression Strength 19,000 psi • Flexural Modulus of Elasticity (Short Term) 735,000 psi,

	(Long Term 519,000 psi). • Elongation < 3% at break. • Manning's "n" =.0009
Materials of Composition	100 % solids - polyurethane
Diameter Range, inches	42" and greater on pipes and unlimited on man entry structures
Thickness Range, inches	up to ½" and 13mm or greater in special applications
Pressure Capacity, psi	735,000 psi Flex Modulus (Short Term)
Temperature Range, ^{o}F	Operating temperature upto 140°F
Renewal Length, feet	Not Available
Other Notes	Complete capability to handle hydrostatic loading if required. Solvent Cleaning (SSPC-SP1) may be necessary for steel. Surfaces to be treated must be cleaned of all oil, grease, rust, scale, deposits and other debris or contaminants. All resins, including SprayWall, require a clean and dry substrate for optimal performance.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 certified
Design Standards	Thickness Design for Structural- F1216-07b Appdx X1
Design Life Range	50 year design life retaining 70% of Flex Modulus
Installation Standards	Per Manufacturer's Guidelines
Installation Methodology	After the A and B components are mixed, SprayWall begins to gel in about 8-12 seconds, with a tack free condition after one minute. Within 30-60 minutes, the initial cure is completed and the structure is capable of accepting flow while the complete curing continues for the next 4-6 hours.
QA/QC	Licensed Installers (Sprayroq Certified Partners, SCP's) are trained in proper substrate cleaning and preparation.
IV. Operation and Maintenance Requirements	
O&M Needs	Can be cleaned with standard cleaning equipment
Repair Requirements for Rehabilitated Sections	Surface preparation per Manufacturer's Guidelines
V. Costs	
Key Cost Factors	Amount of surface preparation
Case Study Costs	Corrosion only $200-300/VF Structural $300-500+/VF
VI. Data Sources	
References	http://www.sprayroq.net/content/view/47/68/lang,english/ Spraywall – Online Brochure

Technology/Method	Pipe Wrapping
Status	Conventional
Date of Introduction	Amcorr Products introduced products in 2000 in the US under its parent company Kleiss en Co BV
Utilization Rates	Widely used across industrial and commercial applications
Vendor Name(s)	VISOTAQ COAT WRAP and EZ WRAP Amcorr Products 8000 IH 10 West #600 San Antonio, TX 78230 Toll Free: 877 586 3710 Fax: 210 524 7732 E-mail: info@amcorrusa.com Web: http://www.amcorrusa.com/
Practitioner(s)	City of Houston, 2004 Application: Use VISCOTAQ EZ WRAP for Soil air interface, Coating rehab, and above ground pipe spans
Description of Main Features	VISCOTAQ is a coating in wrap form for above/underground use It is used to protect components or objects from adverse environmental effects. Examples of such components include couplings, flanges, lifting lugs, thermite welds, and flanges on the detachable shafts of aboveground tank systems, pipelines and pipe joints.
Main Benefits Claimed	It provides Soil/Air Interface rehabilitation, pipe field Joint protections and spot repairing of existing coating. Pipe supports, splash Zones, river and bridge crossings can be coated for protection against environmental actions. Its main benefit is to solve corrosion problems by forming a corrosion protective barrier.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Joints and external protection to pipelines
II. Technology Parameters	
Service Application	Repair
Service Connections	Not Available
Structural Rating Claimed	Adheres or exceeds ASTM G8, ASTM G14, ASTM B117, ASTM D1000, DIN 30672, ASTM D570 and EN 12068 standards
Materials of Composition	Synthetic a-polar polymers
Diameter Range, inches	Not Available
Thickness Range, inches	Pipes having diameter larger than 0.07” can be wrapped.
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	-60^{o}F to 185^{o}F. Can be applied in a humid atmosphere that does not reach the dew point.

Renewal Length, feet	Not Available
Other Notes	It requires a 1 cm. overlap It has an excellent adhesion to steel, FBE, coal tar, etc.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI/ NSF 61 not approved Hence not to be done for the surface in contact with water. Recommended and approved member of IDS Water
Design Standards	Designs adhere or exceed ASTM D 2240, ASTM D 570, ASTM G 95, ASTM G8, EN 12068, ASTM G14, EN 12068, EN 12068/DIN 30672 standards.
Design Life Range	Life Cycle of the product is estimated at 40 years
Installation Standards	Not Available
Installation Methodology	1. Cleaning Prepare surface grade to St 2 Swedish Standard, including cleaning, scrapping, wire-brushing and rust removal. This requirement refers to surfaces of hot-rolled steel. It should then have a faint metallic sheen. Chloride contamination of the surface is of no importance, so washing the substrate prior to the application is not required. Areas of scale and laminations are removed by blast cleaning. 2. Application It should be applied without tension in a relaxed way making sure all the time the VISCOTAQ COAT WRAP is adhering to the total circumference of the substrate surface. Proper application is regardless of the width. It can be mechanically protected by OuterWrap Tap.
QA/QC	Product is manufactured under ISO 9001
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.amcorrusa.com/tdscoatwrap.pdf http://www.amcorrusa.com/index.htm

Technology/Method	Polymer Resin Lining
Status	Conventional
Date of Introduction	Introduced in 1998
Utilization Rates	10000km+ lining applied to date
Vendor Name(s)	Acuro System Acuro Inc. 1641, Comstock Rd. Ottawa Canada K1C 1T1 Tel.: (613) 446-1010 Tel. Toll Free in Canada: 1 (866) 330-6832 Email: info@acuro.ca Web: http://www.acuro.ca
Practitioner(s)	City of Vaudreuil-Dorion, Quebec
Description of Main Features	Cost-effective water main rehabilitation and NSF-61/ANSI compliant fully structural system
Main Benefits Claimed	Restores hydraulic capacity Enhances pipe structure Stops leaks, breaks and corrosions Designed to provide a non to semi to fully structural protection
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Need to be plugged or inspected and connected post-rehabilitation.
Structural Rating Claimed	Meets ASTM F-1216
Materials of Composition	Polymer Resin
Diameter Range, inches	For pipes 6” and up
Thickness Range, inches	Known 3mm thickness case
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	200 meters lined between 2 access pits
Other Notes	Used for asbestos, ductile iron and previously coated pipes Hazen-Williams coefficient more than 120 Polymeric resin shows 10% elongation to help in-case of pipebreaks
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI/NSF 61 compliant
Design Standards	Designed as per ASTM F 1216
Design Life Range	Minimum 50 years
Installation Standards	Following the cleaning of the water main and before lining, the probe is inserted throughout the entire length of the main using a

	pulling and transmission cable. All defects correspond to a loss of material (pitting, corrosion) reduce the attenuation and the phase shift of the electromagnetic field. These variations are then used to evaluate the volumetric importance and depth of the defects.
Installation Methodology	Curing beings in less 10 seconds. No need for bypass systems. With some changes to the Field operations Manual, mostly it is based on the Code of Practice: In-situ Resin Lining of Water Mains from the UK Water Industry, and AWWA M28
QA/QC	Disinfection as per AWWA standards, pressure and Water tightness tests and water samples for laboratory testing
IV. Operation and Maintenance Requirements	
O&M Needs	An electromagnetic probe may be used.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	30% less expensive than CIPP lining in one of the cases
VI. Data Sources	
References	http://www.acuro.ca/html-eng/images/EN-CARE-Page-2.jpg Brochure from No-Dig 2009 ACURO Specifications

Technology/Method	Spray-On Epoxy Lining
Status	Conventional
Date of Introduction	The CuraFlo Spincast System has been in North America over the past 10 years.
Utilization Rates	The CuraFlo Spincast System has been used to line more than 360,000 feet of water pipe
Vendor Name(s)	Curaflow SpinCast System RLS Solutions Inc. Jim Henke 13105 East 61st Street, Suite A Broken Arrow, OK 74012 (800) 324-2810 Web: http://www.rlssolutions.com Email: henkej@rlssolutions.com
Practitioner(s)	1. New York Aqueduct (700 miles of 8 to 20 inch diameter multi-material 125 year-old pipes)
Description of Main Features	The CuraFlo Spincast System is a trenchless, "in situ" technology that rehabilitates water, drain line and industrial process pipes. It repairs and protects metal and cement-based pipes by centrifugally casting 1 to 5+ millimeters of a solvent-free, protective coating on to the interior surface of the pipe.
Main Benefits Claimed	Restores and sustains water quality Restores water pressure Protects against future leaks and corrosion Extend service life of the pipe
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Industrial process pipes
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Not Available
Structural Rating Claimed	Not Available
Materials of Composition	Epoxy
Diameter Range, inches	3” to 36”
Thickness Range, inches	1 to 5+ mm
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Not Available
Other Notes	Not Applicable
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 listing not available
Design Standards	Not Available

Design Life Range	50+ years
Installation Standards	Not Available
Installation Methodology	The Spincast process begins by using specialized equipment to clean the pipes and remove corrosion. Pipes are then lined by centrifugally casting epoxy onto the interior surface of the pipe, creating a seamless barrier. After the epoxy pipe lining is applied, potable water pipes are inspected to ensure water quality. Water service can often be restored the same day
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://rlssolutions.com/ServiceOfferings/PipeRestoration.aspx New York Restoration: Case No. 58

Technology/Method	Epoxy Resin Spray Lining
Status	Innovative
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Fast Line Plus ELC 257/91 Daniel Contractors Ltd Lyncastle Way Appleton Thorn Warrington WA4 4ST Phone +441925860666 Fax: 01925 860504 Web: http://www.subterra.co.uk/index.html Email: info@subterra.co.uk
Practitioner(s)	Not Available
Description of Main Features	ELC 257/91 is a second generation epoxy resin lining material, specially formulated to give a high performance coating with improved durability for water industry in-situ lining applications. Provides a durable, corrosion-resistant barrier layer over the surface to be protected.
Main Benefits Claimed	• Thin, smooth coating enhances flow capacity of previously corroded mains enabling pressure reduction to be readily achieved. • Does not affect pH of conveyed water. • Does not block customer service connections during application.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Repair and Rehabilitation
Service Connections	Not Available
Structural Rating Claimed	Not Available
Materials of Composition	Not Available
Diameter Range, inches	Not Available
Thickness Range, inches	Not Available
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Not Available
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 listing not available
Design Standards	Complies fully with (The Water Research Centre) WRc 'In-situ

	Epoxy Resin Lining - Operational Guidelines and Code of Practice'.
Design Life Range	Not Available
Installation Standards	Not Available
Installation Methodology	Both resins are applied by a centrifugal spray lining machine. The thickness of the coating is controlled by the resin flow rate and the forward speed of the machine. The resin base and hardener are fed through separate hoses and are combined in a static mixer just behind the spray head. The resin is applied to the prepared internal surface of the pipe, forming a thick coating, preventing water penetration and corrosion.
QA/QC	Manufactured under a quality assurance system registered to EN ISO 9002.
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	Brochure and Subterra website

Technology/Method	Continuous Sliplining
Status	Emerging
Date of Introduction	Introduced in November 2003. First commercial installation in 2004
Utilization Rates	Over 1 million linear feet installed since 2004
Vendor Name(s)	Fusible C-900®/Fusible C-905®/FPVC™ Underground Solutions, Inc. (UGSI) 13135 Danielson Street- Suite 201 Poway, CA 92064 Phone: +1 (858) 679-9551 Email: info@undergroundsolutions.com Website: www.undergroundsolutions.com
Practitioner(s)	Over 700 projects with Municipal and Industrial users in 40 out of 50 states, Canada and Mexico.
Description of Main Features	Fusible PVC™ pipe is extruded from a specific formulation of PVC resin which allows the joints to be butt fused together using UGSI's fusion process. Industry standard butt fusion equipment is used with some minor modifications. The resin/compound meets the PVC formulation in PPI Technical Report #2. With the proprietary formulation, the fused joint strength is about as strong as the pipe wall. The fusible pipe is made in DIPS and IPS OD series, as well as Schedule and Sewer sizes. The Fusible C-900 ®, Fusible C-905®, and FPVC™ pipes are NSF 61 certified for potable water.
Main Benefits Claimed	• Corrosion resistant, abrasion resistant. • Fully restrained joint -Fusible PVC™ joints allow long lengths of pipe to be used for HDD, pipe bursting and sliplining applications. • Uses standard fittings and service saddles. • Higher strength enables longer pulls and larger inside diameters.
Main Limitations Cited	Bending radius limitations as per PVC guidelines.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Culverts, Reclaimed water
II. Technology Parameters	
Service Application	Rehabilitation and Replacement
Service Connections	Reinstate with excavation. Tapping procedure per Uni-bell standards. No direct tapping. Connect to MJ or flanged fittings.
Structural Rating Claimed	Fully structural (Class IV)- carry full internal pressure and external loads independent of the host pipe's remaining strength.
Materials of Composition	Fusible PVC™ is extruded with a unique patent pending formulation that meets PPI TR-2 range of composition of qualified PVC ingredients. Meets ASTM cell classification 12454.
Diameter Range, inches	4"-12" for Fusible C-900® (potable water) 14"-36" for Fusible C-905® (potable water) 4"-36" for FPVC™ (potable water in other than C900/C905

	dimensions and non-potable applications)
Thickness Range, inches	Fusible C-900: DR 14, 18, 25 Fusible C-905: DR 14, 18, 21, 25, 32.5, 41, 51 FPVC: DR 14, 18, 21, 25, 26, 32.5, 41, 51, Sch 40, Sch 80 D3034 and F679 Sewer sizes through 36"
Pressure Capacity, psi	165 psi -305 psi under C900; 80 psi – 235 psi under C905
Temperature Range, ^{o}F	Limited to 140°F and below. Above 73°F standard internal pressure de-rating factors apply for long term elevated temperature exposure
Renewal Length, feet	Standard guidance of 300- 500 feet for pipe bursting with length of over 1000' completed in a single burst Slipline length of 3500' in a single pull have been completed HDD lengths of over 5100' in a single length
Other Notes	High "C" factor at 150
III. Technology Design, Installation, and QA/QC Information	
Product Standards	AWWA C900, AWWA C905, NSF 61 Certified (for potable water applications), ASTM D2241, D3034, F679, D1785
Design Standards	AWWA C900, AWWA C905
Design Life Range	100+ years
Installation Standards	ASCE "Pipe Bursting Projects" - ASCE Manual and Report on Engineering Practice #112.
Installation Methodology	For sliplining, host pipe is cleaned and CCTV. Depending on site logistics, the Fusible PVC™ pipes can be strung out and the joints butt fused above grade prior to insertion, or butt fused in the ditch. For pipe bursting, the pipe normally is butt fused in a single length. Static burst methods only are used. The fused PVC pipe is either winched into the host pipe if sliplining, or pulled in behind the expansion head when bursting. A non-rigid connection from the pipe to the expansion head is used. In all installation methods the maximum recommended pull force and the minimum recommended bend radius must be followed.
QA/QC	The stock pipe is subjected to all of the normal QC requirements in AWWA C900/C905, including dimensional conformance, flattening, acetone immersion, hydrostatic, and burst tests. UGSI includes impact, heat reversion, and axial tensile testing as well. In addition 3rd party labs are used to confirm extrusion results on key tests prior to shipment. The fusion process parameters of pressure and the time are recorded for each joint using a datalogger. Additional parameters such as the heat plate temperature are also recorded.
IV. Operation and Maintenance Requirements	
O&M Needs	No special O&M needs.
Repair Requirements for Rehabilitated Sections	Cut out and replace with AWWA PVC of the same OD, using repair clamps and all standard PVC and DI water works fittings
V. Costs	
Key Cost Factors	Benefits: Due to the high tensile strength of PVC (compared to softer

	thermoplastic rehab materials), Fusible PVC™ allows longer lengths of cased and uncased pulls which can reduce the number and cost of pit excavations required. Reduced wall thickness for a given pressure maximizes inner diameter (ID) for a given outer diameter (OD) either maximizing flow in an OD constrained environment or minimizing cost of pipe material and installation as well as risk for a given ID and pressure requirement. Additional ease and reduced cost of reconnections using standard water works fittings. Limitations: Due to limitations of bending radius, Fusible PVC™ may require longer insertion pits for a given application over softer thermoplastics.
Case Study Costs	Fusible PVC™ pipe was used for a 5,120 ft directional drill crossing under the Beaufort River for the Beaufort Jasper Water & Sewer Authority in June of 2007 and was compared in costs to both steel and HDPE pipe. The overall project cost $1.7 million and the customer estimated they saved $400,000 of total cost (materials and installation) by selecting Fusible PVC™ pipe over the other materials for the drill portion.
VI. Data Sources	
References	Website - www.undergroundsolutions.com

Technology/Method	Close-fit Grout-in-place liner
Status	Innovative
Date of Introduction	UK market in 1999 and US market in 2006
Utilization Rates	MainSaver is a new product technology with approximately 5,000 ft installed in the U.S. Annual installations are expected to increase from about 5,000 ft per year to 20,000+ ft per year.
Vendor Name(s)	MainSaver® MainSaver 1819 Denver West Drive, Suite 100 Golden, CO 80401 Phone: +1 (303) 277-8603 Fax: +1 (303) 277-0042 Website: www.mainsaverworld.com Email: info@mainsaverworld.com
Practitioner(s)	MainSaver has been installed in several municipal water systems in the Rocky Mountain region, including several high profile linings (two under Interstate 25, approximately 3,300 ft in neighborhoods, and a school fire line restoration) for the City of Thornton, Colorado. City of Thornton 12450 Washington Street Thornton, CO 80241-2405 Contact: Mr. Jason Pierce, P.E. +1 (720) 977-6274
Description of Main Features	MainSaver is a flexible MDPE tube with integral grout key hooks on the outside surface, which is inserted into the main, then a predetermined quantity of proprietary cement grout is placed between the outside of the tube and the inside of the host pipe. Air pressure is used to move a rounding swab along the length of the liner, which progressively expands the tube and distributes the grout against the interior surface of the host pipe, physically filling all pipe defects. MainSaver is used to renew pipes with holes, displaced joints, leaking joints, offsets of no more than 12.5% of each joint and max. 22^0 long radius elbows. It is NSF 61certified for use with potable water.
Main Benefits Claimed	• Simple system, easy to install • Low installation cost • Suitable for use with all types of pipes, particularly ferrous, asbestos-cement, reinforced concrete and prestressed concrete cylinder pipe. • Cement provides active corrosion protection (ferrous mains) and the PE tube ensures water quality • Prevents leakage

	• Service connections can be reinstated robotically to reduce excavation requirements.
Main Limitations Cited	• Ideal installation temperature range is between 40°F and 80°F, although MainSaver has specific hot and cold weather installation procedures. • Designed for pressure pipes only. • Unsuitable for lining through diameter changes
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Potable water, raw water and force mains
Service Connections	MainSaver uses its RoboTap™ method for remote robotic service connection reinstatement after the MainSaver composite has been installed. This eliminates the need to excavate the main to reinstate service connections.
Structural Rating Claimed	Class III, Interactive and Semi-Structural Liner
Materials of Composition	Medium density polyethylene, cement mortar (Masterflow® 1515 PipeSaver)
Diameter Range, inches	4" to 12"
Thickness Range, inches	Approximately 3/16" (or 3.0 mm), however, grout will often be thicker where it is filling pipe defects.
Pressure Capacity, psi	Max. hole size of 2.4" or gap of 0.4" with pressure up to 294 psi (20 bar)
Temperature Range, ^{o}F	Min. 37^{0}F during installation
Renewal Length, feet	Approx. 500 feet
Other Notes	All installed materials are ANSI/NSF 61 certified for contact with potable water. Cathodic protection can be restored to ferrous pipes to retard external corrosion.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 listed
Design Standards	Not Available
Design Life Range	If properly installed, a 50-plus year design life for the liner would be reasonable.
Installation Standards	Not Available
Installation Methodology	Main must be thoroughly cleaned and CCTV inspected. Robotically plug any open service connections where unwanted grout may migrate. Tube liner is winched into main. At end where grout is to be introduced, fit grout injection fitting to main. Trim other end of liner and install tensioning and anti-twist assembly. Grout slug is pumped into the grout fitting and the rounding swab is advanced down length of lining run to distribute the mortar around the outside of the liner. The liner is held under very low air pressure in order to allow the

	grout to hydrate for up to 16 hours. Once the grout is hydrated, the lining is inspected using CCTV and Infrared thermography. MainSaver's RoboTap is used to remotely, robotically reinstate the service connections and PE end seals are installed to protect the new liner as it is returned to service. The pipe is disinfected (if potable water).
QA/QC	MainSaver/W.S.U.'s Quality Management System is certified to ISO 9001:2000 for the Custom Manufacture of NSF Standard 61 Extruded Tape and In-situ Remediation of Potable Water Lines. The host main is cleaned and CCTV inspected prior to lining, and post-lining the installation is CCTV and IRTV (Infrared) inspected to verify grout distribution behind the liner.
IV. Operation and Maintenance Requirements	
O&M Needs	No special maintenance needs. PE liner is smooth and should maintain low frictional resistance.
Repair Requirements for Rehabilitated Sections	If a lined section needs to be repaired, the MainSaver composite liner can be cut out with the damaged pipe section and conventionally patched with a spool piece.
V. Costs	
Key Cost Factors	• Set up costs (key cost drivers) are generally dependent upon mobilization logistics, traffic control requirements, trench backfilling requirements, and asphalt and concrete replacement. • Material costs are reasonably constant. The real variable is the amount of material required.
Case Study Costs	MainSaver's installation costs are competitive with cement mortar lining, less expensive than CIPP rehabilitation, and less expensive than conventional pipeline replacement.
VI. Data Sources	
References	MainSaver website and brochure.

Technology/Method	Spot Repair
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	NeoPoxy NPR-2000 Neopoxy International 27057 Industrial Blvd Hayward, CA 94545 Phone: (510) 782-1290 Fax: (510) 782-1292 Email: epoxy@neopoxy.us
Practitioner(s)	Not Available
Description of Main Features	NeoPoxy NPR-2000 Series epoxy is approved for potable water use. NPR-2000 is the only epoxy resin approved to ANSI/NSF Standard 61 thickness of two inches.
Main Benefits Claimed	Can be used with special fibers. Can repair overhead point loading cracks.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Repair
Service Connections	Plugged and cleaned
Structural Rating Claimed	Not Available
Materials of Composition	Epoxy Resin
Diameter Range, inches	6 inches and larger
Thickness Range, inches	Upto 2”
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Not Available
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Approved to ANSI/NSF Standard 61
Design Standards	Not Available
Design Life Range	Not Available
Installation Standards	Not Available
Installation Methodology	Water blasting at 10,000 psi removes all deposits. Elimination of thermal shrinkage can be done by curing at room temperature.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available

Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.neopoxy.us/casehistories/cracked-water-pipe-solution.html

Technology/Method	Woven Hose Epoxy Coating
Status	Innovative
Date of Introduction	Introduced in 2002 in Sweden, 2004 in Hong Kong and Canada
Utilization Rates	Approximately 12 miles of Norditube is installed every year
Vendor Name(s)	Nordipipe™ Norditube Technologies (A Sekisui-CPT Company) 501 N. El Camino Real, Suite 224 San Clemente, CA 92672 Phone: +1 (714) 267-1030 Website: www.cpt-usa.com/info
Practitioner(s)	Mr. Jean Lemire, Eng. City of Cornwall 1225 Ontario Street Cornwall (Ontario) Canada K6H 5T9 Tel. (613) 930-2787 Email jelemire@cornwall.ca Mr. Tony Di Fruscia, Eng. P.Eng. City of Montreal 13301, Sherbrooke Street East Suite 209 Montreal (Quebec) Canada H1A 1C2 Tel. (514) 872-6678 Email tonydifruscia@ville.montreal.qc.ca Ms. Annie Fortier, Eng. City of Dorval 60 Martin Avenue Dorval (Quebec) Canada H9S 3R4 Tel. (514) 633-4244 Email afortier@ville.dorval.qc.ca
Description of Main Features	Norditube is a CIPP system that incorporates a glass fiber reinforced layer between two felt layers, impregnated with epoxy resin. A PE coating is on the interior.
Main Benefits Claimed	Fully Structural: no support of the host pipe required for internal or external loads High pressure resistance Negotiate bends up to 45 degrees
Main Limitations Cited	It is not recommended for Low (Ground) temperature with epoxy

Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Internal cut and external re-instatement by excavation
Structural Rating Claimed	AWWA Type 4 – Fully structural
Materials of Composition	Polyethylene coating in contact with potable water, non-woven felt and glass fiber chopped mat, with epoxy or vinyl ester resin
Diameter Range, inches	5”-48”
Thickness Range, inches	0.18” – 0.94” (4.6mm – 24mm)
Pressure Capacity, psi	6” to 250psi and 48” to 60 psi
Temperature Range, ^{o}F	100^{o} F with Epoxy and 160^{o} F with vinyl ester
Renewal Length, feet	500 - 600 feet
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 approved
Design Standards	ASTM F1216 Appendix X1
Design Life Range	50-Year Design
Installation Standards	ASTM F1216
Installation Methodology	Air inversion with air/steam cure, or water column inversion with circulated water cure; service reinstatement by internal robotics or external with saddles
QA/QC	Resin yield check for impregatation; pressure gauges for air inversion; temperature monitoring during cure; hydrostatic pressure test and post installation video for acceptance
IV. Operation and Maintenance Requirements	
O&M Needs	Protection of the PE coating during inspection or cleaning
Repair Requirements for Rehabilitated Sections	Install a spool piece with mechanical adapter. Link-Pipe ring repair
V. Costs	
Key Cost Factors	Factors affecting set-up cost include pit excavation (civil work), mobilization, pipe cleaning/dewatering, site restoration, traffic control, temporary by-pass including road crossings and disinfection, hydrostatic testing, valves, hydrants, tee’s (mechanical work), installation and cure, video inspection Factors affecting material cost include liner, resin, spool pieces, new valves, tee’s and hydrants
Case Study Costs	Not Available
VI. Data Sources	
References	Norditube brochure

Technology/Method	Domestic Line Pipe Repair
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	**Nu Flow Atlanta** 2637 Austell Road SW Marietta, GA 30008 Phone: 678-556-0188 Toll Free: 866-683-5692 Fax: 678-556-0185 **Inquires: 1-800-834-9597** **info@nuflowtech.com**
Practitioner(s)	Not Available
Description of Main Features	The proven technology streamlines restoration in the quickest, most cost-effective way. Nu Flow's non-invasive; epoxy pipe lining process can resolve all plumbing concerns. The epoxy solution minimizes the destruction and disruption to the building and its occupants, while insuring the building will be impervious to these problems in the future.
Main Benefits Claimed	Safe, durable, cost effective and flexible.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Heating and Cooling, risers, gradient piping, branches
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Not Available
Structural Rating Claimed	Not Available
Materials of Composition	Epoxy
Diameter Range, inches	½" - 8"
Thickness Range, inches	Not Available
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	10 feet to 1000 feet
Other Notes	The process can be used on a variety of piping materials including galvanized steel, copper, cast iron, black iron and lead pipe. The abrading agent is EPA-approved sand for open and closed blasting locations. The cured epoxy product is extremely durable and impervious to the corrosive action of acids, alkalis and petroleum.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	UL classified to NSF/ANSI Standard 61 for use in cold and hot

	potable water applications down to 1/2" in pipe diameter.
Design Standards	Not Available
Design Life Range	A rated life of 35-50 years under normal use and has exhibited a potential useful life of up to 80 years in accelerated laboratory mechanical testing.
Installation Standards	Not Available
Installation Methodology	The process follows the following steps: 1. Diagnosis 2. Cleaning 3. Lining 4. Evaluation Pipe segments being restored are typically completed in 2-3 days and returned to service prior to commencing work on subsequent pipe runs.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Building and ground demolition is unnecessary with in-place restoration, making the process highly cost-effective over traditional pipe replacement. Extended downtime and related loss of revenue to businesses is alleviated. Average savings of 50% are typical with our epoxy lining system.
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.nuflowtech.com/content/muni_pipe.php#safe

Technology/Method	Semi-structural CIPP Liner
Status	Conventional
Date of Introduction	1992, Introduced in Germany
Utilization Rates	675,000m installed in 21 years
Vendor Name(s)	Process Phoenix® PRS Rohrsnaierung GmbH Heinrich-Hertz-Straße 23 30966 Hemmingen Germany Fon +49 / 511 / 42 06-354 Fax +49 / 511 / 42 06-305 Web: www.prsrohrsanierung.de Email: info@prsrohrsanierung.de
Practitioner(s)	Not Available
Description of Main Features	Process Phoenix® is a CIPP method which allows the complete internal lining of pipes for all media.
Main Benefits Claimed	Not Available
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other:_____
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Robotically allow access to laterals in the water main?
Structural Rating Claimed	Not Available
Materials of Composition	Polyester
Diameter Range, inches	DN 100 and DN 1000
Thickness Range, inches	Not Available
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Pipe sections up to 500 m (dependent on the nominal diameter) can be lined in one operation.
Other Notes	The pipe bends are easily negotiated. It can have circular cross-sections, oval cross-sections as well as square and special cross-sections.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Approval for use in drinking water pipes (DVGW specification W 270), the KTW test certificate, and gas accreditation (DIN 30658 and GW 478) all attest to the Process Phoenix®CIPP method and serve as method guidelines.

Design Standards	Not Available
Design Life Range	Not Available
Installation Standards	
Installation Methodology	1. The lining used for pressure pipelines consists of endlessly woven polyester onto which a special coating is extruded depending on the medium being transported (PE-LD, Hytrel®). 2. In gravity pipelines, the thickness of the liner is designed according to the external forces affecting the pipe. 3. The use of an epoxy resin with a high E-modulus restricts the subsequent cross-sectional reduction to a minimum -even in the case of high loads. The liner is filled on site with the epoxy resin, drawn into the reversing drum, and the end of the lining tube is then turned inside out and connected to the reversing flange on the outside of the drum. 4. The reversion of the liner in the pipe to be rehabilitated is started with compressed air. 5. A pulling line attached to the liner allows the unfolding speed to be controlled. 6. aOnce the liner is fully reverted in the pipeline section, controlled temperature and pressure is applied to harden the resin.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.prsrohrsanierung.de/englisch/ourproducts/index.html http://www.prsrohrsanierung.de/englisch/ourproducts/phoenix/index.html

Technology/Method	High Build Epoxy
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Waterline Epoxy Hunting Specialized Products 1210 Glendale-Milford Road, Cincinnati, Ohio 45215 U.S.A. Phone: 513-771-9319 Web: http://www.huntingsp.com/index.html Email: info@huntingsp.com
Practitioner(s)	Not Available
Description of Main Features	• A high build, solvent-free epoxy lining system. • A low temperature cured lining system approved for use on pipelines, tanks and equipment that come in contact with potable water. • The two component coating can be hand applied to larger structures or remotely applied within smaller diameter pipelines.
Main Benefits Claimed	• Low temperature cure down to 37º F • Fast re-commissioning time at minimum cure temp of 37º F (3º C). • Compatible with a variety of substrates. • Full contract support services, if required. • Designed and manufactured in an ISO 9001 accredited facility.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Water tanks, industrial piping, cooling water pipes, storm drains, power plants, brine tanks
II. Technology Parameters	
Service Application	Rehabilitation and Repair
Service Connections	Plug service connections and spray in separate phase
Structural Rating Claimed	Not Available
Materials of Composition	Epoxy
Diameter Range, inches	For pipes larger than 4”
Thickness Range, inches	Maximum 0.04 inch wet and dry thickness
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Minimum Application Temperature is 40F
Renewal Length, feet	Not Available
Other Notes	Color Base – Black, Hardener – White, and Mixed - Gray Mix Ratio 2:1 V/V Base:Hardener Coating should not be done under following conditions:

	The temperature is below 40°F (3°C) The relative humidity exceeds 85% (on steel) Substrate temperature is less than 5°F (3°C) above the dew point (on concrete) The substrate has moisture content greater than 50% measured with a Protimeter concrete survey master.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	It is ANSI/ NSF 61 approved
Design Standards	• Theoretical Coverage Rate (m/l) 16 mils/1gal/1ft2 • (1 mm/1 liter/1 m2) • Flash Point Above 212º F (100º C) • Tensile Strength 3225 PSI (2.26 MPa) • Elongation at Yield (%) 1.18 • Young's Modulus 26,300 PSI (1814 MPa) • Compressive Yield Strength 17,200 PSI (118.67 MPa) • Flexural Strength 5,540 PSI (38.21 MPa) • Coating to Concrete Bond Strength 745 lbF (3316 N) • Coating to Metal Bond Strength 620 lbF (2808 N)
Design Life Range	Not Available
Installation Standards	• Maximum Relative Humidity should be 85% and the substrate temperature 5º F above dew point. • Thinning Not Recommended. • Brush/Roller Application Multi-coats are necessary to achieve correct film thickness. • To aid application at low temperatures, both components should be warmed to 60-68º F (15-20º C) prior to mixing. Mix and apply as quickly as possible. • Airless Spray Application.
Installation Methodology	• Cleaning Fluid Hunting Universal Equipment Cleaner can be used to clean the pipes prior to lining. • Including curing method (if applicable); • Drying Times - 40º F (3º C) Touch - 3 Hours • Hard - 6 Hours • Useable - 16 Hours • Final Cure Time and Temperature: 16 hours at 77°F
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available

VI. Data Sources	
References	http://www.huntingsp.com/pdfs/brochures/pipeserve/WaterlineEPOXY.pdf http://www.nsf.com/Certified/PwsComponents/Listings.asp?Company=24760&Standard=061 http://www.huntingsp.com/pdfs/brochures/pipeserve/servicesoverview.pdf http://www.huntingsp.com/productsWaterlineEpoxy.php

Technology/Method	Spray coating epoxy
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Powercrete PW Berry Plastics, Coatings, Tapings Division 11010 WALLISVILLE ROAD Houston, TX 77013 Phone: 713-676-0085 Web: http://www.berrycpg.com/intro.asp Email: cpg@berryplastics.com
Practitioner(s)	Not Available
Description of Main Features	Powercrete PW is an NSF 61 45ºC (113ºF) approved liquid epoxy polymer coating designed for use as a pipe lining for potable and wastewater pipes and storage tanks. Powercrete PW is also very effective for slurries and abrasive applications. PW offers maximum protection from corrosion as it provides high adhesion to bare steel and ductile iron along with superior abrasion resistance
Main Benefits Claimed	• 100% Solids Liquid Epoxy • No V.O.C.s and no isocyanates • Same Formula can be Hand or Spray Applied • Flexibility in difficult to coat field conditions • Excellent Wetting Properties to Bare Steel • Exceptional adhesion, cathodic disbondment and soil stress resistance on bare steel
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storage Tanks, Directional Drilling, Pipe Bends, Fittings, Valves & Odd Shapes, Any bare steel structure in need of protection
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Need to be plugged or done in a second phase.
Structural Rating Claimed	ASTM D-3289-03, ASTM C-109, ASTM D-2240
Materials of Composition	Epoxy
Diameter Range, inches	For pipes larger than 8"
Thickness Range, inches	2.5 - 4.0 mils
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Max Operating temperature is 131ºF
Renewal Length, feet	Not Available
Other Notes	Not Available

III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 approved
Design Standards	ASTM D-570, ASTM D-149, ASTM C-581, ASTM D-4541, ASTM D-4541, ASTM G-14-88, NACE RP-0394, ASTM D-4060-95, ASTM G-95
Design Life Range	Not Available
Installation Standards	If the surface to be coated is below 10ºC (50ºF), preheating of the substrate is recommended. Preheat temperatures should not exceed 82ºC (180ºF) prior to the application.
Installation Methodology	Colors: Black, Tan Number of Coats: 1 Maximum Field Use Dry Film Thickness (in mils): 20 Final Cure Time and Temperature: 1 day at 72°F and 10 days at 104°F Special Comments: Mix ratio A:B is 100:5.5 by weight. CURE SCHEDULE: 24 Hours at 25°C and 10 days at 43°C +/- 3°C for drinking water pipe internal coating, after spray application, standard 61 by NSF
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.berrycpg.com/index.asp?marca=004

Technology/Method	Compression based Symmetrical Reduction Liner
Status	Conventional
Date of Introduction	Outside the UK, Subterra licenses the use of its patented pipeline renovation systems to approved contractors and provides on-site technical support to its licensee network throughout the world.
Utilization Rates	Not Available
Vendor Name(s)	Roll Down Daniel Contractors Ltd Lyncastle Way Appleton Thorn Warrington WA4 4ST UK Phone +441925860666 Fax: 01925 860504 http://www.subterra.co.uk/index.html Email: info@subterra.co.uk
Practitioner(s)	Genoa, Italy Client: Aziend Mediterranea Gas Acqua (AMGA) Site: Via Gramsci, Genoa
Description of Main Features	It is mainly recommended for the following objectives: • Where the pipeline to be renovated is structurally unsound or a liner is needed to correct leakage or bursting. • When pipelines are suffering from water quality problems, corrosion, pitting & perforation and joint leakage. • When there is a need to reduce disturbance to the surrounding area. • Where bore capacity is to be maximised.
Main Benefits Claimed	• Quick installation • Long length capability • Holds its reduced diameter indefinitely prior to reversion, to provide flexibility of installation. • Versatility of insertion procedures with a stop-start capability process.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Gas, Industrial, Electrical lines, Oil, Sewer rising mains
II. Technology Parameters	
Service Application	Replacement and Rehabilitation
Service Connections	Rolldown can negotiate bends up to 11.25
Structural Rating Claimed	As per PE guidelines
Materials of Composition	Polyethylene PE 80 or PE 100

Diameter Range, inches	4” to 20”
Thickness Range, inches	As per PE guidelines
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	As per PE guidelines
Renewal Length, feet	Over 1500mm
Other Notes	Pipe is reduced in diameter upto 10% before installation
III. Technology Design, Installation, and QA/QC Information	
Product Standards	PE 80 and PE 100 is approved under NSF 61
Design Standards	As suggested by PE 80 or PE 100 market guidelines
Design Life Range	Life of un-deformed PE pipes as suggested by guidelines
Installation Standards	Manufacturer’s Guidelines
Installation Methodology	In the Rolldown process standard grade PE (Polyethylene) pipe is pushed through concentric rollers, which reduce the diameter of the liner pipe to allow it to be pulled through the host main. The liner is then pressurized with the water at an ambient temperature to revert it to its original size. Thereby minimizing loss in cross-section area and maximizing capacity.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	ConEdison Website Subterra Website

Technology/Method	Fold-Form Close-fit thin-wall liner
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Developed in the UK by Subterra and North West Water Limited through extensive research, testing and design trials, manufactured by Glynwed Pipe systems and Wavin Plastics, the Subcoil system has been installed by major water utilities throughout the UK.
Vendor Name(s)	SubCoil Daniel Contractors Ltd Lyncastle Way Appleton Thorn Warrington WA4 4ST UK Phone +441925860666 Fax: 01925 860504 http://www.subterra.co.uk/index.html Email: info@subterra.co.uk
Practitioner(s)	Not Available
Description of Main Features	Subcoil is specifically designed as a low cost rehabilitation system for distribution mains and small trunk mains. It uses a Polyethylene (PE) liner which is factory folded and held in a heart shape. This folding process creates a clearance allowing the fast installation of the liner pipe into the host pipe to be renovated.
Main Benefits Claimed	• Low cost and quick installation minimizes disruption and reduces the costs of relining. • Close-fit lining, therefore minimum loss of diameter. • Thin wall and smooth bore - maximizes flow capacity. • Minimal elongation - low winching loads, minimizes residual stresses after installation. • Process stop-start capability -flexibility of insertion procedures.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Distribution Mains, Electricity, Oil and Gas lines
II. Technology Parameters	
Service Application	Rehabilitation and Replacement
Service Connections	Range of dedicated end-terminations and customer service connections available. It can negotiate bends up to 22.50.
Structural Rating Claimed	Not Available
Materials of Composition	Uses standard PE material.

Diameter Range, inches	Available from 95 to 300 mm diameter.
Thickness Range, inches	Not Available
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Long length installation (>1000 m possible in a single insertion) reduces filtering time.
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	ANSI/NSF 61 listing is not available.
Design Standards	Not Available
Design Life Range	50 year plus design life.
Installation Standards	Not Available
Installation Methodology	The folded liner pipe is then inserted into the existing main and pressurized to snap the restraints allowing it to revert back to its original circular shape. The liner forms a close fit with the host pipe, sealing leakage and preventing corrosion, ferrule and end fittings complete the system.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	ConEdison and Subterra Website

Technology/Method	Close-fit PE liner
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	Subline Daniel Contractors Ltd Lyncastle Way Appleton Thorn Warrington WA4 4ST UK Phone +441925860666 Fax: 01925 860504 http://www.subterra.co.uk/index.html Email: info@subterra.co.uk
Practitioner(s)	New York, USA Client: Consolidated Edison Inc. Site: New York, The Bronx and Manhattan
Description of Main Features	Subline is a close fit polyethylene lining technique, developed by Subterra, which is specifically designed for thin wall application.
Main Benefits Claimed	• Low cost • Cures leakage, stops internal corrosion. • Thin wall and smooth bore - maximizes flow capacity. • Quick installation minimizes disruption and reduces the costs of relining.
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Electricity
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	It can do bends up to 45°.
Structural Rating Claimed	Not Available
Materials of Composition	Uses standard Polyethylene material, PE 80 or PE 100
Diameter Range, inches	3” to 59”
Thickness Range, inches	Not Available
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Long length installation >1000 m possible in a single insertion.
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	PE 80/ PE 100 is suitable under NSF 61, but overall product is not certified under NSF 61
Design Standards	Not Available

Design Life Range	50 year plus design life.
Installation Standards	Not Available
Installation Methodology	• The pre-welded polyethylene pipe is pushed through a former to fold it into a "Heart" shape which is temporarily held by restraining bands. • The reduced cross section creates a clearance to facilitate the installation of the PE (Polyethylene) pipe into the original pipe to be renovated. • Once installed the folded pipe is then reverted back to its circular form by pressurisation with water at an ambient temperature which breaks the temporary restraining bands. • This creates a close fit within the host pipe, sealing leakage and preventing corrosion.
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	Subterra and ConEdison website

Technology/Method	Close-fit PE
Status	Conventional
Date of Introduction	1992 in Germany
Utilization Rates	300,000 meters since 1992
Vendor Name(s)	U-Liner® PRS Rohrsnaierung GmbH Heinrich-Hertz-Straße 23 30966 Hemmingen Germany Fon +49 / 511 / 42 06-354 Fax +49 / 511 / 42 06-305 Web: www.prsrohrsanierung.de Email: info@prsrohrsanierung.de
Practitioner(s)	Not Available
Description of Main Features	The U-Liner® method has a proven track record for the extremly cost-effective and time saving rehabilitation of defective pipes.
Main Benefits Claimed	Extruded into long sections
Main Limitations Cited	Not Available
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Gas Pipes
II. Technology Parameters	
Service Application	Rehabilitation
Service Connections	Existing pipe connections can be re-opened with a remotely controlled cutting robot (in sewers) from inside of the new pipe. Domestic inlets/outlets for pressure pipelines are connected up from outside according to DVGW Guidelines.
Structural Rating Claimed	Not Available
Materials of Composition	Polyethylene
Diameter Range, inches	100-400 DN
Thickness Range, inches	Not Available
Pressure Capacity, psi	Maximum 10 bar
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Up to 600 m long for pipes with a diameter of around DN 100, and 100 m long for pipes with a diameter of around DN 400
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF 61 approval not available
Design Standards	DIN 19357, DIN 8074/8075, DVGW G 477 and GW 320/II
Design Life Range	Not Available
Installation Standards	Not Available

Installation Methodology	1. The pipe is thermo-mechanically folded into the U-shape in the factory -which significantly reduces the cross-sectional area- and rolled onto a drum for transport. 2. The pull-through procedure involves a winch and where necessary only requires a small amount of excavation. No excavation is required when renovating sewer pipes because the inspection shafts can be used. 3. The U-Liner® pipe is expanded to its original circular cross-section by inflating high pressure steam (memory effect). 4. The liner then closely fits the inner walls of the old pipe (Fold and Form).
QA/QC	Not Available
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	Not Available
Case Study Costs	Not Available
VI. Data Sources	
References	http://www.prsrohrsanierung.de/englisch/ourproducts/uliner/index.html

Appendix H: REST tool framework code for visual basic

```
'Dimension Variables

Dim rs As New Recordset
Dim strSQL As String
Dim strConnect As String

Dim StrSQL1 As String
Dim rs1 As New Recordset

Dim n_score(3, 94) As Integer
Dim p_score(3, 94) As Integer

Private Sub cmdpopulate_Click()

'Populate comboboxes with categories for each factor
'Step 3 starts here

    With cbxmaterial
    .AddItem "Ductile Iron"
    .AddItem "Cast Iron"
    .AddItem "Asbestos Cement"
    .AddItem "Polyethylene"
    .AddItem "Poly Vinyl Chloride"
    .AddItem "Reinforced Concrete"
    .AddItem "Prestressed Concrete"
    .AddItem "Vitrified Clay"
    End With

    With cbxdepth
    .AddItem "Shallow"
    .AddItem "Medium"
    .AddItem "Deep"
    End With

    With cbxprofile
    .AddItem "Circular"
```

```
.AddItem "Non-circular"
End With

With cbxlocation
.AddItem "Uninhabited Lands"
.AddItem "Townside"
.AddItem "Suburban Areas"
.AddItem "Dense Residences"
.AddItem "Commercial Areas"
End With

With cbxexcavation
.AddItem "Available"
.AddItem "Limited"
.AddItem "Not Available"
End With

'Step 4 starts here

With cbxcorrosion
.AddItem "Only External"
.AddItem "Limited Internal"
.AddItem "Internal"
.AddItem "External & Internal"
End With

With cbxcleaning
.AddItem "Jet Spray"
.AddItem "Flushing"
.AddItem "Pigging"
.AddItem "Scrapping"
.AddItem "Chemical"
End With

With cbxaccess
.AddItem "Small Pit"
.AddItem "Medium Pit"
.AddItem "Large Pit"
End With
```

With cbxdowntime
.AddItem "More than 24 hours"
.AddItem "3 to 24 hours"
.AddItem "Less than 3 hours"
End With

With cbxservice
.AddItem "Clean the Connections"
.AddItem "Limited Reconnection"
.AddItem "Not Recommended"
End With

With cbxspace
.AddItem "Not Required"
.AddItem "Adhesive"
.AddItem "Grouting"
End With

With cbxbends
.AddItem "None"
.AddItem "Horizontal"
.AddItem "Vertical"
End With

With cbxfeature
.AddItem "Rare"
.AddItem "Moderate"
.AddItem "Dense"
End With

With cbxloads
.AddItem "Not Required"
.AddItem "Limited Design"
.AddItem "Full Design"
End With

With cbxwater
.AddItem "Below Bedding Level"

```
    .AddItem "Around Pipe Level"
    .AddItem "Above Crown Level"
    End With

'Step 5 starts here

    With cbxnsf61
    .AddItem "Not Required"
    .AddItem "Required"
    End With

    With cbxstatus
    .AddItem "Conventional"
    .AddItem "Innovative"
    .AddItem "Emerging"
    End With

    With cbxenvironment
    .AddItem "Limited"
    .AddItem "Moderate"
    .AddItem "Severe"
    End With

    With cbxcodes
    .AddItem "Not Available"
    .AddItem "Design codes"
    .AddItem "Specialty codes"
    .AddItem "Design and specialty codes"
    End With

    With cbxinstallation
    .AddItem "Common method"
    .AddItem "Moderate without curing"
    .AddItem "Moderate with curing"
    .AddItem "Complex method"
    End With

    With cbxutilization
    .AddItem "Not Applicable"
```

```
    .AddItem "Less than 50 miles"
    .AddItem "51 to 99 miles"
    .AddItem "More than 100 miles"
    End With

    With cbxreferences
    .AddItem "Limited Information"
    .AddItem "Vendor Articles"
    .AddItem "Independent Reviews"
    End With

    With cbxpractice
    .AddItem "Not available"
    .AddItem "Less than 3 users"
    .AddItem "4 or more users"
    End With

    With cbxqaqc
    .AddItem "Factory-Built Material"
    .AddItem "Site-Built Material"
    End With

    With cbxcosts
    .AddItem "Manufacturing costs"
    .AddItem "Tendered costs"
    .AddItem "Project costs"
    End With

'When you click the start button, Page: Step1 will show
    ufstart.MultiPage1.Value = 1

'Makes the first category as default selection to avoid empty combobox

cbxmaterial.ListIndex = 0
cbxdepth.ListIndex = 0
cbxprofile.ListIndex = 0
cbxlocation.ListIndex = 0
cbxexcavation.ListIndex = 0
```

cbxcorrosion.ListIndex = 0
cbxcleaning.ListIndex = 0
cbxaccess.ListIndex = 0
cbxdowntime.ListIndex = 0
cbxservice.ListIndex = 0
cbxspace.ListIndex = 0
cbxbends.ListIndex = 0
cbxfeature.ListIndex = 0
cbxloads.ListIndex = 0
cbxwater.ListIndex = 0

cbxnsf61.ListIndex = 0
cbxstatus.ListIndex = 0
cbxenvironment.ListIndex = 0
cbxcodes.ListIndex = 0
cbxinstallation.ListIndex = 0
cbxutilization.ListIndex = 0
cbxreferences.ListIndex = 0
cbxpractice.ListIndex = 0
cbxqaqc.ListIndex = 0
cbxcosts.ListIndex = 0

'Once clicked, the button becomes diabled. To restart go back to the worksheet.
'If this is not done, then the combobox will populate repeatedly.

cmdpopulate.Enabled = False

End Sub

Private Sub cmdnext1_Click()

'Command Button takes you to next page

ufstart.MultiPage1.Value = 2

'Renewal Product value must match with User requirements for each radio-button selection
'First radio button is selected by default from radio button properties

*StrSQL1 = "Select * From RenewalProduct Where 1 = 1 "*

```
If optwater = True Then StrSQL1 = StrSQL1 & "and water_main = 1 "
If optsewer = True Then StrSQL1 = StrSQL1 & "and gravity_sewer = 1 "
If optservice = True Then StrSQL1 = StrSQL1 & "and service_line = 1 "
If optforcemain = True Then StrSQL1 = StrSQL1 & "and force_main = 1 "
If optlateral = True Then StrSQL1 = StrSQL1 & "and lateral = 1 "

If opt10 = True Then StrSQL1 = StrSQL1 & "and below10 = 1 "
If opt20 = True Then StrSQL1 = StrSQL1 & "and below20 = 1 "
If opt36 = True Then StrSQL1 = StrSQL1 & "and below36 = 1 "
If opt46 = True Then StrSQL1 = StrSQL1 & "and below46 = 1 "
If opt48 = True Then StrSQL1 = StrSQL1 & "and above48 = 1 "

If optcapacity = True Then StrSQL1 = StrSQL1 & "and capacity = 1 "
If optstructure = True Then StrSQL1 = StrSQL1 & "and structure = 1 "
If optjoint = True Then StrSQL1 = StrSQL1 & "and joint = 1 "
If optsection = True Then StrSQL1 = StrSQL1 & "and sectional = 1 "
If optvelocity = True Then StrSQL1 = StrSQL1 & "and velocity = 1 "


End Sub

Public Sub cmdnext2_Click()

'Command Button takes you to next page

    ufstart.MultiPage1.Value = 3

'Message Box warning for all textboxes if left empty

If txtage = vbNullString Or _
   txtthickness = vbNullString Or _
   txttemperature = vbNullString Or _
   txtlength = vbNullString Or _
   txtpressure = vbNullString Then
MsgBox "Please enter all values to continue!"
cmdprevious3_Click
Exit Sub
End If
```

'Message Box for textbox, no strings/ alphabet characters

txtage_Change
txttemperature_Change
txthickness_Change
txtlength_Change
txtpressure_Change

'Message box for textbox, if values are out of range then show error

strConnect = "Provider=Microsoft.Jet.OLEDB.4.0; Data Source=" & ThisWorkbook.Path & "\database.mdb"
strSQL = "Select Max(maxage) AS MaxAge From RenewalProduct"
rs.Open strSQL, strConnect, adOpenStatic
If rs("MaxAge").Value < CDec(txtage) Then
MsgBox "Current products support age below " & rs("MaxAge").Value & " years ", vbExclamation, "Error"
rs.Close
cmdprevious3_Click
Exit Sub
Else
rs.Close
End If

strSQL = "Select Max(maxpressure) AS MaxPressure From RenewalProduct"
rs.Open strSQL, strConnect, adOpenStatic
If rs("MaxPressure").Value < CDec(txtpressure) Then
MsgBox "Current products support operating pressure below " & rs("MaxPressure").Value & " psi ", vbExclamation, "Error"
rs.Close
cmdprevious3_Click
Exit Sub
Else
rs.Close
End If

strSQL = "Select Max(maxtemp) AS MaxTemp From RenewalProduct"
rs.Open strSQL, strConnect, adOpenStatic
If rs("MaxTemp").Value < CDec(txttemperature) Then

MsgBox "Current products support temperature below " & rs("MaxTemp").Value & " F ",
vbExclamation, "Error"
rs.Close
cmdprevious3_Click
Exit Sub
Else
rs.Close
End If

strSQL = "Select Min(minthick) AS MinThick From RenewalProduct"
rs.Open strSQL, strConnect, adOpenStatic
If rs("MinThick").Value > CDec(txtthickness) And CDec(txtthickness) < 5000 Then
MsgBox "Current products support thickness above " & rs("MinThick").Value & " mils ",
vbExclamation, "Error"
rs.Close
cmdprevious3_Click
Exit Sub
Else
rs.Close
End If

strSQL = "Select Max(maxrenew) AS MaxRenew From RenewalProduct"
rs.Open strSQL, strConnect, adOpenStatic
If rs("MaxRenew").Value < CDec(txtlength) Then
MsgBox "Current products support renewal length below " & rs("MaxRenew").Value & " feet ",
vbExclamation, "Error"
rs.Close
cmdprevious3_Click
Exit Sub
Else
rs.Close
End If

'Select host pipe material

If cbxmaterial.Value = "Ductile Iron" Then StrSQL1 = StrSQL1 & "And ductile = 1 "
If cbxmaterial.Value = "Cast Iron" Then StrSQL1 = StrSQL1 & "And cast = 1 "
If cbxmaterial.Value = "Asbestos Cement" Then StrSQL1 = StrSQL1 & "And AC = 1 "
If cbxmaterial.Value = "Polyethylene" Then strSQL = StrSQL1 & "And HDPE = 1 "

```
If cbxmaterial.Value = "Poly Vinyl Chloride" Then StrSQL1 = StrSQL1 & "And PVC = 1 "
If cbxmaterial.Value = "Reinforced Concrete" Then StrSQL1 = StrSQL1 & "And RCP = 1 "
If cbxmaterial.Value = "Prestressed Concrete" Then StrSQL1 = StrSQL1 & "And PCCP = 1 "
If cbxmaterial.Value = "Vitrified Clay" Then StrSQL1 = StrSQL1 & "And clay = 1 "

'Equation for finding the product that matches material and values are within range

StrSQL1 = StrSQL1 & " And MaxRenew > " & CDec(txtlength) _
      & " And MinThick < " & CDec(txtthickness) _
      & " And MaxTemp > " & CDec(txttemperature) _
      & " And MaxPressure > " & CDec(txtpressure) _
      & " And MaxAge > " & CDec(txtage)

'Before opening the recordset object, check if the recordset is not already open

If TypeName(rs1) = "Recordset" Then
     If rs1.State <> adStateClosed Then
        rs1.Close
     End If
  End If

'Connect with Access, save product in recordset

rs1.Open StrSQL1, strConnect, adOpenStatic

'Message box to indicate no products match criteria

   If rs1.EOF Then
   MsgBox "No Products match given criteria", vbInformation
   Exit Sub
   End If

'Message box to indicate number of products match criteria

MsgBox "There are " & rs1.RecordCount & " products matching given criteria"

'Calculating for factors that are exceeding or Failing criteria

Do While (Not rs1.EOF)
```

```
    If rs1("depth").Value > cbxdepth.ListIndex + 1 Then
    p_score(1, rs1("id").Value) = p_score(1, rs1("id").Value) + rs1("depth").Value -
(cbxdepth.ListIndex + 1)
    Else
    n_score(1, rs1("id").Value) = n_score(1, rs1("id").Value) + (1 + cbxdepth.ListIndex) -
rs1("depth").Value
    End If

    If rs1("profile").Value > cbxprofile.ListIndex + 1 Then
    p_score(1, rs1("id").Value) = p_score(1, rs1("id").Value) + rs1("profile").Value - (1 +
cbxprofile.ListIndex)
    Else
    n_score(1, rs1("id").Value) = n_score(1, rs1("id").Value) + (1 + cbxprofile.ListIndex) -
rs1("profile").Value
    End If

    If rs1("excavation").Value > cbxexcavation.ListIndex + 1 Then
    p_score(1, rs1("id").Value) = p_score(1, rs1("id").Value) + rs1("excavation").Value - (1 +
cbxexcavation.ListIndex)
    Else
    n_score(1, rs1("id").Value) = n_score(1, rs1("id").Value) + (1 + cbxexcavation.ListIndex)
- rs1("excavation").Value
    End If

    If rs1("location").Value > cbxlocation.ListIndex + 1 Then
    p_score(1, rs1("id").Value) = p_score(1, rs1("id").Value) + rs1("location").Value -
(cbxlocation.ListIndex + 1)
    Else
    n_score(1, rs1("id").Value) = n_score(1, rs1("id").Value) + (cbxlocation.ListIndex + 1) -
rs1("location").Value
    End If

    rs1.MoveNext

  Loop

End Sub
```

```
Private Sub cmdnext3_Click()

'Command Button takes you to next page

   ufstart.MultiPage1.Value = 4

'Calculating for factors that are exceeding or Failing criteria

rs1.MoveFirst

Do While (Not rs1.EOF)

      If rs1("corrosion").Value > 1 + cbxcorrosion.ListIndex Then
      p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("corrosion").Value - (1 +
cbxcorrosion.ListIndex)
      Else
      n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxcorrosion.ListIndex) -
rs1("corrosion").Value
      End If

      If rs1("cleaning").Value > 1 + cbxcleaning.ListIndex Then
      p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("cleaning").Value - (1 +
cbxcleaning.ListIndex)
      Else
      n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxcleaning.ListIndex) -
rs1("cleaning").Value
      End If

      If rs1("accesspits").Value > 1 + cbxaccess.ListIndex Then
      p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("accesspits").Value - (1 +
cbxaccess.ListIndex)
      Else
      n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxaccess.ListIndex) -
rs1("accesspits").Value
      End If

      If rs1("downtime").Value > 1 + cbxdowntime.ListIndex Then
```

```
    p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("downtime").Value - (1 +
cbxdowntime.ListIndex)
    Else
    n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxdowntime.ListIndex) -
rs1("downtime").Value
    End If

    If rs1("bends").Value > 1 + cbxbends.ListIndex Then
    p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("bends").Value - (1 +
cbxbends.ListIndex)
    Else
    n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxbends.ListIndex) -
rs1("bends").Value
    End If

    If rs1("connections").Value > 1 + cbxservice.ListIndex Then
    p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("connections").Value - (1
+ cbxservice.ListIndex)
    Else
    n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxservice.ListIndex) -
rs1("connections").Value
    End If

    If rs1("loads").Value > 1 + cbxloads.ListIndex Then
    p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("loads").Value - (1 +
cbxloads.ListIndex)
    Else
    n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxloads.ListIndex) -
rs1("loads").Value
    End If

    If rs1("space").Value > 1 + cbxspace.ListIndex Then
    p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("space").Value - (1 +
cbxspace.ListIndex)
    Else
    n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxspace.ListIndex) -
rs1("space").Value
    End If
```

```
        If rs1("surface").Value > 1 + cbxfeature.ListIndex Then
        p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("surface").Value - (1 +
cbxfeature.ListIndex)
        Else
        n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxfeature.ListIndex) -
rs1("surface").Value
        End If

        If rs1("water").Value > 1 + cbxwater.ListIndex Then
        p_score(2, rs1("id").Value) = p_score(2, rs1("id").Value) + rs1("water").Value - (1 +
cbxwater.ListIndex)
        Else
        n_score(2, rs1("id").Value) = n_score(2, rs1("id").Value) + (1 + cbxwater.ListIndex) -
rs1("water").Value
        End If

        rs1.MoveNext

       Loop

End Sub

Private Sub cmdcalculate_Click()

'Command Button takes you to output page

  rs1.MoveFirst

'Calculating for factors that are exceeding or Failing criteria

Do While (Not rs1.EOF)

        If rs1("nsf61").Value > 1 + cbxnsf61.ListIndex Then
        p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("nsf61").Value - (1 +
cbxnsf61.ListIndex)
        Else
        n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxnsf61.ListIndex) -
rs1("nsf61").Value
        End If
```

```
    If rs1("status").Value > 1 + cbxstatus.ListIndex Then
    p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("status").Value - (1 +
cbxstatus.ListIndex)
    Else
    n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxstatus.ListIndex) -
rs1("status").Value
    End If

    If rs1("environment").Value > 1 + cbxenvironment.ListIndex Then
    p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("environment").Value - (1
+ cbxenvironment.ListIndex)
    Else
    n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 +
cbxenvironment.ListIndex) - rs1("environment").Value
    End If

    If rs1("codes").Value > 1 + cbxcodes.ListIndex Then
    p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("codes").Value - (1 +
cbxcodes.ListIndex)
    Else
    n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxcodes.ListIndex) -
rs1("codes").Value
    End If

    If rs1("installation").Value > 1 + cbxinstallation.ListIndex Then
    p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("installation").Value - (1
+ cbxinstallation.ListIndex)
    Else
    n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxinstallation.ListIndex)
- rs1("installation").Value
    End If

    If rs1("historical").Value > 1 + cbxutilization.ListIndex Then
    p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("historical").Value -
(cbxutilization.ListIndex + 1)
    Else
    n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (cbxutilization.ListIndex + 1) -
rs1("historical").Value
```

```
        End If

        If rs1("references").Value > 1 + cbxreferences.ListIndex Then
        p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("references").Value -
(cbxreferences.ListIndex + 1)
        Else
        n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (cbxreferences.ListIndex + 1)
- rs1("references").Value
        End If

        If rs1("quality").Value > 1 + cbxqaqc.ListIndex Then
        p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("quality").Value - (1 +
cbxqaqc.ListIndex)
        Else
        n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxqaqc.ListIndex) -
rs1("quality").Value
        End If

        If rs1("practitioners").Value > 1 + cbxpractice.ListIndex Then
        p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("practitioners").Value - (1
+ cbxpractice.ListIndex)
        Else
        n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxpractice.ListIndex) -
rs1("practitioners").Value
        End If

        If rs1("costs").Value > 1 + cbxcosts.ListIndex Then
        p_score(3, rs1("id").Value) = p_score(3, rs1("id").Value) + rs1("costs").Value - (1 +
cbxcosts.ListIndex)
        Else
        n_score(3, rs1("id").Value) = n_score(3, rs1("id").Value) + (1 + cbxcosts.ListIndex) -
rs1("costs").Value
        End If

        rs1.MoveNext

Loop

   rs1.MoveFirst
```

```
'Enter Column header in output sheet


   If Not (rs1.BOF And rs1.EOF) Then

   Application.ScreenUpdating = False
      reccount = rs1.RecordCount
      Sheets.Add After:=Sheets(Sheets.Count)
      Range("A1").Value = "Exceeding Criteria"
      Range("B1").Value = "Failing Criteria"
      Range("C1").Value = "ID #"
      Range("D1").Value = "Product Name"
      Range("E1").Value = "Technology"
      Range("F1").Value = "Material"
      Range("G1").Value = "Application"
      Range("H1").Value = "Step 3"
      Range("I1").Value = "Step 4"
      Range("J1").Value = "Step 5"
      Range("K1").Value = "Reliability"
      Range("L1").Value = "Constructability"
      Range("M1").Value = "Design"

'Enter scores for upto 7 recommended products

      irow = 1
      Do While (Not rs1.EOF And irow <> 8)

         irow = irow + 1

         Range("A" & irow).Value = p_score(1, rs1("id").Value) + p_score(2, rs1("id").Value) +
p_score(3, rs1("id").Value)
         Range("B" & irow).Value = n_score(1, rs1("id").Value) + n_score(2, rs1("id").Value) +
n_score(3, rs1("id").Value)

         Range("C" & irow).Value = rs1("ID").Value
         Range("D" & irow).Value = rs1("product").Value
         Range("E" & irow).Value = rs1("technology").Value
         Range("F" & irow).Value = rs1("material").Value
```

```
        Range("G" & irow).Value = rs1("applicability").Value

        Range("H" & irow).Value = p_score(1, rs1("id").Value) - n_score(1, rs1("id").Value)
        Range("I" & irow).Value = p_score(2, rs1("id").Value) - n_score(2, rs1("id").Value)
        Range("J" & irow).Value = p_score(3, rs1("id").Value) - n_score(3, rs1("id").Value)

        Range("K" & irow).Value = rs1("costs").Value + rs1("practitioners").Value +
rs1("references").Value + rs1("historical").Value
        Range("L" & irow).Value = rs1("accesspits").Value + rs1("connections").Value +
rs1("downtime").Value + rs1("cleaning").Value
        Range("M" & irow).Value = rs1("loads").Value + rs1("water").Value +
rs1("bends").Value + rs1("space").Value


'Color code cells in output sheet for Step 3

        If Range("H" & irow).Value < -5 Then
        Range("H" & irow).Interior.Color = 255
        End If

        If Range("H" & irow).Value >= -5 And Range("H" & irow).Value < -2 Then
        Range("H" & irow).Interior.Color = 65535
        End If

        If Range("H" & irow).Value >= -2 And Range("H" & irow).Value <= 2 Then
        Range("H" & irow).Interior.Color = 5296274
        End If

        If Range("H" & irow).Value > 2 And Range("H" & irow).Value <= 5 Then
        Range("H" & irow).Interior.Color = 65535
        End If

        If Range("H" & irow).Value > 5 Then
        Range("H" & irow).Interior.Color = 255
        End If

'Color code cells in output sheet for Step 5

        If Range("J" & irow).Value < -5 Then
```

```
Range("J" & irow).Interior.Color = 255
End If

If Range("J" & irow).Value >= -5 And Range("J" & irow).Value < -2 Then
Range("J" & irow).Interior.Color = 65535
End If

If Range("J" & irow).Value >= -2 And Range("J" & irow).Value <= 2 Then
Range("J" & irow).Interior.Color = 5296274
End If

If Range("J" & irow).Value > 2 And Range("J" & irow).Value <= 5 Then
Range("J" & irow).Interior.Color = 65535
End If

If Range("J" & irow).Value > 5 Then
Range("J" & irow).Interior.Color = 255
End If

'Color code cells in output sheet for Step 4

If Range("I" & irow).Value < -5 Then
Range("I" & irow).Interior.Color = 255
End If

If Range("I" & irow).Value >= -5 And Range("I" & irow).Value < -2 Then
Range("I" & irow).Interior.Color = 65535
End If

If Range("I" & irow).Value >= -2 And Range("I" & irow).Value <= 2 Then
Range("I" & irow).Interior.Color = 5296274
End If

If Range("I" & irow).Value > 2 And Range("I" & irow).Value <= 5 Then
Range("I" & irow).Interior.Color = 65535
End If

If Range("I" & irow).Value > 5 Then
Range("I" & irow).Interior.Color = 255
```

```
        End If


        rs1.MoveNext
    Loop

    rs1.MoveFirst

'Format Column width after entering text and values

    Rows("1:1").Select
    Selection.Font.Bold = True
    Columns("A:A").EntireColumn.AutoFit
    Columns("B:B").EntireColumn.AutoFit
    Columns("C:C").EntireColumn.AutoFit
    Columns("D:D").EntireColumn.AutoFit
    Columns("E:E").EntireColumn.AutoFit
    Columns("F:F").EntireColumn.AutoFit
    Columns("G:G").EntireColumn.AutoFit
    Columns("H:H").EntireColumn.AutoFit
    Columns("I:I").EntireColumn.AutoFit
    Columns("J:J").EntireColumn.AutoFit
    Columns("K:K").EntireColumn.AutoFit
    Columns("L:L").EntireColumn.AutoFit
    Columns("M:M").EntireColumn.AutoFit

'Provide Sheet number

    Columns("H:H").Select
    sheet_name = ActiveSheet.Name
    sheet_code_name =
ActiveWorkbook.VBProject.VBComponents(ActiveSheet.Name).Properties("_CodeName").Value
    ActiveWorkbook.Worksheets(sheet_name).Sort.SortFields.Clear

' Rank recommended products based on exceeding and failing criteria

    ActiveWorkbook.Worksheets(sheet_name).Sort.SortFields.Add Key:=Range("A1"), _
        SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
    ActiveWorkbook.Worksheets(sheet_name).Sort.SortFields.Add Key:=Range("B1"), _
```

```
    SortOn:=xlSortOnValues, Order:=xlAscending, DataOption:=xlSortNormal
  With ActiveWorkbook.Worksheets(sheet_name).Sort
    .SetRange Range("A2:M" & irow)
    .Header = xlNo
    .MatchCase = False
    .Orientation = xlTopToBottom
    .SortMethod = xlPinYin
    .Apply

  End With

  ActiveWorkbook.Worksheets(sheet_name).Range("A1:A" & irow).RowHeight = 20


'Develop chart for Reliability, Constructability and Design Index

rs1.MoveFirst

  Set chartobj = ActiveSheet.Shapes.AddChart(Left:=Range("A10:E10").Width + 5,
Top:=Range("A1:A9").Height + 5)
  chartobj.Chart.SetSourceData Source:=Range("'" & sheet_name & "'!$K$2:$M$8")
  chartobj.Chart.ChartType = xlColumnClustered
  chartobj.Chart.SeriesCollection(1).XValues = ("'" & sheet_name & "'!$D$2:$D$8")
  chartobj.Chart.SetElement (msoElementChartTitleAboveChart)
  chartobj.Chart.ChartTitle.Text = "Indices"
  ActiveSheet.ChartObjects("Chart 1").Activate
  ActiveChart.SeriesCollection(1).Name = "='" & sheet_name & "'!$K$1"
  ActiveChart.SeriesCollection(2).Name = "='" & sheet_name & "'!$L$1"
  ActiveChart.SeriesCollection(3).Name = "='" & sheet_name & "'!$M$1"

  rs1.MoveFirst

'Develop chart for Exceeding and Failing criteria

  Set chartobj = ActiveSheet.Shapes.AddChart(Left:=40, Top:=Range("A1:A9").Height + 5)
  chartobj.Chart.SetSourceData Source:=Range("'" & sheet_name & "'!$A$2:$B$8")
  chartobj.Chart.ChartType = xlColumnStacked
  chartobj.Chart.SeriesCollection(1).XValues = ("'" & sheet_name & "'!$D$2:$D$8")
  chartobj.Chart.SetElement (msoElementChartTitleAboveChart)
```

```
        chartobj.Chart.ChartTitle.Text = "Threshold Variance"
        ActiveSheet.ChartObjects("Chart 2").Activate
        ActiveChart.SeriesCollection(1).Name = "='" & sheet_name & "'!$A$1"
        ActiveChart.SeriesCollection(2).Name = "='" & sheet_name & "'!$B$1"


        rs1.Close

        Application.ScreenUpdating = True

End If

Unload ufstart
cmdpopulate.Enabled = True

End Sub

Private Sub cmdprevious1_Click()

'Go to Previous Page

    ufstart.MultiPage1.Value = 0

End Sub

Private Sub cmdprevious2_Click()
    ufstart.MultiPage1.Value = 1

'Close recordet to restart the process of saving recommended products

If TypeName(rs1) = "Recordset" Then
       If rs1.State <> adStateClosed Then
          rs1.Close
       End If
   End If

End Sub

Private Sub cmdprevious3_Click()
```

```
    ufstart.MultiPage1.Value = 2

'Restart calculating values

i = 0
Do While (i < 95)


n_score(1, i) = 0
p_score(1, i) = 0
i = i + 1

Loop

End Sub

Private Sub cmdprevious4_Click()
    ufstart.MultiPage1.Value = 3

'Restart calculating values

i = 0
Do While (i < 95)


n_score(2, i) = 0
p_score(2, i) = 0
i = i + 1

Loop

End Sub

Private Sub cmdrestart_Click()

'When you click the exit to restart button, excel page will show

    Unload ufstart
End Sub
```

```
Private Sub txtstructure_Change()
   If txtstructure = vbNullString Then Exit Sub
   If Not IsNumeric(txtstructure) Then
      MsgBox "Structural Grade must have numerical value!"
      txtstructure = vbNullString
   End If
End Sub


Private Sub txtcapacity_Change()
   If txtcapacity = vbNullString Then Exit Sub
   If Not IsNumeric(txtcapacity) Then
      MsgBox "Hydraulic Capacity must have numerical value!"
      txtcapacity = vbNullString
   End If
End Sub

Private Sub txtage_Change()
   If txtage = vbNullString Then Exit Sub
   If Not IsNumeric(txtage) Then
      MsgBox "Pipe Age must have numerical value!"
      txtage = vbNullString
   End If
End Sub

Private Sub txtpressure_Change()
   If txtpressure = vbNullString Then Exit Sub
   If Not IsNumeric(txtpressure) Then
      MsgBox "Operating Pressure must have numerical value!"
      txtpressure = vbNullString
   End If
End Sub

Private Sub txttemperature_Change()
   If txttemperature = vbNullString Then Exit Sub
   If Not IsNumeric(txttemperature) Then
```

```
        MsgBox "Operating Temperature must have numerical value!"
        txttemperature = vbNullString
    End If
End Sub

Private Sub txthickness_Change()
    If txtthickness = vbNullString Then Exit Sub
    If Not IsNumeric(txtthickness) Then
        MsgBox "Required Thickness must have numerical value!"
        txtthickness = vbNullString
    End If
End Sub

Private Sub txtlength_Change()
    If txtlength = vbNullString Then Exit Sub
    If Not IsNumeric(txtlength) Then
        MsgBox "Renewal Length must have numerical value!"
        txtlength = vbNullString
    End If
End Sub
```