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State of Technology for Rehabilitation of Water Distribution Systems

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STATE OF TECHNOLOGY FOR REHABILITATION OF WATER DISTRIBUTION SYSTEMS

by

Robert Morrison, P.E., Tom Sangster, C.Eng., and Dec Downey, Ph.D., C.Eng.
Jason Consultants

John Matthews, Ph.D. and Wendy Condit, P.E.
Battelle Memorial Institute

Sunil Sinha, Ph.D., P.E. and Saumil Maniar
Virginia Tech University

Ray Sterling, Ph.D., P.E.
Trenchless Technology Center

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Ariamalar Selvakumar, Ph.D., P.E.
Task Order Manager

U.S. Environmental Protection Agency
Urban Watershed Branch
National Risk Management Research Laboratory
Water Supply and Water Resources Division
2890 Woodbridge Avenue (MS-104)
Edison, NJ 08837

National Risk Management Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

DISCLAIMER

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ABSTRACT

The impact that the lack of investment in water infrastructure will have on the performance of aging underground infrastructure over time is well documented and the needed funding estimates range as high as $325 billion over the next 20 years. With the current annual replacement rate averaging 0.5%, pipes would be expected to last for 200 years, but most pipes are designed for 50 or 100 year life cycles. While this replacement rate may be sufficient in the immediate term because pipes are still relatively young, as systems grow older, the necessary replacement rates will inevitably increase. In addition to the necessary funding, congestion above and below ground is making the replacement of water mains more difficult for utility owners as is the lack of public tolerance for the disruption caused by construction work. There is an increasing availability of technologies for rehabilitation of existing pipes, which provides solutions that minimize or alleviate these problems, while providing realistic and potentially cost-effective alternatives to traditional open cut replacement. The primary objectives of the report are:

- To review current and emerging rehabilitation technologies for water distribution mains and services.
- To understand the needs of water utilities for renewal of their infrastructure and to identify technology gaps that should be addressed in order to meet these needs.
- To identify key performance parameters for various rehabilitation technologies and to gather and document this information for rehabilitation technologies that are available for use in the market.

This report contains a comprehensive review and evaluation of existing and emerging renewal technologies for water distribution system mains and services. This report covers technologies used for the repair, rehabilitation, and replacement of water mains and service lines. The available technologies for water pipeline renewal leave "gaps" in terms of certain needs that are unmet that fall into two main categories: data gaps in terms of knowledge of the existing pipe condition; and capability gaps in terms of the available renewal technologies. Accurate data on pipe condition is necessary for the successful selection and design of renewal technologies. Data gaps relate to the amount and/or quality of direct physical inspection data on a pipe, which may be obtained either externally or internally. Obtaining external data requires costly excavation, while internal data can be obtained over the full internal surface area of the pipe, but this typically requires the main to be shutdown and dewatered.

Capability gaps remain, despite the available rehabilitation technologies generally meeting renewal needs. Reopening service connections after lining still requires excavation with some technologies at each connection location and where service connections are frequent; this becomes as disruptive as a full-length excavation. Operational aspects such as access requirements and the length of time that the main is out of service are also areas where gaps exist between capability and customers' needs. A gap also remains in the understanding of the long-term performance of various rehabilitation technologies and their materials. These materials and methods have been introduced recently and therefore their installed performance has not been studied over time.

To overcome the gaps identified, it is recommended that innovative rehabilitation technologies be demonstrated in field conditions and measured against a clearly defined set of performance criteria. An additional research need is to identify accelerated aging test protocols that would help system owners to predict the long-term performance of the products and technologies used. It is also recommended that a retrospective analysis of water main rehabilitation materials be conducted to understand service life performance of field-installed materials. These data, along with the documented performance evaluation from a demonstration program, would be essential in providing utility decision makers with the information needed for selecting technologies and materials that meet their needs.

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EXECUTIVE SUMMARY

Introduction

This report contains a comprehensive review and evaluation of existing and emerging renewal technologies for water distribution system mains and services. This report covers technologies used for the repair, rehabilitation, and replacement of water mains and water service lines. The research team identified several renewal technologies that are in the early stages of adoption within the U.S. water distribution rehabilitation industry and are considered to be appropriate targets for inclusion in a demonstration program. In addition, there is a need to track how rehabilitation systems are performing in terms of structural deterioration and functionality and hence to assess the expected service life of the rehabilitated structure. The primary objectives of the report are:

- To review current and emerging rehabilitation technologies for water distribution system mains and services.
- To understand the needs of water utilities for renewal of their infrastructure and to identify technology gaps that should be addressed in order to meet these needs.
- To identify key performance parameters for various rehabilitation technologies and to gather and document this information for rehabilitation technologies that are available for use in the market.

Background

The impact that the lack of investment in water infrastructure will have on the performance of aging underground infrastructure over time is well documented and the needed funding estimates range as high as $325 billion over the next 20 years. With the current annual replacement rate averaging 0.5%, pipes would be expected to last for 200 years, but most pipes are designed for 50 or 100 year life cycles. While this replacement rate may be sufficient in the immediate term because pipes are still relatively young, as systems grow older the necessary replacement rates will inevitably increase. In addition to the necessary funding, congestion above and below ground is making the replacement of water mains more difficult for utility owners as is the lack of public tolerance for the disruption caused by construction work. There is an increasing availability of trenchless technologies for rehabilitation and replacement, which provides solutions that minimize or alleviate these problems while providing realistic and potentially cost-effective alternatives to traditional open cut replacement.

The financing of water infrastructure and the timely renewal of water pipe is an issue that pipe rehabilitation may help to address. Water rates are politically sensitive and it is difficult to raise the necessary funds for improving the condition of water mains. Many water utilities have well developed repair strategies, and currently find a largely reactive approach cheaper than establishing a proactive, systematic rehabilitation program. The main driver pushing utilities to undertake rehabilitation work is the direct and indirect costs associated with cumulative failures in a water main, but there may be an underappreciated driver that rehabilitation now can lead to a longer life of water mains. Main breaks of smaller mains for the most part have limited consequence and actually contribute to the difficult task of condition assessment. Large transmission mains are another story, as major breaks can flood entire areas of a city with serious and costly consequences and some utilities are now experiencing these types of breaks for the first time. For most mains, the repeated failure of a pipeline that subsequently leads to repeated repairs are slow to become economically unfavorable in comparison to rehabilitation or replacement. The driver for pipe renewal is often the customer’s intolerance of repeated or prolonged downtime.

Characteristics of Water Mains

Various studies have estimated the size of the U.S. water distribution network from 980,000 to nearly 1.8 million miles of mains. Selection of the pipe materials used for water supply applications is dependent upon pressure, durability, installation, and water quality approvals such as National Sanitation Foundation (NSF)/American National Standards Institute (ANSI) Standard 61. Environmental factors such as soil corrosivity and composition, ground temperature, and groundwater actions are also important.

Until the 1940s, water mains were mainly unlined cast iron (CI) and steel. CI manufacturers turned to ductile iron (DI) pipe and CI ceased being manufactured altogether in the mid 1980s. Today, more than 40% of all underground water mains are CI pipe. CI pipe is strong (but brittle) and usually offers a long service life, but it is subject to internal and external corrosion. Internal corrosion (tuberculation) can lead to water quality issues, reduced flow and pressures, and eventually leakage. CI pipes are also susceptible to corporation stop failure due to galvanic action, which leads to leakage, and to bending loads induced by a loss of beam support, which results in circumferential cracks.

DI pipe was introduced to the utility market in 1955 and makes up 22% of water mains in the U.S. Internal corrosion is prevented by cement mortar lining and by 1975 most DI marketed for water mains was cement-mortar lined. External corrosion is prevented by wrapping the pipe in a polyethylene film, bonded coatings, or cathodic protection.

Asbestos cement (AC) pipe was first introduced in North America in 1929 and it was a popular choice for potable water mains from 1940s to the 1970s. Production ceased in the U.S. in 1983 and it still makes up 16% of U.S. water mains. AC pipe is made of asbestos fibers, silica sand, and Portland cement and is not subject to galvanic corrosion. However, soft water removes calcium hydroxide from the cement and this eventually leads to deterioration of the pipe interior (e.g., softening accompanied by the release of asbestos fibers). External exposure to acidic groundwater or sulfates in the soil can also lead to deterioration of the cement.

Thermoplastic pipes, in the form of polyvinyl chloride (PVC) initially and then polyethylene (PE), are also widely used for underground water mains. PVC pipes have been used significantly in U.S. water distributions systems since the late 1970s and it makes up 13% of the U.S. water mains, while PE makes up around 0.4% of U.S. water mains. Thermoplastic pipes are not subject to electrochemical or galvanic corrosion or to internal or external corrosion, and have a high resistance to chemical and biological degradation. They are, however, subject to permeation and degradation by petroleum hydrocarbons and may not be suitable for installation in petroleum-contaminated soils.

Other commonly used pipe material used over the years include steel, prestressed concrete cylinder pipe (PCCP), and glass reinforced polymer (GRP) pipe. Steel pipe is usually used for large diameter or high pressure applications due to its high strength and rigidity, but is subject to internal and external corrosion. Internal corrosion can be prevented by various measures such as cement mortar lining and water treatment, while external corrosion is minimized by wrapping the pipe in a PE film, bonded coatings, or with cathodic protection. PCCP was first manufactured in the 1940s and consists of a concrete core, thin steel cylinder, high tensile pre-stressing wires, and a mortar coating. PCCP tends to be larger diameter, making failure of this pipe relatively catastrophic and costly. GRP pressure pipe for use in potable water applications is manufactured as a composite of wound glass fibers, resin, filler, and sand applied in centrifugal and other processes. GRP can be manufactured with various resins including polyester, vinyl ester, and epoxy.

The failure mechanism of each pipe material varies, which means that rehabilitation solutions must be tailored to match the problems experienced by a specific pipe material, or be flexible enough to cover a multitude of performance problems that may vary depending on operating and environmental conditions. Each failure mechanism has some indicators that can be measured. An understanding of the failure modes and their indicators is useful in assessing the condition of the pipe material and selecting the appropriate timing and type of renewal technique to use.

Renewal Technologies

Renewal of pipes falls into one of three distinct categories (e.g., repair, rehabilitation, and replacement). Repair techniques are used when the existing pipe can be readily restored to a structurally sound condition, providing the pipe has acceptable flow capacity and supports good water quality. Rehabilitation methods include internal coatings, sealants, and linings which are often used to extend operational life and restore much or all of the pipe's hydraulic capacity and improve water quality. Other rehabilitation methods are directed at restoring structural functionality. Replacement of an existing pipe is used when the main is severely deteriorated, collapsed, or increased flow capacity is needed.

Methods used for renewal may be conventional open cut or trenchless technologies. One disadvantage of some trenchless methods is the need to excavate for reconnection of existing service connections. Significant reductions in the cost of water main rehabilitation are being achieved with methods that can reliably reconnect services without further excavation.

Technologies used for repair are typically short-term solutions used for small segments of the pipe and specifically for localized problems or poor workmanship. These technologies include open cut or trenchless spot repairs including internal joint seals, pipe sleeves, chemical grouts, spray-on epoxy and polyurethane coatings, and reinforced carbon fiber pipe wrapping (some of which are structural solutions). The majority of these techniques were designed for applications other than water main renewal, but each has ANSI/NSF approval for use in water mains.

Rehabilitation focuses on the renewal aspects of water mains where the existing pipe becomes part of the renewal work. If the rehabilitation is to provide only corrosion protection, or the existing pipe is only partially deteriorated, then the remaining structural strength of the existing pipe can be incorporated into the fabric of the completed system. For fully deteriorated situations, the existing pipe acts merely as a right-of-way for the installation of the structural liner. The choice of method will largely depend on the perceived condition of the pipe, project objective, and estimated cost. Rehabilitation technologies include spray-on linings such as cement mortar, epoxy, polyurea, and polyurethane; segmental and continuous sliplining; cured-in-place pipe (CIPP) linings; inserted hose linings; and close-fit lining by symmetrical reduction or fold and form. Pipe bursting can also be considered a rehabilitation method, but is covered in this report as a replacement method.

A significant component in water distribution system rehabilitation projects concerns service reinstatement and restoration or replacement of service lines. If a water line runs along one side of a street, then the service lines to the properties on either side of the street could be renewed quite differently. Frequently "short side" service lines involve open cut works in sidewalks, yards, and gardens, whereas "long side" replacements may require lengthy excavations in road pavements and restoration of costly traffic-bearing surfaces. Renovation of service lines with longer runs may be an opportunity for a trenchless replacement option such as impact moling or ramming or a trenchless rehabilitation method such as lining. Traffic impacts and shallow burial may increase the likelihood of leakage and increase the need for pipe renewal. The technologies available for service line rehabilitation include epoxy lining and plastic liners, although their use is not common.

Water main replacement is a primary option when a pipe does not have enough structural strength and becomes prone to failure and where precise condition assessment and residual life estimation may be costly or otherwise difficult to implement. These technologies include open cut, pipe bursting, pipe splitting, pipe reaming, pipe pulling, microtunneling, pipe jacking, pipe ramming, impact moling, and horizontal directional drilling (HDD). Sliplining can also be considered a method of online replacement, but is covered in this report as a rehabilitation method.

Service Lines

The service connection typically comprises two sections: the service line from the main to the edge of the street or easement right-of-way; and the customer line from the right-of-way or street into the customer premises. In general, the service line is owned by the water utility and the customer line by the property owner, though some locations place ownership of the service line in the right-of-way on the customer. An estimated 880,000 miles of piping are used as water service lines in the U.S. These service lines typically have a diameter of ¾ in. to 2 in. and are typically made of copper, PE, PVC, or polybutylene (PB). In some older systems, lead service lines still exist, as do galvanized steel (GS) and brass.

On average, copper has shown a life expectancy normally in excess of 75 years and it makes up approximately 61% of all water services. The rising cost of copper appears to be accelerating a transition to plastic materials. PE service lines are characterized by their toughness, excellent chemical resistance, low coefficient of friction, and ease of processing; and they now make up 12% of U.S. water services. GS service lines, usually found in older homes, are roughly 9% of the U.S. water services. They were covered with a protective coating of zinc to extend the pipe life expectancy about 40 years, but the coating generally fails and they corrode inside and out. PVC, making up 6% of U.S. services, is not subject to corrosion and the surface remains smooth, eliminating tuberculation that can reduce hydraulic capacity and increase pumping costs. PB pipe was a popular material in the 1970s through the early 1990s. Although PB is corrosion-proof, it has a widespread record of failure possibly owing to its reaction to chlorinated water, but it still makes up 3% of U.S. water services.

Lead service piping has not been used by most U.S. cities since the 1940s and lead has been banned for use in plumbing systems since 1986. Depending on site-specific connection details, lead service lines have a life expectancy of 60 to 75 years; however, because of potential health risks associated with excessive lead levels in water, it has been replaced in new installations by alternatives such as copper and PE. The revisions to the Safe Drinking Water Act (SDWA) in 1996 resulted in a reduction of allowable leaching levels for materials that come into contact with potable water supplies.

In addition to the rehabilitation of the line itself, service lines pose three main issues for rehabilitation technologies: finding the service connection post-rehabilitation; re-establishing the service opening; and connecting the service to the liner or carrier pipe. Techniques exist for all three operations, but remain under development for re-establishing the service connection in order to make them more cost-effective and reliable. The inability to accomplish these tasks quickly and cost-effectively and to achieve a reliable watertight connection is a barrier to the greater introduction of trenchless rehabilitation methods for water mains.

Technology Selection Considerations

For water main renewal, the challenges fall into two categories: assessing the condition of existing pipes (e.g., defining the problem) and selecting the appropriate technique to restore the pipe condition to a desired level (e.g., solving the problem). Prior to technology selection, it is important to understand and define the performance and condition of the water main and to understand the cause of its deterioration. This will include an evaluation of structural issues, hydraulic capacity, external corrosion, joint leaks, and/or water quality problems.

Once the problem is well defined, different solutions can be developed based upon a review of available technologies that can address the current asset condition and extend the remaining asset life. From there, the cost required to renew the water main is often the most important technology selection criteria. Cost calculations for reliable renewal options should include both capital or direct construction costs and life-cycle costs, which include operation and maintenance (O&M) and social costs. Next, an appropriate rehabilitation solution should be selected based upon life-cycle costs and other factors such as maintenance requirements, bypass piping requirements, disinfection requirements, NSF/ANSI 61 requirements, accessibility issues, and criticality of the water main.

Design and Quality Assurance/Quality Control Requirements

Multiple design manuals and regulatory standard specifications exist in the U.S. water utility market from organizations such as the American Water Works Association (AWWA), ANSI, and American Society of Testing and Materials (ASTM). Material standard specifications and installation and testing advisories are sometimes also developed by trade association and industry research organizations. Some standards, such as ASTM F-1216, incorporate design procedures, while others are used to regulate product acceptance, installation methodology, or in situ evaluation and acceptance procedures.

Renewal design needs to take into account all of the same structural and hydraulic parameters as new pipe design, and follows the same codes and standards. Similarly, water quality requirements are the same as for new pipes. In addition, the interaction with the host pipe and any loads imposed during installation, especially if using trenchless methods, must also be considered. The normal design life of linings and renewed pipes is 50 years, so durability aspects such as lasting structural strength and corrosion resistance also influence design decisions. Similarly, the hydraulic effect of different materials, in terms of surface roughness, needs to be considered in relation to loss of cross-sectional area when a pipe is lined. Unfortunately, many of the rehabilitation materials in use today have not been in the ground for 50 years to verify their true length of life. Partial solutions like semi-structural spray-on linings also rely upon continued performance of some portion of the original pipe.

Installation of renewal techniques may differ substantially from that of new pipes, so there are specific installation standards or recommended practices for many techniques, many of which are developed by technology vendors, industry organizations, and regulators outside North America. Where the installed pipe or lining is dependent on support from the host pipe as with AWWA Class I, II, and III linings, it is important that the appropriate installation procedures are followed so that the lining can perform as designed. This applies equally to non-structural methods such as cement mortar linings (Class I) and semi-structural (Class II and III) methods. Fully-structural (Class IV) methods do not depend on the host pipe for support, but the design is still important to ensure the structural criteria are met by the renewal system.

Quality assurance/quality control (QA/QC) procedures are required and specified in many cases by the utility owners and basic requirements are enshrined in the product and process specifications developed by AWWA, ASTM, and vendor organizations. QA in the form of test certificates can be provided by the manufacturer or by the licensed seller of the product. The contractor in most cases provides a level of process QC, which may be supervised by third party consultants and testing agencies.

Short-term quality monitoring encompasses compliance checks on raw materials, equipment and calibration, and on the finished product, often following procedures set out in ANSI, AWWA, and NSF standards. Long-term quality monitoring may cover water quality, to ensure that the installed materials are not adversely affecting water quality and the monitoring regime is driven by regulatory compliance. Similarly, some monitoring of the material performance is necessary to ensure that it continues to perform through its intended service life and water-tightness is also an aspect that requires long-term monitoring.

QA is the responsibility of the system owner, the designated project engineer, and the authorized quality manager or agency. Whether utilizing prescriptive specifications or performance specifications, it is important that this communication with the installer convey what QA testing will be performed and that the contract documents establish these requirements as mandatory and specify such remedial measures as may be necessary. Independent laboratory testing for compliance normally should be under a contract between the laboratory and the owner, and not between the laboratory and the contractor. Contractually, there should be a list of known problems that can arise and a specified remedy prescribed that is clear before the work begins.

Operation and Maintenance

O&M of water networks encompasses many activities that can be affected by rehabilitation. The impact of O&M on water distribution networks after rehabilitation is widely unknown mainly because of the young age of water rehabilitation techniques. However, there are essential elements to consider:

- Can the rehabilitated pipe be readily located?
- Can the rehabilitated pipe be controlled (i.e., shutdown) for making future repairs?
- Can future defects (e.g., leaks) be readily identified and pinpointed?
- Can anticipated future connections and controls be installed?

The ability of a utility's repair crews to skilfully carry out emergency repairs on rehabilitated water mains is another important consideration. There is a demonstrated need for suppliers of linings and similar technologies to develop repair procedures for their products in water main applications and to train utilities in their application. In addition, proper cleaning is essential both prior to rehabilitation activities and during routine operations to improve the capacity and hydraulic performance of water mains. The selection and use of appropriate cleaning methods can be an important factor in the success or failure of a water main renewal effort. For example, there is experience that high pressure water jetting can cause damage to lining systems. Similarly, drag scraping of water mains may damage linings and/or corporation stops prior to rehabilitation, which makes service reconnection very challenging.

There are several best practices for O&M that can be effective in either prolonging the life of a water main or allowing a utility to monitor real-time performance so action can be taken as needed to repair, rehabilitate, or replace the water main before a catastrophic failure occurs. These methods include cathodic protection, corrosion monitoring, water audits, and leak detection.

Findings and Recommendations

The available technologies for water distribution system renewal offer several benefits to open cut replacement, but they do leave some "gaps" in terms of certain needs that are unmet. These gaps fall into two main categories: data gaps in terms of knowledge of the existing pipe condition; and capability gaps in terms of the available renewal and rehabilitation technologies.

Accurate data on pipe condition is necessary for the successful selection and design of renewal technologies. Data gaps relate to the amount and/or quality of direct physical inspection data on a pipe, which may be obtained either externally or internally. Obtaining external data requires excavation for inspection on the pipe surface, which can be costly and impracticable, although vacuum excavation may be used to obtain data in a spot location. As a result, the sample size is extremely small and the confidence level of the findings in terms of being representative of the pipeline as a whole is very low. Internal data can be obtained over the full internal surface area of the pipe, but this typically requires the main to be shutdown and dewatered for inspection, which is also costly due to the service interruption, although some technologies do exit for live inspections.

The available rehabilitation technologies in the market currently generally meet the required water distribution system renewal needs, but some capability gaps remain. Reopening service connections after lining still requires excavation with some technologies at each connection location for manual reopening and reconnection to the service pipe, often requiring a new fitting. Where service connections are frequent, this becomes as disruptive as a full-length excavation, thereby negating the benefits of some trenchless solutions. Operational aspects such as access requirements and the length of time that the main is out of service are also areas where gaps exist between capability and customers' needs. A gap also remains in the understanding of the long-term performance of various rehabilitation technologies and their materials. These materials and methods have been introduced recently and therefore their installed performance has not been studied over time.

To overcome the barriers and gaps identified, it is recommended that innovative rehabilitation technologies be demonstrated in field conditions and measured against a clearly defined set of performance criteria, which can inform water utilities of the capabilities, applicability, and costs of innovative technologies. An additional research need is to identify accelerated aging test protocols that would help system owners to predict the long-term performance of the rehabilitation products and technologies that are emerging in the market and to identify appropriate design and performance standards for their use. It is also recommended that a retrospective analysis of water main rehabilitation materials be conducted to understand service life performance. A retrospective study of materials in use for up to 20 years or more can provide data on the performance of field-installed materials. These data, along with the documented performance and applicability evaluation performed under a demonstration program, would be essential in providing utility decision makers with the information they need for selecting the proper technologies and materials to meet their system needs.

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DEFINITIONS

Cement mortar lining (CML) – A technique that spray applies a cementitious based lining to the interior surface of a pipe in need of non-structural rehabilitation.

Cured-in-place pipe (CIPP) – A hollow cylinder consisting of a fabric tube with cured thermosetting resin. The CIPP is formed within an existing pipe and takes the shape of the pipe.

Folded pipe – Pipe that has been manufactured and calibrated in a round shape, and then subsequently cooled and deformed into a folded shape for insertion into the existing pipe.

Partially deteriorated pipe – The existing pipe can support the soil and surcharge loads throughout the design life of the pipe, but the soil adjacent to the existing pipe must provide adequate side support.

Fully deteriorated pipe – The existing pipe is not structurally sound and cannot support soil and live loads, or it is expected to reach this condition over the design life of any rehabilitation.

Joint repairs – A technique that uses mechanical systems for internal joint sealing or repair systems that inject grouts through leaking joints.

Pipe bursting – A process that utilizes equipment to fracture brittle pipe materials and split ductile pipe materials and displace the old pipe into the soil while forming a cavity in the soil sufficiently large enough to place a new pipe of equivalent or larger size in the space formerly occupied by the old pipe.

Reduced diameter pipe – Pipe that is shaped on site for insertion and then reshaped to form a close-fit liner.

Renewal – The application of infrastructure repair, rehabilitation, and replacement technologies to return functionality to a drinking water distribution system or a wastewater collection system.

Repair – A technique is typically a spot restoration used when the majority of the existing pipe is structurally sound, except in some spot locations.

Rehabilitation – Internal coatings, sealants, and linings used to extend operational life and restore much or all of the pipe's hydraulic and structural functionality.

Replacement – An existing pipe is usually replaced when it is severely deteriorated, collapsed, or increased flow capacity is needed.

Sliplining – The installation of a smaller-diameter replacement pipe inside an existing pipe, leaving an annular gap between the two. The replacement pipe can be continuous or made up of discrete segment lengths. It may be considered a replacement rather than rehabilitation.

Spray-on polymeric lining – A technique that spray applies a polymeric (e.g., epoxy, polyurethane, or polyurea) based lining to the interior surface of a pipe in need of rehabilitation.

Trenchless technology – A family of techniques that allow installation and rehabilitation of buried utilities without the need to excavate a continuous trench to access the utility.

Open cut – Excavation from the surface to install or rehabilitate a buried utility.

ABBREVIATIONS AND ACRONYMS

AC	asbestos cement
ACI	American Concrete Institute
AI	Aggressivity Index
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society of Testing and Materials
AWWA	American Water Works Association
AWWARF	American Water Works Association Research Foundation
BNQ	Bureau de Normalisation du Québec
BS	British Standards
CCFRPM	centrifugally cast fiberglass reinforced polymer mortar
CCTV	closed circuit television
CFR	Code of Federal Regulations
CFRP	carbon fiber reinforced polymer
CHIP	controlled head inversion process
CI	cast iron
CIPP	cured-in-place pipe
CML	cement mortar lining
CO_2	carbon dioxide
CSO	combined sewer overflow
DI	ductile iron
DIPRA	Ductile Iron Pipe Research Association
DIPS	ductile iron pipe standard
DOT	U.S. Department of Transportation
DR	Dimension Ratio
DVGW	Deutscher Verein des Gas- und Wasserfaches
ECP	embedded cylinder pipe
EES	Economic and Engineering Services
EPA	U.S. Environmental Protection Agency
EPB	earth pressure balance
EPDM	ethylene propylene-diene modified
FRP	fiberglass reinforced plastic
GAO	Government Accounting Office
GIS	geographic information systems
gpm	gallon per minute
GRP	glass reinforced polymer/plastic
GS	galvanized steel

HDB	hydrostatic design basis
HDD	horizontal directional drilling
HDPE	high density polyethylene
HDS	hydrostatic design stress
ID	Inner Diameter
IJS	intermediate jacking stations
IPS	iron pipe size
ISO	International Organization for Standardization
LCP	lined cylinder pipe
LSI	Langelier Saturation Index
MDPE	medium density polyethylene
MFL	magnetic flux leakage
NACE	National Association of Corrosion Engineers
NIPDWR	National Interim Primary Drinking Water Regulations
NPDWR	National Primary Drinking Water Regulations
NRC	National Research Council
NRMRL	National Risk Management Research Laboratory
NSF	National Sanitation Foundation
O&M	Operation and Maintenance
OD	Outside Diameter
OSHA	Occupational Safety and Health Administration
PAP	polyethylene -aluminum-polyethylene
PB	polybutylene
PCCP	prestressed concrete cylinder pipe
PE	polyethylene
PHC	petroleum hydrocarbons
PPI	Plastic Pipe Institute
PPL	Pressure Pipe Liner
PPM	Progressive Pipeline Management
PU	polyurethane
PVC	polyvinyl chloride
PWAP	Pipe Wrap A+ Wrap™
QA/QC	quality assurance/quality control
RCP	reinforced concrete pipe
SDR	standard dimension ratio
SDWA	Safe Drinking Water Act
SOT	state-of-technology
SRF	State Revolving Fund
SSO	sanitary sewer overflow
TO	Task Order

UL	Underwriter Laboratories
UV	ultraviolet
VOC	Volatile organic compounds
WaterRF	Water Research Foundation
WRAS	Water Regulations Advisory Scheme
WRc	Water Research Center

1.0: INTRODUCTION

The U.S. Environmental Protection Agency's (EPA's) Aging Water Infrastructure Research Program directly supports the Agency's Sustainable Water Infrastructure Initiative. Within this program, scientific and engineering research is being conducted to evaluate promising innovative technologies that can reduce costs and improve the effectiveness of operation, maintenance, and replacement of aging and failing drinking water distribution and wastewater conveyance systems (EPA, 2007a). Task Order (TO) 58 under EPA STREAMS Contract No. EP-C-05-05758 involved a comprehensive review and evaluation of existing and emerging renewal technologies for water distribution systems.

1.1 Project Background

This state-of-technology (SOT) report is one of three SOT reports (see EPA, 2010a and 2010b) prepared under TO 58. This report covers the rehabilitation of drinking water infrastructure including water mains and service lines. The companion reports cover separately the SOT for wastewater collection systems and sewer force mains, respectively. This more detailed report follows a previously released *State of Technology Review Report on Rehabilitation of Wastewater Collection and Water Distribution Systems* (EPA, 2009) that provided a brief overview of the current state-of-the-practice and current state-of-the-art for rehabilitation of pipes and structures within the wastewater collection and water distribution system and discussed the common issues needing improvement that apply to both water and wastewater applications.

During the course of TO 58 activities, including a technology forum and the preparation of the SOT reports, the research team identified several renewal technologies that are in the early stages of adoption within the U.S. water industry. These technologies are considered to be appropriate targets for inclusion in a field demonstration program of emerging and innovative trenchless technologies for water network rehabilitation. The demonstrations will provide an opportunity for third-party documentation of the application of new technologies and capture the design and installation data that will be important later in tracking the deterioration rates for the rehabilitated structure. These field trials are meant to illustrate the overall technical approach to the evaluation and acceptance of a novel or emerging technology in an effort to lower the risk for water utilities in implementing new technologies and processes in their networks.

The technology forum also reinforced a key need in applying asset management principles to water and wastewater systems – the need to track how the rehabilitation system is performing in terms of structural deterioration and functionality and hence to assess the expected service life of the rehabilitated structure. A significant volume of treated, potable water is lost to leakage and main breaks and the cost of the lost water itself is an increasing concern, which adds to the true costs of allowing a distribution system to deteriorate.

Renewal of distribution pipes is carried out by various technologies, allowing them to successfully fulfill their purpose of transmission or distribution. Innovative contractors and pipe manufacturers have developed various trenchless technologies for permanently correcting or controlling water main failures. For example, structural liners can be used for pipes with a history of breakages, while a non-structural liner may be suitable for corrosion protection of structurally sound pipes.

1.2 Project Objectives

The project aims to understand the repair, rehabilitation, and replacement technologies for water mains and water services available to water utilities. Recently, there has been a significant increase in the range and type of rehabilitation technologies available for water mains in the market, but only limited adoption to date has taken place. The scope of this project is to provide an overview of key technical parameters to assist water utilities in identifying and selecting commercially available rehabilitation/repair technologies for deployment in the field. Therefore, the main objectives of the report are to:

- Review current and emerging rehabilitation/repair technologies for water distribution system mains and services.
- Understand the needs of water utilities for renewal of their pipeline infrastructure and to identify technology gaps that should be addressed in order to meet these needs.
- Identify key performance parameters for various rehabilitation/repair technologies and to gather and document this information for rehabilitation technologies that are available for use in the market.

1.3 Project Approach

The research team reviewed available rehabilitation technologies in the water utility market for both water mains and service lines. As part of the review, the researchers documented key technical parameters associated with each technology including:

- Technical application parameters;
- Design standards;
- Case studies;
- Acceptance and use data;
- Quality assurance/quality control (QA/QC) requirements;
- Installation methods and standards; and
- Costs and key costing factors.

The rehabilitation of a water main is also not an individual event in itself. The sequence of activities in a water main rehabilitation program can be complex. Several site preparation tasks such as cleaning, drying, and setting up bypass piping precede the rehabilitation, while other activities such as verification, inspection, and disinfection prior to a return to service follow the rehabilitation. The conduct of these various activities can have significant bearing on the success or failure of the selected repair or rehabilitation technology and these issues are also reviewed in this report.

1.4 Organization of Report

- **Section 2** describes the current state of renewal practices by water utilities.
- **Section 3** discusses the common characteristics and pipe materials used in the nation's drinking water infrastructure systems. It highlights the advantages and disadvantages of each, including their frequency of use in the distribution/transmission network. Failure modes of these pipes are also provided in this section.
- **Section 4** identifies and describes the renewal technologies that are currently available for water infrastructure repair, rehabilitation, and replacement of water mains and service lines.
- **Section 5** similarly discusses the characteristics of service lines in water infrastructure.
- **Section 6** covers technology selection considerations for choosing renewal techniques.
- **Section 7** briefly reviews designs and standards used in the water industry and introduces QA/QC requirements from the perspective of the manufacturers and licensed vendors.

- **Section 8** covers operation and maintenance (O&M) activities, which can be used to extend the life of existing pipe assets and drives the need for future repair, rehabilitation, and replacement activities.
- **Section 9** provides a compilation of gaps between needs and available technologies and provides recommendations to further the widespread use of renewal technologies in water utilities.

2.0: BACKGROUND

Numerous studies have reported on the impact that the lack of investment will have on the performance of the aging underground infrastructure over time. For example, the American Water Works Association (AWWA) previously estimated that there were more than one million miles of water mains serving 273 million people in the U.S., and that $325 billion would have to be spent over a 20-year period to revitalize the aging underground infrastructure (AWWA, 2001a). The Government Accounting Office (GAO) stated that 33% of water utilities did not adequately maintain assets and a further 29% had insufficient revenues to even maintain current water service levels (GAO, 2002). The EPA report *The Clean Water and Drinking Water Infrastructure Gap Analysis* attempted to reach a common quantitative understanding of the potential magnitude of investment needed to address growing population and economic needs (EPA, 2002). It highlighted the concerns of increasing per capita usage of treated drinking water from the year 1950 to the year 2000, as shown in Table 2-1, combined with a 159% growth in population, which led to about a 207% growth in drinking water usage (EPA, 2002).

Table 2-1. Increasing Per Capita Use of Treated Drinking Water

	1950	2000	Percent Change
Population (Millions)	93.4	242	159%
Usage (Billions of Gallons per Day)	14	43	207%
Per Capita Usage (Gallons per Person per Day)	149	179	20%

The annual American Society of Civil Engineers (ASCE) Infrastructure Report Card 2009 assigned a 'D-' rating to the nation's drinking water infrastructure. A shortfall of at least $11 billion in annual worth is what is estimated to replace the aging water infrastructure just to comply with existing and future federal water regulations and without taking into account growth in the demand for drinking water over the next 20 years (ASCE, 2009). ASCE also indicates that leaking pipes lose an estimated 7 billion gallons of clean drinking water per day, which is around 15% of the daily drinking water usage.

2.1 Current Utility Practices

Water utilities in the U.S. currently replace about 0.5% of their pipeline assets each year, with individual programs typically ranging from 0 to 1.5% per year (AWWA, 1998). As a long-term rate, this appears inadequate since most experts do not expect the average water main to last 200 years. In the near term, this replacement rate may be sufficient, but only because most pipes within the water distribution network are relatively young. However, as systems grow older, replacement rates will increase dramatically.

Congestion both above and below the ground is making the replacement of water mains more difficult. Due to utility congestion, it is becoming increasingly difficult to find space within many rights-of-way for new pipelines. It is equally difficult to find enough space in many public thoroughfares to perform the construction, due to traffic congestion. Public tolerance for the disruption caused by construction work is also diminishing.

Pipeline rehabilitation has the potential to alleviate some of these problems. For the past 20 years, utility managers have had two basic options when it came to pipeline infrastructure issues: fix leaks or replace pipes, both of which were largely reactive in nature. Also, there were only a few options available for extending the life of a pipe, but with technological advances that is changing. It is now possible to assess pipelines and perform their repair and/or rehabilitation through excavations at both ends of a section of pipeline rather than excavating the entire length of pipe. However, with more tools and choices, the management decisions are not necessarily getting any easier since more options require the understanding of the applicability of the increasing number of techniques.

Unless significant action is taken quickly, the problem will worsen as the average pipe age continues to increase without significant replacement or renewal. As shown in Figure 2-1, the average pipe age in 2000 was about 38 years, but by the year 2050 the average pipe age will be more than 50 years. This is because of the boom in water pipeline installations that took place after World War II. From 1870 to 1945, less than 20,000 miles of pipe was installed each decade; however, after 1945, this rate increased to over 80,000 miles of pipe per decade (EPA, 2002).

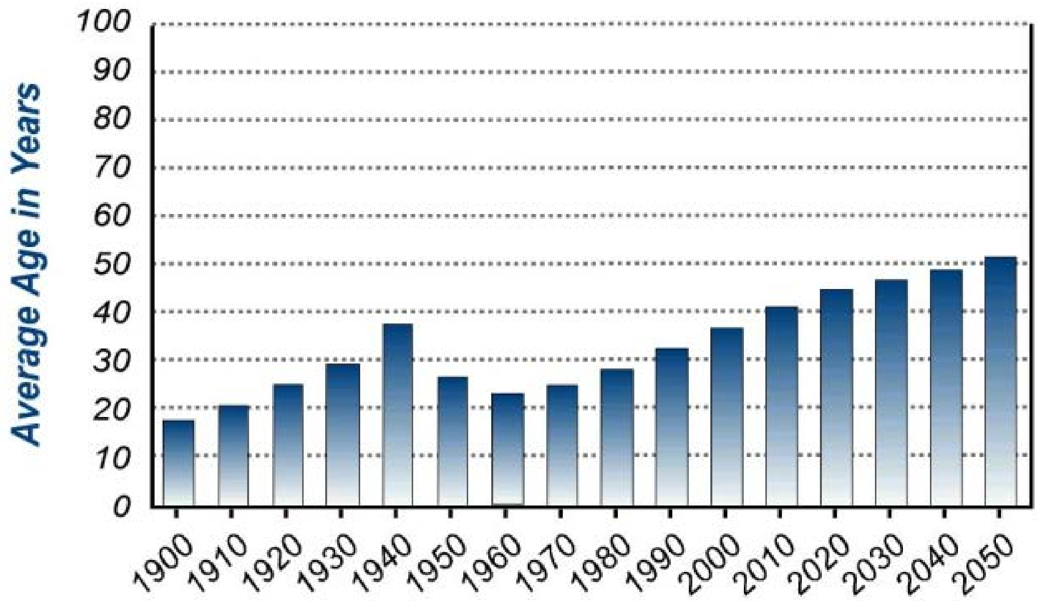

Figure 2-1. Historical and Projected Age of Water Pipes in the U.S.

The U.S. water distribution industry has an environment that is very different from the wastewater collection industry when it comes to the amount of rehabilitation undertaken or even contemplated. Formal enforcement action by the EPA on communities with excessive combined sewer overflows (CSOs) and sanitary sewer overflows (SSOs) during wet weather has been a driver of action for the wastewater industry. For example, the threat of fines for overflows or spills is driving many communities to undertake infiltration and inflow (I&I) reduction programs that often involve some form of sewer main rehabilitation. Without the threat of such costly external enforcement actions, the political environment in many communities would make it difficult to raise the necessary funds to improve the condition of the wastewater system to an acceptable level of performance. Water systems also are more difficult to inspect and require expensive and time consuming temporary services and disinfection in connection with rehabilitation. With well-developed repair strategies, many water utilities currently find a largely reactive approach cheaper (in the short term) than establishing a systematic rehabilitation program.

The Clean Water and Drinking Water Infrastructure Gap Analysis stated the need for an improved decision-making process for maintaining, upgrading, and expanding infrastructure (EPA, 2002). The relationship between O&M needs and capital stock is not fully understood. Clean water and drinking water systems will incur significant costs due to deteriorating pipes over the next 20 years at the same time as they expand capacity to serve current and future growth, as shown in Figure 2-2 (EPA, 2002). This analysis would benefit from research into an array of factors that ultimately will determine, or at least influence, the scale of future capital investment needs. These factors will also determine how future capital investment needs are met. These factors include asset management processes, restructuring to gain economies of scale, understanding elasticity of demand for water, demographic shifts, efficiency in latest technologies, operating trends, criticality analysis, and the effects of non-like-for-like replacement of assets or repair and rehabilitation options.

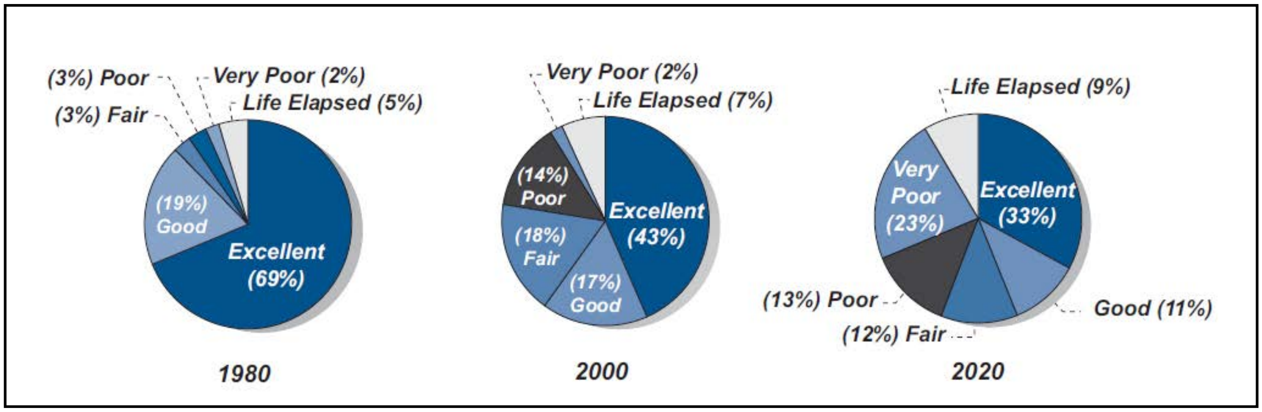

Figure 2-2. Estimated Pipe Condition in 20-Year Spans

2.2 Current Market

Approximately 160,000 public water systems in the U.S. are subject to the Safe Drinking Water Act (SDWA) – a Federal law (EPA, 2009). The SDWA requires the EPA to establish National Primary Drinking Water Regulations (NPDWR) for contaminants. Mandatory maximum contaminant levels and non-enforceable maximum contaminant level goals are established by EPA. The 1996 Amendment to the SDWA established the Drinking Water State Revolving Fund (SRF). States can use the funds to help water systems make infrastructure improvements or assess and protect source water. The amount of money allocated to the revolving funds has decreased over the years with the result being that the amount of money available in the SRF is low compared with the amount needed to rebuild the water infrastructure.

States have administrative penalty authority, and many types of formal enforcement action are possible. However, fines are small in comparison to those for wastewater overflows, so utility efforts tend to focus more on source water and treatment issues than on distribution and transmission improvements. For example, service interruptions as a result of failure, inadequate flow or low pressure, all of which can be very upsetting to the utility customer, do not warrant enforcement action under the SDWA.

The main driver pushing utilities to undertake any rehabilitation work on their underground water infrastructure is the direct and indirect cost associated with cumulative failures in a water main, but there may be an underappreciated driver that rehabilitation now can lead to a longer life of water mains. As an example, Cleveland, Ohio has experienced two breaks in a 36-in. cast iron water main located in the center of the business district. The Cleveland press reported that the cost to repair the first break, and restore damage done by flooding, combined with the business losses associated with a complete shutdown for two days, was about $1.5 million. After the second failure, the City decided to aggressively take action to upgrade this line because the estimated cost of doing so was less than the costs associated with these failures.

Main breaks of smaller mains for the most part have limited consequence and actually contribute to the difficult task of condition assessment. Large transmission mains are another story, as major breaks can flood entire areas of a city with serious and costly consequences and some utilities are now experiencing these types of breaks for the first time. For most mains, the repeated failure of a pipeline that subsequently leads to repeated repairs are slow to become economically unfavorable in comparison to rehabilitation or replacement. The driver for pipe renewal is often the customer's intolerance of repeated or prolonged downtime.

As stated earlier, SRFs are insufficient to cover the costs for rehabilitating an aging water system and rate structures for pubic water utilities typically are not designed to provide the level of funds needed. Water rates are politically sensitive and, without significant increases over the years, often do not cover the cost of providing clean water to stakeholders. Public utilities will need to find a way to raise rates to match the value of water to society so that money becomes available for renewing the aging infrastructure.

It may take a significant disaster in the U.S., such as occurred in Walkerton, Ontario, to push politicians to take action on rate increases. An outbreak of *E. coli* due to operator error in Walkerton, Ontario, in May of 2000 resulted in the death of seven people from drinking contaminated water and another two thousand people suffered from the symptoms of the disease (Holme, 2003). The disaster resulted in a surge of regulations and other enforcement measures, resulting in water rates tripling in many Canadian municipalities. Utility operators have commented, however, that there is actually few documented water quality events related to pipe failure.

The rehabilitation of potable water distribution systems is an emerging market in the U.S. and abroad. An exception is in the UK, primarily due to privatization of the water utilities in 1989, which resulted in an accelerated adoption of new rehabilitation methods. This is not to say that the needs for water rehabilitation are small. The needs are presented in the report *Dawn of the Replacement Era: Reinvesting in Drinking Water Infrastructure* (AWWA, 2001a):

> *"For the first time, in many of these utilities a significant amount of buried infrastructure—the underground pipes that make safe water available at the turn of a tap—is at or very near the end of its expected life span. The pipes laid down at different times in our history have different life expectancies, and thousands of miles of pipes that were buried over 100 or more years ago will need to be replaced in the next 30 years. Most utilities have not faced the need to replace huge amounts of this infrastructure because it was too young. Today a new age has arrived. We stand at the dawn of the replacement era. Extrapolating from our analysis of 20 utilities, we project that expenditures of the order of $250 billion over 30 years might be required nationwide for the replacement of worn-out drinking water pipes and associated structures (valves, fittings, etc). This figure does not include wastewater infrastructure or the cost of new drinking water standards. Moreover, the requirement hits different utilities at different times and many utilities will need to accelerate their investment. Some will see rapidly escalating infrastructure expenditure needs in the next 10–20 years. Others will find their investment decisions subject to a variety of factors that cause replacement to occur sooner or at greater expense, such as urban redevelopment, modernization, coordination with other city construction, increasing pipe size, and other factors."*

These massive financial needs were also reported by EPA, which estimated that $183.6 billion need to be invested by 2023 in distribution and transmission infrastructure pipelines (EPA, 2005).

3.0: CHARACTERISTICS OF WATER MAINS

Estimates of the length of water distribution piping in the U.S. ranges from 980,000 miles by AWWA (2004a), to more than one million miles by Grigg (2004), to nearly 1.8 million miles by Lafrance (2011). Various materials are used in distribution systems and each material can be categorized differently based on use and applicability. Each material can behave differently based on age, environmental conditions, and water quality. This section discusses the characteristics of water distribution systems.

3.1 Pipe Materials

Current materials used in water distribution systems are steel, ductile iron (DI), polyvinyl chloride (PVC), polyethylene (PE), prestressed concrete cylinder pipe (PCCP), and some glass reinforced plastic (GRP). Materials no longer used for new installations, but present in the systems from the past include asbestos cement (AC) and cast iron (CI). The following subsections identify the use and applicability of each material from known sources including the Water Research Foundation (WaterRF) formally known as the AWWA Research Foundation (AWWARF) and EPA reports.

3.1.1 Material Usage. Water mains can be categorized as distribution piping (2 to 10 in.) or transmission mains (12 in. and greater) (EPA, 2009). Approximately 73% of all water mains, on a length basis, are distribution pipes. Typically, pipe diameters less than 30 in. are considered non-man entry size so any inspection or trenchless rehabilitation needs to be done remotely. This covers 93% of the entire population of water mains. Tables 3-1, 3-2, and 3-3 provide some statistics on the distribution of pipe materials, pipe diameter, and age in the U.S. water distribution network (AWWA, 2004a).

Table 3-1. Water Distribution Systems by Material

Material	Miles Installed	% of Total
CI (unlined, cement mortar lined, and other)	341,715	39.6
DI (unlined, cement mortar lined, and other)	189,115	21.9
AC	136,196	15.8
PVC	114,152	13.2
Steel	34,047	3.9
PCCP	23,584	2.7
PE	3,349	0.4
GRP	665	0.1
Other/Not known	20,169	2.3
Total	**863,000**	**100**

Table 3-2. Water Distribution Systems by Diameter

Diameter Range (in.)	Miles Installed	% of Total
< 6	107,200	12.4
6 – 10	523,200	60.6
12 – 16	138,600	16.1
18 – 24	29,700	3.4
30 – 48	57,700	6.7
> 48	6,600	0.8
Total	**863,000**	**100**

Table 3-3. Water Distribution Systems by Age

Age (years)	Miles Installed	% of Total
0 – 10	245,000	28.4
10 – 25	325,500	37.6
25 – 50	156,500	18.1
>50	137,000	15.9
Total	**863,000**	**100**

For rehabilitation of water pipes, it is important to select a pipe material that is suitable for the operating environment. Certain technologies require a specific pipe material and most replacement technologies have preferred materials for the replacement pipe. Environmental factors, such as soil corrosivity, soil composition, ground temperature, and groundwater actions, are important in choosing the right pipe material for installation.

Selection of pipe materials for water supply applications is dependent upon pressure, durability, installation, and water quality approvals such as National Sanitation Foundation (NSF)/American National Standards Institute (ANSI) Standard 61 certification. Compatibility with existing materials in the system is also a consideration. The selection process is both quantitative and qualitative and, as a result of different experiences and preferences of utility managers, can result in a broad range of materials being found within a single water distribution system.

3.1.2 Applicability. Until the 1940s, water mains were mainly unlined CI and steel. CI manufacturers turned to DI pipe and CI ceased being manufactured altogether in the mid 1980s. Today, more than 40% of all underground water mains are CI pipe. Although no longer used to replace old water mains, there are more miles of CI pipe in use today than of any other material. Today, more than 475 U.S. utilities have had CI mains in continuous service for more than 100 years and they still function well in daily use (AWWA, 2003a). Each of the pipe materials discussed in the sub-sections below have a history of changes, application, improvements that might be important considerations in deciding which technology to use and references that provide more detail are listed for each material as appropriate.

3.1.2.1 Cast Iron Pipe. The primary problems with unlined CI pipe are internal and external corrosion. Internal corrosion (tuberculation) can lead to water quality issues, reduced flow and pressures, and eventually leakage. CI pipe is also susceptible to external corrosion if not protected. Graphitization of CI pipe weakens the pipe wall with the removal of iron ions leaving graphite behind. Graphitization is not easily detected as the appearance of the pipe remains unchanged. The weakened pipe wall can then fail with any increase in pressure (i.e., surge), frost heave, or ground movement. Also, the wall thickness of new CI pipe was reduced over the years as the production process changed from pit cast to spun cast. Consequently, younger CI pipe can actually pose a greater failure threat because it has thinner walls. CI pipes are also susceptible to service connection corporation stop failures due to galvanic action, which leads to leakage and to bending loads induced by loss of beam support (e.g., as a result of an adjacent excavation), which results in circumferential cracks. CI pipe is strong but brittle, usually offers a long service life, and is reasonably maintenance-free. However, CI is no longer used for manufacturing pipe in the U.S. because of the greater strength of DI pipe, although it is still used in the manufacturing of some valves and fittings. More information on cast iron water distribution pipes can found in Rajani et al. (2000), Maker et al. (2005), and Rajani and Kleiner (2011).

3.1.2.2 Ductile Iron Pipe. DI pipe was introduced to the utility market in 1955 and has completely displaced CI pipe. The DI pipe industry is represented by the Ductile Iron Pipe Research Association (DIPRA). Initially, DI was unlined, like CI, but by 1975 most DI marketed for water service was cement mortar lined. Internal corrosion is prevented by cement mortar lining and water treatment (e.g., pH adjustment, calcium carbonate addition, or metallic phosphate addition), while external corrosion is prevented by wrapping the pipe in a PE film, bonded coatings, or cathodic protection (Deb et al., 2002). Loose PE sleeves were later made available to electrically isolate the pipe from the soil with varying effectiveness (Szeliga, 2007).

The U.S. DI pipe industry currently does not offer DI with bonded coatings. A bonded coating to the exterior surface, in conjunction with cathodic protection to handle any inadvertent holidays in the coating, is generally considered to offer the highest level of corrosion protection (Peabody, 2001). DI pipe is most frequently used with the open trench installation method, but with restrained joint systems it can be installed using pipe bursting and sliplining methods. More information on ductile iron water distribution pipes can found in Rajani and Kleiner (2003), Liu et al. (2008), WaterRF (2011b).

3.1.2.3 Asbestos Cement Pipe. AC pipe was first introduced in North America in 1929 and it was a popular for potable water mains from 1940s to the 1970s (Hu and Hubble, 2007). Production ceased in the U.S. in 1983 and it still makes up 16% of U.S. water mains. AC pipe is made of asbestos fibers, silica sand, and Portland cement. Being non-metallic, AC pipe was not subject to galvanic corrosion. However, soft water removes calcium hydroxide (free lime) from the cement and this eventually leads to deterioration of the pipe interior (softening accompanied by release of asbestos fibers) (EPA, 2009). External exposure to acidic groundwater (e.g., mine waste) or sulfates in the soil can also lead to deterioration of the cement matrix. The use of Type II Portland cement reduced the negative impact of sulfates, but this was not always used. The production of AC pipe ceased in the U.S. in 1983, but despite this cessation, a high percentage of all water mains today are asbestos cement (AWWA, 2004a). This percentage is much higher on the West coast (closer to 20%) where AC pipe was used more widely. More information on asbestos cement water distribution pipes can found in Hu and Hubble (2007), Hu et al. (2009), and WaterRF (2011c).

3.1.2.4 Thermoplastic Pipe. Thermoplastic pipes initially in the form of PVC and more recently PE have also found use as underground water mains. PVC pipes have been used significantly in U.S. water distributions systems since the late 1970s (Burn et al., 2005). In Europe, PE is the dominant plastic pipe material in water systems, but the reverse is the case in the U.S., although PE pipes are being increasingly used in the U.S. A 2005 WaterRF study suggests that the flexibility of PVC pipe is a function of the amount of plasticizers and lubricants mixed with the PVC resin in the manufacturing process (Burn et al., 2005). PVC has a coefficient of thermal expansion five times that of DI or steel and PE has a coefficient of thermal expansion nearly 20 times that of DI or steel and allowance for this expansion and contraction must be made in the design (AJ Design, 2011). Thermoplastics are not subject to internal or external corrosion and have a high resistance to chemical and biological degradation. They are, however, subject to permeation and degradation by petroleum hydrocarbons (PHC) and may not be suitable for installation in PHC-contaminated soil. Thermoplastic pipes are not subject to electrochemical or galvanic corrosion.

The strength of PVC is related to the operating temperature and as the operating temperature decreases, the pipe's stiffness and tensile strength increase, which increases the pipe's pressure capacity and makes it better able to resist deflections due to soil loading. On the other hand, as temperature decreases, PVC pipe also becomes less ductile and loses impact strength, requiring greater care in handling and placement in the trench. Care should be taken to avoid excessive deflection of PVC pipe (AWWA, 2002). PVC pipes have experienced premature fatigue-related failures when used in cyclic pressure applications (e.g., irrigation systems and force mains). A recent WaterRF study provides evidence that the longevity of a PVC pipe is directly related to its resistance to slow crack growth, which is dependent on the pipe's fracture toughness and distribution and size of defects in the extruded pipe wall (Burn et al., 2005). Most PVC pipe failures tend to be brittle, not ductile, which tends to support the conclusions of the WaterRF study.

Since PE pipe is light weight and available in various lengths, it is relatively easy to handle and install. PE is the material most frequently used in water supply applications in the UK. It is estimated that PE represents 4 to 6% of the potable water market in the U.S. and nearly 100% of the gas distribution market (Anon, 1999). More information on thermoplastic water distribution pipes can found in Moser and Kellogg (1994), Burn et al. (2005), and Davis et al. (2007).

3.1.2.5 Steel Pipe. Steel pipe is very strong and rigid, but it is subject to internal and external corrosion. Internal corrosion can be prevented by various measures. Common measures being used by utilities include cement mortar lining and water treatment such as pH adjustment, calcium carbonate addition, or metallic phosphate addition, while external corrosion is minimized by wrapping the pipe in a PE film, bonded coatings, or with cathodic protection systems. Steel pipe sections can be either welded together or connected using mechanical gasketed joints. Fittings and adapters are easily available in the market to connect steel pipe to PE and PVC pipe and to DI pipe and valves. Steel pipe is usually used for large diameter or high pressure applications. Steel pipe (usually lined) can also be used as a replacement pipe in pipe bursting applications and steel pipe is compatible with pipe jacking techniques. AWWA Manual M11 (AWWA, 2004b) is a guideline for steel pipe design and installation, and more information on steel water distribution pipes can found in WaterRF (2011d).

3.1.2.6 Prestressed Cylinder Concrete Pipe. PCCP was first manufactured in the 1940s and consists of a concrete core, thin steel cylinder, high tensile pre-stressing wires, and a mortar coating. PCCP is typically used for large diameter mains, making failure of this pipe type relatively catastrophic and costly. PCCP can be one of two types, either embedded cylinder pipe (ECP) or lined cylinder pipe (LCP). PCCP with diameters greater than 48 in. are ECP and PCCP with diameters up to and including 48 in. are LCP. AWWA C304-07 describes the various design specifications, requirements, etc. for PCCP (AWWA, 2007a). Figure 3-1 illustrates a brief classification of PCCP. The various components of the PCCP are the mortar coating, prestressed wire, steel cylinder, and concrete core ECP. More information on PCCP water distribution pipes can found in Romer et al. (2008) and Zarghamee et al. (2011).

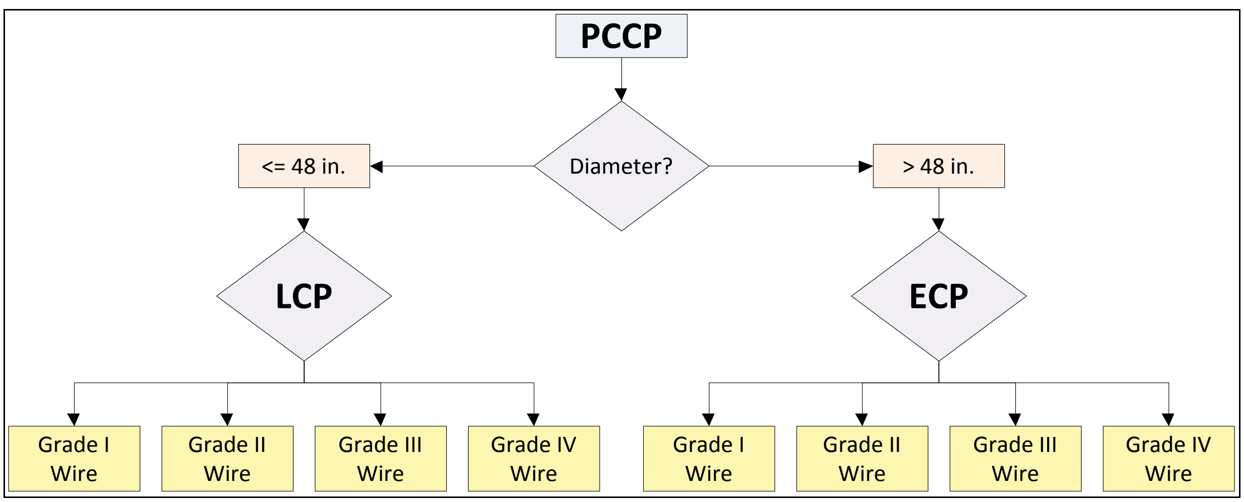

Figure 3-1. Classification of PCCP Pipes

3.1.2.7 Glass Reinforced Plastic Pipe. GRP is known by several names including glass reinforced plastic, glass reinforced polyester, and fiberglass reinforced plastic (FRP). GRP is manufactured to meet a wide variety of service requirements. It is commonly used in sewer gravity pipe applications in Europe and GRP pressure pipe has been approved and available for use in potable water applications in the U.S.

for a few years. Some GRP is manufactured as a composite of wound glass fibers, resin, filler, and sand applied in a centrifugal process, while other uses a winding type process.

GRP is joined with gasketed pressure joints and is normally supplied with ethylene propylene-diene modified (EPDM) gaskets, which are not resistant to hydrocarbons (Le Gouellec and Cornwell, 2007). GRP can be manufactured with various resins including polyester, vinyl ester, and epoxy. GRP does not corrode and has an expected useful life in excess of 100 years. GRP has been used in sliplining and pipe jacking applications. Its rigidity does not allow it to be passed through bends greater than 3° and it cannot be tapped. In sliplining applications, GRP is limited to straight runs with few service connections and its size makes it more compatible with transmission mains rather than distribution mains. Without a restrained joint, it must be pushed rather than pulled through the host pipe. For potable water pressure pipe applications, an epoxy coating is applied to the inside surface of the pipe.

3.2 Pipe Failure Modes

There is a vast array of pipe types, with and without corrosion protection systems, in the more than one million miles of aging water mains. The failure mechanism of each type of pipe is different – meaning that 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 that may vary depending on operating and environmental conditions.

CI, DI, and steel piping may be subject to internal and external corrosion, resulting in pitting and wall thinning, which can lead to leakage and eventual burst failures. Cement-based pipes such as AC, reinforced concrete pipe (RCP), and PCCP are also subject to deterioration due to corrosion of the cement matrix, and the underlying steel reinforcement in the case of reinforced concrete pressure pipes. In addition, all types of pipe including thermoplastics are subject to joint failure between pipe lengths and hence excessive leakage, which can in turn lead to washout of bedding and loss of structural support. If the pipe is not structurally sound, it becomes a candidate for repair, rehabilitation, or replacement (AWWA, 2001b).

For all pipe types, leaks, breaks, pressure complaints, and discolored water are all indicators that pipelines are in need of attention. An understanding of the failure modes and their indicators is useful in assessing the condition of the pipe material and selecting the appropriate timing and type of renewal technique to use. These failure mechanisms and failure indicators have been discussed in the literature such as AWWA (2001b), Royer (2005), Reed et al. (2006), and Grigg (2007).

Any asset management program must start with a thorough review of available historical data about pipe performance and failure indicators. A properly assembled database with utility asset information can help to more precisely analyze and define the priority of pipe renewal work required. Figure 3-2 summarizes the type of information that is useful to collect regarding pipe assets for an asset management program. Analysis of this information in a database, relative to specific pipe segments, material types, sizes, manufacturer date, performance criteria, or other defining characteristics will likely generate patterns indicating those assets most in need of renewal.

Once the necessary data is gathered, deterioration models or engineering analysis can be used to provide insight into the condition of pipeline assets and to target specific pipelines for renewal. A cost-effective inspection program that complements the historic data can then be used to fill in gaps that remain in order to facilitate the design, selection, and implementation of renewal options. More information on inspection technologies, deterioration modelling, and asset management tools for the prioritization of water main renewal can be found in *Condition Assessment Technologies for Water Transmission and Distribution Systems* (EPA, 2011a).

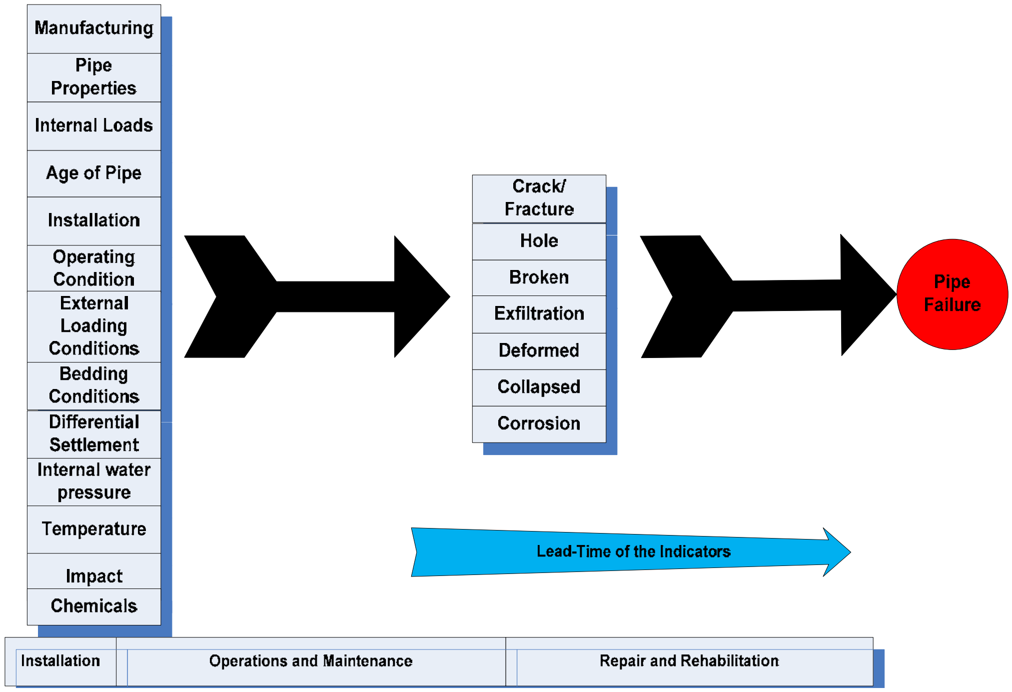

Figure 3-2. Factors Contributing to Pipe Failures

4.0: RENEWAL TECHNOLOGIES

System rehabilitation is the application of infrastructure repair, renewal, and replacement technologies in an effort to return functionality to a drinking water distribution system or a wastewater collection system (EPA, 2007a). Generally, rehabilitation includes a broad spectrum of approaches, from repair to replacement, that attempt to return the system to near-original condition and performance. Various AWWA reports define repair, rehabilitation, and replacement in the following way:

- **Repair.** Techniques used when the existing pipe can be readily restored to a structurally sound condition, providing the pipe has acceptable flow capacity and supports good water quality
- **Rehabilitation.** Techniques that are often used to extend the operational life and restore much or all of the pipe's hydraulic capacity, improve water quality, and/or restore structural functionality.
- **Replacement.** When the existing pipe is severely deteriorated, collapsed, or increased flow capacity is needed, it is usually replaced.

The concepts of repair, rehabilitation, and replacement can be collectively termed as renewal. The pipe systems can be addressed by rehabilitation, repair, and replacement methods such as open cut (conventional) or trenchless technologies. Pipe relining is considered as a structural and/or water quality measure, while pipe replacement (with the same or a larger diameter pipe) improves both the structural integrity and hydraulic capacity of the line (Kleiner et al., 2001).

Because most rehabilitation methods are relatively new to the U.S. water market, the advantages and disadvantages and capabilities and limitations of each system are seldom clearly understood. A pipeline renewal program should therefore start with a review and analysis of the various pipeline rehabilitation techniques that are available. As part of this analysis, the utility should investigate the service line reconnection requirements for each type of rehabilitation technology. These requirements vary considerably, as do the impacts on customer service, project risk, and final cost.

Significant reductions in the cost of water main rehabilitation are being achieved now that new methods are emerging to reconnect services without excavating large access pits for each service connection. With this problem addressed, pipeline rehabilitation could become the most common method of renewing water mains, just as it is now for wastewater mains. Ultimately, utilities could complete many more miles of pipeline renewal each year, with the side benefits of causing fewer inconveniences to their customers. Service lines can certainly be connected without digging access pits. Many promising concepts for service reconnection have already been developed and several have been implemented in practice.

Renewal technologies can be divided into repair, rehabilitation, and replacement technologies as shown in Figure 4-1. One of the simplest forms of renewal is a spot repair, usually implemented on a reactive basis to a failure. More extensive renewal technologies are rehabilitation (using the existing structure of the water main) and replacement (installing a new independent pipe). This new pipe can be installed offline using a different alignment or online using the same line and grade of the existing pipe. Both offline and online replacement can involve trenchless technologies. These technologies have been further divided into different sub-sections based on technical parameters as seen in the data sheets and described in industry standards.

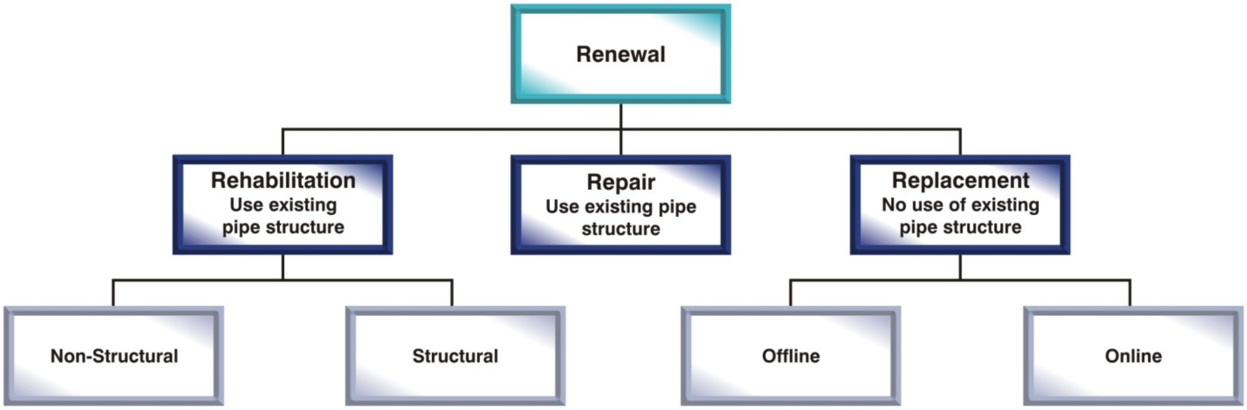

Figure 4-1. Renewal Approaches for Water Mains

A technology-specific datasheet was created for the majority of the technologies reviewed in this SOT report and these datasheets are included in Appendix A. Table 4-1 summarizes the datasheets along with the diameter range and upper pressure limit(s) for each of the renewal methods. Vendor contact information can be located on each datasheet along with the technology history, description, and applicability; material composition and technical envelope; relevant product, design, and installation standards; O&M requirements; relevant case study information as available; and references.

Table 4-1. Summary of Renewal Technologies for Water Distribution Systems

Technology	Category	Brand Name	Vendor	Diameter (in.)	Pressure (psi)	Pg. #
Spot Repair	Wrap	QuakeWrap™	QuakeWrap, Inc.	>36	500+	A-51
		Tyfo® FibrWrap®	Fyfe Company	>24	350	A-77
		CarbonWrap™	CarbonWrap™	>36	N/A	A-13
		A+ Wrap™	Pipe Wrap LLC	>0.5	N/A	A-47
		Frey-CWRAP®	Freyssinet LLC	60-120	290	A-19
		Duraloop®	Freyssinet LLC	60-120	290	A-19
	Sleeve	Hydro-Seal™	Link-Pipe	4-54	150	A-35
	Spray-On Epoxy	Belzona® 5811DW	Belzona, Inc.	>36	N/A	A-11
		Powercrete® PW	Protection Engr.	>8	N/A	A-49
	Spray-On Polyurethane	SprayWall®	Sprayroq	>36	450	A-61
		SprayShield Green® I	Sprayroq	>36	N/A	A-59
Joint Repair	Seals	Weko-Seal®	Miller Pipeline	16-216	300	A-39
		HydraTite	HydraTech	18-218	300	A-23
		Amex-10®	Amex GmbH	10-230	290	A-7
		Clock Spring®	Clock Spring Co.	4-56	N/A	A-17
	Chemical Grout	AV-202/AV-303	Avanti Intl.	>30	N/A	A-9
Spray-On Lining	Cement Lining	Cement Lining	Mainlining, et al.	>4	N/A	A-15
	Epoxy Lining	WaterLine	HydraTech	>4	70-650	A-25
		AquataPoxy®	RLS Solutions	3-36	N/A	A-55
		Subterra ELC 257-91	Daniel Contr.	4-24	N/A	A-65
	Polyurea Lining	Scotchkote™ 169	3M	4-48	N/A	A-3
		Polymeric Resin	Acuro Inc.	>2	200	A-5
	Polyurethane Lining	Subterra Fast-Line Plus™	Daniel Contractors	3-60	N/A	A-67

Table 4-1. Summary of Renewal Technologies for Water Distribution Systems (Cont.)

Technology	Category	Brand Name	Vendor	Diameter (in.)	Pressure (psi)	Pg. #
Sliplining	Segmental	HDPE, DI, et al.	HOBAS et al.	18-110	50-250	A-21
	Continuous	Fusible C-900®	Underground Solutions	4-12	165-305	A-81
		Fusible C-905®		14-36	80-235	A-81
		FPVC®		4-36	N/A	A-81
CIPP	Semi-Structural and Structural	Insituform PPL®	Insituform	8-60	200	A-31
		Aqua-Pipe®	Sanexen	6-12	150	A-57
		InsituMain®	Insituform	6-60	150	A-29
		Tubetex™	Sekisui NordiTube	4-40	460	A-43
		NordiPipe™	Sekisui NordiTube	6-48	60-250	A-41
		Starline® 1000/ HPL-W	Starline Trenchless	4-24	150-250	A-63
Inserted Hose Lining	Woven Liners	Primus Line®	Rädlinger	6-15	1000	A-53
		Subterra Subcoil	Daniel Contr.	3-10	90	A-71
		Thermopipe®	Insituform	2.75-12	170-230	A-33
Close-Fit Lining	Fold and Form	InsituGuard® - Folding	Insituform	12-48	150	A-27
		Subterra Subline	Daniel Contr.	3-60	90	A-73
	Symmetrical Reduction/ Reduced Diameter Pipe	Subterra Rolldown	Daniel Contr.	4-20	230	A-69
		Tite Liner®	United Pipeline	2-52	N/A	A-83
		InsituGuard® - Flexing	Insituform	6-10	150	A-27
		Swagelining™	Swagelining Ltd.	4-60	N/A	A-75
	Expandable PVC	Duraliner™	Underground Solutions	4-16	150	A-79
	Grout-in-Place	MainSaver™	MainSaver™	4-12	294	A-37
	Melt-in-Place	Aqualiner	Aqualiner	6-12	150	A-87
Service Line	Close-Fit Lining	Neofit Process	Wavin/Flow-Liner®	.5-1.5	87-116	A-85
	Epoxy Coating	Nu Flow Epoxy	Nu Flow Technology	.5-10	N/A	A-45

Renewal approaches vary for small diameter pipes (i.e., pipes less than 16 in. in diameter) and large diameter pipes (i.e., pipe 16 in. in diameter and larger). Small diameter mains are typically easier to replace than large diameter mains, except in areas where access is limited or impossible. Small diameter mains are typically less consequential when they fail and can be monitored based on their break and leak history to determine when to renew. When replacement of small diameter mains in not possible due to access limitations or disruption concerns, many of the technologies in Table 4-1 are appropriate for renewing them. Large diameter mains are typically more consequential when they break and therefore require a more proactive strategy to determine the condition of the main and an appropriate renewal strategy. The technologies available for small and large diameter renewal are signified by their diameter range in Table 4-1 and are discussed in the following sub-sections.

4.1 Repair

Repair technologies are used for small segments of the pipe and specifically for localized problems or poor workmanship. They can be short or long term in nature.

4.1.1 Open Cut Repair.

4.1.1 Open Cut Repair. Water utilities undertake open cut repairs on an as-needed basis or put out larger works for tender. Regular repairs on large diameter mains due to inappropriate pressure readings, hydrant checks, or as a result of monitoring policies is common practice. Many utilities retain direct labor crews of skilled workers to install and repair corporation stops, maintain and replace water meters, and service existing infrastructure. Such crews have their own tool set and materials such as epoxy and cement mortars, pipe wraps, and rubber gaskets that are approved by NSF/ANSI Standard 61 certified or by the State regulatory body.

More adverse situations require open cut repairs as well. This is particularly true with pressure pipes such as water mains that handle high pressures. With numerous valves, hydrants, and bends in the system, small- and medium-sized utilities follow a simple process. They put into service a redundant line and shut down supply to the distressed line in the network. The area is then excavated either for local repairs or more substantial structural provisions on the external surface of the pipe. These measures are the result of emergency response to pipe failures or customer complaints. Complaints may range from discoloration, turbidity or odor in water, reduced pressure, or no water at all. The response time to such measures is different from utility to utility, but aims at same day return to service in all but major breaks. Installation methods on open cut construction job sites require traffic planning, following of standard Occupational Safety and Health Administration (OSHA) guidelines, and adequate training and skills for repair crews. Larger utilities may follow more elaborate procedures, routine maintenance, preventive maintenance, or reliability-centered maintenance procedures (Basson et al., 2006). These procedures may require valve, junction entry, or an open cut repair of pipe or joint sections. Large utilities thus require scheduling specialized crews and equipment.

4.1.2 Spot or Localized Repairs. Water utilities faced with problems of localized corrosion or structural damage (particularly in pipes greater than 30 in.) increasingly make use of localized repair techniques. These methods may be external involving local exposure of the buried pipe, including the methods mentioned in the previous section; or internal involving temporary interruption of water supply service, creation of access, and disinfection before returning the pipe to service. Spot repair methods for pressure pipelines are often more complex than those applied in gravity pipe applications, requiring careful consideration of pipe structural condition and required capability so that a robust design with proper consideration of engineering material properties and long-term performance can be considered. Water main shutdown for this work requires careful planning and implementation to minimize disruption of service.

4.1.2.1 QuakeWrap™. QuakeWrap, Inc. offers a fiber reinforced epoxy system using a variety of woven fabric and pre-impregnated plates of glass and carbon fiber reinforcement for hand and machine applied wraps to strengthen deteriorated pipes and structures. Developed from work at the University of Arizona, it has been used for repair of PCCP and cast-in-place reinforced concrete pipe (Ehsani and Pena, 2009) in spot locations and for large sections of pipe as shown in Figure 4-2.

The company offers QuakeWrap™ fabrics and plates and QuakeBond™ epoxy resins. The QuakeWrap™ system using QuakeBond™ J201TC tack coat and QuakeBond™ J300SR saturating resin with QuakeWrap™ VU18C carbon fabric is NSF/ANSI Standard 61 certified.

Figure 4-2. Application of QuakeWrap™ (courtesy of QuakeWrap)

4.1.2.2 Tyfo® FibrWrap® Systems. Fyfe Company, which was recently purchased by Insituform, has a Tyfo® SCH-41 composite system that is a patented carbon fiber reinforced polymer (CFRP) system for strengthening deteriorated structures including PCCP, reinforced concrete pipe, and metallic pressure pipe (Carr, 2007). This pipeline rehabilitation system has been used for approximately 13 years to add structural strength and protect against corrosion. The FibrWrap® System, which has a typical design life of 50 years, can provide a stand-alone design that does not rely on the integrity of the host pipe or it can act in conjunction with the host pipe to provide a compositely designed structural system, depending on the requirements of the project. The Tyfo® FibrWrap® System is made up of Tyfo® S epoxy and Tyfo® SCH-41 reinforcing fabric as shown in Figure 4-3.

Figure 4-3. Wrapping Large Diameter Mains with Tyfo® FibrWrap® System (www.fyfeco.com)

The carbon fabric is a custom weave, uni-directional system with glass cross fibers. American Society for Testing and Materials (ASTM) standard D-3039/D-3039M is followed for determination of structural properties such as tensile strength, strain, and tensile modulus (ASTM, 2008a). The composite system including Tyfo® WP, TC and PWC epoxies as well as the Tyfo® 41 fabric is NSF/ANSI Standard 61 certified. Fyfe Company's Tyfo® SCH-41 fabric's suggested saturation level is 3 to 4 units of epoxy per 600 square foot roll. The standard shipping size of the Tyfo® SCH-41 roll is 24 in. by 300 linear feet; however, the composite fabric can be pre-cut to desired lengths to meet the pipe diameter. Prior to installation, the surface must be clean, dry, and free of cavities and protrusions. Sandblasting, grinding, or other scarifying techniques are required to enhance the bonding capabilities between the composite system and the existing substrate. The fabric is saturated with epoxy using a mechanical saturator, and is applied to pipes using wrapping equipment or approved hand methods. Tyfo® FibrWrap® System applications are performed by FibrWrap Construction to ensure proper QA/QC procedures are followed to meet material property specifications.

4.1.2.3 CarbonWrap™. CarbonWrap™ is a pipe wrapping system developed by Dr. Saadatmanesh at the University of Arizona. This system was developed in 1987 and has been available in the market since 1994. CarbonWrap™ is a composite fabric containing glass, carbon, or aramid fibers. It may be supplied as a fabric or in pre-cured strips. The flexible fabric or strip is saturated in the field and is bonded to the pipe wall, using a specially formulated structural epoxy. It can be installed externally or internally, as shown in Figure 4-4. In the case of man entry diameter pipes, access is made through prepared access points and all operations are conducted internally. If the pipe can be accessed from the outside, the wrapping can be installed on the outside face of the pipe resulting in the same benefits.

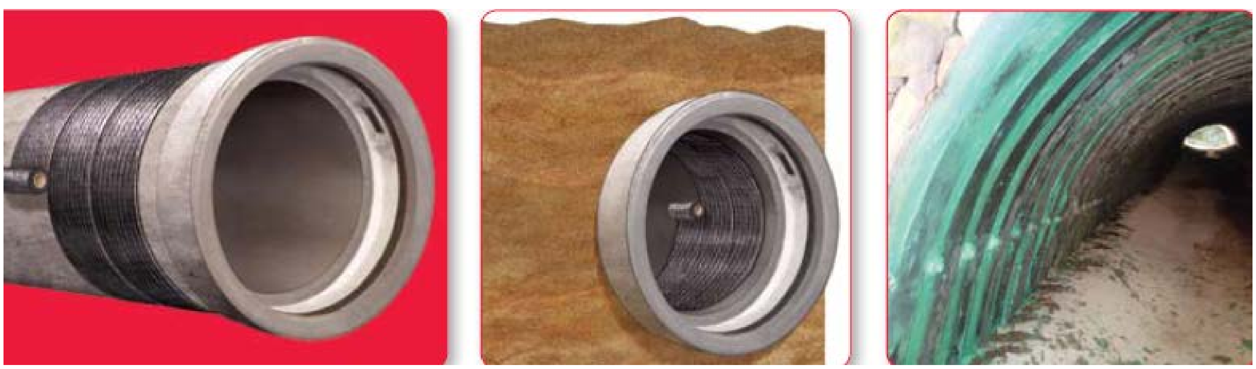

Figure 4-4. Options of CarbonWrap™ (www.carbonwrapsolutions.com)

CarbonWrap™ fabrics are available in the range of 24 to 50 in. wide and up to 150 yard length in rolls. The fabric thickness ranges from 0.014 to 0.04 in. and several layers can be applied to build up to the design thickness, typically 0.125 in. Material property tests are detailed in ASTM D-3039/D-3039M (2008a) and ASTM D-638 (2008b) and design parameters are detailed in American Concrete Institute (ACI) 440-R (ACI, 2007).

4.1.2.4 A+ Wrap™. Pipe Wrap's A+ Wrap™ (PWAP) is used to rehabilitate U.S. Department of Transportation (DOT) regulated pipelines. PWAP works as a corrosion barrier and structural reinforcement against external defects (Figure 4-5). PWAP is allowed for DOT pipeline repairs under 49 Code of Federal Regulations (CFR), parts 192 and 195 (CFR, 2011), and it has been validated and certified for use under the American Society of Mechanical Engineers (ASME) PCC-2 article for B31.3, B31.4, and B31.8 (ASME, 2011); and the International Organization for Standardization (ISO) standard 24817 (ISO, 2006).

Figure 4-5. Application of A+ Wrap (courtesy of Pipe Wrap LLC)

PWAP uses an epoxy undercoating that is wrapped with a water activated moisture cured urethane resin impregnated woven fiberglass material. This must be sprayed with water before each layer of undercoating and wrap is applied. It has a setting time of 1 hour and a 100% curing time of 24 hours.

4.1.2.5 Frey-CWrap®. Freyssinet LLC is a well established company specializing in bridges and other prestressed and post-tensioned structures. Frey-CWrap® is their CFRP solution for rehabilitation of pipes, which can be used to address full lengths of pipes or spot repairs. It is an internally applied composite made up of a carbon fiber fabric saturated with epoxy resins, which is then bonded to the pipe wall, as shown in Figure 4-6. The Frey-CWRAP® resin and fabric is NSF/ANSI Standard 61 certified for use in potable water mains. It can be applied manually by a specially designed robot called the Foreva® Frey-CWrap® Robot in 60 to 120 in. diameter pipes.

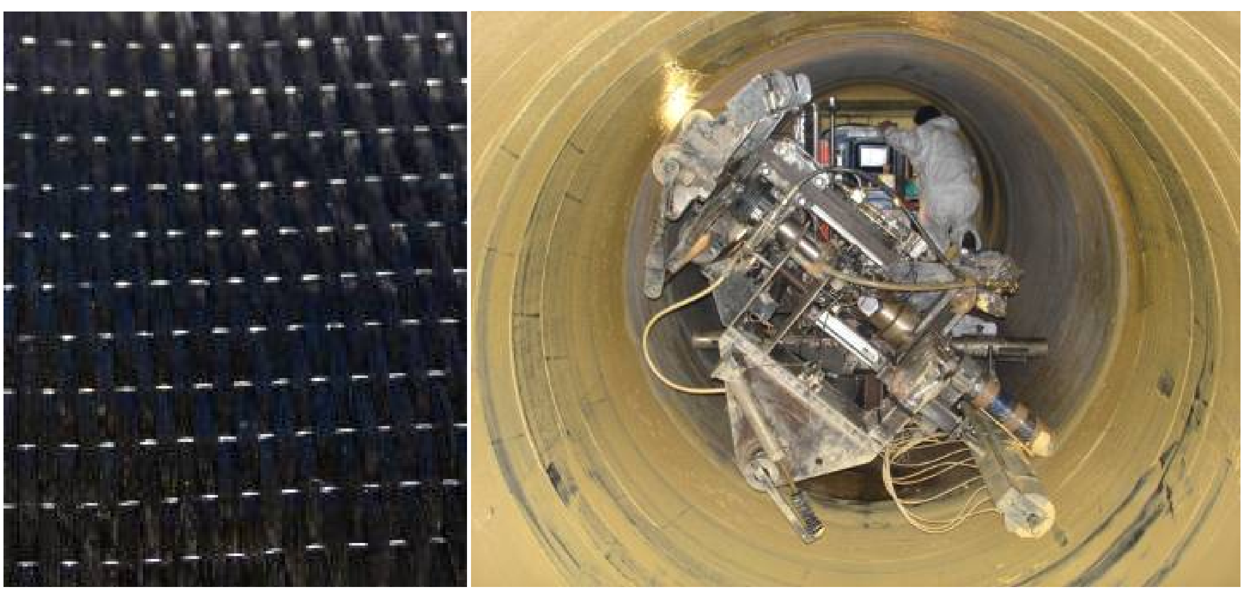

Figure 4-6. Frey-CWRAP Material and Robotic Repair (courtesy of Freyssinet)

The main advantage of the robot is the increased speed of application. The robot is a self motorized module carrying a rotating arm which helically wraps CFRP on the inner surface of a pipe. It can apply the fabric at a speed of up to 16 ft per minute. The material is manually applied at certain spot locations such as elbows, slope changes, and valves. Freyssinet also offers an externally applied pre-grouted PE sheathed post tensioning system called Duraloop®.

4.1.2.6 Hydro-Seal™. The Link-Pipe Hydro-Seal™ is an internal repair method, designed to seal joints and isolate lead in the joints from leaching into the potable water in old CI mains. Placing the sleeve on the internal face of the pipe can be done using closed circuit television (CCTV) and winching equipment. This is similar to the grouting sleeves used in gravity sewer rehabilitation. It seals leaks using mechanically locked stainless steel sleeves and an NSF/ANSI Standard 61 certified resin sealant. The sleeve core is made of stainless steel SST-316 with an internal locking mechanism. The external fabric is saturated with resin that is mechanically pressed against the host pipe when the sleeve is expanded and locked in place. The resin is ambient temperature cured, which seals the sleeve in place and mechanically bonds to the host pipe, thus sealing the joints, pin holes, and cracks in the pipe. The cross section is detailed in Figure 4-7.

Hydro-Seal™ ranges in diameters from 4 to 54 in. (100 to 1350 mm) having a wall thickness such that the sleeve should not protrude more than 3/8 in. (10 mm) into the host pipe. It is tested up to 560 pounds per square inch (psi) (37 bar) ultimate pressure over a 3/8-in. wide open joint and the maximum recommended working pressure in the pipe is 150 psi. Hydro-Seal™ is available in the market in standard lengths of 12 in. (300 mm), 18 in. (450 mm), 24 in.(600 mm), and 36 in. (900 mm).

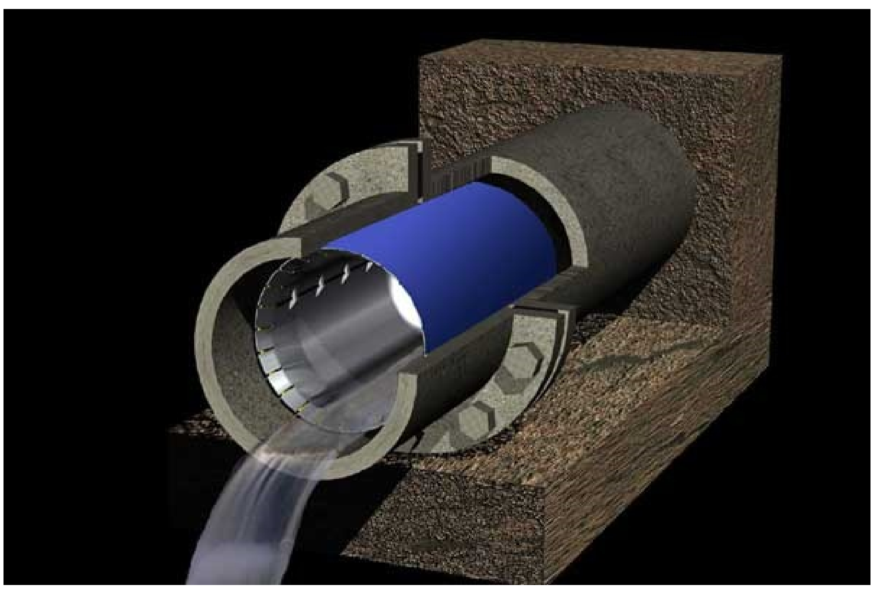

Figure 4-7. Cross Section of Stainless Steel Pipe Sleeve (www.linkpipe.com)

4.1.2.7 Epoxy Coatings. Several epoxy lining materials are currently approved for use in potable water systems under NSF/ANSI Standard 61 guidelines. Two-component epoxy resin products, 100% solids by volume with no reactive solvents or thinners present may be suitable for making local repairs. They may be hand applied, but are usually applied in the case of large applications with specially designed machines. These machines have separate, heated reservoirs from which positive-displacement pumps precisely control the proportions of resin and hardener applied to the pipes. Examples of spray or brush applied epoxy for local repair are Belzona® 5811DW and Powercrete® PW.

Belzona® 5811DW (Immersion Grade) is a two-component system for protection of metallic and non-metallic surfaces, such as concrete as shown in Figure 4-8, operating under immersion conditions in contact with aqueous solutions and aggressive chemicals.

Figure 4-8. Belzona® 5811DW on a Concrete Surface (courtesy of Belzona, Inc.)

5811DW can be applied to pipe diameters greater than 36 in. internally and has a final cure time of roughly 7 days at 68°F or 4 days at 86°F according to NSF. It can repair and protect weld seams and seal pipe expansion bellows, linings, and leaking pipes. It can also be used in chemically aggressive environments and can resist attacks of a wide variety of hydrocarbons.

Powercrete® PW is a liquid epoxy resin providing corrosion resistance and abrasion resistance in steel and DI pipes. It can be spray or hand applied, internally or externally in pipes 8 in. in diameter and larger. The final cure time is up to 10 days at 104°F.

4.1.2.8 Polyurethane Coatings. In addition to other vendors, Sprayroq provides a polyurethane based liner called SprayWall®, which is shown in Figure 4-9. SprayWall® is a golden colored, spray-applied, 100% volatile organic compounds (VOC)-free polyurethane coating that provides both structural reconstruction and chemical resistance against elements that eat away at underground structures.

Figure 4-9. Polyurethane Lining by SprayWall® (www.sprayroq.net)

Once the two components are mixed, SprayWall® begins to gel in about 8 to 12 seconds, with a tack-free condition after one minute. Within 30 to 60 minutes, the initial cure is completed and the structure is capable of accepting flow, while the complete curing continues for the next 4 to 6 hours. It has a 50-year design life retaining 70% of its flexural modulus and adheres for thickness design to ASTM F-1216 Appendix X1 (ASTM, 2009a).

Spray Shield Green® I is a similar light green colored polyurethane product with lower petrochemical derivatives, non-structural physical properties, and 35% biobased content for enhanced environmental performance. SprayWall® and Spray Shield Green® I are NSF/ANSI Standard 61 certified and may be used for protection of valve chambers and other water pipeline appurtenances.

4.1.2.9 Joint Repairs. Corrosion is one of the main reasons for leakage from joints in metallic pipes. Replacement of the bolts holding the sealant and ring system is the simplest procedure to renew the joint. Structural failures require a more complex approach such as a cut-out or spool pieces. A small piece of pipe may replace the distressed area with mechanical couplings at both ends. With certain PE pipes it is also possible to use electrofusion couplers that have a copper heating coil embedded in them. A current is passed through the system to melt the PE and fusion takes place between the pipe and the coupler. Instead of using repair clamps, some method variations require grout packing and a wrap-around material.

Mechanical systems for internal joint sealing generally involve the mechanical compression of a polymeric seal both for man-entry and non man-entry pipes. EPDM is a preferred seal material for use with potable water mains. Weko-Seal® (Hayre, 1986), HydraTite (Figure 4-10), and Amex®-10 seals are examples of profiled seal gaskets clamped in place across a leaking joint or at the termination of a lining system. Stainless steel retaining bands are hydraulically expanded into place to seal the EPDM against the pipe wall and locked in place to make the seal leak tight.

Figure 4-10. Application of a HydraTite Retaining Bands (courtesy of HydraTech)

Techniques from the oil and gas industry for joint repair include external encapsulation where the polymer resin is applied on a leaking joint through a mould or by hand with the main still in service. To bond joints in irregularly shaped pipes, Clock Spring® or HydraWrap® products are available. Clock Spring® is comprised of a coil shaped composite sleeve wrapped around the distressed segment which is then bonded to the pipe with an adhesive and a high strength filler material mix. The HydraWrap® system provides a corrosion barrier for degrading pipe and is certified to NSF/ANSI Standard 61.

Joint repair systems that inject grouts through leaking joints are commonly used in the wastewater industry. Typically, an inflatable packer is winched in position and centered on a defective joint, the packer is inflated so that the outer sections of the packer seal are against the pipe, and chemical grout is pumped through the leaking joint to surround the joint and prevent ingress of groundwater. Certain grouting chemicals are NSF/ANSI Standard 61 certified for contact with potable water and may be suitable for sealing leaky joints in low pressure water mains. Hydrophilic and hydrophobic polyurethane grouts such as Avanti AV-202, AV-330, and AV-333 (which is equivalent to the former 3M Scotch-Seal 5600) may be suitable. These grouts are generally pumped from inside the pipe into joints or cracks.

4.2 Rehabilitation

Rehabilitation focuses on the renewal aspects of water mains where the existing pipe becomes part of the renewal work. If the rehabilitation is to provide only corrosion protection, or the existing pipe is only partially deteriorated, then the remaining structural strength of the existing pipe can be incorporated into the fabric of the completed system. For fully deteriorated situations, the existing pipe acts merely as a right-of-way for the installation of the structural liner. Sliplining, which is sometimes considered a replacement method, is also included in the discussion in this section. Pipe bursting can also be considered a rehabilitation method, but is covered in this report as a replacement method. The rehabilitation methods for water mains are shown in Figure 4-11 and include the use of spray-on lining, sliplining, CIPP, inserted hose lining, and close-fit lining systems.

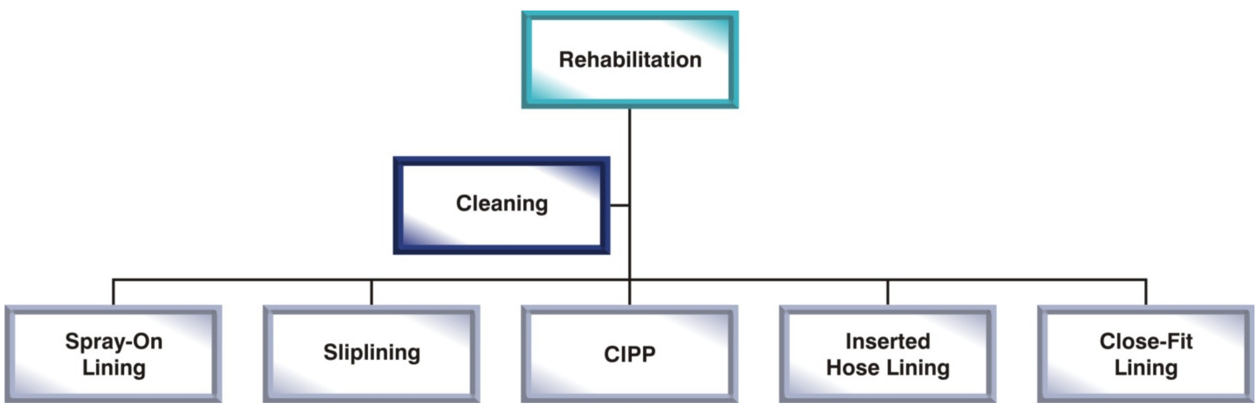

Figure 4-11. Rehabilitation Approaches for Water Mains

The summary from a 2007 WaterRF report shown in Table 4-2 remains an excellent summation of generic methods and their advantages and disadvantages (Ellison et al., 2007). Another paper discussing various rehabilitation technologies is Bontus et al. (2007). The choice of method will be largely dictated by the perceived condition of the pipe, project objectives, and estimated costs. Determining which method is the most economical for any given situation is difficult since it 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. It is a good idea to permit alternative methods to bid, letting the marketplace decide which is the most economical for a particular situation. Where the alternatives do not provide equally desirable products, the bid documents need to clearly indicate how the alternative bids will be compared.

Table 4-2. Various Rehabilitation Techniques

Method	Advantages	Disadvantages
Cement Mortar Lining (CML)	Time tested 25 to 50% of replacement cost Several contractors available	Non-structural pH problems where water is very soft Requires bypass system Uncertain pipe life extension
Spray-On Epoxy Lining	Works with soft water Cost competitive with CML on small diameter piping Faster placement of line back into service than CML	Non-structural Small defects lead to combined corrosion Few U.S. customers Cost for large pipes higher than CML Requires Bypass system Uncertain pipe life extension
Other Spray-On Plastic Linings	Short cure times may mean shorter service outages. Bypass system may not be needed, if done sanitarily.	Uncertain long-term performance Limited experience Uncertain pipe life extension
Polyester Reinforced PE	Provides full-pressure restraint	Proprietary Special fittings required Uncertain long-term performance
Cured-in-place pipe Lining	Provides some structural improvement Several contractors available Can handle pipe bends	More costly than CML or epoxy lining Requires bypass system Uncertain pipe life extension NSF/ANSI 61 approval depends on materials used (usually epoxies)
Reinforced CIPP	Can provide full structural rehab Can handle pipe bends	Proprietary Requires bypass system Uncertain pipe life extension
Straight (Loose-Fit) Sliplining	Provides full structural renewal No special equipment or expertise needed Various materials can be used Can be very cost-effective	Reduced hydraulic capacity Requires bypass system Requires area to lay out pipe string Excavation to reinstate service connections needed
Tight-fit high density PE (HDPE) Sliplining	Generally provides partial structural improvement Can be cost effective	Required special equipment/ license Requires bypass system Requires area to lay out pipe string End connections challenging
Tight-fit PVC Sliplining	Full pressure rating Can be cost effective	Proprietary Uncertain long-term performance Requires bypass system Requires area to lay out pipe string
Tight-fit Steel Sliplining	Cost effective for large-diameter pressure pipes	Reduced hydraulic capacity Welding problems have led to failures

4.2.1 Spray-On Linings. Spray-on linings have been one of the most widely used methods for rehabilitating a pressurized main when the primary objective was to provide corrosion protection to the interior surface. Spray-on linings are either cementitious or polymer-based as shown in Figure 4-12. In this report, the term spray-on includes conventional spray applications and spin-cast, projectile, or centrifugal applications. More information on spray-on linings can be found in Ellison et al. (2010).

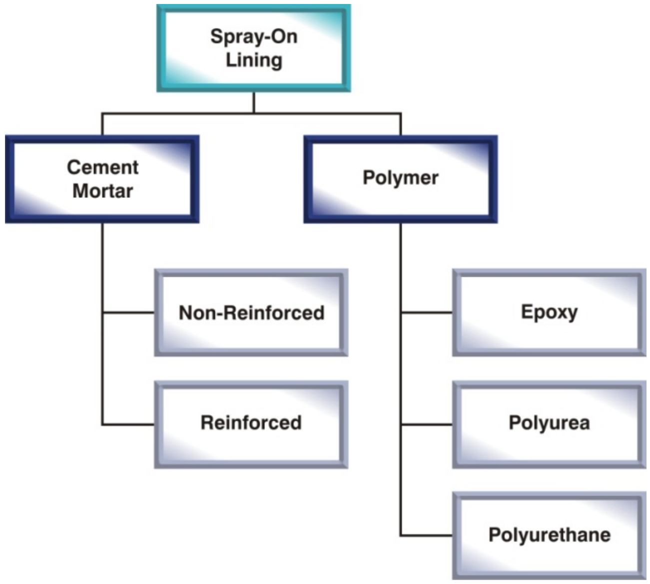

Figure 4-12. Summary of Spray-On Lining Technologies

4.2.1.1 Cement Mortar Lining. CML is one of the most common rehabilitation techniques in use today for rehabilitating water mains. Principal contractors include Spiniello (Figure 4-13), Mainlining, J. Fletcher Creamer, Dakota Pipelining, Heitkamp, and Walsh. CML is applied to a wide variety of pipe diameters including 4 in. (100 mm) and above shop applied, and 4 in. (100 mm) to 28 ft (9.2 m) in place. For pipes greater than 30 in. (750 mm) in diameter, reinforcement can be added in the form of wire mesh or reinforcing bar. Lining thickness is typically 6 mm for 4 to 10 in. (100 mm to 250 mm) pipe and 13 mm for 36 in. (900 mm) or larger pipe. The lining is placed by either the centrifugal or projectile method. In the centrifugal process, typically for pipes 4 to 48 in., the mortar is applied by compressed air through a spinning head and is generally smoothed by a conical trowel. In pipes 6 to 24 in., a cable winch that is controlled above the ground pulls the unit through the pipe as outlined in Figure 4-14. The cement mortar is pumped to the unit through the supply hose.

Figure 4-13. Spiniello Projectile Rig for CML (www.spiniello.com)

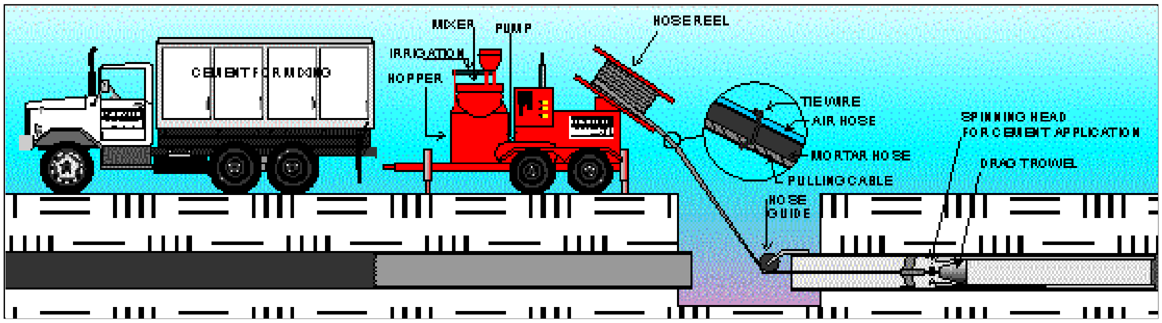

Figure 4-14. Dakota Pipelining Centrifugal Small Diameter Rig (www.dakotapipelining.com)

For pipes that are larger than 24 in. in diameter, an operator can ride the machine through the pipe, controlling the centrifugal unit. For larger pipes, using the projectile method, a rapidly revolving arm slings mortar onto the pipe wall shown in Figure 4-15. The machine has a rotating head that dispenses the mortar and a series of trowels that smooth it to the interior walls of the pipe. Before either process is initiated, pipes should be thoroughly cleaned and dried.

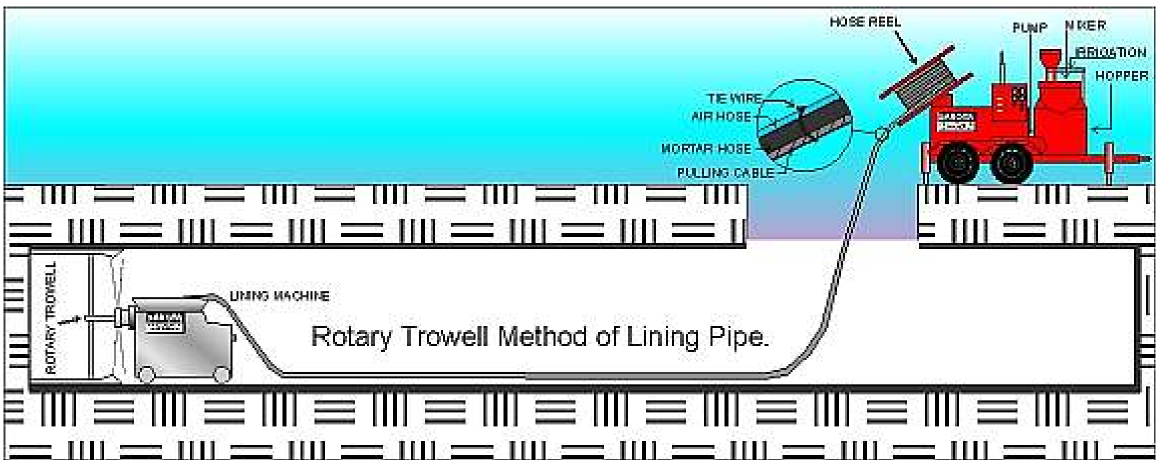

Figure 4-15. Dakota Pipelining Large Diameter Projectile Method (www.dakotapipelining.com)

One of the main limitations of this technique is that the length of water main that can be lined between excavations is dependent on the length of the hose and cable and the diameter of the pipe. The maximum working distance between excavations in winch-controlled processes is 750 ft for 10 to 12 in. pipes. The maximum working distance will decrease as the diameter of the pipe decreases to approximately 350 ft for 4 in. pipes. In applications where an operator controls the machine from inside the pipe, the distance between excavations can be up to 1,500 ft. Generally, the longer the length of pipe that can be lined in one operation, the lower the cost will be per unit length for the same diameter.

When lining smaller pipes up to 24 in. in diameter, service connections are blown through with compressed air to remove mortar blockage before it sets. In larger pipes, the connections can be plugged before lining. After placing the mortar, the pipe ends are capped to keep the pipe free from moisture during curing. Exposed pipe can be sprayed to keep it cool and prevent cracking. After CCTV or person entry inspection of the overall surface finish and absence of local defects, the line can be returned to service. Defects can be repaired by patching, but machine application is preferred for defects extending around the full circumference.

Shotcreting is an additional method of application of a cement-based lining that can be used for point repair and larger sections of large diameter pipes and water tunnels. The low water-cement ratio mortar is sprayed at the pipe wall and although there can be large volumes of waste, about 75% of the mortar remains. The mortar can be sprayed over reinforcing bar or wire mesh. This method has most commonly been used for the renewal of storm water drains. It may be applicable to water transmission pipes, but with some loss of diameter due to the thickness of shotcrete applied. Reinforced shotcrete can improve the structural strength of the pipe, but design is inexact and it is most usually a repair method.

4.2.1.2 Epoxy Lining. The process for in situ epoxy resin relining of iron and steel pipelines was developed in the UK in the late 1970s and has been performed in North America since the early 1990s. The epoxy materials approved for use were first certified to NSF/ANSI Standard 61 in 1995. Epoxy lining of potable water mains is currently classified as a non-structural renewal method. The process involves cleaning the pipe to remove existing corrosion buildup and then spraying a thin 40 mil (1 mm) liquid epoxy coating onto the inner wall of the pipe. The coating cures in 16 hours and provides a smooth, pinhole free and durable finish thought to be resistant to mineral deposits and future buildup of tuberculation. Most lining machine models are computer controlled with warning devices that alert operators if the minimum lining thickness is not being achieved. A lining machine applies the epoxy material with an application head attached to the lining hoses.

The applicator head and hoses are pulled to the far end of the cleaned pipe and then winched back through the pipe at a speed linked to the rate of supply of the resin mixture. After lining, the ends of the pipe are capped and the resin is allowed to cure overnight at ambient temperature. The pipe is then flushed, disinfected, and returned to service. Epoxy lining involves the application of complex epoxy bisphenol amines and hardeners to the interior surface of pipes. In the U.S., this method has not seen widespread use and its application was restricted to industrial pipelines until the NSF/ANSI Standard 61 approval was obtained for epoxy materials in potable water mains.

More so than for many other lining techniques, pipelines must be thoroughly cleaned, free from corroded material, and dried before application of the epoxy lining. The epoxy is required to bond to the metal surface to provide durable service for the expected service life. The WaterRF report *Service Life Analysis of Water Main Epoxy Lining* states that properly constructed epoxy linings can be expected to last 40 to 60 years, but various defects can significantly reduce this longevity (Deb et al., 2006). The defects, however, can be reduced or eliminated by implementing careful QA/QC procedures during lining application.

Epoxy resin is applied to the wall of the pipeline using a centrifugal method. A spinning head is winched through the pipeline at a constant rate depositing the heated pre-mixed epoxy and hardener mixture onto the pipe wall. The material and air supply for the motor are contained in an umbilical cord, which also forms part of the winching system. It is possible to use NSF/ANSI Standard 61 certified, spray applied epoxies to renew large diameter pipes which may require a higher resin build than normal for rapid return to service. Adequate cure time must be allowed for the epoxy lining to harden before putting the main back into service, which can be a problem in cold climates where an excessive cure time may be required.

Several epoxy products are NSF/ANSI Standard 61 certified for potable water systems currently including: HydraTech Waterline, RLS Solutions AquataPoxy®, and Warren Environmental S-301 Epoxy (Warren and Nance, 1997). It is important to verify that epoxies for water pipe rehabilitation are designed and approved for rapid return to service and to check the certification for specified conditions of use, particularly in respect of permitted pipe diameter, thickness, and cure temperatures. Not all NSF/ANSI Standard 61 certified epoxy materials are suitable for field application and rapid return to service. Listings are regularly updated and currently may be verified on the NSF Web site (www.nsf.org).

4.2.1.3 ***Polyurea Lining.*** In 2009, 3M Corrosion Protection Products acquired the business of E Wood Ltd., makers of the Copon™ Hycote range of polyurea coatings approved by the UK Drinking Water Inspectorate for spray-on lining and immediate return to service. Copon™ Hycote 169 is marketed in North America as Scotchkote™ 169 (Figure 4-16) and is NSF/ANSI Standard 61 approved for a maximum wall thickness of 80 mils (2 mm) with 3M specifying 40 mils (1 mm) as the target thickness in its guidelines. 6,000 miles of water mains have been lined with this material since its launch by E Wood in 2000, mostly in the UK and Canada.

A high build version of this material (Hycote 169HB) has been used in the UK to provide more than 200 miles of 3 to 5 mm linings for regional water companies, but it was not successful in obtaining NSF/ANSI Standard 61 approval (Najafi et al., 2009). Accordingly, a modified polyurea material marketed as Scotchkote™ 269 semi-structural lining was approved and launched in North America early in 2009, but due to failures in field applications a new product called Scotchkote™ Renewal Liner 2400 was launched in 2011 (EPA, 2012a).

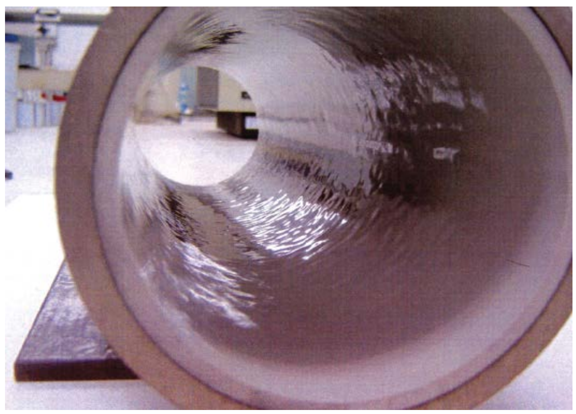

Figure 4-16. 3M Scotchkote™ 169HB Lining (www.3m.com)

Another polyurea lining product available since 2007 for use in potable water pipelines is the Acuro Polymeric Resin Lining (Figure 4-17). This product has been used predominately in Canada and also in Cleveland, OH. The product meets ASTM F-1216 structural requirements and is applied in increments of about 1 mm each, to a total thickness of 3 mm and up, depending on the pipe's characteristics and requirements. Acuro lining materials can be used to form non-structural, semi-structural, or fully structural rehabilitations and same day return-to-service is possible.

Figure 4-17. Acuro Polymeric Resin Lining (www.acuro.ca)

4.2.1.4 ***Polyurethane.*** Fast-Line Plus™ polyurethane lining is manufactured by Subterra, a division of Daniel Contractors Ltd., UK. The product is currently seeking NSF approval for both a 1 mm and high build version. Like two-component epoxy resin systems, polyurethane 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 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. Cleaning and condition assessment must precede this activity, while disinfection, inspection, and proper curing follow the job. Generally, there is no need to excavate service connections since the spraying application rarely blocks the connection.

This product and other fast-setting high build polymers have potential for water main lining and they have been used in various European countries. Such developments when confirmed and NSF/ANSI Standard 61 certified could help utilities in cutting down direct costs incurred during water main lining in bypass pumping and minimize indirect social and economic costs.

4.2.2 **Sliplining.** Sliplining is a method of pipe rehabilitation in which a new pipe of smaller diameter is inserted directly into the deteriorated pipe by pulling or pushing. This technique, when undertaken by contractors using proprietary NSF/ANSI Standard 61 certified pipe products, will provide a serviceable pipeline with some loss of cross section, typically a loss of at least 3 inches (75 mm) in diameter in water mains, and may be a viable option depending upon hydraulic requirements. Cross-sectional loss can be minimized by using stronger pipe materials, which allows for a thinner wall for a given pressure rating than with weaker pipe materials. The line being rehabilitated will normally have a decreased coefficient of friction after being sliplined, which reduces some of the effect of the reduced cross section. Sliplining may be accomplished by insertion of short lengths of pipe, joined during insertion, or longer lengths of pipe welded at or near the work site to provide a continuous length of pipe for insertion, as outlined in Figure 4-18.

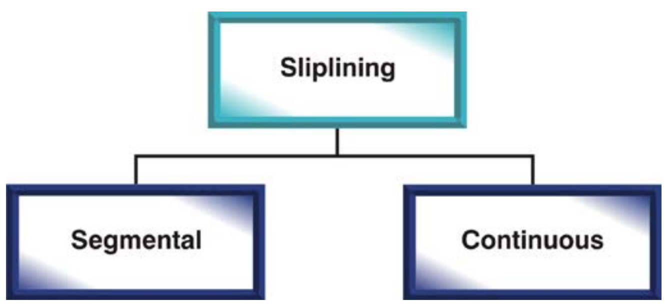

Figure 4-18. Summary of Sliplining Technologies

Sliplining may be a very cost effective option, especially when a fully structural replacement is needed. Access requirements for the insertion of continuous pipe can be considerable in order to bring the pipe down to the proposed alignment while not exceeding the maximum bending radius of the insertion pipe. Sliplined pipe should be grouted in place to secure the pipe and distribute the load uniformly.

4.2.2.1 ***Segmental Sliplining.*** Segmental sliplining uses short pipe segments that are assembled at the entry point of the existing pipe where the liner is pulled or pushed into the pipe for the length of each added segment. After installation of the entire slipliner, the annular space is grouted. Care must be taken during grouting that the grouting pressure does not exceed the buckling resistance of the liner pipe. Sliplining pipes can be HDPE, PVC, centrifugally cast fiberglass reinforced polymer mortar (CCFRPM) pressure pipe (i.e., HOBAS, Figure 4-19), steel, GRP, or DI. Pipe with spigot and socket joints contained within an expanded bell socket are not usually appropriate for sliplining because the additional cross section required for the spigot and socket joint will reduce the cross sectional area available for the liner pipe substantially. However, some types of socketed pipe supplied with a restrained joint may be pushed or pulled in place if required.

Figure 4-19. Segmental Sliplining using HOBAS Pipe (courtesy of HOBAS Pipe USA)

4.2.2.2 Continuous Sliplining. Continuous sliplining uses a liner that has been manufactured as a continuous pipe or one that is assembled in the field prior to insertion to match the entire length of the existing pipe. Continuous sliplining pipe can be HDPE, fusible PVC pressure pipe, or welded steel. PE pipe has been successfully welded for more than 30 years and working codes and regulations have been established to ensure that weld processes and practices can be reliably implemented. Manufacturers' recommendations in terms of operator training, welding pressures, and temperatures and all aspects of site practice should be followed. Small diameter pipe delivered to the work site in coil form should be straightened prior to welding, and proprietary equipment such as the McElroy LineTamer™ and PolyHorse™ can be used to improve operating efficiency and reliability.

Welding of PVC pipe was commercially introduced in 2004 and over 3,500,000 ft have been installed with trenchless methods. Fusible C-900® can be used for long length sliplining operations among other replacement techniques as shown in Figure 4-20. Fusible PVC® pipe is extruded from a specific formulation of PVC resin (cell class 12454), which allows the joints to be butt fused together using the manufacturers' fusion process (Botteicher, 2008).

Figure 4-20. Continuous Sliplining by Fusible PVC® (www.undergroundsolutions.com)

Industry standard butt fusion equipment is used with some minor modifications and the resin compound meets the PVC formulation in the Plastic Pipe Institute (PPI) Technical Report #2 (PPI, 2011). The fusible pipe is made in ductile iron pipe standard (DIPS) and iron pipe size (IPS) outside diameter (OD) sizes. For sliplining, the host pipe is cleaned and inspected with 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 pit if dimensions allow. For pipe bursting or horizontal directional drilling (HDD), the pipe is normally butt fused in a single length and static burst methods 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.

Fusible C-900® 4 to 12 in. and Fusible C-905® 14 to 36 in. are available for potable water applications and FPVC® 4 to 36 in. is available for potable water in other than C-900®/C-905® dimensions and non-potable applications. Renewal length of fusible pipes is 300 to 500 feet for pipe bursting with lengths of over 1,000 feet completed in a single burst. Sliplining of 3,500 feet in a single pull and horizontal directional drilling of over 6,400 feet in a single length have been accomplished. The fusible range of products meets ASTM cell classification 12454 and the Fusible C-900®, Fusible C-905®, and FPVC® pipes are NSF/ANSI Standard 61 certified for potable water. Products comply with AWWA C900 (2007b), AWWA C905 (2010), ASTM D-1785 (2006a), and ASTM D-2241 (2009b).

4.2.3 Cured-in-Place Pipe. CIPP lining is a well established lining method in which a resin-saturated tube is introduced into the pipe by air or water inversion or pulled into place with a winch, and expanded using air or water pressure. The resin is subsequently cured at ambient or elevated temperature (using steam or hot water), or using ultraviolet (UV) light, to create a new pipe. The resin-impregnated fabric forms a new pipe wall in close contact with and conforming to the host pipe wall. Depending on the materials used and the thickness of the new pipe, it can be considered as a fully structural or semi-structural liner. Variations on this technology have been used for sectional or spot pipe repairs as well. This technology has been widely used in gravity and low pressure wastewater and storm water applications. It has also been used to renew raw water mains and water distribution pipe where local regulations permit.

Over the years there have been many new variations made to the original patented CIPP product introduced by Insituform in the early 1970s. As Figure 4-21 shows, variations exist in resin types, installation methods, curing methods, and tube construction and only some of these options are applicable for water main rehabilitation. The requirements of NSF/ANSI 61 determine the type of resin or resin and coating that can be employed. Currently, UV curing is only being used in sewer systems.

Various Insituform products have been used for pressure applications since the mid 1970s. Initially, coated felt liners impregnated with thermoset resins were used to line cooling mains, industrial process pipes, and raw water and this usage has continued intermittently with some product development. Current pressure pipe lining products include Insituform's Pressure Pipe Liner (PPL®) and InsituMain®, Sekisui NordiTube's NORDIPIPE™, and Sanexen Environmental Services' Aqua-Pipe®, all of which are certified to NSF/ANSI Standard 61 (Heavens and Gumbel, 2004). These products have been used in water mains applications in the Europe, North America, and Asia.

In the early 1980s, collaboration between Japanese gas companies and their suppliers gave rise to hose lining products, which are polymer coated woven polyester fabrics bonded to the mains using epoxy resin. Paltem and Phoenix (also known as TUBETEX™) were well established products developed as Type II gas main liners which have evolved for use as AWWA Class III and Class IV (AWWA, 2001b) water mains liners. The current version offered in North America by Sekisui NordiTube, Inc. is

NORDIPIPE™. There are a number of other products developed in Europe seeking entry into the North American market such as Starline® Trenchless Technology.

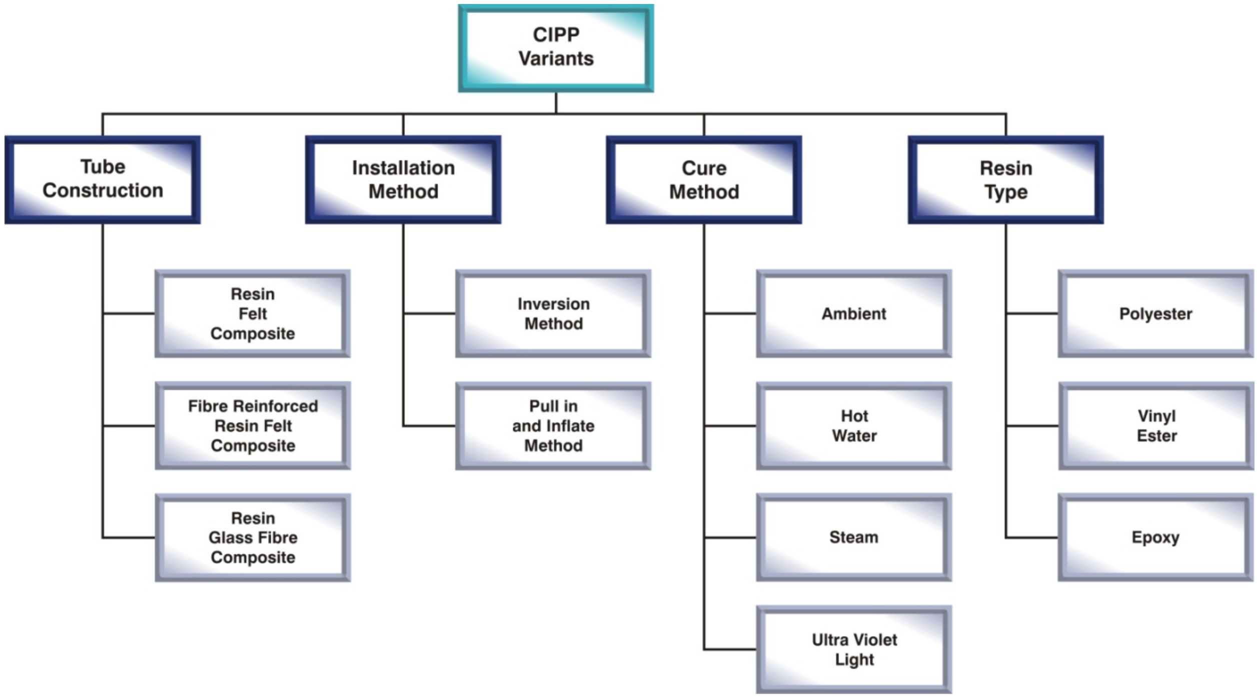

Figure 4-21. Summary of Cured-in-Place Pipe Technologies

For CIPP rehabilitation, prior to installation, the water main is typically prepared by cleaning to restore the cross section of the host pipe by removing encrusted corrosion product and then plugging the existing services to prevent resin migration into the service. Cleaning is usually undertaken by drag scraping, high pressure jetting, or rack feed boring. The pipe surface should be free from debris and running or static water, particularly if the lining system involved is required to bond to the pipe wall. Where installation involves an inversion procedure, the inversion pressure may be developed using a column of water contained within a drop tube suspended from a scaffold tower, a controlled head inversion process (CHIP) unit, or an air or water inversion vessel (i.e., elephant, snail, torpedo, etc.). This pressure turns the resin impregnated liner inside out while propelling it through the host pipe and pressing the resin-coated face against the host pipe wall. The resin is then cured using hot water or steam. For water applications, the tube can be made from PE or polyurethane (PU) coated fabric of woven polyester or glass-fiber, or non woven felt and glass reinforcement. The resin used for water applications is typically epoxy, and the product must be certified to meet NSF/ANSI Standard 61 requirements for contact with potable water. Equipment used for the installation is dedicated for the water application to minimize risks of cross-contamination from other non-drinking water pipeline applications.

How the service connections and end seals are treated is particularly important for water pipe rehabilitation. Service connections and any cut ends or extremities of the CIPP need to be pressure tight to prevent tracking behind the liner through any annulus which may be present between the liner and the host pipe. Service reinstatement may be undertaken externally by access to the lined pipe by local excavation from the ground surface or internally by location and reinstating using a cutter to reopen the connection. In various developments, a multi-task robot is used to reopen the connection and reinstating services robotically (i.e., Insituform, Progressive Pipeline Management [PPM], Aqua-Pipe, etc.). Locating the position of the existing connections after lining can be difficult. Careful survey and measurement from a defined base datum are required and plugs can be placed in the service connections to prevent resin blockage. Some novel location techniques using magnets placed by robot in the service connection before lining have had some success.

Pressure testing for CIPP lined pipe is prescribed in ASTM F-1216 (ASTM, 2009a). It is recommended that lined pipe be tested at twice the working pressure or working pressure plus 50 psi, whichever is the lesser. It must be recognized that a thermoplastic or thermosetting resin liner will expand under the imposed pressure and transfer load onto the host pipe. Accordingly it may be important to demonstrate that the host pipe will sustain the test pressure prior to lining. It is good practice, where possible, to test pressure capability before and after lining. During pressure testing, a stabilization period, which could take anywhere from half an hour to three hours, should be allowed prior to testing to allow the system to settle, and air should be carefully expelled from the system prior to testing.

4.2.3.1 InsituMain®. InsituMain® is represented as an AWWA Class IV fully structural pressure rated CIPP technology for transmission and distribution mains. It was introduced into the market in March 2009. The InsituMain® system, as shown in Figure 4-22, relies on a polyethylene-coated, woven glass and polyester fiber lining tube impregnated with an epoxy resin and InsituMain® is certified to NSF/ANSI Standard 61.

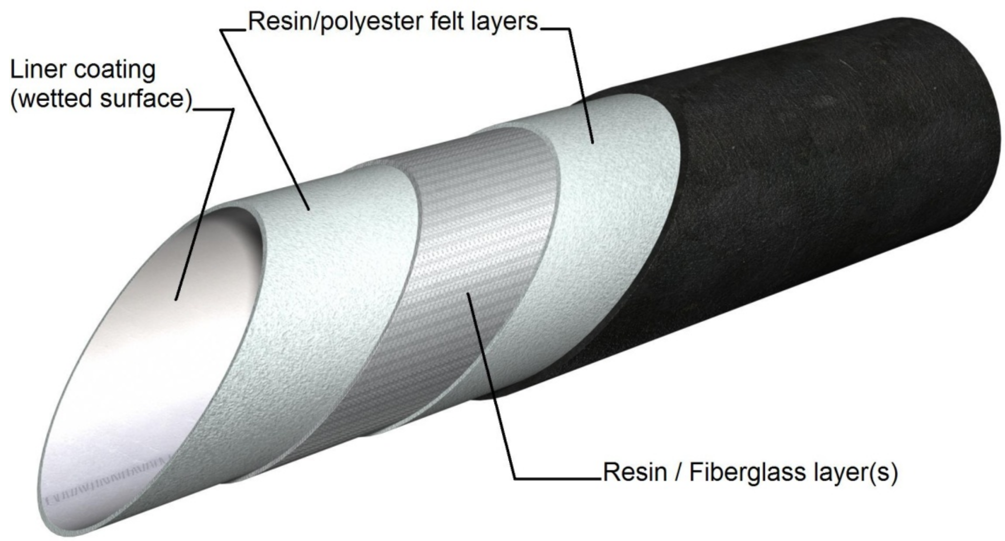

Figure 4-22. Cross Section of InsituMain® (courtesy of Insituform)

The resin impregnated tube is inserted into the host pipe by either a pull-in or inversion method, and hot water is used to cure the thermosetting resin. The pipe is cooled, tube ends are cut off, service connections re-opened, and after disinfection the pipe is returned to service. Lined sections are re-established to the existing system using standard pipe fittings.

InsituMain® is currently aimed at water main lining projects in the range of 6 to 36 in., with the largest project to date being 24 in. and a successful field test of 36 in. The liner is designed and tested using the procedures set out in ASTM F-1216 and physical property requirements are set out in ASTM F-1216 (2009a) and ASTM F-1743 (2008c). InsituMain® is suitable for applications having operating temperatures up to 120°F and operating pressures of 150 psi. The product can handle bends up to 45°, but the number and location of the bends in which the product can be used is evaluated on a case-by-case basis for factors such as pipe geometry and layout. Service connections can be made by a robotic remote access system. Projects have been completed in several states including Illinois, Arizona, Florida, Texas, New Jersey, and Missouri.

4.2.3.2 Aqua-Pipe®. Sanexen, in collaboration with the National Research Council (NRC) of Canada, developed Aqua-Pipe® around the year 2000. At present, the company advises that more than 1.5 million linear feet has been installed throughout North America. The company has different licensees in North America and has undertaken a small number of projects in the U.S. (e.g., New York City, Cleveland, Minneapolis, Atlanta, etc.). The Aqua-Pipe® liner consists of two woven polyester jackets, of which the inner jacket has a PU coating. The liner is impregnated at the work site in a purpose built vehicle where the resin is injected between the jackets and distributed by feeding the liner through a nip roller. The liner is designed and tested in accordance with the procedures set out in ASTM F-1216 and physical properties are determined in accordance with ASTM F-1216 (ASTM, 2009a). The cross section can be seen in Figure 4-23.

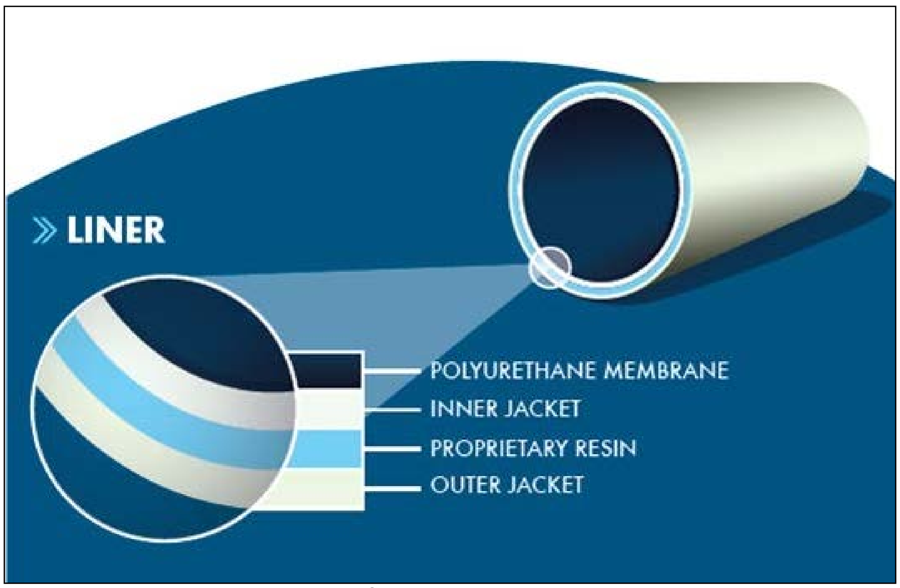

Figure 4-23. Aqua-Pipe® Cross Section (courtesy of Sanexen)

Aqua-Pipe® is available in diameters of 6, 8, 10, and 12 in. and has a pressure capability of up to 150 psi (10 bar). The smooth PU coating provides for a Hazen-Williams coefficient of 120 or greater. Aqua-Pipe® can be installed in lengths up to 500 feet between access pits. The Aqua-Pipe® liner is installed by pulling the liner in place and pushing a pig through the liner using water pressure to form the liner to the pipe wall. Circulating hot water for two hours and then holding under pressure for up to 12 hours completes the curing process. The service connections are reinstated from within using a remote controlled mechanical robot to cut open the taps. Aqua-Pipe® is certified to NSF/ANSI Standard 61 and it has also been certified to the Bureau de Normalisation du Québec (BNQ) Standard 3660-950 (BNQ, 2003).

4.2.3.3 NORDIPIPE™. NORDIPIPE™, from Sekisui NordiTube, Inc., has its origins in the hose lining technology transferred by Osaka Bosui to Le Joint Interne in 1983. Process Phoenix (TUBETEX™) became well established in Europe and evolved through a chain of ownership including NordiTube and Chevalier Pipe Technologies to its present ownership. TUBETEX™ is a polyester woven hose coated with PE, which is impregnated with epoxy resin and inverted by air from a pressure vessel into the host pipe and pressed and bonded against the pipe wall while being cured with steam. A Hytrel polyester version is used for gas pipe lining. The product is widely used for diameters of 4 to 40 in. (100 to 1,000 mm) in Europe and Asia for gas and water pipe lining. In North America, the company offers its higher performance NORDIPIPE™ product for water and force mains and its cross section is shown in Figure 4-24.

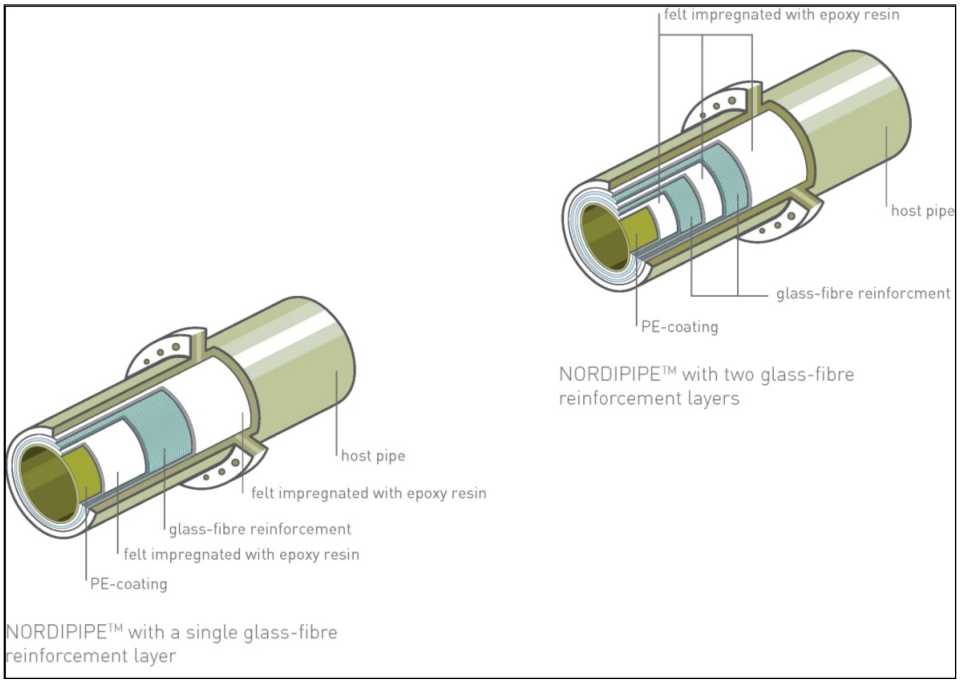

Figure 4-24. NordiPipe™ Cross Section (www.sekisuispr.com)

NORDIPIPE™ is a AWWA Class IV fully structural pipe liner and can be used for pipe diameters of 6 to 48 in. The liner is a glass reinforced felt impregnated with epoxy resin. The thickness of the pipe liner ranges from 0.18 to 0.94 in. (4.6 to 24 mm). Once in place, the system is rated for operating pressures up to 250 psi. Operating temperatures vary with different impregnating materials, i.e., 100ºF with epoxy and 160ºF with vinyl ester. The system can achieve renewal lengths up to 1,000 feet in certain conditions.

The NORDIPIPE™ liner is designed and tested in accordance with ASTM F-1216 and has been granted potable water approval in accordance with the Australian/New Zealand Standard (AS/NZS) 4020 (2005), Water Regulations Advisory Scheme (WRAS) British Standard (BS) 6920 (WRAS, 2000), NSF/ANSI Standard 61, and BNQ Standard 3660-950. The liner can be installed by water or air inversion or pulled in place and inflated. It can be cured with air, steam, or hot water. The service connections can be reinstated by robotics. Key installation check points include resin yield check for impregnation, pressure gauges for air inversion, temperature monitoring during cure, hydrostatic pressure test, and post-installation video for acceptance.

4.2.3.4 Starline® 2000/HPL-W. Starline Trenchless Technology LLC, a joint venture between the Gas Research Institute (now the Gas Technology Institute, GTI) and Karl Weiss GmbH, a Berlin-based rehabilitation specialist, was formed in 1999. The most widely used Starline product is Starline 2000, which can be used on diameters ranging from 3 to 40 in. for pressure up to 100 psi. Starline 2000 has successfully demonstrated a UV cure option which has been used by PSG&E, National Grid, and Consolidated Edison. Figure 4-25 illustrates the cross section of the HPL-W product designed for high pressure water main rehabilitation. Starline's licensee, PPM, has installed the product in fire water lines at Exelon Nuclear Power and in lines for TW Phillips Gas and Oil. Karl Weiss GmbH has some success and experience in selling and installing products for water pipe rehabilitation in Europe and it is likely that the Starline 2000 and HPL-W products could be employed in North America with a suitable distribution partner. Once NSF/ANSI Standard 61 certification is achieved, these Starline products can be used for rehabilitation of drinking water mains with diameters up to 40 in. and operating pressures up to 450 psi.

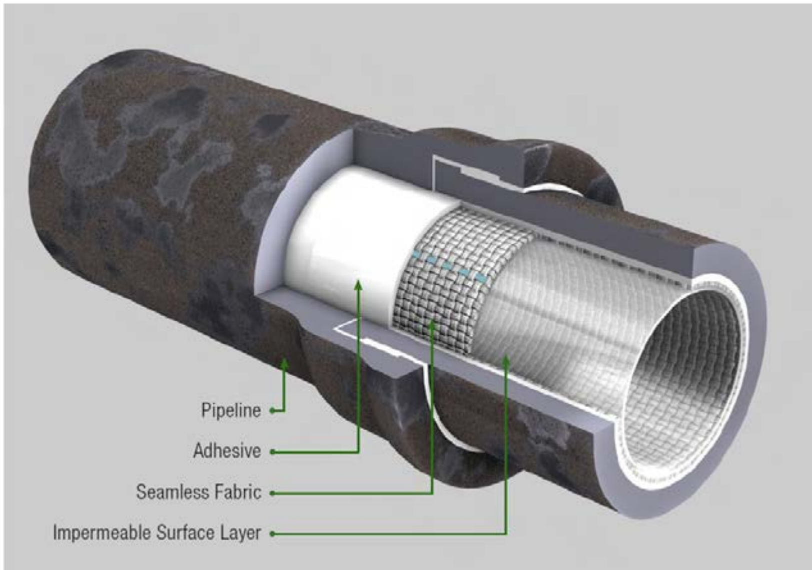

Figure 4-25. Starline HPL-W Cross Section (www.starlinett.com)

Other products include Starline HPL-G 180, a hose lining product for 6 to 48 in. gas pipe rehabilitation for pressures up to 180 psi. Also, Starline 1000 is a 4 to 24 in. CIPP hose lining technology using a polyester woven hose and epoxy resin to bond to the host pipe. It is fully approved for use in gas and water in Germany by Deutscher Verein des Gas- und Wasserfaches (DVGW) the German Technical and Scientific Association for Gas and Water. It is a hole and gap spanning liner, AWWA Class II, bonded to the host pipe and capable of spanning 2 in. (50 mm) diameter holes and gaps at its rated pressure capability. All of the Starline products mentioned above require a clean, dry surface for ideal bonding and preparation for lining which usually involves sand blasting. Connections are reopened by robotic cutter and end seals may be used for fitting flange connectors and spool pieces. The liners can negotiate multiple bends up to 45° depending on pipe diameter, location and number of bends.

4.2.4 Inserted Hose Lining. Inserted hose liners can be woven from polyester or Kevlar® and coated on the inside and out with PE or entirely PE. These liners are winched into place in factory folded shapes and reverted to a round shape with the use of air, steam, or water.

4.2.4.1 Thermopipe®. Developed in the UK in 1992 by Angus Flexible Pipelines Ltd., Thermopipe® was acquired by Insituform Technologies, Inc. and introduced in the U.S. in 1997. More than 800,000 ft of Thermopipe® has been installed worldwide. As shown in Figure 4-26, Thermopipe® is a woven polyester fiber jacket coated inside and out with PE. It was designed for rehabilitation of water distribution mains and other pressurized piping systems. Prior to lining and once the bypass has been put online, the service connections are located and the pipe is cleaned to restore the cross section by scraping, high pressure jetting, or rack feed boring.

Thermopipe® is available in thicknesses ranging from 0.08 to 0.2 in. and diameters ranging from 2.75 in. (0.08 in. thick) to 12 in. (0.2 in. thick). Thermopipe® has a pressure rating of 170 psi (230 psi for 4 to 8 in. diameters). Supplied as a factory-folded "C" shape liner with up to 1,600 ft on a reel, the

Thermopipe® liner is pulled into the host pipe (Figure 4-27) by a winch and reverted to its original shape with air and steam. Once heated and inflated, the liner forms a close-fit within the host pipe, creating a jointless system. The installation process can usually be completed within 3 to 4 hours. Thermopipe® can accommodate bends up to 45°.

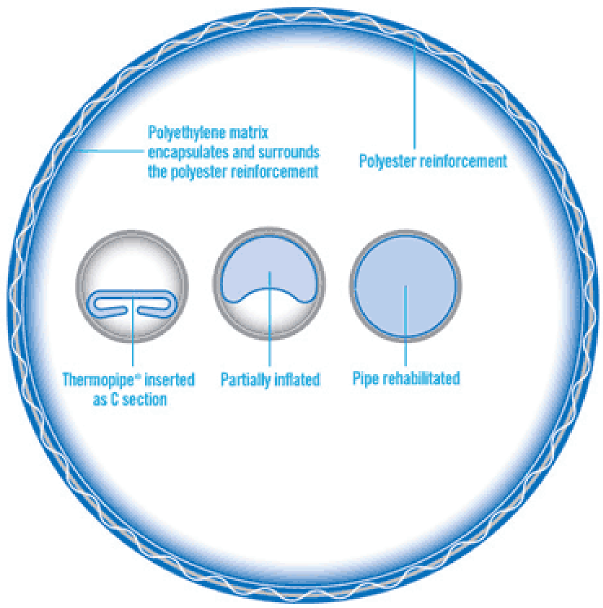

Figure 4-26. Thermopipe® Cross Section (www.insituform.com)

Pressure testing is carried out after the liner has cooled to the original ambient ground temperature and before reinstatement of the service connections. End seals, mechanical joint couplings, or similar fittings are used to clamp the ends of the hose liner to the existing pipe and provide flange connections for reinsertion of a spool piece.

Figure 4-27. Installation of Thermopipe® (courtesy of Insituform)

Service connections can be reinstated eternally by excavation, followed by tapping a hole in the host pipe and liner and fitting an external fitting to the liner. In pipe 6 in. and greater, service reconnections can be reinstated internally using a remote controlled robotic system. The Thermopipe® liner may be tested to an internal pressure equal to twice the known operating pressure, or operating pressure plus 50 psi, whichever is less. Thermopipe® is currently being used in limited installations in the U.S. market by Insituform.

4.2.4.2 Primus Line®. Primus Line® also is a woven plastic coated liner and has been developed by Rädlinger in Germany. The woven hose is made from Kevlar® and the coating that encapsulates the reinforcement is PE as shown in Figure 4-28. The liner is pulled into the host pipe and inflated so the liner ends and service connectors can be attached and the line disinfected before return to service. Because of the nature of the reinforcement, Primus Line®, which is offered in diameters up to 18 in., can accommodate operating pressures up to 1,000 psi (using a double layer in a 6 in. pipe), depending on pipe diameter and design (i.e., single or double layer). The liner can be installed in lengths up to 6,000 ft. Experience is in Germany, Austria, Italy, France, Belgium, Russia, Ukraine, Kazakhstan, and Brazil.

Figure 4-28. Primus Line® (www.raedlinger.com)

4.2.5 Close-Fit Lining. Close-fit lining is a family of methods, shown in Figure 4-29, for pipe rehabilitation in which a thermoplastic liner pipe is temporarily deformed, either in the field or at the manufacturing factory, to reduce its cross section before its insertion into an existing host pipe. The deformed liner is subsequently restored to its original diameter forming a close-fit with the original pipe. Close-fitting PE liners can be classified as Class II and Class III (i.e., semi-structural) or Class IV (i.e., fully structural) liners depending on the liner pipe standard dimension ratio (SDR) and the operating pressure of the host pipe (AWWA, 2001b).

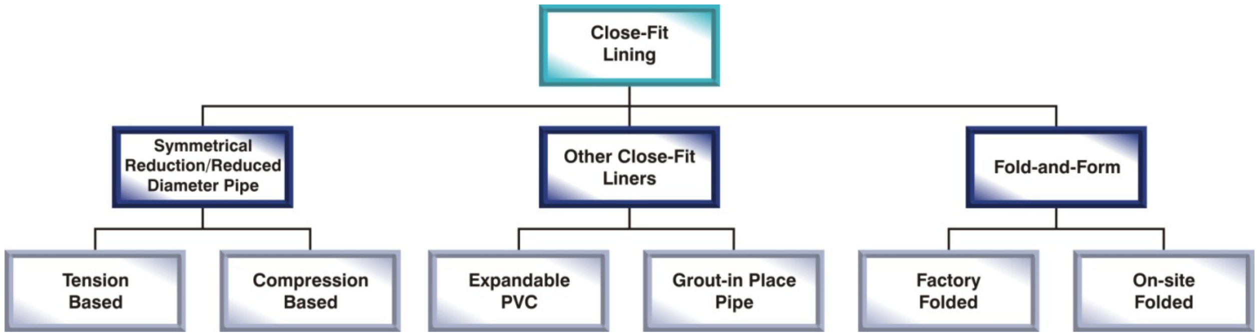

Figure 4-29. Summary of Close-Fit Lining Technologies

Close-fit lining methods can be used to install a semi-structural AWWA Class II and III liner in the host pipe, typically SDR 22 to 61. The liner is installed in the same way as a structural liner but uses a thinner wall pipe, which on a final installation and reversion relies upon the host pipe for sufficient structural strength to resist internal pressure. These hole and gap spanning liners can be designed to have sufficient stiffness to resist external buckling forces and vacuum pressures without collapse when the pipeline is out of service or running at less than full flow. The utilization of this technique is ideal for situations where the existing potable water pipe is in relatively good structural condition but suffers from joint leakage, internal corrosion, water quality, or tuberculation problems. The loss of cross section is small and the hydraulic capacity can be restored or improved as the lining material provides a smooth bore with a lower friction coefficient than the rougher host pipe.

Thicker walled liners require more effort to deform, but when installed can provide a fully structural AWWA Class IV liner that will support the internal pressure in the event that the host pipe fractures or fails due to external corrosion. These liners can also withstand the external forces due to soil and traffic and, importantly, withstand the rapid transfer of load when the host pipe fails.

The objective of close-fit lining is to overcome the traditional problems of sliplining (i.e., significant reduction in pipe cross section and an annular space between the host pipe and the newly inserted pipe). In this technique, the liner pipe is deformed either in field or during manufacture to reduce its diameter for insertion into the host pipe. The PE or PVC pipe is selected and sized according to the required stand-alone pressure and the host pipe interior size. In fully structural close-fit lining, the host pipe is used solely to sustain the hole in the ground for installation purposes, as it ultimately makes no contribution to the performance of the new replacement pipe. The close-fit liner will operate as a stand-alone pipe able to take on all the imposed loads and perform as a fully structural pipe. With the pipe in its deformed condition, it becomes a sliplining operation to install the new pipe into the host pipe. After the installation into the host pipe, the new pipe is reverted back to its original size usually by application of internal pressure, resulting in a tight fit between the replacement pipe and the host pipe, thus maximizing the available diameter of new pipe. Existing services are reinstated by direct excavation, robotic, or man entry methods.

The installation of close-fit liners may require lengthy access pits to install continuous liners, particularly in larger diameters and lower SDRs where the longitudinal stiffness of the liner will not easily permit the change in alignment from ground level to the level of the host pipe. Lengthy insertions will also demand good and extensive access for stringing and welding the liner pipe prior to insertion. Attention to safe storage of the pipe on site, clean and dry surfaces for welding, and the avoidance of abrasion damage when pulling it in is important to the longevity of the installed pipe. Care must also be taken to protect the public when storing and moving long lengths of pipe.

Thermoplastic pipes may be deformed and inserted into the host pipe and reverted to their original size or inserted and expanded to form a close fitting liner. Deformed and reformed pipes can be reduced in cross section by pulling or pushing through a die or folded (either in the field or in the factory prior to delivery to the project site). Where folded, small diameter pipe, typically up to 15 in. (450 mm), may either be deformed after extrusion and delivered to the work site on a reel, or folded at the work site. Larger pipe will typically be deformed at the work site. The reversion or expansion process, particularly for stiffer PVC pipe, will involve the use of steam to soften the pipe material to facilitate the process. With folded liner pipes, it is important that the liner is sized always slightly less than the internal circumference of the host pipe to ensure the reformed liner cross section is fully rerounded and circular.

4.2.5.1 Fold and Form Close-Fit Liners. Fold and form liners can be PVC or PE. The liner folding can occur in the factory or at the site prior to liner installation. The liners are typically winched into place and then reverted back to their original shape by air or water pressure.

4.2.5.1.1 Subterra Subline. Subline, a close-fit PE lining technique, was developed by Subterra in the UK in 1986. It is a relatively thin-walled semi-structural liner able to accommodate some bends in the host pipe. Installations of 3,000 feet (900 m) in length can be achieved in a single insertion. The business was acquired in 2008 by Daniel Contractors Ltd., a UK based construction and renovation specialist.

The pre-welded PE pipe is pushed through a former to fold it and it is temporarily held by restraining bands as shown in Figure 4-30. The reduced cross section creates sufficient clearance to facilitate the installation of the liner into the original pipe accommodating joint offsets and local deviations from alignment. Once installed, the folded pipe is reverted back to its circular form by pressurization with water at ambient temperature, which breaks the temporary restraining bands (Boot and Toropova, 1999). This creates a close-fit liner within the host pipe, sealing leakage and preventing corrosion. It is important that the liner is sized slightly less than the internal circumference of the host pipe to ensure the reformed liner cross section is fully rerounded and circular. If the liner external diameter exceeds the host pipe internal diameter, the reverted liner will not be fully circular and this may compromise buckling resistance in the event of external hydrostatic pressure or vacuum loads.

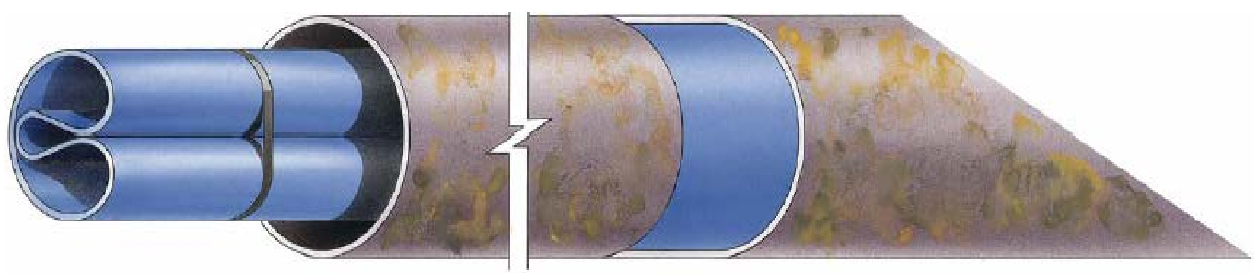

Figure 4-30. Section of Subline (www.subterra.co.uk)

The liner is available in the market in diameters ranging from 3 to 60 in. It uses standard PE 80 or PE 100 designated pipes, SDR 26 to 61. Subline PE liner pipes can typically negotiate long radius pipeline bends of up to 22.5°, depending on their number and location on the section being lined. Subline demonstration projects have been undertaken in the U.S.

4.2.5.1.2 InsituGuard® - Folding. InsituGuard® is usually an AWWA Class III semi-structural or Class IV fully structural liner depending upon SDR, pipe resin grade, working pressure, and host pipe condition. InsituGuard® is offered in two versions denoted as folding and flexing types, describing the process of deformation utilized prior to insertion. In the folding version, the SDR of the pipe is typically SDR 17 or higher and is available in the market in diameters of 12 to 48 in. The pipes are pressure rated up to 125 psi for fully-structural applications (i.e., Class IV) and lengths of up to 2,000 feet can be installed depending on winching capacity, existing pipe conditions, bends and valves, and the site footprint.

Introduced in the U.S. market in 2001, this product is similar to Subline in principle. Both are methods of site folding high-performance PE pipe prior to insertion into a new or existing pipeline and reversion to achieve a close-fit liner against the inner wall of the host pipe, as shown in Figure 4-31. It differs from Subline in some details of the apparatus for folding.

Figure 4-31. InsituGuard® - Folding Apparatus and Restraining Bands (www.insituform.com)

Excavations are required for installation and to remove any existing fittings. Next, the PE pipe selected for the project is welded into lengths suitable for installation, which can be the entire length or shorter segments to accommodate available work space. The welded pipe is pushed by hydraulic-powered clamping jaws 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 as it exits the machine. The liner is first pulled into the host pipe, then cut to length and the end fittings are attached, and finally pressurized to snap the restraining bands. Any 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.

4.2.5.2 Symmetrical Reduction/Reduced Diameter Pipe. Symmetrical reduction, sometimes called reduced diameter pipe, uses a roller reduction box to reduce the diameter of a thin-walled PE pipe to allow for insertion into the host pipe. Once fully inserted, the tension force can be released and the liner reverts back to its original diameter.

4.2.5.2.1 Swagelining™. Swagelining™ was developed by British Gas in 1986 for renovation of gas mains. It has been used to line gas, oil, and mining pipes and it is thought that about 1,500 miles have been installed in water applications. The process was acquired by Swagelining Ltd. in 2009 and is offered worldwide by licensed contractors. Originally executed by hot swaging, with improved equipment and experience, cold or ambient swaging is now the usual form of process. The Swagelining™ system uses a PE pipe with an OD slightly larger than the inside diameter of the pipe to be lined (Wrobel et al., 2004). After sections of PE pipe are fused together to form a continuous pipe, the pipe is pulled through a reduction die, as shown in Figure 4-32, which temporarily increases its thickness while reducing the outside diameter by about 10% and lengthens the pipe accordingly. The induced deformations are largely viscoelastic, so that after release of the reduction die force, the lining natural reverts to its original dimensions (Boot and Toropova, 1999). This allows the pipe to be pulled into the existing pipeline.

Figure 4-32. Swagelining™ Process (courtesy of Swagelining)

After the pipe has been pulled completely through the pipe, the pulling force is released and the pipe returns towards its original diameter until it presses tightly against the inside wall of the host pipe. Due allowance must be made for shortening of the liner as it reverts back to its original size. The tight fitting liner results in a flow capacity close to the original pipeline design.

The Swagelining™ process can install diameters ranging from 2 to 60 in. (50 to 1500 mm) and can achieve renewal lengths of up to 3,000 feet between excavations. Pulling force depends on the pipe rating as well as whether or not the pipe is to be used as a semi or fully structural liner. Thicker liners, with SDR in the 11 to 17 range, may require a powerful winching system and a supplementary pushing rig to be employed to minimize the tensile force acting on the pipe. Installation pulling loads are designed by Swagelining's proprietary software to ensure that max load is no greater than 50% maximum yield strength of the material. PE pipes used in the Swagelining™ process are manufactured to local and international standards and thus have clearly defined properties and an established expectation of service life. Standard fittings are available to allow sections of PE-lined pipe to be reconnected to the rest of the water transmission or distribution system. A wide variety of PE pipes and a full complement of tapping, branching, and connection methods can be provided. It is critical that the tension on the lining is maintained as it is being inserted; a loss of tension can allow the liner to increase in diameter and become stuck in the host pipe.

4.2.5.2.2 Subterra Rolldown. Rolldown is a close-fit PE lining technique, developed by Subterra in the UK in 1986 for British Gas. It can install a fully or semi-structural liner for a deteriorated pipe. In the Rolldown process, standard grade PE pipe slightly greater than the pipe to be lined, as shown in Figure 4-33, is gripped by hydraulic clamps and pushed through concentric rollers, which reduce the outside diameter of the liner pipe by about 10% to allow it to be pulled through the host pipe (Boot et al., 1996).

The diameter reduction is stable at typical ambient temperatures and the installation and reversion to its original size may be undertaken quite separately, days or even weeks after the initial reduction.

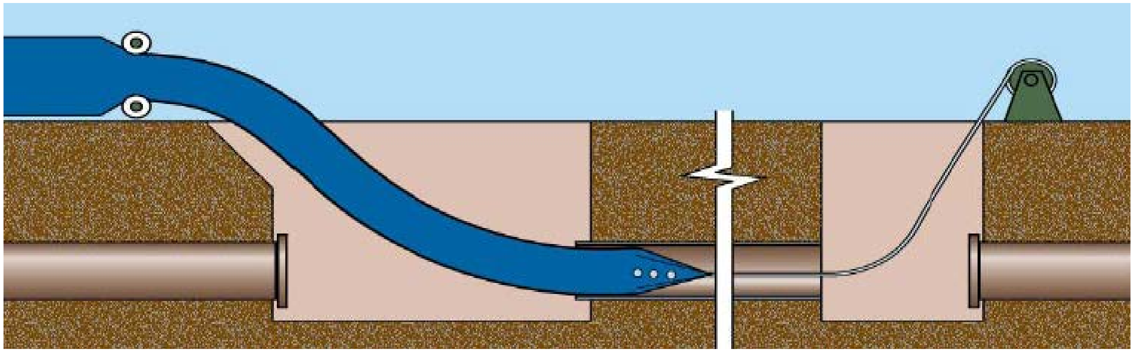

Figure 4-33. Rolldown Process (www.subterra.co.uk)

The diameter reduction in such processes is up to 10% and it is generally carried out using PE 3408 (PE 80) or PE 4710 (PE 100). Rolldown can be undertaken in diameter ranges from 4 to 20 in. with SDR 11 to 33, and can negotiate bends up to 11.25°. Thin liners are not suitable because they may buckle during the reduction process. After insertion, the liner is pressurized hydraulically with cold water to revert it to a close-fit with the host pipe. Lengths in excess of 4,000 ft (1200 m) have been installed and demonstration projects of Rolldown have been undertaken in the U.S.

4.2.5.2.3 Tite Liner®. Tite Liner® was developed by United Pipeline Systems in 1985 and has achieved success in industrial pipeline protection. It is a tension-based process, which uses a roller reduction box, shown in Figure 4-34, to reduce the outside diameter of a thin walled PE pipe so that long lengths, up to 2,500 feet, can be drawn into the host pipe and reverted by release of the pull force. Typically 2 to 52 in. PE 3408, SDR 17 to 44, the liner forms a thin corrosion barrier in raw water, mineral process lines, and in the energy sector. United Pipeline Systems was acquired by Insituform Technologies, Inc. in 1996 and has provided a body of experience of PE pipe processing from which the InsituGuard® range of products has been developed. It can be used to install a corrosion protection liner using a pipe certified to NSF/ANSI Standard 61. As discussed above, the tension must be maintained consistently during insertion.

Figure 4-34. Tite Liner® Roller Reduction Box (www.unitedpipeline.com)

4.2.5.2.4 InsituGuard® - Flexing. The PE pipe selected for the project is welded into lengths suitable for installation. The welded pipe is driven by rollers through a roller reduction box shown in Figure 4-35, which alters the outside diameter of the pipe, resulting in a diameter reduction of up to 10% of the cross-sectional area prior to insertion so that the liner can be winched into place. Once the reduced diameter liner is installed, end fittings are attached and the liner is pressurized to form a close-fitting liner. 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.

Figure 4-35. InsituGuard® - Flexing Roller Reduction Machine (www.insituform.com)

InsituGuard® - Flexing uses high-performance PE pipe to develop an AWWA Class IV fully structural liner or an AWWA Class III semi-structural liner. The pipes are also pressure rated up to 125 psi for fully-structural applications and the technology can install lengths up to 2,000 feet depending on winching capacity, existing pipe conditions, bends and valves, and the site footprint.

4.2.5.3 Other Close-Fit Liners. Other close fit-liners include expandable PVC and grouted in place PE, which are outlined below.

4.2.5.3.1 Duraliner™. A close-fitting liner technology called Duraliner™ uses an expandable PVC pipe, which has been developed for structural pipe rehabilitation. Duraliner™ has all of the usual characteristics of PVC including resistance to water disinfectant induced oxidation and hydrocarbon permeation. It also has a fusion capability and ease in connection with fittings and valves. The starting stock, pipe sections typically 2 in. (50 mm) smaller than the diameter of the existing pipe, is fused together and inserted into the entire length of the host pipe (Figure 4-36). The liner is fitted with end caps and filled with water. Heat and pressure are applied to expand the pipe tightly against the internal diameter of the host pipe. A computer control system is used to manage the process and equipment parameters. As the line is expanded, the molecular structure of the PVC is reoriented to a circumferential direction. This new molecular orientation increases the tensile strength properties of the liner and compensates for the loss of wall thickness due to expansion.

DI mechanical joint fittings and DI push-on type fittings can be installed directly onto Duraliner™. Any joint restraint devices that are commonly used with standard PVC can be used with Duraliner™. The Uni-Bell PVC Pipe Association's guidance for tapping PVC is applicable to Duraliner™ installations.

Figure 4-36. Butt-Fusion Welding of Duraliner™ (www.undergroundsolutions.com)

Duraliner™ works for 4 to 16 in. diameter pipes and can handle operating pressure typically up to 150 psi. The expanded pipe meets the performance standards for AWWA C900 and AWWA C905 PVC pipe and the material conforms to cell classification 12454 as defined in ASTM D-1784 (ASTM, 2008d).

4.2.5.3.2 MainSaver™. MainSaver™ is a PE liner with anchors (i.e., closely spaced hooked tabs) on the outside of the liner that serve as spacers maintaining an annulus to the inner surface of the pipe. The annular space created is filled with a high strength cementitious grout, as shown in the cross section in Figure 4-37. A rounding swab is passed through the pipe, applying air pressure, rounding the liner tube, distributing the grout evenly against the interior surface of the host pipe, and filling all pipe surface defects. It was developed in the UK as CemPipe and renamed on its launch in the U.S., where approximately 7,000 feet has been installed. MainSaver™ is used to renew pipes with holes, displaced joints, leaking joints, and maximum bends of 11.25°. It is NSF/ANSI Standard 61 certified for use with potable water.

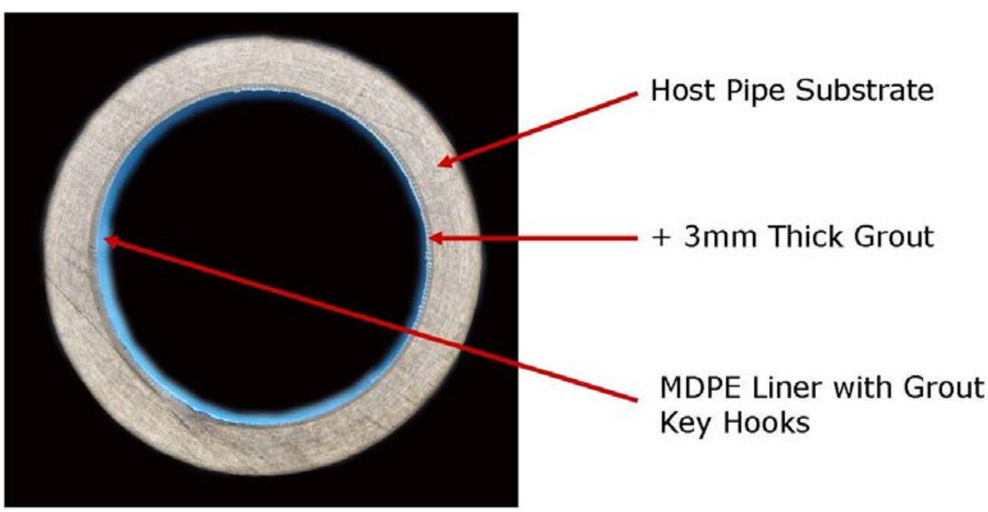

Figure 4-37. Cross Section of MainSaver™ (courtesy of MainSaver™)

MainSaver™ is an AWWA Class III, semi-structural liner available for 4 to 12 in. pipes (Sterling, 2007). The thickness of the system would be approximately 3 mm, but the grout will often be thicker where it is filling pipe defects. It can renew lengths of approximately 500 ft. MainSaver™ installation requires a minimum ambient temperature of 37°F or greater during installation. The product can sustain operating pressures of up to 294 psi. All installed materials are NSF/ANSI Standard 61 certified for contact with potable water. Cathodic protection can be restored to ferrous pipes to retard external corrosion.

4.2.5.3.3 Aqualiner. Aqualiner, which was developed by a consortium of three UK water companies, a Danish contractor, and a plastics consultant, is patented process used to rehabilitate water mains with a thin thermoplastic polymer composite liner in diameter of 6 in. to 12 in. (150 to 300 mm). The process is referred to as melt-in-place pipe and the first trial was completed for Wessex Water in the UK. The composite liner is made up of glass fiber reinforced polypropylene and a woven tube. Once winched into place, the liner is heated by an electrically powered air driven heating pig that raises the temperature of the liner to 200°C, melting the thermoplastic, and a removable silicon inversion bag is used to pressurize the liner tightly against the host pipe. Pressure in the inflation bag is kept at 45 psi until the liner cools, at which point the bag is deflated and removed. The finished liner is able to perform as a standalone Class IV liner capable of handling the internal pressure, and external loads. The product is BS 6920 potable water contact certified in the UK and the structural design procedures are based on the methods describe in ASTM F-1216 (Boyce and Downey, 2010). There are no product standards yet for this new class of liner product, but the closest applicable standard might be EN ISO 15874 *Polypropylene for Hot and Cold Water Installations*.

4.2.6 Service Line Rehabilitation. A significant component in water distribution system rehabilitation projects concerns service reinstatement and restoration or replacement of service lines. Frequently short side service lines involve open cut works in sidewalks, yards, and gardens, whereas long side replacements may require lengthy excavations in road pavements and restoration of costly traffic-bearing surfaces. Renovation of service lines with longer runs may be an opportunity for a trenchless replacement option such as impact moling, pipe bursting, or a trenchless rehabilitation method such as lining. Traffic impacts and shallow burial may increase the likelihood of leakage and increase the need for pipe renewal. Technologies that can be used for service line rehabilitation include the following.

4.2.6.1 Nu Flow Technology. Nu Flow Technology has an epoxy pipe lining process that can be used for plumbing and domestic piping. The in situ epoxy lining solution minimizes the destruction and disruption to the building. It can be used for lining lead, copper, and galvanized steel service connection pipes ranging from ½ in. up to 10 in. Prior to epoxy lining, the pipe is sand blasted and blown through with hot air to dry and remove debris (Boyd et al., 2000). Minimal building component and soil removal is necessary with in situ lining, and access to the pipe from a valve or fittings is required to blow a thin film (12 mils) of the epoxy through the plumbing system. Curing involves blowing hot air (100°F) through for an hour followed by a 24 hour cure.

4.2.6.2 Flow-Liner Neofit Process. The Neofit Process, developed for ½ to 1½ in. service connections in 1998 by Wavin, is available through master distributor Flow-Liner® in North America. The process involves insertion of a small diameter polyester tube, as shown in Figure 4-38, which is expanded to 2 to 2.5 times its original diameter using hot water and pressure. Thus, it provides a barrier layer, preventing further internal corrosion and stopping leaks. The system was designed in Europe to solve lead pipe issues by creating a barrier between the lead pipe wall and drinking water. It has been used in France, Australia, Japan, Malaysia, and in North America including Louisville, KY; Calgary, AB; and Ohio. The liner can span corrosion holes 1½ times the diameter of the service pipe. Access at both ends of the section of pipe to be relined is required for insertion and inflation. The lined pipe is then reconnected to existing pipes using special fittings (Boyd et al., 2000). The process is quick to install with typical access requiring only 2 to 3 hours.

Figure 4-38. Neofit Liner, Before, and After Inflation (www.wavin.com)

4.2.6.3 Deposition of Calcite Lining. A process for the development of a controlled growth of limescale was invented by Hasson at the Israel Institute of Technology in 1981 in collaboration with Mekorot Water to rehabilitate small diameter mains and lead service pipes (Hasson and Karmon, 1984). The patent rights were assigned to Technion Research and Development Ltd. A hard calcite lining is deposited on the inside of the pipe from a saturated aqueous solution of calcium carbonate, providing a barrier to degradation which seals the surface of lead service pipes. The process requires specialized equipment to circulate the solution through the pipe and the buildup of the layer can take several hours. There is no evidence of significant commercial use.

4.3 Replacement

Water main replacement is a primary option where renovation of a pipe is necessary. It is frequently used when a pipe does not have enough structural strength and becomes prone to failure and where precise condition assessment and residual life estimation may be costly or otherwise difficult to implement. The two broad categories of water main replacement methods are trenched construction and trenchless construction.

Trenched construction, which makes up 70 to 75% of water main replacement work, has historically been the predominant method and traditionally trenches are categorized as narrow or wide trench. For many utilities, the practice is to install the new mains in a trench parallel to the old main. In some cases, removal of the old main is not worthwhile or necessary. When AC pipes are replaced, it is usually considered good practice to leave the old main buried and undisturbed. Since the old main is kept in service until the new main is in place and ready for connection to the customers' lines, service interruptions are minimized. In those cases where the old main has to be shut down before the new main is in place, bypass pipes can be laid to provide uninterrupted service to the customer. A detailed breakdown of the replacement technologies is shown in Figure 4-39. Sliplining can also be considered a method of online replacement, but has been covered as a rehabilitation method in Section 4.2.2.

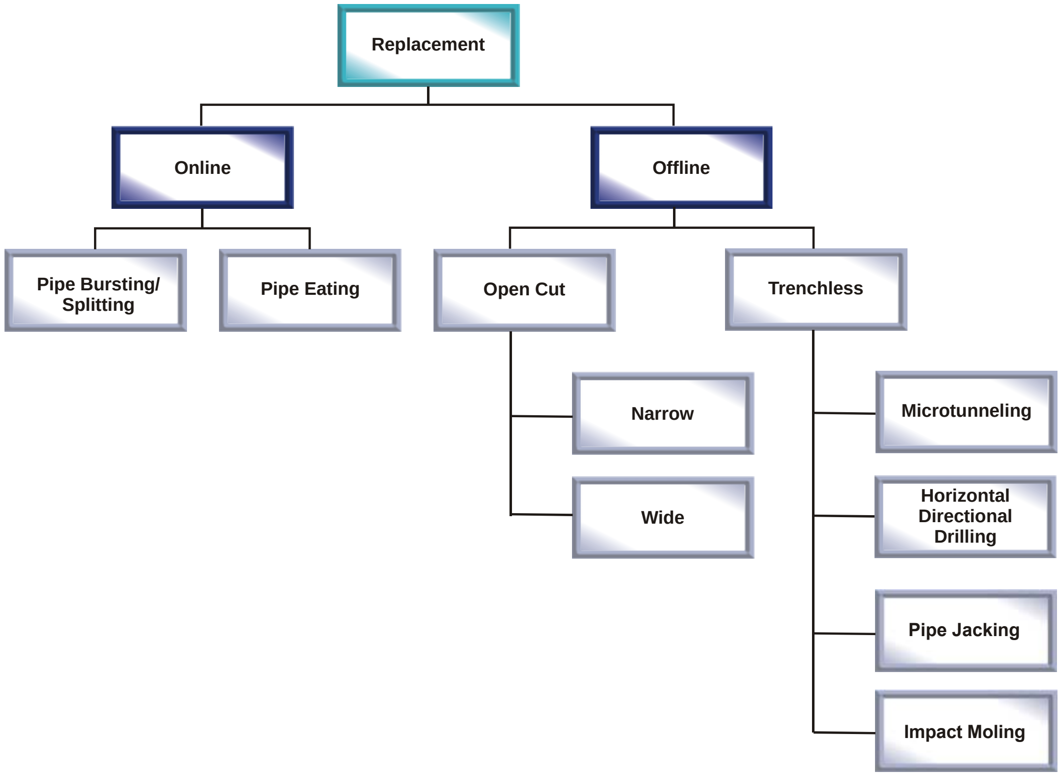

Figure 4-39. Summary of Replacement Technologies

4.3.1 Trenched (Open Cut) Replacement. Traditional open cut or trenched replacement can be categorized into either narrow trench or wide trench construction as described below.

4.3.1.1 Narrow Trench Construction. Narrow trenching or confined trench techniques can substantially reduce the impacts of the open cut trenching methods. By reducing the trench width, the amount of excavation and soil disposal, bedding and material importation, pavement restoration, and construction time to complete the project and associated construction costs can be reduced. The loads on the installed pipe are related to the trench width for rigid pipes and are reduced by the friction forces generated between the existing compact soils and the settling installed bedding. Accordingly, a lower strength pipe may be used with some resultant cost savings. Narrow trench construction requires good supervision and may call for improved shoring techniques such as trench boxes. Greater care and supervision in placing the pipe through the trench shoring, jointing in confined working space, and placing and compacting bedding may be necessary, but the approach can be of considerable benefit in reducing the disruption normally associated with poorly regulated trenching.

4.3.1.2 Wide Trench Construction. A narrow trench becomes a wide trench when the friction forces generated at the trench sides are negligible and the settlement of the fill in the trench does not shed any load to the existing ground at the sides of the trench. In a typical trench, very substantial amounts of soil, equivalent to 50 to 100 times the volume of the pipe installed, are removed to prepare the foundation and much of this material is then used for trench fill after the bedding and pipe is placed. Wide trench conditions can encourage settlement over a wide area and may be damaging to building foundations if they are within the zone of influence of the ground movements caused by trenching. Substantial costs in pavement restoration may be incurred in wide trench conditions and higher strengths of pipe may be required.

4.3.2 Trenchless Replacement. Confidence is growing in trenchless options and according to Underground Construction's 14th annual municipal survey, 15.6% of the $2.7 billion spent on new water main construction and 18.1% of the $1.4 billion spent on water main rehabilitation in 2010 was done using trenchless methods (Carpenter, 2011). Both figures show an increase in trenchless usage. Trenchless water main construction methods used for new works and for replacement can be used online, that is along the alignment of the old pipe, or offline that is taking a new alignment (Iseley and Gokhale, 1997). Principal trenchless options include the following.

4.3.2.1 Pipe Bursting. Pipe bursting is a process that utilizes specialized equipment to fracture brittle pipe materials and split ductile pipe materials and displace the old pipe into the soil while forming a cavity in the soil sufficiently large enough to place a new pipe of equivalent or larger size in the space formerly occupied by the old pipe. Pipe bursting has the advantage that it involves the installation of a new pipe, often an upsized diameter, and eliminates any need for detailed condition assessment. However, prior to pipe bursting, a good deal of information about the old pipe and its construction, in particular the placement and surroundings including the existence of other buried utilities and adjacent building foundations, is required.

Pipe bursting is easy to install in compressible soil, but rock trenches or reinforced concrete surrounding the existing pipe preclude its implementation. The alignment must be deep enough to prevent excessive heave of the ground by the action of bursting or upsizing. Parallel and crossing pipes in the proximity of the old pipe may be exposed by digging to avoid transfer of the bursting forces and any associated damage. Removal of service connections is required before bursting to minimize collateral damage. For this reason, the service connections will often be replaced by trenching or, if lengthy and under the road pavement, by impact moling. When bursting relatively shallow pipe, the road or driveway pavement may be stripped back and resurfaced upon reinstatement. Pipe bursting is becoming a popular method of trenchless replacement of water mains (Deb et al., 1999).

4.3.2.2 Pneumatic Pipe Bursting. The pneumatic pipe bursting method was developed by British Gas in 1986. It uses compressed air pressure to drive a spring loaded impact hammer behind a bursting head through the existing pipe, which may be a brittle material such as CI or AC. The bullet shaped bursting head, as shown in Figure 4-40, is larger than the existing pipe and may have stress raising bars or blades set into the head to focus the fracture of the existing pipe with each blow from the pneumatic pressure.

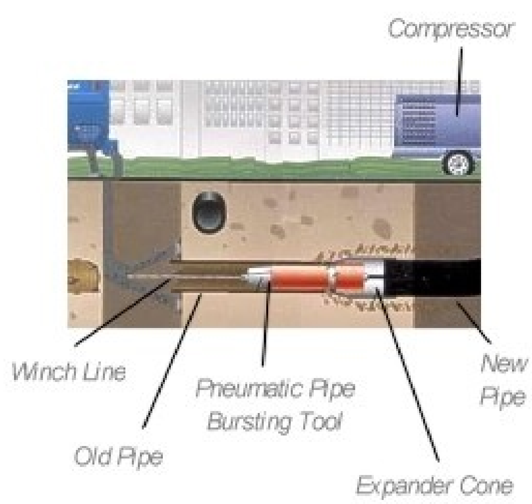

Figure 4-40. Pneumatic Pipe Bursting (www.tttechnologies.com)

An expanding cone may be placed behind the bursting head to encourage the displacement of the pipe fragments into the surrounding soil, which creates a cavity large enough to accommodate a new pipe. This new pipe is usually a continuous length of PE attached to a pulling attachment located behind the head or expanding cone. PVC pipe should not be used with the pneumatic pipe bursting method.

4.3.2.3 Hydraulic Pipe Bursting. Hydraulic pipe bursting was also developed by British Gas to provide extra force and displacement during busting. The process initially employed a hydraulic ram and expander arm mounted in the bursting head to supplement the bursting force and overcome the extra resistance encountered at joints and repair clamps, as shown in Figure 4-41.

Figure 4-41. Hydraulic Pipe Bursting Head (courtesy of Perco)

The equipment evolved as an expanding head employing hydraulic cylinders to open the petals of the head and apply a uniform radial force and extra displacement. The hydraulic power is used to open and close the bursting head, thus breaking the existing pipe. The bursting head is attached at the front of a winch chain or cable that passes through the pipe. Once the head opens and breaks the pipe, it is closed and pulled forward and the process of expansion and forward movement is repeated as the head is pulled along the line to seat against the next unbroken section of pipe. An HDD rig may also be used to pull the bursting head through the line. New pipe, usually PE or PVC, is pulled into the formed cavity or jacked by a hydraulic ram located in the access pipe.

4.3.2.4 Static Pipe Bursting. Static pipe bursting involves pulling a static pipe bursting head through the line using a winch, chain, or a series of rods as shown in Figure 4-42. Static bursting, using an automated hydraulic rod puller, provides the opportunity for excellent productivity and efficiency with minimal risk to workers in the access pit. Typically, rods can be automatically screwed or otherwise linked together to push a semi-rigid assembly capable of traveling through gradual bends through the line to the starting pit. The static bursting head, usually an oversize cone shape, is attached to the rod assembly and drawn back through the line, bursting the old pipe and pulling the new PE or PVC line into the formed cavity. In the receiving pit, rods can be automatically decoupled and returned to a storage carousel.

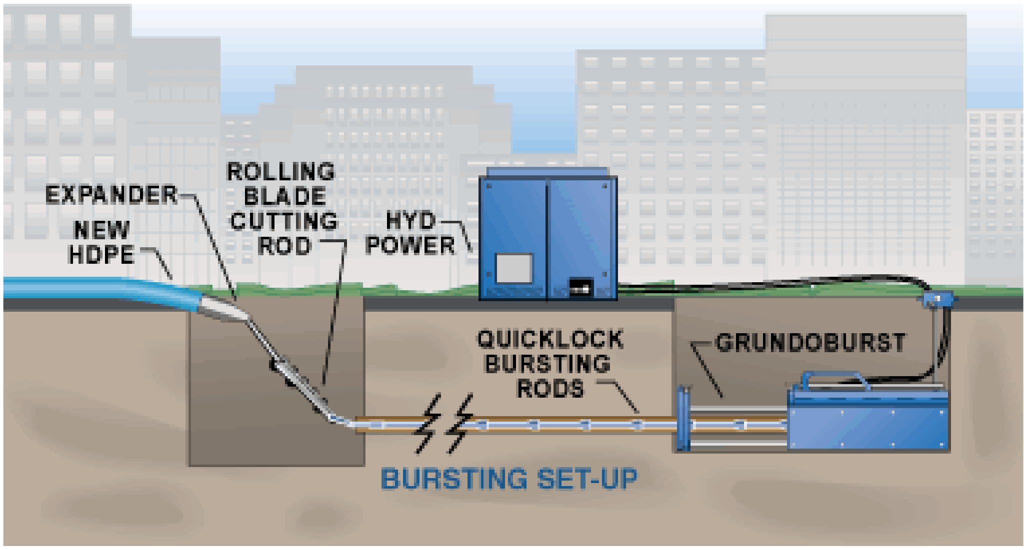

Figure 4-42. Static Pipe Bursting (www.tttechnologies.com)

4.3.2.5 ***Pipe Splitting.*** For steel or plastic pipe which behave in a ductile manner, a modified bursting head incorporating cutting wheels or blades is necessary to initiate pipe failure. The blades score the pipe so that it readily splits as the head is pulled through it. The split pipe is opened up using an oversize expander and the new PE or PVC main is pulled into place.

4.3.2.6 ***Pipe Reaming.*** An HDD machine can be used to rotate and pull a specially designed reaming head through an AC or plastic pipe, breaking the pipe into fragments and displacing the fragments in bentonite slurry while pulling in a replacement PE or PVC pipe.

4.3.2.7 ***Pipe Pulling.*** A variety of pipe pulling techniques are described in *Lead Pipe Rehabilitation and Replacement Techniques* (Kirmeyer et al., 2000). The basic pipe pulling method consists of passing a cable through the existing pipe, locking the cable, attaching the replacement pipe, and simultaneously pulling out the cable and old pipe with a winch. These include the Superior Bullet technique, developed in the U.S., which consists of a cone shaped tool attached to a cable passed through the lead pipe. The replacement pipe is pulled into the space previously occupied by the lead pipe.

The SADE™ pipe pulling system involves pulling a cable fitted with a series of shaped cones fixed along the cable. As the cable is tensioned, the cones lock into the lead pipe allowing the pipe to be pulled from the ground (Boyd et al., 2000). Problems can occur due to buckling, crushing, or rupture of the lead pipe and the failure to remove the pipe due to compacted ground.

Perhaps the best known pipe pulling method is the Hydros™ system developed in Berlin by Karl Weiss for pulling CI and AC water mains. Line lengths of up to 300 feet can be replaced with a continuous PE or PVC pipe. There are a range of variants on the pulling theme: Hydros™ Boy for small diameters up to 2 in.; Hydros™ Lead for lead service pipes; and Hydros™ Plus for water and gas pipes up to 15 in. in diameter. The Hydros-Lead system, Figure 4-43, uses a different method to transfer the pulling force from the cable to the lead pipe.

Figure 4-43. Hydros™ Plus (courtesy of Karl Weiss Technologies)

The technology utilizes an inflatable hose in addition to the steel cable. Both hose and cable are pulled into the lead pipe where the hose is inflated to grip the inside wall of the lead pipe. The replacement PE pipe is attached to the service end of the lead pipe via an adapter. The inflated hose plus the cable and lead pipe are pulled out of the ground by a winch situated above the excavation, while simultaneously pulling the new pipe into place.

4.3.2.8 Microtunneling and Pipe Jacking. This pipe installation method involves pushing the new pipe horizontally through the ground with an arrangement of remotely controlled hydraulic jacks while excavating the soil ahead of the pipe with a rotating cutting head. Developed largely in Japan in the 1970s, the technique can be used to install pipelines from 8 in. up to 10 ft (200 mm to 3 m) or more in diameter. Microtunneling systems have been used to install pipes in a single pass operation in lengths typically from 200 to 1,500 ft. Microtunneling systems are usually categorized according to the method of soil removal as auger, slurry, or earth pressure balance (EPB) machines shown in Figure 4-44.

Figure 4-44. EPB Machine (www.midwestmole.com)

Considerable planning and geotechnical survey work are required for a microtunneling project to determine the location of starting and receiving shafts, pipeline alignment, and selection of machinery. Microtunneling can be undertaken in a wide range of soils and groundwater conditions. It is an expensive and relatively slow form of construction which may be justified for water mains construction in crowded urban surroundings and for river, road, and rail crossings.

For short and shallow buried crossings and dry conditions in stable soils, pipe jacking, which includes the methods shown in Figure 4-45, can also be used. In this option, a pipe fitted with a cutting shield is jacked from a prepared starting shaft by pushing the pipe with an array of hydraulic cylinders against a thrust wall while workers at the face hand dig the soil and transport the spoil to the surface.

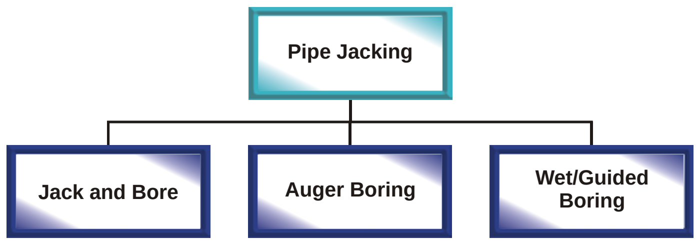

Figure 4-45. Summary of Pipe Jacking Technologies

The selection of the right jacking pipe is paramount. Typically, the loads imposed on the jacking pipe during installation are going to control the pipe design. Jacking loads of up to 1,000 tons are possible, so the jacking pipe needs to have high axial compressive strength and stiffness. "In wall" joints are used to avoid projections beyond the OD of the shield and to minimize friction between the pipe wall and the soil. Bentonite slurry is usually introduced between the pipe barrel and the soil to minimize friction, but smooth, non-porous pipe surfaces are also beneficial. The intermediate jacking stations (IJS) used on long drives are operated in sequence so that only sections of the jacking pipe are slid through the ground at any one time. This minimizes the jacking force needed to drive the tunneling machine and pipe column forward. Typical pipes that have been used for jacking of pressure pipes are GRP, polymer concrete, reinforced concrete, steel, and DI. PVC can also be jacked, but requires a large number of IJS, making it somewhat uneconomical.

4.3.2.9 Pipe Ramming. Pipe ramming utilizes an impact hammer fixed on rails at the start point to drive an open-ended steel pipe fitted with a cutting shoe through the ground, as shown in Figure 4-46. It can be used to place steel casing pipe from 4 to 144 in. in diameter. The casing pipes are equipped with bentonite lubrication by welding ½ inch pipe on the outer surface. The soil can be left inside the pipe until the drive is complete or partial soil removal can be undertaken to reduce friction loads during ramming. Various methods, including compressed air, can be used to remove the soil from the interior of the pipe. Excess soil also can be displaced from inside of the casing through vents in the hammer adaptor piece. Ramming is a non-steerable method for pipe installation, which is normally used for short installation, typically 150 feet, but up to 300 feet under roads or railway embankments where settlement is not permissible. It is used for construction of pipelines in clay, silt, and sandy soils, and quite large boulders and gravel can be accommodated. The installed casing may be filled with carrier pipe or cable. Ramming can also be combined with an initial steerable pilot bore to provide accurate crossing alignments. It is generally a very safe method of construction in regards to ground settlement, but loose existing soils that may be compacted by vibration should be carefully evaluated.

Figure 4-46. Pipe Ramming Under a Railroad (www.midwestmole.com)

4.3.2.10 Impact Moling. Impact moles are also known as earth piercing tools, soil displacement hammers, impact hammers, percussive moles, and pneumatic moles. Impact moling is a process whereby the pneumatic impact tool drives itself through the ground, unguided, to form a new hole in the ground into which a new pipe (usually PE or PVC) is pushed or pulled, as shown in Figure 4-47. This method is used for short lengths and small diameters (i.e., drives of pipe up to 10 in. in diameter, less than 200 feet long). Different heads are available for different soil types. Moles are typically launched from a pit using a launching cradle. The long body of the mole helps to keep the drive reasonably straight, though the drive path will follow the line of least resistance through the soil. Hand held monitoring equipment can determine the path of the mole by tracking the signal emitted from a sonde in the mole head. Moles that provide for a steering capability have been developed, but none yet have proved reliable enough for regular commercial practice.

Figure 4-47. Impact Moling Tool (www.tttechnologies.com)

4.3.2.11 Horizontal Directional Drilling. HDD rigs, as shown in Figure 4-48, are used to install pipelines crossing roads, railroads, rivers, and other obstacles. The HDD process has experienced significant usage since its development in 1970 and has become a commonplace method of installation. HDD is ideal for the installation of several replacement pipe materials, such as HDPE, PVC, and steel pipe. HDD is generally performed in a three-step process: pilot hole drilling; pilot hole reaming and drilling mud injection; and pipe pull-back. The drilled hole is typically 30 to 50% larger than the pipe to be installed and the hole is stabilized with bentonite while the excavated material is flushed out with the drilling fluid.

Figure 4-48. HDD Rig (www.tttechnologies.com)

The pilot hole establishes the path of the installed pipe. Typically, the path of the drill head is tracked electronically using a sonde located in the drill head and either a hand held detector above ground (walkover system) or a path tracking system based on the use of natural or artificial electromagnetic fields and wired back to the drilling machine (wireline system). Design considerations include soil characteristics, radius of curvature of the bore path, and its effect on the pipe to be installed, particularly the pull-back force. A detailed geotechnical survey is required to determine the suitability of the chosen alignment. The HDD drill path can be steered around known obstacles provided the locations are identified in time for gentle deviation. Mini-HDD rigs can handle pipes up to 12 in. in diameter and are used primarily for utility construction in urban areas. Large (maxi) HDD rigs are capable of handling pipes as large as 54 in. in diameter and, under reasonable ground conditions, can install moderate diameter pipelines (e.g., 18 to 24 in.) over lengths of 1 mile or more. The length of the bore, diameter of the replacement pipe, and geotechnical properties of the soil determine the size of the drill rig required. Gravel soils are not recommended, as it can be difficult to sustain an open borehole prior to the pipe pull. Mud motors are used for drilling through rock and stiffer soils.

5.0: SERVICE LINES

5.1 Characteristics of Service Lines

Estimates of the length of water distribution piping in the U.S., which range up to 1.8 million miles, do not include the more than 65 million estimated service lines in use in the U.S. (EPA, 2007b). Kirmeyer et al. (1994) estimated that there are more than 880,000 miles of service lines in the U.S.

According to Economic and Engineering Services (EES) and Kennedy/Jenks/Chilton (1989), the types of pipe in common use vary widely. The service line typically has a diameter of ¾ to 2 in. Most service lines are made of copper, PE, galvanized steel (GS), and PVC. Other materials remaining in use include lead and polybutylene (PB) and brass. Lead service lines still exist in some older systems and studies estimate the number of lead services to be around 3.3% of all services, which is close to 2.3 million service connections (EPA, 2007b). If not removed or lined, lead service lines are potentially a source of lead entering customers' drinking water.

5.1.1 Service Line Materials. AWWA's Water Stats 2002 Distribution Survey collected data on the water distribution systems, including customer service lines, from 337 water utilities located in the U.S. and Canada (AWWA, 2004a). A breakdown of the types of service line materials and the estimated installed percentage of each material is shown in Table 5-1.

Table 5-1. Types of Service Line Materials

Service Line Material	Percent of Total
Copper	60.5
Polyethylene	12.4
Galvanized Steel	8.6
PVC	6.3
Lead	3.6
Polybutylene	2.6
Steel	1.7
Cast Iron	1.3
Asbestos Cement	0.4
Other	2.2

5.1.1.1 Copper. Copper is popular for its longevity and biostatic characteristics. Copper tube, shown in Figure 5-1, used for water service and distribution piping is manufactured to ASTM B-88 Standard specification for seamless copper water tube (ASTM, 2009c). ASTM B-88 tube is available in three grades (i.e., K, L, and M) with type K being the heaviest walled followed by Type L and Type M, respectively. Types K and L are available in both annealed (soft) temper and drawn (hard) temper, while Type M is only available in drawn (hard) temper. Types K and L are the most common copper service lines used in distribution systems today.

The life expectancy of copper service lines varies depending on soil conditions, acidity of water, stray currents, and type of disinfectant used at the treatment plant. On average, copper has shown a life normally in excess of 75 years. Also, U.S. copper tube manufacturers provide a limited warranty of 50 years, depending on the specific situation (NSF, 2005). Copper tubing (Types K, L, and M) is commercially available in 20-foot rigid lengths or coiled. This material also has high water-flow efficiency, since there are generally no fittings in water services. Copper is easy to bend with proper mechanical bending tools. Copper service lines can be joined by soldering, brazing, compression, or flare connections depending on utility practices and specifications. Local codes should be followed (e.g., solder joints are unacceptable in many municipalities and areas for underground installation of copper tubing). Copper has a low friction coefficient, therefore smaller diameter services can be installed than with other materials with higher friction coefficients, which would require larger diameters to achieve equivalent flows. Copper piping can be readily detected underground with the use of ground penetrating radar, sonic evaluation, and/or using an electromagnetic emission pulse device.

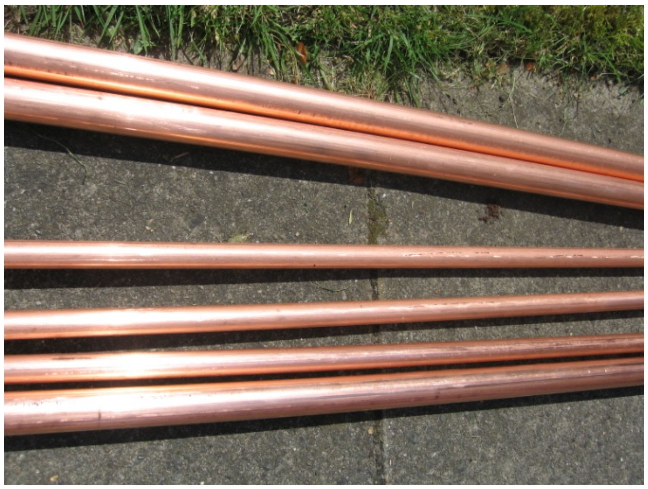

Figure 5-1. Copper Piping

5.1.1.2 Polyethylene. PE service lines are characterized by their toughness, excellent chemical resistance, low coefficient of friction, and ease of processing. PE service lines offer many advantages including high ductility, corrosion resistance, flexibility, light weight, and reduced installation costs as well as excellent long-term performance as pressure pipes. According to PPI, the life expectancy of PE pipes is more than 50 years. PE was first used for water service line applications in the early 1950s, and since that time both the material standards and materials have evolved. PE does not need cathodic protection and it is also resistant to aggressive soils and the bacteria and fungi found in them. It also has good resistance to some organic substances, such as solvents and fuels (PPI, 2007). Additionally, PE service lines have proven to have high tolerance to handling and bending in cold weather.

Joints in PE piping are not made with adhesives or solvent cements, but with mechanical fittings or with stainless steel band clamps. Service line segments can be heat-fused, which requires skilled labor and special tools for proper installation. The most common problem with PE pipes and other plastic service pipes is kinking from improper installation and the difficulty of locating PE lines when they are buried (Thompson et al., 1992). Many utility lines require a tracer wire to be installed above the service line so it can be located by magnetic pulse. PE service lines are installed as per AWWA C901 (AWWA, 2008).

5.1.1.3 Galvanized Steel. Usually found in older homes, GS service lines are covered with a protective coating of zinc to extend the pipe life expectancy about 40 years, but the coating generally fails and they corrode inside and out depending on soil conditions, temperature, and acidity of water being transported. Some issues with GS service lines, which are commonly sold in rigid lengths of 22 ft, include having lower water flow efficiency than copper because of the required number of fittings which may increase head loss. Also, GS service saddles were found to corrode within 5 to 25 years depending on local soil conditions and external effects of the environment.

Other issues include cutting GS, which is more difficult to cut than copper or plastic. Once cut, the service line has to be threaded and a small amount of pipe joint compound must be applied on the thread for the screw-on connections needed for fittings. GS service lines have a history of corroding in alkaline water more than any other piping metal (Grigg, 2004). According to 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. Also, iron oxide can build up over time, especially in small diameter pipes, causing the water to become rust colored when the tap is first turned on. Eventually the service line will corrode completely through the pipe wall, usually at the joints first, resulting in leaks. If a leak occurs, corrosion products can be used to form a coating over the leak and temporarily sealing it.

Another problem associated with GS service lines is the galvanic corrosion effect of joining brass valves and steel piping shown in Figure 5-2. Whenever the steel pipe meets copper or brass, a rapid corrosion of the steel service line will occur due to electric charge flowing from one material to the other, which accelerates deterioration. Dielectric unions can be used between copper and steel pipes to prevent the flow of electric charge. GS service lines are mostly recommended in locations where the line may be subject to impacts although the issues mentioned above would still be factors.

Figure 5-2. Corrosion Failure of Galvanized Steel Pipe Coupling

5.1.1.4 Polyvinyl Chloride. PVC service lines are readily available, economical, and corrosion resistant and have been predicted to have a life expectancy of a hundred years or more (Burn et al., 2005). Since PVC, like other plastics, is not subject to corrosion, the surface remains smooth, eliminating tuberculation that can reduce hydraulic capacity and increase pumping costs. The smooth internal wall surface of PVC service lines minimizes fluid friction and flow resistance, thereby providing high flow efficiency similar to copper and other plastic service lines. PVC service lines for most water distribution applications are designed with deep insertion joints engineered not to leak. Because gasketed, push-together PVC pipe joints are relatively easy to assemble, they can be tested and placed in service quickly.

5.1.1.5 Lead. The revisions of the SDWA in 1996 resulted in reduction of allowable leaching levels for materials that come into contact with potable water supplies (15 μg/L for lead and 1.3 mg/L for copper). Many utilities, especially older municipalities, are faced with lead material in their water distribution systems. Lead service piping has not been used by most U.S. cities since the 1940s and lead has been banned for use in plumbing systems since 1986 (Kirmeyer et al., 2000). Depending on site specific connection details, lead service lines have a life expectancy of 60 to 75 years. However, because of potential health risks associated with excessive lead levels in water, lead has been replaced in new installation by alternatives such as copper and PE.

Utilities may be driven to implement a lead service line replacement program that can require enormous field work to identify lead service lines service by service. Lead line replacement can be either conducted as a stand-alone project or in combination with main rehabilitation projects. However, partial replacement of lead service lines usually entails disturbance of lead scales, lead burrs where the service line is cut, and galvanic corrosion when the remaining lead service line (i.e., customer owned) is coupled to a copper service line. It is important to note that when the lead service lines are removed, a high lead content can be observed immediately afterwards, even when the entire lead service line has been removed. This is due to lead particles being dislodged during shut-off and subsequent pressurization of the service line. It is recommended that new lines be flushed for about 60 minutes following the completion of all renewals. Changes in secondary disinfectant and water quality may also result in lead leaching. Kirmeyer et al. (2000) discuss lead pipe services in more detail and WaterRF has funded a project to evaluate lead service lining technologies (WaterRF, 2011a).

5.1.5.6 Polybutylene. PB pipe was a popular material in the 1970s through the early 1990s. PB service lines come in rolls of flexible plastic and require special fittings that are neither soldered nor cemented but mechanical. This material is relatively easy to cut with a saw or a knife and need not be threaded. Although PB is corrosion-proof, it has a widespread record of failure possibly owing to its reaction to chlorinated water. PB has a lower material cost than copper and lower installed cost as well, because the skills required for installation and the lightness of the material result in reduced installation time. The useful life of PB service lines is significantly shorter (in some cases, less than 16 years). Many plumbers may have used improper fittings to join the service lines and it is possible that use of semi-skilled laborers has led to improper pipe joint installation, mostly by over-tightening the fitting clamps. However, the current theory is that residual disinfectants in the public water supply react with PB and the acetal resin in the fittings and thus weakens the service lines and joints. The PB industry is currently developing a stronger product that will address the past common problems associated with PB installation and operation to match, or exceed, the performance of other available piping materials.

5.1.5.7 Other Service Line Materials. Tri-layer service lines such as PE-aluminum-PE (PAP) composite pipes combine the characteristics of both materials to form a service line that is light, strong, and resists corrosion. By combining the two materials, it is claimed by some manufacturers that tri-layer pipes avoid the thermal expansion and deformation of plastic service lines (IPEX, 2009) while retaining the flexibility, frost resistance, and ease of use associated with plastic. PAP pipes are not recommended at continuous service temperatures above 104°F. Like most plastic service lines, this product requires few fittings and joints, making for faster installation than metal service lines. Unlike most plastic tubing, tri-layer pipes permanently hold their shape and do not need additional clips or brackets to retain their shape in bends or curves. Similar to plain PE pipes, PAP pipes have a smooth inner wall and a design life span in excess of 50 years (IPEX, 2009). Municipal experience with this relatively new product is very limited.

Fiberglass pipes are known for their application in corrosive environments. The smooth internal wall minimizes fluid friction and flow resistance, similar to copper and plastic service lines. Use of fiberglass piping in service lines is rare because standard products start at 1 in. in diameter.

5.1.2 Ownership and Legal Issues. The information provided in this section is intended for information only and is not intended as legal advice. Service connections are generally comprised of two parts:

- Service line from the main to the edge of the street or easement right-of-way
- Customer line from the right-of-way or street into the customer premises

In general, the service line is owned by the water utility and the customer line by the property owner, though some locations place ownership of the service line in the right-of-way on the customer. Responsibility for maintenance rests with the owner of each portion of the connection. There are several possible points of change of ownership including: the main itself; the property boundary; the meter; the curb box; or the building itself.

Municipal codes will define the point of change of ownership. In most cases, but not all, the utility aims to place the meter and/or curb box at the property boundary and to have change of ownership at this point. Meters themselves remain the property of the utility irrespective of their location, including inside buildings.

In some communities, the utility or municipality maintains the whole of the service connection. In most communities, however, the property owner is responsible for maintenance of the service connection, in particular the customer line. There has been a tendency among communities to avoid programs that require work on private property or may create future liability from activity on the private portion of the service connection. However, any rehabilitation program that includes the services will inevitably require such work.

5.1.2.1 Property Access Issues. Many communities remain unsure of the legal authority to test, maintain, and rehabilitate service connections. To address these issues, policies related to public health for work on service connections, work related to inspection, and to enforcement of municipal codes need to be clarified so that service connections remain in good working condition and do not represent a public health hazard. For example, there is large variation in municipal codes concerning backwash prevention devices.

Access to private property for such purposes constitutes exercise of the police power of local authorities. Legal and constitutional issues involving private rights must be considered, in terms of both right of access to private property and of potential liability for personal injury or property damage arising from works undertaken on private property. There are also restrictions on the use of public funds for private property improvement.

If a public authority wishes to gain access to private property, the most common approach is to use right of entry permit forms signed by each individual property owner. However, any regulations to permit inspection of private property must take into account the Fourth Amendment provisions concerning unreasonable search and seizure or restrict activities to within established easements except in cases of emergency.

The U.S. Supreme Court determined in 1967 that regulatory agencies must obtain a warrant prior to conducting an administrative search. Administrative search warrants can be used to permit a large number of inspections within problem areas without the need to obtain permission from each property owner in advance, or where owners deny voluntary access, for example through refusal to sign a right of entry permit form. In emergency situations, an emergency exemption exists, where access may be gained without a warrant, for example to protect public health or safety.

5.1.2.2 Funding Issues. Most states have constitutional provisions that limit the use of public funds to expenditure for public purposes (i.e., the public purpose doctrine). State laws vary considerably and should be reviewed with care before implementing specific programs. It is generally accepted that private owners may derive some benefit from public funds provided that it is incidental to the benefit accruing to the public at large through public health, safety, and the environment. Such programs generally fall under municipal legislation or policy, so local government determines whether that is the case. Very few projects for public benefit are without elements of personal benefit to certain individuals so there is not a fixed definition. Local government officials make determinations based on the merits of each case and generally have broad discretion to do so.

There may be an impact on existing private property rights from the adoption of new regulations. Both the Fifth and Fourteenth Amendments impact this. A regulation that has a clear and rational relationship to preventing or reducing a threat to the public health and environment would generally be considered to meet the requirements of these amendments irrespective of their effect on private property rights.

Experience from some utilities has shown that legal issues associated with the inspection, rehabilitation, and repair of service connections on private property and privately-owned can be managed, provided that there is clear benefit to the public at large and the political will exists to do so.

5.2 Renewal of Service Lines

Service line rehabilitation technologies were discussed in Section 3.2.6. A summary of the technologies available for the rehabilitation or replacement of water service lines is presented in Table 5-2. Each technology is capable of rehabilitating or replacing lead service lines, and other pipe materials, thereby improving water quality when necessary.

Table 5-2. Summary of Renewal Technologies for Service Lines

Category	Type	Brand Name	Vendor	Diameter, in.
Rehabilitation	Close-Fit Lining	Neofit Process	Wavin/Flow-Liner®	0.5 - 1.5
Rehabilitation	Epoxy Coating	Nu-Flow Epoxy	Nu-Flow Technology	0.5 - 10
Rehabilitation	Calcite Lining	N/A	Israel Institute of Technology	N/A
Replacement	Impact Moling	Various	Various	1.75 - 7
Replacement	Pipe Bursting	Various	Various	0.5 - 2
Replacement	Pipe Pulling	Hydros™ Boy	Hydros™	0.5 - 2

5.3 Reconnection of Service Lines

For most of the pipeline rehabilitation techniques, there are three basic issues that must be overcome in order to reconnect a service without excavating. These challenges include: finding the service connection post-rehabilitation; re-establishing the opening; and connecting the service to the liner or carrier pipe.

5.3.1 Finding the Service Connection. To accomplish reconnections without excavation at the service location, work from within the pipeline will likely be required. The insertion of a pipe or liner within the old main generally obscures the position of each service line. In the wastewater industry, where laterals are larger, a dimple is often visible in the liner, indicating that a lateral is present. In water mains, the service lines are generally smaller and more difficult to see and the liners have stiff reinforced fabrics that limit deflections at openings. The techniques that have been proposed for finding services include:

- Homing in on a radio frequency signal transmitted on the service line
- Homing in on a transmitter or magnet inserted within the service line
- Using remote-field eddy current technology to detect the corporation stop and tap
- Precisely mapping the service line location prior to lining

5.3.2 Re-establishing the Opening. Most concepts for re-establishing service lines involve a pipeline robot that drills a hole through the liner or carrier pipe. Similar devices are used routinely in the wastewater field for this exact function. Re-establishing the opening should not be difficult if its location is known with precision, but precision is the key. Since the average water service line is small, a liner hole that is off the mark by a fraction of an inch may be useless and particularly poorly made holes might interfere with the reconnection process. Another approach to re-establish the opening would be to drill from the outside in. For example, a drill-bit attached to a plumbing snake or small boring device that is deposited in the corporation stop prior to lining, and later signalled to bore its way back to the main. Such outside in technologies are concepts and/or prototypes at present and there is no evidence of their commercial use in the field to date.

5.3.3 Connecting the Service Line to the Liner or Carrier Pipe. Achieving a positive connection between a service line and the liner pipe is the issue that most profoundly separates water system conditions from wastewater system conditions. In the case of water mains, pipelines are pressurized, and leakage to the annulus at service connections and liner terminations must be prevented. Where a tight-fitting liner or a well-adhered spray-on liner is used, the sealing may not be a significant issue. Grouts, sealants, and adhesives of various types may be capable of preventing this leakage. The problem becomes more difficult if a loose liner is used or if a material such as HDPE pipe is used, which is resistant to most chemical and mechanical bonding methods. In such cases, a small connecting piece that is inserted into the corporation stop and fused or mechanically connected to the liner pipe may be needed.

One of the difficulties in making the connection between the liner and service line is dealing with the numerous variations in conditions that will be encountered within existing water systems including: difference in pipeline materials; scaling and other surface conditions; uncertainties regarding structural integrity of old mains; and differences in diameter and dimensions.

6.0: TECHNOLOGY SELECTION CONSIDERATIONS

For water main renewal, the challenges fall into two categories: assessing the condition of existing pipes (e.g., defining the problem) and selecting the appropriate technique to restore the pipe condition to a desired level (e.g., solving the problem). For the water main requiring renewal, the problem to be addressed needs to be well defined and understood such as the performance and condition of the asset and the cause of its deterioration. Once the problem is defined, different solutions can be developed based upon a review of available technologies that can address the current asset condition and extend the remaining asset life. Next, an appropriate rehabilitation solution should be selected based upon consideration of several factors including technology costs (both capital and life-cycle), maintenance requirements, bypass piping requirements, disinfection requirements, NSF/ANSI 61 requirements, accessibility, and criticality of the water main. Decision support systems have been developed to assist decision-makers with selecting water main rehabilitation technologies including Deb et al. (2002) as shown in Figure 6-1, Matthews (2010), and Ammar et al. (2010).

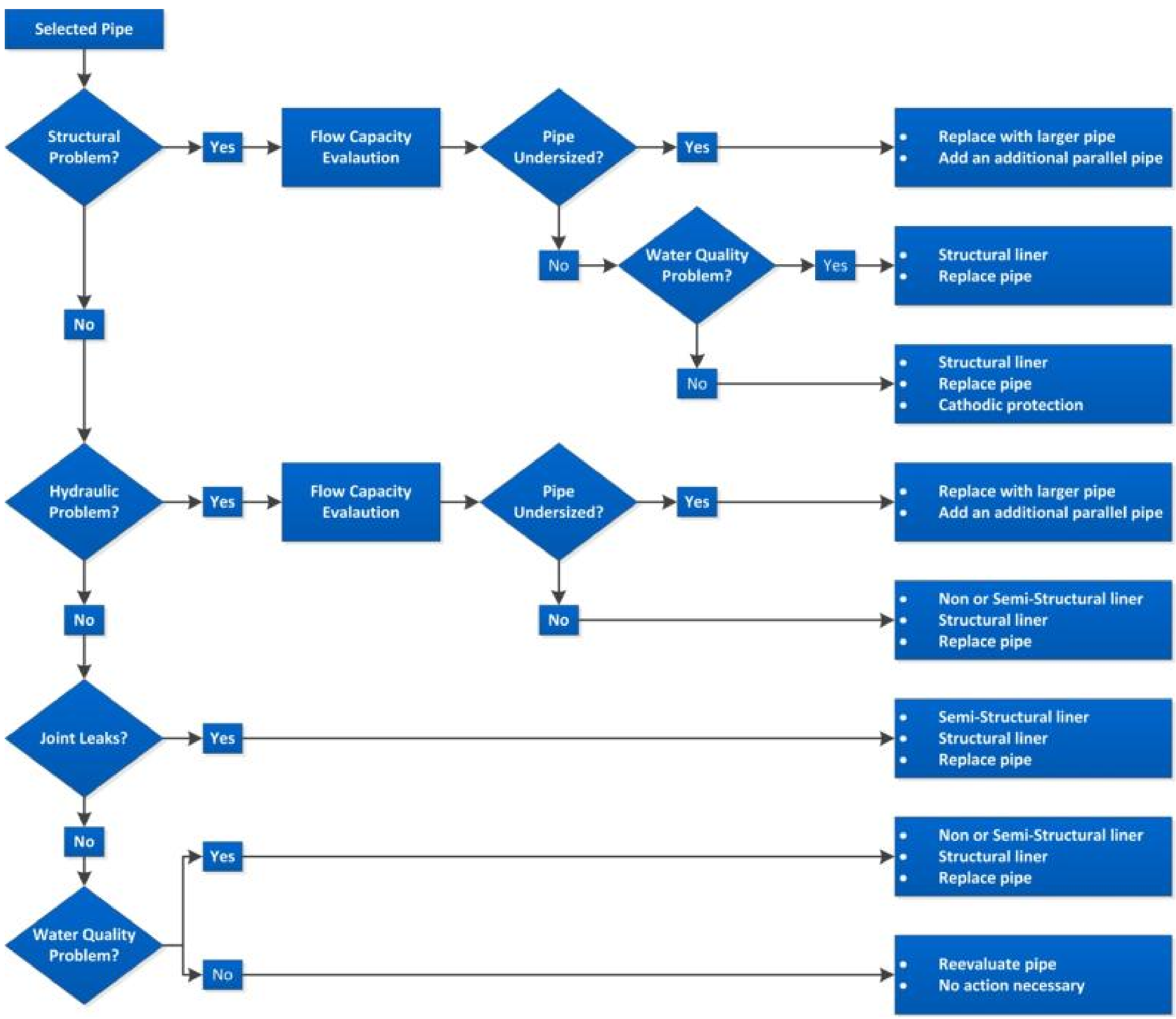

Figure 6-1. Technology Selection for Water Main Rehabilitation (Adapted from Deb et al., 2002)

6.1 Defining the Problem

Once the pipe to be renewed has been identified, the various problems or performance issues associated with the pipe are evaluated to determine the types of renewal options available. The AWWA M28 Manual, *Water Main Rehabilitation*, describes a number of possible solutions to problems ranging from corrosion to deposition, as described in the sub-sections below (AWWA, 2001b). These solutions range from simple periodic cleaning to replacement of the pipe using trenchless techniques. All of the solutions discussed in the manual make some use of the existing pipe, either as part of the rehabilitated system (renovation solutions) or as a convenient route for the installation of a new piping (replacement solutions). According to the AWWA M28 Manual, the categories of issues that should be evaluated include: structural, hydraulic capacity, external corrosion, joint leaks, and water quality.

6.1.1 Structural Problem. Any structural problems in the host pipe must be well defined in order to select and design an appropriate rehabilitation technology. The AWWA M28 Manual has established four classes of design: non-structural (Class I), semi-structural (Classes II and III), and fully-structural (Class IV). Class I liners only act as corrosion barriers. Lining systems that span holes and gaps in the host pipe, but require support from the host pipe to prevent collapse are considered semi-structural Class II liners. Semi-structural Class III liners also span holes, but they have sufficient thickness to resist bucking from external hydrostatic load or vacuum load. Class IV liners will carry the full internal pressure without support from the host pipe.

Condition assessment may be used to determine the degree of deterioration of the host pipe and if it is partially deteriorated (suitable for semi-structural Class II and III solutions) or fully deteriorated (suitable only for a Class IV structural solution). Therefore, the assessment of the condition of the water main and how it compares to the “as new” pipe condition plays an important role when selecting technologies for renewal. Inspection is also done after rehabilitation of the pipe has been carried out as part of the rehabilitation QC process.

A brief description of the available water main inspection technologies is provided in Table 6-1. More detailed information can be found in *Condition Assessment Technologies for Water Transmission and Distribution Systems* (EPA, 2011a) and Lillie et al. (2004). Effective inspection and condition assessment of water mains is generally difficult and may be extremely costly to carry out. Cost effective inspection methods to be used both before and after rehabilitation are a high priority research need in order to fill data gaps and improve the success of water main renewal efforts.

Table 6-1. Water Main Inspection Methods and Methodologies

Technology	Comments
Visual Inspection and Sounding	Used to assess the condition of liners and in PCCP to locate distress (potential wire breaks, etc.). Generally used for larger diameter man-entry pipes and visual inspection with CCTV used on small diameters.
Leak Noise Correlators	Leak detection from the surface using pipe features, but it fails to determine the leak type (i.e., joint or barrel). Generally not effective on large diameter pipes.
Acoustic Leak Detection	Sometimes limited due to pipeline geometry and presence of valves and fittings. Online that requires only a small diameter access point of 2 to 4 in.
Acoustic Emission Monitoring	Inserted under pressure to monitor PCCP for wire breaks. Fiber optic cable used for long-term monitoring or accelerometers for short-term.
Ultrasonic Inspection	Non-intrusive technique if applied from the exterior. Can detect the loss of wall due to erosion or corrosion but will not be very successful in pipes with heavy tuberculation. Also not reliable with cast iron pipe.
Seismic Pulse Echo	Technique requires dewatering and man-entry. Technique is not available for diameters below 54 in. and is essentially used for online monitoring.
Remote Field Technology	Requires limited cleaning prior to inspection. Remote field pigs can be inserted into live water mains, 4 to 12 in. Measures average wall thickness over an area.
Near Field (Broadband Electromagnetic)	If internal, requires limited cleaning and dewatering. Measures average wall thickness over an area (1 to 2 in. square) and evidence of graphitization. Hand scanning tool used externally without interruption of service.
Electromagnetic	Man-entry for 36 in. and above, robotics used for smaller diameters down to 24 in. Used to detect wire breaks in PCCP.
Magnetic Flux Leakage (MFL)	Mainly used where pipe is exposed or by digging pits. Requires cleaning of pipe exterior. Measures remaining wall. Oil and gas industry use MFL intelligent pigs to survey long transmission lines. This is not practical with water mains.
Laser Profiling	Laser light projected on pipe wall and used to measure internal diameter around circumference. Locate areas of loss of inner wall on mortar lined pipes. Good for proper sizing of liners. 2D and 3D profilers available.
Tracer Gas Injection	Tracking gas under roads and pavement surfaces becomes tough to analyze. Relatively low cost for leak detection.

6.1.2 Hydraulic Capacity. The availability of capacity and need for additional capacity can affect the selection of renewal technologies for water mains. If the existing pipe's capacity is insufficient, then the need for a larger size pipe will further limit the renewal options. The flow capacities of the original and renewed pipe can be estimated by the Hazen-Williams formula. Typically, new renewal liners are going to improve the flow properties such that a slight reduction in diameter is offset by the higher C-factor. If the pipe's capacity is adequate, trenchless replacement using sliplining or a structural liner are recommended options. These rehabilitation options will also rectify any previous joint leak or water quality problems.

One contributing factor to reduced hydraulic capacity is the buildup of debris and tuberculation inside the distribution system piping. The Hazen-Williams C-factor, and hence the flow in a pipeline, depends on the smoothness of the interior surface of the pipe. For a given velocity, increased internal surface roughness can lead to a reduction in overall pipeline efficiency. Field testing techniques allow distribution system operators to calculate Hazen-Williams C-factors for their systems. These data help in making informed decisions about which process to employ to restore hydraulic efficiency. Collecting data for the Hazen-Williams C-factor before and after employing any cleaning or pipe rehabilitation process is also a very useful way to gauge the impact of the system improvements.

The capacity of a pipe can be significantly reduced after it has been rehabilitated using some methods. Certain structural rehabilitation techniques have thicknesses larger than 1 in., which can reduce capacity.

There may be improvement in hydraulic performance due to the lower friction of the new surface, but in some cases the operating pressure of the pipe has to be increased. Also, as pipes reach the end of their service life; hydraulic modeling of the system can help to determine if additional capacity will be needed.

An interactive liner that does not leave an annulus between the liner and the host pipe reduces the potential for capacity reduction. Sliplining, which has an annulus, results in a greater loss of cross-sectional area although again the friction coefficient will typically be decreased. Close-fit liners result in moderate reductions in capacity and typically increase the Hazen-Williams C-factor to 145 or more (EPA, 2010b). The utility must determine what type of capacity loss is allowable.

Surface friction is very important for water mains as compared to gravity sewers since the smoothness of the surface becomes important to facilitate hydraulic flow. Many technologies, such as woven hose liners, provide a smooth coating that comes in direct contact with water. Lining pipes with polymers or cement mortar does two things: (1) it avoids metallic pipe material from coming in direct contact with water; and (2) it facilitates smooth hydraulic flow. It is typically recommended that lining the internal surface of mains, service lines, and plumbing with approved material be regularly done to avoid loss in hydraulic capacity.

A cost trade-off becomes a key in deciding whether pipe diameter has to be increased to improve hydraulic capacity. In these instances, a utility might opt for replacing the existing main even if rehabilitation measures can be achieved. Online replacement techniques such as pipe bursting or microtunneling could be used, thereby reducing the impact on pavements, the environment, and regular traffic (AWWA, 2001b).

6.1.3 External Corrosion. If external corrosion is the cause of the buried pipe deterioration, and there are no water quality problems and adequate capacity is available, then the addition of cathodic protection would be recommended if the remaining strength of the pipe is adequate for the working pressure, surge pressure, and external loads. If a considerable amount of the pipe wall has already graphitized, then cathodic protection may not be a good long-term investment. A proper condition assessment and understanding of the pipe's remaining strength should be done before embarking on cathodic protection as a solution to structural problems (AWWA, 2001b).

6.1.4 Joint Leaks. Over time with pipe movement and aging of elastomeric gaskets, joints may start to leak, resulting in loss of water and diminished pipe support due to eroded bedding materials. Liners can prevent these leaks by spanning gaps in joints. For joint leaks, a semi-structural liner capable of bridging joint gaps would be a solution worth considering. Other solutions include mechanical joint repair systems (AWWA, 2001b).

6.1.5 Water Quality. The quality of drinking water varies considerably, both from system to system and within a system, as a result of deterioration after water leaves the treatment plant and comes into contact with the interior of distribution system piping. Over time, changes in the water chemistry can cause problems throughout the distribution system, ultimately affecting the quality of water delivered to the end user. Water quality problems can primarily be addressed by cleaning and lining. The type of water conveyed might impact the decision to use either a cement mortar lining or a polymeric lining. The specific nature of distribution system water quality problems varies with water chemistry. However, the majority of problems fall into three categories: sedimentation, encrustation, and fouling (AWWA, 2001b).

6.1.5.1 Sedimentation. Sedimentation is the process whereby solids settle out of water moving at low velocity in a main, reducing interior cross section and capacity. Source water pipelines or pipelines carrying improperly treated water can be subject to deposits of sand, silt, or organic materials. In extreme cases, sedimentation can also contribute to hydraulic problems, particularly at low points in the pipe.

Even slight overtreatment of water can result in post-treatment precipitation within the distribution system of deposits containing alum, lime, or calcium carbonate. A utility may promote controlled precipitation to lay down a thin layer (eggshell coating) of calcium carbonate on the metallic pipeline interior. However, excessive or irregular deposits can easily occur, requiring cleaning of the distribution pipe (AWWA, 2001b).

6.1.5.2 Encrustation. Encrustation is a byproduct of corrosion (tubercules) mixed with mineral deposits such as iron, manganese, and carbonates. Before the 1960s, many iron pipes were installed without linings to protect the interior surfaces. These unlined pipes experience internal corrosion. As corrosion occurs, the interior of the pipe develops pits from which material is removed and tubercules where material is deposited. Additionally, corrosion can create red water complaints from end users. Corrosion can result from direct oxidation or electrolytic action, but fostered by aggressive water. Tuberculation may vary with water chemistry from very soft to very hard water. Encrustation can be removed by cleaning. Such removal of encrustations often increases a system's disinfectant residual. If the encrustation is removed and the pipe not lined with a corrosion barrier, the encrustation will return (AWWA, 2001b).

6.1.5.3 Fouling. Fouling represents a very significant problem, but one that is not always well understood. A fouling problem can develop with any type of pipe material. The condition is usually due to naturally occurring biological activity and results in buildup of an organic deposit on the interior of the pipe. Although this deposit is often soft and filamentous, it can severely affect water turbidity and cause taste and odor problems. Bacteriological activity from organisms, such as iron-fixing bacteria, can result in development of slimes and severe deposits in the pipe (AWWA, 2001b).

6.2 Capital Costs

Cost is typically the most important selection criteria utilities use to make renewal method selection decisions. If technologies are capable of meeting the needs of the utility, which is to provide quality service to its customers, then cost is the primary driver when selecting between multiple options. Capital cost estimates can vary from engineering order of magnitude estimates to contractor firm prices, the tightness of the estimate depending on the overall objective of the project, and the degree of project definition (Corbitt, 1990). Order of magnitude estimates are used in feasibility studies and provide guidance on basic decision making. Comparative estimates combine an order of magnitude estimate with the specific factors of a particular project and are developed for comparing alternative solutions to a particular problem (Corbitt, 1990). As the needed accuracy increases, the information required for developing the costs becomes more extensive.

Capital costs are both direct and indirect. Direct costs include equipment, labor, materials, and disposal costs. Indirect costs include services such as administrative and legal costs, engineering fees, and contractor profit and overhead. These latter costs are generally derived from cost indices. Among the more common indices used are the Bureau of Labor Statistics, Construction Cost Index, and the Engineering News Record Building Cost Index for the various regions of the country. EPA also has its own indices that are published by the Municipal Facilities Division. These indices are updated periodically by monitoring various components of costs, such as labor, material, etc., and comparing them with the costs of a base year.

During the data collection process, cost information was sought for each of the technologies described in the datasheets, but very little cost data were able to be collected from the vendors and manufacturers. However, Table 6-2 presents representative costs that can be used to estimate order of magnitude costs for water distribution pipeline rehabilitation and replacement methods (Selvakumar et al., 2002).

Table 6-2. Summary of Rehabilitation Method Order of Magnitude Costs

Method	Diameters (in.)	Generic Cost ($/in. diameter/ft)	Reference
Cement mortar lining	4 – 60	1 – 3	Gumerman et al., 1992
Sliplining	4 – 108	4 – 6	Gumerman et al., 1992
Close-fit pipe	2 – 42	4 – 6	Authors, 1999
Fold and form pipe	8 – 18	6	Jeyapalan, 1999
CIPP	6 – 54	6 – 14	Gumerman et al., 1992
Pipe bursting	4 – 36	7 – 9	Boyce and Bried, 1998
Epoxy lining (cost in $/ft)	4 – 12	9 – 15	Conroy et al., 1995
HDD	2 – 60	10 – 25	Boyce and Bried, 1998
Microtunneling	12 – 144	17 – 24	Boyce and Bried, 1998

The costs presented in Table 6-2 only address base installation costs of the various techniques for order of magnitude purposes. Separate items which would need to be considered in the total cost include: replacement of valves; fire hydrants; other contingent work; traffic control; utility interference; obstruction removal; bypass piping; and temporary service connections (Selvakumar et al., 2002).

Another study developed average costs for water main rehabilitation based on previous projects in central Ohio (Osthues et al., 2005). Although not broken down by method, the study reported average minor (non-structural) rehabilitation to be approximately $3.75/in. diameter/ft; and major (structural) rehabilitation to be approximately $6.50/in. diameter/ft.

Although some rehabilitation options are less expensive than replacement methods, some are inherently more risky. This additional risk can, in some cases, outweigh the benefits of rehabilitation technologies and potentially offset the cost savings. For example, some rehabilitation technologies will have shorter service lives than replacement methods and would require additional investments prior to the end of a replacement pipe's service life. Therefore, the full life-cycle cost of a given technology should be taken into account, along with the anticipated extension provided to the water main's remaining asset life.

6.3 Life-Cycle Costs

Life-cycle costing is an important consideration when selecting renewal alternatives. It is important that the selection of the appropriate renewal method be made using as many appropriate evaluation criteria as possible, and not based solely on economic considerations. For many investment decisions, the cost of investment can be compared with the anticipated return to determine the financial viability of the project. For a water utility, however, the decision is not purely economic as the public welfare, philosophical and policy criteria are also key components. Deb et al. (2002) suggests that the cost categories in any life-cycle cost model include capital costs (or installation costs, Section 6.2), O&M costs, and social costs. Other elements of the cost analysis include the time value of money, the cost of capital, and the life of the asset or planning period over which future costs or benefits are amortized. Given all this information, the most cost effective technology can then be selected using either net present value analysis or an equivalent uniform annual cost analysis. More information on how to conduct a life-cycle cost analysis for water mains can be found in Deb et al. (2002) and on social cost considerations in Matthews (2010).

6.4 Maintenance Requirements

Maintenance of the pipe pre- and post-renewal is equally important. Maintenance measures can be proactive and reactive. Routine and non-routine maintenance programs may incorporate new technologies to maintain rehabilitated sections. Such sections behave differently from existing infrastructure. After installation, these rehabilitated sections may be subject to increased costs to inspect their condition and to understand their behavior at joints with existing pipe materials.

Maintenance of lined pipes requires additional steps. The techniques needed for the repair of pipes with liners are not well understood by crews in charge of O&M in a water utility. Adding a new unfamiliar material and/or technology can be a factor in technology selection as it may be reluctantly received by utility crews. Therefore, the O&M requirements should be considered early in the technology selection process to understand the vendor recommendations. In addition, if hydrants or valves are replaced on such pipes, it becomes important to check the compatibility of appurtenances with the rehabilitated pipe. A good connection is imperative as is the chemistry between materials, adhesives, and other chemicals that are used in the process.

6.5 Bypass Piping System Requirements

For most water rehabilitation techniques, keeping the customers supplied with potable water is a major consideration. This is typically done using temporary pipe laid in gutters on each side of the street. The temporary pipes are generally 2 to 4 in. in diameter and are supplied from nearby fire hydrants as illustrated in Figure 6-2 (AWWA, 2001b). Under extraordinary circumstances, bypass pipes can range up to 12 in. in diameter and sometimes a tap or connection to an adjacent main is required.

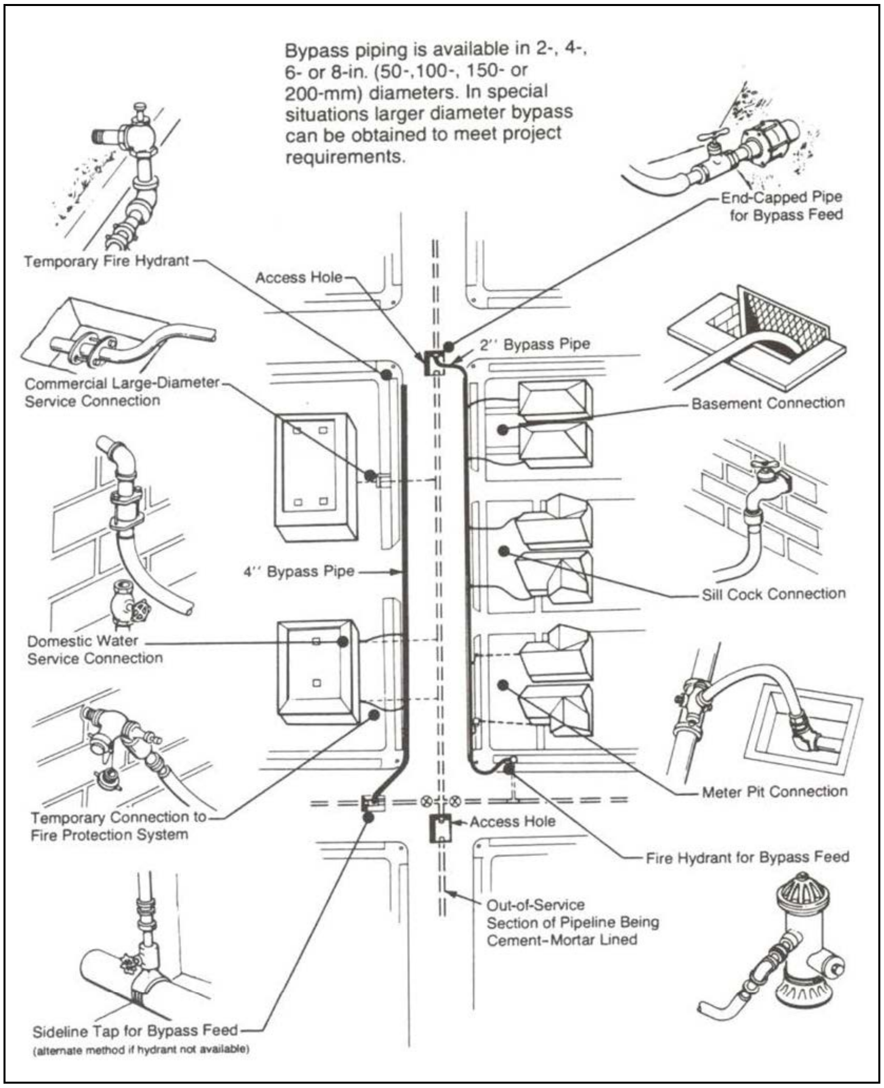

Figure 6-2. A Typical Layout of Bypass Piping

Processes and equipment used in water systems must provide assurance that the system is kept free of any contamination, and the system must be disinfected and tested for bacteria before return to service. Because invasive work on water systems will often involve time-consuming bacterial testing, bypass supply systems may be needed. This is true even if the in-pipe work takes only a few minutes. Short sections of hose are used to connect the bypass pipe to the services at the meter or directly to an exterior faucet. Where the bypass pipe crosses driveways, special rubber ramps or cold asphalt mix mounded over the pipe permit the passage of vehicles. Rehabilitation contractors often have crews that specialize in installation and removal of such systems, and the work can be a major project in itself. Another issue that must be taken into account is ensuring enough hydrants remain in service.

6.6 Disinfection Requirements

Any new or repaired water main must be thoroughly flushed, disinfected, and tested for bacteriological quality before it can be put into use. Flushing is primarily necessary to remove any mud or debris that was left in the pipe from the installation. One or more fire hydrants should be used to perform the flushing. A blow-off connection, if one has been installed, can also be used. The velocity in the pipe should be maintained long enough to allow two or three complete changes of water for proper flushing. If the pipeline is large or if the water plant capacity is not sufficient to supply the quantity of water required for flushing a new main, the pipe can be cleaned with pigs.

Chlorine compounds are the most common chemicals used to disinfect large pipes. Calcium hypochlorite and sodium hypochlorite solutions are generally used for smaller pipes. The chlorine solution is usually injected through a corporation stop at the point where the new mains connect to the existing system. Water utility personnel must ensure that excess chlorine does not flow back into the potable water supply. All high points on the main should be vented to make sure there are no air pockets that would prevent contact between the chlorinated water and portions of the pipe wall. These chlorination requirements should normally conform to the AWWA Standard C651 for disinfecting water mains, unless there are other overriding local, federal or State requirements (AWWA, 2005). In general, the rate of application should result in a uniform free chlorination of at least 25 mg/L at the end of the section being treated. Methods of rapid chlorination are discussed in Rockaway and Ball (2007). Calculations on chlorine and water needed for proper disinfection involve determining:

- Capacity of the pipeline
- Desired chlorine dosage
- Concentration of the chlorine solution
- Pumping rate of the chlorine solution pump
- Rate at which water is being admitted to the pipeline

Materials in some rehabilitation technologies may be sensitive to contact with chlorine. If this is the case, the manufacturer will recommend a maximum dosage of free chlorine during the disinfection process and a minimum flushing volume (e.g., duration and flow rate) prior to return to service.

6.7 NSF/ANSI 61 Requirements

Federal and State governments encouraged the development of a consensus standard that could filter out products not suitable for use in the conveyance of potable water. NSF in Ann Arbor, Michigan spearheaded the development of NSF/ANSI Standard 61, which covers products in direct contact with potable water. Pipe and joining materials must undergo a searching evaluation of formulation, toxicology, and product use and a rigorous testing program that includes water immersion under controlled conditions and testing for migration of contaminants, odor, and taste. The testing protocol can take up to 6 months and the cost to the supplier interested in getting an NSF listing against Standard 61 will reach tens of thousands of dollars.

NSF/ANSI Standard 61 *Drinking Water System Components - Health Effects* establishes minimum health and safety requirements for chemical contaminants and impurities that may be indirectly imparted to drinking water and covers many items including, but not limited to:

- Plastic materials, plastic and metal pipe and related products (fittings, tanks, etc.)
- Protective materials (coatings, linings, cement, cement admixtures, etc.)
- Joining and sealing materials (adhesives, lubricants, elastomers, etc.)
- Process media (carbon, sand, ion exchange resin, etc.)
- Treatment/transmission/distribution devices (valves, pumps, filters, chlorinators, etc.)
- End-point devices (faucets, end-point control valves, etc.)

NSF/ANSI Standard 61 does not address all aspects of product use. The standard is limited to addressing potential health effects except where specific application and performance standards are referenced. Some items not addressed by this standard are performance (such as long term pressure), microbiological growth support, and electrical safety. Other standards may address these aspects of products. NSF/ANSI Standard 61 is divided into nine sections and four annexes that can be found at www.nsf.org.

In the U.S., it is virtually impossible to supply a pipe, liner, or sealing mechanism (i.e., gasket) for a potable water application that is not NSF/ANSI Standard 61 listed. Products that are made from organic compounds, such as polyester resins and their catalyst systems, especially if they incorporate styrene, have particular difficulties in this regard.

When the chemistry is brought to the field and curing is done under non-laboratory or less controllable conditions, it becomes even more difficult to get an NSF/ANSI Standard 61 listing. Some CIPP liners have achieved acceptance by using epoxy resins, which are more costly than polyester resins, or by incorporating a PE or PU coating that separates the resin body from the potable water stream.

6.8 Accessibility Issues

Access to the pipe, leakage, or the segment that is to be renewed is a critical factor in choosing the technology. Certain pipes are buried deep below cable and electricity lines, while some water mains are laid close to the surface. In each of these cases, the cost and application of technologies will be different. Renewal of buried lines requires additional steps at the job site. Obtaining permissions and regulatory approval for digging large areas, pavements, and private properties can be a complex process. In such cases, it would be very helpful for the utility to use techniques and methods that give flexibility in accessing the pipe at locations that are removed from the point of replacement. Improvising access to pipes can become a factor in pipe renewal.

Access to pipes for rehabilitation or replacement is not the only concern. Excavation to make service line reconnections is also a key issue. Mains that have risers, bends, valves, and hydrants at fairly short distances can affect the total project cost. The cost of making such excavations could make open cut replacement an equally feasible option for the utility. Service line reinstatement also increases the cost of restoration work, fees, and the number of permits required to do the job.

6.9 Asset Criticality

Water distribution systems can be considered critical infrastructure and the capability to operate at normal operating requirements is of prime importance. Customers expect access to drinking water on a 24 hour a day basis. If they are notified of interruptions to supply for maintenance works they expect the period to be minimized and adhered to. Therefore, undertaking construction or renewal jobs on an active pipeline network has to be well managed. Scheduling machinery, material, and manpower 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 are necessary for completion of the work within the designated time. Curing time of a renewal technique is important for the utility. If renewal is taking place in a network that has limited or no redundancy, then the renewal of the pipeline has to be done in a short period of time. Certain mains may be the sole distribution mains to a town or a cluster. In that case, the utility may consider replacing the pipe. Conservative policies can sometimes be the right approach with new technologies, especially because water transport is critical to life and day-to-day activities.

7.0: DESIGN AND QA/QC REQUIREMENTS

This section presents existing design concepts and QA/QC requirements that pertain to renewal of water mains. Multiple design manuals and regulatory specifications exist in the U.S. water utility market. AWWA, ANSI, ASTM, ASME standards are primarily used and BS or ISO standards may be referenced where relevant. Material standard specifications and installation and testing manuals are also developed by trade associations and industry research organizations such as PPI, DIPRA, or Uni-bell. Some standards, such as ASTM F-1216, incorporate design procedures, while others are used to regulate product acceptance, installation methodology, in situ evaluation, and acceptance procedures. This section also covers the QA/QC aspects of renewal by looking at short-term factory and field requirements, as well as long-term qualification requirements.

7.1 System Design

Water infrastructure is a system from which continuous performance is demanded. Since some intervention is inevitable for maintenance during the service life of the system, it is desirable to incorporate either redundancy or reticulation into the design. This enables supply to be maintained by alternative routes through the system when interventions for maintenance or rehabilitation take place. However, such redundancy is rarely extensive within water distribution networks.

7.2 Renewal Design

Water main renewal design based on the AWWA M28 Manual *Rehabilitation of Water Mains* and can be categorized into four classes of design for rehabilitation, ranging from non-structural to fully structural (AWWA, 2001a). The four classes are described below:

<u>Non-Structural</u>

- Class I – provides no structural support, only acts as an internal corrosion barrier and improves water quality.

<u>Semi-Structural</u>

- Class II – resists external hydrostatic pressure from groundwater, bridges over holes and gaps in the host pipe, but not able to carry the full internal pressure independently, adheres to the interior surface of the host pipe.
- Class III – same as Class II except has sufficient thickness to resist bucking from external hydrostatic load or vacuum load and is not dependent on adherence to the host pipe wall.

<u>Full Structural</u>

- Class IV – independently capable of resisting external hydrostatic pressure from groundwater, and can handle the full internal pressure without support from the host pipe.

Water mains must have adequate strength to sustain external loads and internal pressure. Structural capacity can be expressed in terms of an internal pressure rating, its D load (load capacity per unit length), tensile strength, and flexural strength. External load is the pressure exerted on the buried pipe. This pressure is a result of the backfill, groundwater pressure, and traffic loads. The pipe must be able to resist loads imposed during installation (such as jacking forces when installed by microtunneling, or pulling forces if installed by HDD). Additionally, the pipe must be able to accommodate a reasonable amount of external damage from impact during transportation and temporary storage at the worksite. Pipe characteristics are frequently defined as follows:

- **Internal pressure** is the hydrostatic pressure within the pipe. Normal water pressure depends on local conditions and requirements. Surge, also known as water hammer, is a momentary increase in pressure. It may be caused by a sudden change in velocity or direction of water flow, the rapid opening or closing of valves or hydrants, or the sudden starting or stopping of pumps. Water hammer may result in shock, or transient pressure several times normal pressure. It can cause extensive damage, such as a ruptured pipe and damaged fittings. One of the more significant advantages that thermoplastic pipes provide is that surge pressures are lower than those associated with higher modulus materials of similar dimensions such as DI pipe. These lower pressure surge responses enable PVC and PE pipe systems to provide conservative factors of safety with regard to handling dramatic transient velocity changes. PVC and PE pipes are able to withstand short duration pressure surges, which are of the order of three times their pressure ratings. This helps to prevent failures resulting from power outages and system interruptions.

- **Tensile strength** is a measure of the resistance a material has to longitudinal stress, the applied force per unit area, or lengthwise pull before that material fails. Tensile strain is the increase in length of a specimen subject to tensile stress. Tensile modulus is the ratio of tensile stress to tensile strain. Metallic materials are characterized by high strength and relatively low strain at failure and have a relatively high modulus. Plastic materials have lower strength and greater strain at failure and exhibit lower modulus. Cementitious materials have relatively low tensile strength and strain at failure due to the presence of microcracks which causes brittle failure.

- **Flexural strength**, strain, and modulus are the corresponding values measured in bending without breaking. Materials may also exhibit characteristic yield that is a significant increase in strain without a corresponding increase in stress. After the yield point, materials tend to behave plastically until failure occurs. Ductility, the ability to absorb energy on impact, is often measured as the area under the stress-strain curve. Plastic materials exhibit a large area under the curve whereas brittle materials like concrete have low area under the stress-strain curve.

- **Pipe shear** or beam failure may occur due to ground movement, uneven bedding, or excessive traffic loading. Smaller diameter pipes, particularly brittle materials like CI or AC, may be prone to shear failure. Failure may be initiated at a defect in the pipe wall such as a corrosion pit.

7.2.1 Pressure and Stiffness Rating. Pipes and pipe linings should be carefully selected to ensure that the pressure and stiffness rating of the pipe or lining are sufficient to sustain the internal pressure and external loads indicated in the design. Pressure and stiffness ratings for pipes are usually specified by the manufacturer and ratings can be calculated for linings using formulas and tables found in current AWWA and ASTM standards. Distribution system piping should have a pressure rating of 2.5 to 4 times the normal operating pressure. When a section of pipe is being replaced, the new piece must have a pressure rating equal to or greater than that of the piece being replaced.

Specific minimum requirements or standards for all types of pipe have been established and published by AWWA to ensure adequate and consistent quality of water mains. Other agencies that have established standards for pipe include federal and state governments and organization such as Great Lakes-Upper Mississippi River Board (GLUMRB, 2007) of State Public Health Environmental Managers, Underwriter Laboratories (UL), NSF International, ASTM, and the manufacturers. These standards, which cover methods for design, manufacture, suitability for contact with potable water, and installation in detail may be used for specifying pipe or liners for specific applications.

7.2.2 Durability. Durability is the degree to which a pipe will provide satisfactory and economical service under normal conditions of use. It implies long life, toughness, and the ability to maintain tight joints with little or no maintenance throughout the service life of the pipe. The expected durability for pipe and liners is generally at least 50 years. Some standard specifications include tests intended to demonstrate durability. Pipe and linings may be subjected to internal pressure or external loading for 10,000 hours in wet or chemically aggressive conditions to determine creep rupture or strain corrosion performance as a demonstration of resistance to service conditions.

7.2.3 Corrosion Resistance. Consideration must be given to pipe's resistance to both internal and external corrosion. Metallic pipes (e.g., steel or DI) may be corroded by the water they carry and may be coated internally with cement mortar, calcite, phosphate, or epoxy. Metallic pipe may be prone to attack from corrosive soils unless special coatings are applied to the pipe exterior as well. The pipe may be protected by a plastic wrap or provided with special cathodic protection.

7.2.4 Smoothness of Inner Surface. Smooth pipe walls ensure maximum flow capacity for water pipe. The roughness coefficient or C-factor of a pipe is a measure of the pipe wall roughness that retards flow because of friction. A high C-factor denotes a smooth pipe. When a pipe is renewed by lining, there may be a loss of cross-sectional area and a smooth lining may compensate for this loss and restore original flow capacity.

7.2.5 Ease of Tapping and Repair. The pipe or liner selected should be easy to repair and tap for service connections. It should support the service connection firmly without cracking, breaking, or leaking. The tapping connection should be easily replaceable or at least repairable. Where a pipe is renewed by lining, remote reinstatement of the service connection is preferred to minimize disruption, although these techniques are relatively new. However, reinstatement of the service connection by an open cut method may be acceptable where it is also necessary to renew the service pipe.

7.2.6 Water Quality Maintenance. The pipe or liner must be able to maintain the quality of the water distributed by the system. It should not add taste, color, odor, chemicals, or other undesirable qualities to the water. Pipes or liners and all fittings used for renewal must be suitable for contact with potable water. Inorganic coatings such as factory applied CML and site applied CML have been available since the 1930s. The in situ applied coatings, such as calcite developed by McCauley in 1958 or zinc orthophosphate, may be effective in preventing corrosion for some years and have little impact on water quality. Polymer coatings such as epoxy and polyurethane have been developed more recently. Concerns have been raised that these coatings may release chemicals into the water and only coatings having ANSI/NSF 61 certification should be used in water mains. In the U.S., ANSI/NSF 61 certification is the principal water quality determination and acceptance criterion. The certification procedure described earlier involves identification and screening of all chemicals used in manufacture, processing and installation, process and procedure audit, and extensive testing for specific potentially harmful substances.

7.3 Product Standards

Various ASTM standards are available in the market for product design and testing. Typically, vendors perform the testing according to the ASTM standards (Table 7-1) to provide assurance for their product.

Table 7-1. Key Parameters for Renewal Design

Parameter	ASTM	Definition and Testing Procedure
Abrasion Resistance	D-4060 (2010a)	Tests a liner's ability to withstand the constant flow of liquid and particulates. The Taber abrasion test involves rotating a sample under a specific weight against a grinding wheel for a defined number of revolutions. The samples are evaluated by measuring the weight of the sample before and after the test. The resulting weight loss indicates the ability of the liner to resist abrasion.
Adhesion	D-4541 (2009d)	Adhesion of a lining system to the substrate is considered a good indicator of the liner's ability to resist corrosion. Generally, the better the adhesion, the longer the liner will last. The adhesion test measures the pull-off strength of a lining system by determining the perpendicular force the material will withstand before releasing from the surface or pulling apart cohesively.
Cathodic disbondment and Salt spray resistance	G-95 (2007) and B-117 (2009e)	Cathodic disbondment and salt spray resistance both measure the undercutting resistance of a lining system. Cathodic methods are found to be more consistent in their ability to predict actual lining performance. Liners with better cathodic disbondment resistance have better corrosion resistance and greater longevity.
Chemical Resistance	D-714 (2009f)	Chemical resistance test methods monitor the effect of a chemical solution when the liner is applied to a metal coupon. The evaluation is completed by observing the sample for blisters and general appearance after immersion in test solutions. Accelerated testing using higher concentrations can be performed to provide long-term service life estimates.
Flexibility	D-522 (2008e)	Flexibility is an indicator of the liner's ability to withstand cracking, disbonding, or other mechanical damage that can occur from handling and bending of the pipe in the field and in the factory. Lined steel samples are bent to determine their ability to withstand bending before liner failure.
Impact Resistance	D-2794 (2004)	The impact resistance test represents the liner's ability to withstand damage due to impact with another object. The test method consists of a fixed weight being dropped from varying heights to produce a point impact on the liner surface. The results are measured in terms of energy required to rupture the liner and create a holiday or discontinuity.
Water Absorption	D-570 (2010b)	A measure of the ability of a waterborne chemical or gas to penetrate the liner to the substrate. Samples are immersed in potable water at 50°C for 48 hours and the weight of the samples before and after immersion in water are noted. Results are noted in percentage of weight change. The lower the resulting number, the better the liner is at resisting blisters and disbondment.

7.4 Installation Standards

Installation standards vary for different rehabilitation techniques. The AWWA M28 manual provides a comprehensive list of installation standards (AWWA, 2001b). Vendor and industry organization approved standards and recommended practices are also available. Many of the pipe and liner products used for water main renewal are flexible pipes where the performance of the installed pipe or liner is heavily dependent on support from the pipe bedding or surrounding pipe. It is important that the manufacturer's recommendations are followed during the installation process so that the pipe or liner is able to mobilize the surrounding support in service. Technology specific installation standards are summarized in the following sections.

7.4.1 Cement Mortar Lining. CML is not designed to replace the host pipe, but to prevent further structural weakening by preventing corrosion of the pipe. CML has been used in the U.S. since the mid-1930s and its use is widespread throughout the world (AWWA, 2001b). It relies on the integrity of a cement mortar layer to provide a protective barrier and the alkalinity of the mortar to inhibit corrosion. AWWA C602-06, *Standard for Cement Mortar Lining of Water Pipelines in Place – 4 in. (100 mm) and Larger*, provides details of process monitoring and pipeline acceptance testing (AWWA, 2006).

7.4.2 Polymer Spray Linings. In situ spray lining of water pipelines with epoxy resin was developed in the UK in the late 1970s (AWWA, 2001b). Epoxy spray lining was adopted by many UK water companies in the 1990s and first approved in the U.S. to ANSI/NSF 61 in 1995. Recently, polyurethane spray lining, which offers a more rapid cure and the potential to deliver high build linings, has displaced epoxy from the UK marketplace and is entering the U.S. market. Polyurea spray linings are also being introduced in the U.S. AWWA C620-07, *Standard for Spray-Applied In-Place Epoxy Lining of Water Pipelines, 3 in. (75 mm) and Larger*, provides details of process monitoring and pipeline acceptance testing (AWWA, 2007c). Water Research Center (WRc) publications IGN 4-02-02, *Code of Practice: In Situ Resin Lining of Water Main* (WRc, 2007) and IGN 4-02-01, *Operational Requirements: In Situ Resin Lining of Water Main* (WRc, 2010) provide additional insight into UK experience in the application of polymer spray lining of water mains.

7.4.3 Sliplining. For sliplining, the insertion pipe should be sized so that its OD is typically 3 to 4 in. (75 to 100 mm) smaller than the inside diameter of the host pipe to allow for smoother insertion. Possible obstructions at the pipe joints and taps, and the normal friction created during the insertion process dictate a conservative approach to liner pipe sizing. Pipe manufacturers typically recommend sizing of available liners. Most pipe sizes are standard iron pipe size, but special diameters are also available for sliplining. The operation procedures for sliplining are discussed in AWWA M28 (AWWA, 2001b).

7.4.4 Close-Fit Lining: Symmetrical Reduction. Close-fit lining by symmetrical reduction may be achieved with a tension based or compression based process. A liner pipe with an OD close to inside diameter of the host pipe is pulled through a die or pushed or driven through rollers to achieve the required symmetrical reduction. The reduced diameter pipe is pulled into place and reverted to size to form a close-fitting liner by application of internal pressure. Close-fit liners may perform as semi-structural or fully structural liners (AWWA Class III or IV) depending on the installed thickness achieved with the reduction process. The operation procedures for close-fit lining are discussed in AWWA M28 (AWWA, 2001b).

7.4.5 Close Fit Lining: Fold and Form. Close-fit lining by the fold and form process involves the reduction of the outside diameter of a liner pipe selected to fit tightly within the pipe to be lined. The selected pipe must be smaller than the pipe to be lined so that when reverted, the liner pipe is fully circular and not prone to buckling failure. The liner is reverted by application of internal pressure. The forces required to fold thicker walled liner pipes may be substantial and many fold and form systems are employed as semi-structural pipes (AWWA Class III). The operation procedures for fold and form lining are discussed in AWWA M28 (AWWA, 2001b). Installation standards for fold and form with PVC materials are included ASTM F-1867 (ASTM, 2006b) and for PE materials in ASTM F-2719 (ASTM, 2009g).

7.4.6 Cured-in-Place-Pipe. The tube may be manufactured from polyester felt, reinforcing fiber fabric, or fiber reinforced felt to suit specific host pipe dimensions. The liner is impregnated with an appropriate resin either at the work site or in the factory. The requirements of ANSI/NSF 61 determine the type of resin or resin and coating employed. The resin-impregnated liner may be cured at ambient or elevated temperature using steam or hot water or by exposure to UV light. The installation, curing, and cooling recommendations of the system provider should be implemented to ensure adequate cure. CIPP liners may be semi-structural or fully structural (AWWA Class III or IV). ASTM F-1216 includes calculations for pressure capability for hole and gap spanning and fully structural liners (ASTM, 2009a). Other CIPP installation standards include ASTM F-1743 (ASTM, 2008c) and ASTM F-2019 (ASTM, 2009h).

7.4.7 Woven Hose Lining. Woven hose linings generally provide a semi-structural (AWWA Class II) capability at typical operating pressures and are used for severe internal corrosion, pinhole leaks, or faulty joints. The installed liner is very thin and its high 'C' value and joint-free construction may allow flow rates identical to original pipe. Some variants of the woven hose liner, which incorporate additional impregnated felt layers to impart stiffness, can also be considered as semi-structural self supporting Class III liners when cured, reducing their dependence on the condition of the host pipe. Design considerations for Class II and III liners include hole and gap spanning in accordance with ASTM F-1216 and an additional determination of resistance to buckling for Class III liners when empty and subject to external hydrostatic load and internal vacuum (ASTM, 2009a).

7.5 QA/QC Requirements

QA/QC procedures are required and specified in many cases by the utility owners and basic requirements are included in the product and process specifications developed by AWWA, ASTM, and vendor organizations. Assurance in the form of test certificates can be provided by the manufacturer or by the licensed seller of the products. The contractor in most cases provides a level of process QC, which may be supervised by third party consultants and testing agencies. Technology specific QA/QC practices are covered in details in the EPA report, *Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains* (EPA, 2011b).

7.5.1 Short-Term Quality Monitoring. To take full advantage of the estimated design life of the various rehabilitation technologies, it is important that the installer follows the manufacturer's or system provider's recommendations and implements proper installation procedures, and that the finished installation quality is confirmed by good QA/QC practices. Qualification (i.e., proof of design) testing is typically performed on the materials and the related installation process to define applicability of a particular technology. The installation process is given control limits by the technology system manufacturer or the standard specifications of relevant agencies that allows the installer to demonstrate the finished quality of the installation during the execution of the work and prior to acceptance testing by the owner. QA and acceptance testing confirms that the installation is consistent with the product that was pre-qualified in the design phase and that it should meet its design performance expectations.

Short-term quality monitoring activities include checks of raw materials for lining, testing of materials applied in the field to ensure design parameters are met, and pressure and hydraulic testing of the system post-installation to ensure system requirements are met. Specific monitoring activities for the rehabilitation technologies are listed in Table 7-2. Detailed checklists for technology specific QA/QC practices can be found in the EPA report, *Quality Assurance and Quality Control Practices for Rehabilitation of Sewer and Water Mains* (EPA, 2011b).

Table 7-2. Short-Term QA/QC Standards

Technology	Standard	Comment
CML	AWWA C602 (2006)	Includes checks on raw materials, cement, sand, and water.
Polymer spray liners	AWWA C620 (2007c)	Includes checks on raw materials and approvals.
Fold and form liners	ASTM F-1871 (2002)	Includes evaluation and testing for fold and form PVC.
Close-fit PE liners	ASTM F-2718 (2009i)	Includes evaluation and testing for close-fit PE materials.
CIPP	ASTM D-5813 (2008f)	Includes evaluation and testing for CIPP materials.

QA is the responsibility of the system owner, the designated project engineer, and the authorized quality manager or agency. Whether utilizing prescriptive specifications or performance specifications, it is important that communication with the installer convey what QA testing will be performed, and that the contract documents establish these requirements as mandatory and specify such remedial measures as may be necessary. Pipeline construction and renovation projects often have adequate specifications for QA testing, but implementation and supervision are important as well. Samples of the finished installation need to be taken, placed in safe custody, and properly tested by qualified third-party laboratories to confirm that the minimum mechanical properties have been achieved. It is generally preferable that the relationship with the testing laboratory providing the results of the testing undertaken be between the owner and the laboratory, not the laboratory and the contractor. Contractually, there should be a list of known problems that can arise and a specified remedy prescribed that is clear before the work begins.

7.5.2 Long-Term Quality Monitoring. Any long-term performance testing requirements for products to be used for water main rehabilitation are specific to the type of materials in the product as most products or rehabilitation processes designed for renewal or replacement of deteriorated water mains are relatively new. Aside from CML, there is relatively little information available on the long-term performance of these new materials. QC procedures for the various technologies discussed herein are typically given to the installation contractor by the system manufacturer. To further reinforce a system's commitment to having a quality installation, the manufacturers will develop an ASTM installation standard for their system. The following sections examine some of the requirements for PVC, PE, and CIPP products.

7.5.2.1 PVC Long-Term QA/QC Requirements. PVC pipe meeting AWWA C900 (AWWA, 2007b) or C905 (AWWA, 2010), or ASTM D-2241 (ASTM, 2009b) *Standard Specification for Polyvinyl Chloride (PVC) Pressure-Rated Pipe (SDR Series)* is subjected to long-term pressure regression testing to establish a hydrostatic design stress (HDS) for the pipe. Pipes are tested in accordance with ASTM D-1598 (ASTM, 2009j) and the results analyzed in accordance with ASTM D-2837 (ASTM, 2008g). A HDS or hydrostatic design basis (HDB) is determined, which is the maximum tensile stress the material is capable of withstanding continuously with a high degree of certainty that failure of the pipe will not occur. Fusible PVC and expandable PVC are made from standard C900 or C905 stock, so these are qualified.

7.5.2.2 PE Long-Term QA/QC Requirements. PE pipe meeting AWWA C901 (AWWA, 2008) or C906 (AWWA, 2007d) or ASTM D-3035 (ASTM, 2008h) is similar to PVC in that these products are also subjected to long-term pressure regression testing. These tests establish a basis for the long-term pressure rating of the products. There are no other long-term tests for standard PE pipe. PE used for deformed liners under ASTM F-1533 is to be made from materials that have a PPI HDB of either 1,600 psi for PE 3408 or 1,250 psi for PE 2406 (ASTM, 2009k). However, there is no requirement for the reformed PE liner to demonstrate that it has a similar HDB rating.

7.5.2.3 CIPP Long-Term QA/QC Requirements. ASTM D-5813 includes a long-term qualification test for chemical resistance, which includes two requirements (ASTM, 2008f). The first is that the CIPP specimens retain 80% of their flexural modulus of elasticity after one-year exposure to six chemical solutions. The other chemical resistance requirement is the strain corrosion test requirement of ASTM D-3681, developed for fiberglass pipes used in gravity sewers (ASTM, 2006c). Neither of these long-term requirements is particularly meaningful for a CIPP liner in a water main application. Unfortunately, there is currently no long-term pressure regression testing requirement for CIPP liners used in pressurized water mains, similar to that for PVC and PE products.

8.0: OPERATION AND MAINTENANCE

O&M of water networks encompasses many activities that can be affected by rehabilitation. The impact of O&M on water distribution networks after rehabilitation is widely unknown mainly because of the young age of water rehabilitation techniques. However, there are essential elements to consider:

- Can the rehabilitated pipe be readily located?
- Can the rehabilitated pipe be controlled (i.e., shutdown) for making future repairs?
- Can future defects (e.g., leaks) be readily identified and pinpointed?
- Can anticipated future connections and controls be installed?

The ability of a utility's repair crews to skillfully carry out emergency repairs on rehabilitated water mains is another important consideration. In addition, proper cleaning is essential both prior to rehabilitation activities and during routine operations to improve the capacity and hydraulic performance of water mains. This section also reviews best practices for O&M that can be effective in either prolonging the life of a water main or allowing a utility to monitor real-time performance so action can be taken as needed to repair, rehabilitate, or replace the water main before a catastrophic failure occurs. These methods include cathodic protection, corrosion monitoring, water audits, and leak detection.

8.1 Maintenance and Emergency Repair of Rehabilitation Systems

Maintenance departments at utilities have set procedures for emergency repairs of water mains. These are dependent on material, type of emergency (break, leak, joint leak, etc.), and location. A rehabilitated main effectively adds to the range of material that must be potentially repaired in an emergency. There are no set procedures for repair of rehabilitated (i.e., lined) water mains. This is an area of concern for utilities and certainly makes them reluctant to line their mains because they do not know how to deal with them when emergency repair becomes necessary. This further influences the choice of replacement over rehabilitation. The onus is on the suppliers of lining technologies to develop repair procedures for their products in water main applications and to train utilities in their application. Procedures that require the vendors' personnel to attend and undertake specialized work will not be adequate in emergency situations where swift action is necessary.

8.2 Cleaning Methods

The selection and use of appropriate cleaning methods both before and after rehabilitation can be an important factor in the success or failure of a water main renewal effort. For example, there is experience that high pressure water jetting can cause damage to lining systems. Similarly, drag scraping of water mains may damage linings and/or corporation stops prior to rehabilitation, which makes service reconnection very challenging.

Cleaning is primarily undertaken to remove tuberculation and corrosion byproducts, which lead to reduction in diameter of the host pipe and cause taste, color, and turbidity problems in the delivered water. More rigorous cleaning may be required for detailed pipe surface and pipe wall inspections to assess the host pipe condition. Prior to rehabilitation activities, rigorous cleaning will remove corrosion products and expose bare metal, restoring the original diameter and providing a key for bonded linings or an enhanced mechanical fit. Rigorous cleaning may also reduce the residual strength of the host pipe and therefore could influence the choice of rehabilitation method.

Various cleaning methods are summarized in Table 8-1. Some are commonly used by water utilities, while others are patented technologies used in tandem with the rehabilitation technology by a certain licensed operator. Descriptions are provided below of water jetting, pipeline pigs, drag scrapers, and power borers that are commonly used in the water industry. More detailed information on these cleaning methods can be found in Ellison (2003).

Table 8-1. Summary of Cleaning Methods Available to a Water Utility

Method	Summary
Flushing	Involves isolating sections of a main and allowing water to flow until the main flows clear.
Drag scraping	Mechanical scrapers are pulled through the pipe with a winch to remove hard encrustations.
Hydraulic jets	High-pressure water jets are used to dislodge and remove encrustations from pipe surfaces.
Electric scrapers	Rotating scrapers on a cart controlled by an operator for use in larger diameter pipe.
Rack feed boring	Steel rods simultaneously rotate and are pushed through the main by an operator.
Fluid propelled devices	Requires water pressure to move though the pipe and requires chemicals to remove hard encrustations. Readily available and commonly used by utilities.
Chemical cleaning	Solutions of acid can be used to dissolve mineral deposits within the pipes. Various acids are used with additives that do not harm rubber gaskets or valve seats.
Air cleaning	Air at high pressure is forced through smaller diameter sections to remove scales and deposits after draining the water.
Abrasive particle cleaning	Flint rock to steel shot or grit specified particles are air blown at high pressures. Such cleaning is restricted to straight runs of a pipe and needs a particle collection system.

8.2.1 Water Jetting. High volume, low pressure water jetting is commonly used for pipe cleaning prior to inspection and prior to non-structural rehabilitation such as CML and polymer spray lining. Low volume, high pressure water jetting may be used where access to water is restricted or where water disposal may be problematic. High pressure jetting may also be used to clean stubborn deposits, but may exacerbate local corrosion damage or impact polymeric pipes. Jetting is particularly useful for removal of light corrosion products rich in iron and manganese, which gives rise to water quality problems. Typical jetting pressures range from 2,000 psi to 20,000 psi with flow rates from 2 to 80 gpm.

8.2.2 Pipeline Pigs. Utility pipeline pigs are usually made from a flexible solid or foamed plastic fitted with solid plastic ribs, abrasive strips, or components such as carbide studs and wire brush heads assembled on a mandrel tube. Pigs are propelled down water mains by pressure and can be propelled several miles. Cleaning is accomplished by the frictional drag, and abrasive and flexible characteristics of the foam pig, which removes foreign objects and leaves the metallic or plastic surfaces smooth and free from debris and loosely adherent detritus and corrosion products. When water pressure is applied for propulsion, a certain amount of water bypass (about 10%) helps to keep loose debris suspended out in front of the foam pig. Cleaning of deteriorating mains may require a series of swabs and foam pigs applied in progressively larger diameters until the pipe is restored to its original diameter.

8.2.3 Drag Scrapers. A metal cleaning scraper consists of a steel frame shaped like a piston. Specially tempered steel blades are attached around the scraper at various angles to create a scraping and brushing action (Figure 8-1). The cleaner is pulled through the main by winch via a steel tension cable while water flows through the main under pressure to carry away debris. Cleaning is often accomplished with a single pass in a continuous operation, however, interior pipe conditions may require more passes.

Figure 8-1. Winch Cable with Drag Scrapers Attached

The length of pipe that can be cleaned hydraulically in one operation is limited by the availability, volume, and pressure of water and a proper means of disposing of water and sediments. An opening must be provided at each end of the section to be cleaned for entry and exit of the scraping tool. The volume of water required to hydraulically clean a pipe will depend on how dirty the water is. Sufficient water must be added behind the cleaner to fill the pipe as it moves ahead. The water that passes the cleaner scours the wall of the pipe and washes ahead the material that is scraped off the pipe. While the velocity of water ahead of the cleaner is independent of cleaner speed, it must be sufficient to remove the deposits. Experience indicates that a flow velocity ahead of the cleaner of 2 to 10 ft/sec is required to remove the deposits. The cleaning water and deposits must be discharged from the pipe in a way that avoids creating an environmental problem. A sandbag dam can be used to create a pond for particle settlement, which allows the clean water to be decanted to a storm drain while solid materials are collected and disposed of.

8.2.4 Power Boring. A rack feed boring machine is a compact, diesel powered unit that uses hydraulic pressure to deliver up to 31 horsepower to a bore head (Figure 8-2) to clean and remove debris from the pipe at a rate of up to 300 ft/day. The boring head is designed to accommodate steel boring rods 15 ft long, fitted with spring-loaded quick connects for connecting into suitable lengths for cleaning various lengths of pipe. The end of a boring rod assembly is fitted with a spring steel cutter blade that can rotate at 750 rpm through the pipe. This cleaning process is conducted against a controlled, upstream water flow to flush loosened debris from the pipe.

Figure 8-2. Example of a Rack Feed Bore Head

The rack feed boring machine may be equipped with an adjustable boom to accommodate various pipe depths and to control the angle at which boring rods are inserted into the pipe. The ratio of boring rate to spring cutter blade revolutions can be predetermined and fixed to eliminate operator error. This setting ensures consistent results throughout the cleaning operation. The rack feed boring method leaves a pipe's interior surface free from tuberculation and encrustation and can be effective for bends up to 22.5°.

8.3 Cathodic Protection

Cathodic protection systems may be used in association with a protective coating to provide long-term corrosion protection. Interior coating systems will last significantly longer because the cathodic protection will halt under-film corrosion at coating gaps. Cathodic protection systems can be designed primarily using two methods: (1) impressed current and (2) corrosion inhibitors (National Association of Corrosion Engineers [NACE], 1984).

8.3.1 Impressed Current. The choice of methods depends largely on the integrity of the interior coating and its compatibility with cathodic protection. Typically, impressed current systems are used due to their ability to be adjusted to protect an increased amount of exposed steel surfaces. Impressed current systems can cause damage to certain polymeric paint systems if not carefully installed and operated. NACE publishes the recognized standard for designing and testing cathodic protection systems for use in water distribution systems (www.nace.org). A clear understanding of the soil characteristics and pipes are required for effective use of the procedures.

8.3.2 Corrosion Inhibitors. Corrosion inhibitors are a useful source of cathode protection. Corrosion can be controlled by adding chemicals to the water, which form a protective film on the surface of a pipe and provide a barrier between the water and the pipe. These chemicals, called inhibitors, reduce corrosion, but do not prevent it. The three most commonly used chemical inhibitors approved for use in potable water systems are $CaCO_3$ scale formation, inorganic phosphates, and sodium silicates. There are several hundred of commercial products listed in various State and Federal agencies.

The success of any inhibitor in controlling corrosion depends upon three basic requirements. First, it is best to start the treatment at two or three times the normal inhibitor concentration to build up the protective film as fast as possible, which minimizes the opportunity for pitting to start before the entire metal surface has been covered by a protective film. Second, the inhibitor must be fed continuously and at a sufficiently high concentration, since interruptions can cause loss of the protective film by redissolving it, which may lead to pitting. Thirdly, flow rates must be sufficient to continuously transport the inhibitor to all parts of the metal surface otherwise an effective protective film will not be formed and maintained and corrosion will then be free to take place.

8.4 Corrosion Monitoring

There are two primary categories of corrosion monitoring, namely indirect and direct. These two methods are described in the following sections (Singley et al., 1985).

8.4.1 Indirect Methods. Indirect methods do not physically measure corrosion rates. Rather, the data from these methods must be interpreted to determine trends or changes in the system. The indirect methods include customer complaint logs, corrosion indices, and water sampling, which are described in the following three sub-sections.

8.4.1.1 Customer Complaint Logs. Customer complaint logs can be the first evidence of an internal corrosion problem in a water system, although the complaints may not always be due to corrosion. For example, red water may also be caused by iron in the raw water that is not removed in treatment. Therefore, in some cases further investigation is necessary before attributing the complaint to internal corrosion in the system. Complaints can be a valuable corrosion monitoring tool if records of the complaints are organized. The complaint record should include a customer's name and address, date of complaint, and description. The following information should also be included:

- Type of material used in the customer's system and type of lining
- Whether the customer uses home treatment devices prior to consumption
- Whether the complaint is related to the hot water system and if so what types of material are used in the hot water tank and its associated appurtenances
- Any follow-up action on previous or current complaints by the utility or the consumer

These records can be used to monitor changes in water quality due to system or treatment changes. The development of a complaint map is useful in pinpointing problem areas. The complaint map could be combined with the materials map by overlaying GIS layers, which indicates the location, type, age, and use of particular types of construction materials. If complaints are recorded on the same map, the utility can determine whether there is a relationship between the complaints and the materials used.

8.4.1.2 Corrosion Indices. Attempts have been made to develop indices that would predict whether or not water is corrosive; unfortunately most of these indices are of limited value. However, several of the indices can be useful for predicting corrosion. These indices can be calculated by all utilities and can be used in an overall corrosion program. The National Interim Primary Drinking Water Regulations (NIPDWR) requires all community water supply systems to determine either the Langelier Saturation Index (LSI) or the Aggressivity Index (AI) and report these values to the State regulatory agencies. The LSI is based on the effect of pH on the solubility of calcium carbonate, while the AI is defined by AWWA Standard C400 as the sum of pH and log of total alkalinity and calcium hardness (AWWA, 2003b).

Other corrosion indices include the Reynar Stability Index that uses the same parameters as the LSI, but reverses the signs and doubles the pH. The Riddick's Corrosion Index is based on field observations, and the values obtained are applicable to soft water on the East Coast, but not to the hard water found in the middle part of the U.S. McCauley's Driving Force Index is also based on calcium carbonate solubility and attempts to predict the amount of $CaCO_3$ that will precipitate.

8.4.1.3 Water Sampling and Chemical Analysis. Since internal corrosion is affected by the chemical composition of water, sampling, and chemical analysis of the water can provide valuable corrosion-related information. Some waters tend to be more corrosive than others because of the quality of water. For example, waters having a low pH (<6.0), low alkalinity (<40 mg/l), and high carbon dioxide (CO_2) tend to be more corrosive than waters with a pH greater than 7.0, high alkalinity, and low CO_2. Corrosion, however, depends on the action of water on the pipe material. Most utilities routinely analyze their water to ensure that they are providing safe water to their customers and to meet regulatory requirements. The 1980 Amendments to the NIPDWR require all community water supply systems to sample for certain corrosive characteristics. Recommended sample locations for additional corrosion monitoring within the system are:

- Water entering the distribution system
- Water at various locations in the distributions system prior to household service lines
- Water in several household service lines throughout the system
- Water at the customer's tap

Further analysis of the corrosion by-product material and an approved sampling technique is required of utilities.

8.4.2 Direct Methods

8.4.2 Direct Methods. Direct corrosion measurements can involve the actual examination of a corroded surface of the pipe or the measurement of corrosion rates, particularly actual metal loss. The direct methods included are discussed in the following two sub-sections.

8.4.2.1 Examination of Pipe Sections. Examining the scale found inside a pipe is a direct measure of corrosion, which can tell a great deal about water quality and system condition. It can be used as a tool to determine why a pipe is deteriorating, or it can be used to monitor the effectiveness of any corrosion control program. A high concentration of calcium in the scale may shield the pipe wall from dissolution and reduce the corrosion rate. Direct inspection techniques include physical inspection, X-ray diffraction, or Raman spectroscopy.

8.4.2.2 Rate of Wall Loss Measurements. Rate measurement is another method used to identify and monitor corrosion activity. The corrosion rate of a material is commonly expressed in mils (.001/inch) penetration per year. Common methods used to measure corrosion rates include: weight loss method (coupon testing and loop studies); and electrochemical methods. Weight-loss methods measure corrosion over a period of time. Electrochemical methods measure either instantaneous corrosion rates or rates over a period of time. The coupon weight-loss method uses calculations from ASTM D-2688 Method B, while the loop system weight-loss method uses Method C (ASTM, 2005). Another method that can be used is the use of ultrasonics to measure wall loss over a period of time.

8.5 Water Audits and Leakage Detection

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. Leak detection is a survey of the distribution system to identify leak sounds and pinpoint the exact location of hidden underground leaks. Basic leak noise detectors may be used by utility teams and specialist contractors may be employed to survey water mains using tethered or free flowing acoustic devices to pinpoint and quantify leakage sources.

The overall goal of the audit is to help the utility select and implement programs to reduce distribution system losses. The cost of a water audit is the sum of in-house work and field work. The total cost depends on the size of the service area to be audited, the completeness, currency, and accuracy of the utility's records, including meter-testing programs and records, and the extent to which utility staff or outside contractors and consultants are used to conduct the audit.

According to AWWA M36 *Manual of Water Supply Practices: Water Audits and Leak Detection*, leaks usually can be divided by type into six categories, as shown in Table 8-2, based on where they occur (AWWA, 2009). Leaks may be located in the main, the service line, a residential meter box, residential service, or in valves and other appurtenances. Causes of leaks include improper installation, settlement, overloading, third party damage, corrosion, and others.

The suitability for a water utility of a single leak detection technique or combination of techniques is subject to a number of factors. The economic value of water that is being lost will play an important role in determining an appropriate leak detection strategy. Water utilities with a high cost of water and large losses may be able to justify an extensive system-wide leak detection program using sophisticated tools.

Table 8-2. Various Categories of Leaks in a Network

Leaks	Comments
Main Leaks	Leaks range from 1 gallon per minute (gpm) to over 1,000 gpm and may start due to corrosion. Occur due to excessive pressure, improper installation, settlement, and overloading.
Service Line Leaks	Leaks range from a low of 0.5 gpm to over 15 gpm. Leaks can be caused by a variety of factors.
Residential Meter-box Leaks	Leaks range from less than 1 gpm to 10 gpm. Leaks can be caused by loose spud nuts on the meter, loose packing nuts, damaged or broken angle stops, couplings, broken meters, or meter yokes.
Residential Leaks	Leaks range from less than 1 gpm to 15 gpm. Leaks can be caused by holes, breaks, inefficient hose-bib or shutoff valves, interior plumbing lines, or fixtures.
Valve Leaks	Leaks range from 1 gpm to 500 gpm. Leaks are caused by loose packing, broken parts, etc. and sometimes start in system controls.
Miscellaneous Leaks	Excessive pressure, settlement, overloading, improper installation, improper materials and operation can also cause break in the valves.

The chosen techniques must also take into account the water system geography, infrastructure materials, age, and expected condition. Also important is the ability of the water utility personnel in using the chosen techniques, as adequate training and supervision may be required. More information on leakage management technologies can be found in Fanner et al. (2007). The methodologies for leakage management can be grouped into two distinct categories:

- **General Methods** for localizing leaks, which are those techniques that indicate the general vicinity of a leak (e.g., visual, comprehensive, step testing, noise loggers).
- **Specific Methods** for pin-pointing a leak, which are those techniques that indicate the estimated position of a leak where excavation for repair will take place (e.g., acoustic, general, leak noise mapping).

A summary of specific characteristics of some leak detection techniques is given in Table 8-3.

Table 8-3. Various Leak Detection Techniques

Techniques	Comments
Visual Survey	Most basic form of leak detection. Survey done by walking above the lines and looking for signs of leaks, such as water pooling on the surface.
Acoustic Survey Sounding	Various kinds of leak noise detection equipment are used. Frequency and magnitude of noise generated by a leak varies with the type of leak, pipe material, diameter, and pressure.
Comprehensive Survey	Listens to all available fittings on the pipe and service connections. Time consuming but effective in detecting leaks in the system.
General Survey	Referred to as hydrant survey because it uses geophones and leak noise correlators for pinpointing leaks. Less suitable for non-metallic pipes or pipes with many service lines.
Step Testing	Involves isolating sections of main from the zone and meter. Each time a section with a leak is isolated there will be a marked drop on the data loggers that represents the leak volume.
Noise Logger Survey	Most useful for areas with high background noise and those where the avoidance of night crew work for leak detection is necessary.
Leak Noise Mapping	Leak is pinpointed immediately after localization and is most appropriate for areas with high density hydrants.

9.0: FINDINGS AND RECOMMENDATIONS

9.1. Gaps between Needs and Available Technologies

The available technologies for water pipeline renewal leave certain gaps or needs unmet. The following subsections address these gaps and how they may be closed to provide utilities with decision-making processes and rehabilitation technologies that will enable them to implement water main rehabilitation programs. The gaps fall into two main categories: data gaps in terms of knowledge of the existing pipe condition; and capability gaps in terms of the available renewal and rehabilitation technologies.

9.1.1 Data Gaps. The renewal process comprises three sequential elements: inspection of the existing pipe; assessment of its condition from the inspection data; and renewal to restore the condition to the desired for future service and performance requirements, and this process begins with data. Data may be obtained either externally or internally. Obtaining external data requires excavation for inspection on the pipe surface. For reasons of cost and practicality, this can only be done at a small number of discrete locations along a pipeline. As a result, the sample size is extremely small and the confidence level of the findings in terms of being representative of the pipeline as a whole is very low. Internal data can be obtained over the full internal surface area of the pipe, but this typically requires the main to be shutdown and dewatered for inspection, although some technologies do exit for live inspections. This is extremely costly due to the service interruption. Alternative methods that obtain data from inside a pipe in service are costly and still in early stages of development.

A broad range of inspection and monitoring tools is available in the market, and each provides data on specific materials or characteristics. In general, the inspection technologies for pressure pipelines are material-specific (i.e., they are suitable for just one, or a small range of pipe materials). The ability to obtain some data of value from condition assessment is good for most pipe materials. Sophisticated electromagnetic techniques exist for inspecting ferrous and PCCP that provide a robust basis for condition assessment and renewal technology design. For other pipe materials, in particular AC and plastics, there remain gaps in the ability to obtain such data without removing coupons or sections of pipe for off-site inspection.

A further gap exists in terms of understanding the cost-effectiveness of obtaining data. This is closely related to taking a risk-based approach. Condition data and subsequent assessment identify the likelihood of failure. This is of value where the consequence of failure is serious (e.g., for large diameter mains or main in critical areas). However, where the consequence of failure is not serious the value of the data is low because it has no impact on decisions or actions (e.g., small diameter mains). Therefore, the cost of obtaining it must also be low otherwise the data are not economic. There is a need for more economic inspection technologies that can provide data more cost-effectively for lower risk locations or for assessment methodologies that can work with limited data. Development of clear maintenance guidelines and linking of O&M data, such as cathodic protection system and power consumption data, to condition assessment is also necessary.

9.1.2 Capability Gaps. Through the course of these research efforts, it was recognized that only a select number of water utilities in the U.S. have begun to utilize trenchless rehabilitation technologies, other than CML. This suggests that significant market barriers still exist for water main rehabilitation compared to what exists today on the wastewater side. This is due to the fact that most water utilities are unfamiliar with emerging and innovative rehabilitation technologies and water utilities are typically reluctant to be one of the first to try out new technologies. Section 4 of this report identified a large range of technologies for repair, rehabilitation, and replacement of both mains and services for the full range of transmission and distribution diameters, many of which are emerging in the U.S. water market. These are able to provide renewal that meets structural and hydraulic requirements in a variety of circumstances. There remains a need to demonstrate innovative rehabilitation technologies that are new to the U.S. market to evaluate their capabilities and performance and demonstrate their applicability to water utilities. This will help to reduce the risk to water utilities in experimenting with new technologies and new materials on their own.

Significant capability gaps do remain. There are a wide variety of piping materials in water distribution systems requiring rehabilitation including challenges associated with appropriate and safe rehabilitation options for AC pipe. There is a need for rehabilitation methods suitable for AC pipe materials, which could help to reduce the need to remove AC pipe materials from the ground when renewals are required. Thinner composite liners that reduce the amount of cross section loss would be favored by water utilities.

For some technologies, reopening service connections after lining still generally requires excavation at each connection location for manual reopening and reconnection to the service pipe, often requiring a new fitting. Where service connections are frequent, this becomes almost as disruptive as a full-length excavation, thereby negating the benefits of a trenchless lining solution. Operational aspects such as access requirements and the length of time that the main is out of service are also areas where gaps exist between capability and customers' needs. Simplifying or minimizing access requirements could remove a major barrier to the use of many rehabilitation methods and developing processes that limit service interruption to one day will also overcome a significant operational barrier. The ability of a utility's repair crews to skillfully carry out emergency repairs on rehabilitated water mains is also an important consideration. There is a demonstrated need for suppliers of lining and similar technologies to develop repair procedures for their products in water main applications and to train utilities in their application.

A gap also remains in the understanding of the long-term performance of the various rehabilitation technologies and their materials. These materials and methods are young in terms and usage for water main rehabilitation and they have not been subjected to retrospective analysis, which involves the study of the installed performance of materials over their lifetime. There is a need to conduct a retrospective study of the materials that have been used in distribution systems for more than 20 years to determine how well these materials are performing and to determine if these materials can remain in service for their intended designed service lives.

9.1.3 Benefits, Costs, and Challenges in Closing Gaps. Table 9-1 summarizes the technology gaps identified in knowledge of the existing pipe condition and in the capability of the available renewal and rehabilitation technologies.

Table 9-1. Benefits, Costs, and Challenges in Closing Gaps

Gap	Close By	Benefit	Cost	Challenge
Live Internal Inspection	Developing technologies	Reduces cost and disruption of service	High	Cost (likely beneficial for large and high risk mains).
Assessment with Limited Data	Statistical methods	Lower cost assessment	Low	Determining adequate level of data for more robust models.
Applicability of Rehabilitation Methods	Demonstrating innovative technologies	Evaluation of the applicability of new technologies	Medium	Utilities are typically hesitant to be the first to try out new technologies.
Reopening Service Connections	Developing technologies	Substantial reduction of required excavation	Medium	Different materials require different approaches.
Long-term Performance of Materials	Retrospective study of installed materials	Understanding of actual material service life that could improve designs	High	Difficult to obtain samples without interruption of service and destructive testing.

9.2 Conclusions and Recommendations

There is a growing range of rehabilitation technologies available for water mains. Many of these are relatively new to the market and in the introductory stage of their life-cycle with the exception of CML, which is a large and mature segment of the market. Several barriers and challenges still need to be overcome and in doing so this will help to establish a market in which customers (owners and operators of water supply networks) will have clearly defined needs and an equally clear understanding of appropriate technologies that can meet those needs.

In order to overcome the barriers and challenges identified, it is recommended that innovative rehabilitation technologies be demonstrated in field conditions and measured against a clearly defined set of performance criteria. These demonstrations can inform water utilities of the capabilities, applicability, and costs of innovative technologies. Demonstrations of innovative structural CIPP and semi-structural polyurea lining have already been conducted under an EPA demonstration program (EPA, 2012a; 2012b) and the results of the studies provide valuable resources to water utilities in need of actual installation, performance, and cost information. An additional research need is identifying appropriate accelerated aging test protocols that would help system owners to predict the long-term performance of the rehabilitation products and technologies that are emerging in the market. A WaterRF project is underway to study the use of CFRP for the repair of PCCP, but other technologies (e.g., pipe bursting or spray-on lining for the rehabilitation of asbestos cement pipe) should be studied to identify appropriate design and performance standards.

It is also recommended that a retrospective analysis of water main rehabilitation materials be conducted to understand service life performance. Although water main rehabilitation is relatively new except for CML, retrospective study of materials in use for up to 20 years or more can provide data on the performance of field installed materials. These data can assist utility decision makers in selecting the proper situation where these technologies and materials should be used in their systems. Decision-support methodologies could also be developed to build an improved understanding of the condition of a utility's networks and to assist with decision support for determining the most appropriate solutions. These data along with the documented performance and applicability evaluation performed under a demonstration program would be essential in providing utility decision makers with the information they need for selecting appropriate technologies and materials to meet their system needs.

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APPENDIX A: TECHNOLOGY DATASHEETS

The datasheets that follow represent a useful collection of technology and product descriptions related to the rehabilitation of water mains and service pipes in water distribution systems. Datasheets that were prepared as part of the companion wastewater collection rehabilitation and force main rehabilitation reports have also been included in this set where the product/technology has a clear applicability and/or a stated market in the water distribution sector. Not all applicable products have been included in the datasheets provided, since there may be many similar commercial offerings of a similar technology. In general, datasheets from major or long-standing providers have been sought to represent each class of product. The datasheet information was prepared initially by the research team from existing knowledge, product brochures, and company Websites. The datasheets were then forwarded to the technology provider for additional information and/or clarification. This process has resulted in some variation in the quantity and quality of information available for each product. The authors hope that this will be a useful compilation of information on the range of technologies available. Contact information has been provided for the reader to access additional information, as needed.

LIST OF DATASHEETS

Datasheet A-1. 3M™ Scotchkote™ 169 Polyurea Lining

Technology/Method	**Scotchkote™ 169/Spray-On Polyurea Lining**
I. Technology Background	
Status	Conventional
Date of Introduction	Formally known as Copon Hycote 169 and introduced in the UK in 1999.
Utilization Rates	About 6,000 miles have been lined, bulk of which is in UK.
Vendor Name	**3M Corrosion Protection Products Division** Austin, Texas 78726-9000 Phone: (512) 984-5515 Email: gsnatwig@mmm.com Web: www.3m.com
Practitioners	• Pierre Leblanc, Alltech Solutions, Canada Email: leblanc@alltechsolutions.ca • David Brown , Yorkshire Water UK Email: david.brown@yorkshirewater.co.uk • Les Metcalfe, South West Water UK Email: lmetcalfe@southwestwater.co.uk
Description of Main Features	3M™ Scotchkote™ 169 is a two component Polyurea based coating designed for use in water pipe rehabilitation applications. For pipe application, the material is pumped to a remote spray head and is moisture tolerant to provide high build, slump resistant coatings with adhesion characteristics assuming a properly prepared surface. Finished coatings are hard, glossy, and free of surface tack. The lining forms a barrier coating and is an alternative to conventional pipe replacement methods.
Main Benefits Claimed	• No large scale disruption and small carbon footprint • Abrasion resistance • Long term (design life of 50 years) corrosion protection material • Equivalent to AWWA M28 Class I Rehabilitation technology • Well suited for minimal local host pipe damage
Main Limitations Cited	• Not recommended for pipe with residual asset life less than 20 years • Not recommended for use in PVC due to failure pattern in host pipe
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Oil, Gas, and Industrial pipelines</u>
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	• Service connections are not normally blocked. • If CCTV inspection shows a blocked service connection, it can be repaired with a drill tool on the camera.
Structural Rating Claimed	• Ultimate tensile strength is 25.0 MPa • Flexural strength is 55.0 MPa • Flexural Modulus is 3,200 MPa • Hardness 85 Shore D • (LC8 standards clearance)
Materials of Composition	Polyurea • Base Component: White thixotropic liquid • Activator Component: Black thixotropic liquid • Mixed Material: Light Grey • Mix ratio 2.5:1 base to activator
Diameter Range	4 in. to 48 in.

Technology/Method	**Scotchkote™ 169/Spray-On Polyurea Lining**
Thickness Range	• Maximum film thickness of 80 mils. • Practical applications of 40 to 80 mils are specified.
Pressure Capacity, psi	Not Available
Temperature Range, °F	• To be stored in the original sealed containers at temperatures between 0°C and 40°C. • Applied when substrate/water temperatures are less than 3°C • Material temperature at the application head is 25-35°C (75-95°F).
Renewal Length	100 ft to 500 ft (typical installation lengths)
Other Notes	• Approved manufacturing facility is in North Yorkshire, UK • Recommended deflection in pipe of up to 12°
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• NSF/ANSI Standard 61 Certification • DWI approved (UK) • Approved under Regulation 31(4)(a) of the Water Supply Regulations • Norwegian, Spanish, and Polish approvals
Design Standards	Not Available
Design Life Range	30 years (Some studies suggest 40 to 60 years).
Installation Standards	Not Available
Installation Methodology	• Host pipe cleaning and drying are required. • One coat 40 mils (1 mm) thick is applied in a single pass of the head. • Coating should be allowed to cure for at least 60 minutes at ambient temperature after lining before disinfection and flushing procedures. • CCTV inspection of the coating may be carried out after a minimum cure period of 10 minutes from completion of lining. • One hour flush required prior to being placed into service. • Disruption of around 10 hours if bypass water supply is not used.
QA/QC	Equipment needs special head and cleaning.
IV. Operation and Maintenance Requirements	
O&M Needs	Using a maximum of 100 mg/litre of free chlorine
Repair Requirements for Rehabilitated Sections	Leakage detection tests and recoating
V. Costs	
Key Cost Factors	• Lining materials • Spraying equipment • Entry and exit access pits • Time for installation • Tarmac coating required at excavation pits
Case Study Costs	Not Available
VI. Data Sources	
References	• http://solutions.3m.com/wps/portal/3M/en_US/Corrosion/Protection/Products/Catalog2/?PC_7_RJH9U523001R40I49E2FVI20E3_nid=KFJDBHV60QbeMD6XD483P9gl • www.nsf.org • International Pipelines Article (Najafi et al., 2009) • Email correspondence with Gary Natwig

Datasheet A-2. Acuro Polymeric Resin Lining

Technology/Method	**Acuro Polymeric Resin/Spray-On Polyurea Lining**
I. Technology Background	
Status	Conventional
Date of Introduction	Introduced in 1999 in U.S., potable water since 2007
Utilization Rates	10 km+ lining applied to date
Vendor Name(s)	**Acuro Inc.** 2126, Principal Ave. St-Zotique, QC, Canada J0P 1Z0 Phone: (450) 267-0747 51194 Romeo Plank Macomb, MI 48042 Phone: (810) 499-9318 Email: info@acuro.ca Web: www.acuro.ca
Practitioner(s)	• City of Vaudreuil-Dorion, Quebec • City of Beauceville, Quebec • City of Peterborough, ON • City of Napanee, ON • City of Cleveland, Ohio
Description of Main Features	Water main rehabilitation that is a NSF/ANSI Standard 61 compliant fully-structural, semi-structural, and/or non-structural system.
Main Benefits Claimed	• Restores hydraulic capacity • Enhances pipe structure • Stops leaks, breaks, and corrosion • Designed to provide a non-, semi-, or fully-structural protection • Same day return-to-service possible
Main Limitations Cited	• Current equipment unable to negotiate 90° bends
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> <u>Laterals</u> <u>Manholes</u> Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	Need to be plugged or inspected and drilled open from inside the main (normally do not need to be drilled).
Structural Rating Claimed	Meets ASTM F-1216 structural requirements
Materials of Composition	Polymeric Resin
Diameter Range	2 in. and up
Thickness Range	3 mm and up
Pressure Capacity, psi	200+ psi (third-party testing)
Temperature Range, ^{o}F	Not Available
Renewal Length	Up to 650 ft (200 m.) between access pits
Other Notes	• Used for AC, DI, CI, PVC, steel, clay, and previously coated pipes • Hazen-Williams coefficient around 110 • Polymeric resin shows 10% elongation to help in-case of pipe breaks
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61-5 approved by Truesdail Laboratories (not listed on the NSF website)
Design Standards	Designed as per ASTM F-1216
Design Life Range	50 years (75-100 years claimed)

Technology/Method	Acuro Polymeric Resin/Spray-On Polyurea Lining
Installation Standards	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 (currently working on new ASTM Standard)
Installation Methodology	Following the cleaning and drying of the water main, the resin is spray-formed to the host water main by use of a robotic sprayer and umbilical cord. The polymeric resin is a thermoset material cure applied using impingement mixing under hydraulic pressure within the tube. The liner is continuous and tight fitted to the host structure. The liner consists of one or more layers of applied liner to meet the level of rehabilitation required (i.e., non-, semi-, or fully-structural). Curing begins in less than 10 seconds. A structural assessment may take place to help determine the level of rehabilitation required. A 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) and 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.
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 to check for wall thickness loss.
Repair Requirements for Rehabilitated Sections	Internal repair of any holes larger than 1/8 in. prior to spraying.
V. Costs	
Key Cost Factors	• Polymeric resin materials • Spraying equipment • Entry and exit access pits
Case Study Costs	30% less expensive than CIPP lining in one of the cases
VI. Data Sources	
References	• www.acuro.ca/eng/services/water-main-rehabilitation.html • Brochure from No-Dig 2009 • ACURO Specifications • Email correspondence with Stephane Joseph

Datasheet A-3. AMEX®-10 Joint Seal

Technology/Method	**Amex®-10/Internal Joint Seal**
I. Technology Background	
Status	Conventional
Date of Introduction	1970s in Germany
Utilization Rates	Over 1.3 million units worldwide
Vendor Name(s)	**AMEX GmbH** Rondenbarg 16 Hamburg, Germany 22525 Phone: +49 (405) 590-0199 Email: info@amex-10.de Web: www.amex-10.de
Practitioner(s)	Not Available
Description of Main Features	AMEX–10 profiles are produced in endless sections and are joined together to any required size by a special production method. The physical characteristics, resistance, and special shape with its three fold seal between the main seal, ensure a permanent seal in the pipe. The special elastic quality of various rubber types with the ability to bridge axial and radial displacements without influencing the sealing properties is the basis for a permanent sealing function reached by radial tension via the retaining bands, which are manually installed without the use of a robot or adhesives.
Main Benefits Claimed	• For circular, elliptical, egg shape, mouth, and cornered profiles • By variable shaping any installation length can be realized • Absolute sealing caused by gearing
Main Limitations Cited	• Bypass pumping required • Applicable for accessible pipes only or end of non-accessible pipes • Very rough surfaces have to be treated with a coating
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Spot Repair with Internal Joint Seals
Service Connections	Not applicable
Structural Rating Claimed	Not-structural
Materials of Composition	• Medium density PE (MDPE) backing • SS retaining bands • EPDM rubber
Diameter Range	20 in. to 230 in. (500 mm to 5800 mm) accessible pipes 10 in. to 20 in. (250 mm to 500 mm) non-accessible pipe ends
Thickness Range	Not Available
Pressure Capacity, psi	Up to 290 psi (20 bar)
Temperature Range, °F	14°F to 212°F (–10°C to over 100°C)
Renewal Length	Spot repair technology, seal is 10 in. long
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• Complies with NSF/ANSI Standard 61 (not listed on the NSF website) • German Institute for Standardization EN 681-1 2003 – 05 • KTW – Recommendation 1.3.13

Technology/Method	**Amex®-10/Internal Joint Seal**
Design Standards	Not Available
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• All pollution has to be removed mechanically in such a way that a clean and smooth surface exists. In case of depressions of the pipe wall, a suitable material has to be applied to reach a smooth surface. • Put in the pipe and transported together with the retaining bands to the place of installation. • Placed exactly onto the clean and smooth pipe surface and adjusted. • Set up of the seal is completed by the two retaining bands. • After the hydraulic expander has been fitted to the retaining bands a slight press on follows. (Correct fitting of the seal and the retaining bands has to be controlled). • Installation of the safety spindle for bracing follows. • By slow activation of the hydraulic pump and hammering simultaneously onto the retaining bands the pressure is slowly increased until the pressure gauge does not show a loss of pressure.
QA/QC	• In order to guarantee an optimal installation it is necessary, depending on the pipe material, to after-pressure the seal once. • The perfect fit and tightness of the seal can be tested by putting pressure through a super flat test valve to the seal. • After having inflated the seal a leak detecting spray is applied to the end wall of the seal in order to detect escaping air. • For leaking joints, temporary sealing of the joint is required.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Seals and equipment • Mobilization • Entry access pits • Cleaning • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.amex-10.de/en/pdf/AMEX_Imagebroschuere_en.pdf

Datasheet A-4. Avanti AV Chemical Grouting

Technology/Method	**Avanti AV-202, AV-330 and AV-333/Chemical Grouting**
I. Technology Background	
Status	Emerging
Date of Introduction	2005 for potable water use
Utilization Rates	• Approximately 500,000 lbs/yr of AV-202 • Approximately 125,000 lbs/yr of AV-333.
Vendor Name(s)	**Avanti International** 822 Bay Star Blvd. Webster, TX 77598 Phone: (800) 877-2570 Fax: (281) 486-5600 Email: jim.gentry@avantigrout.com Web: www.avantigrout.com
Practitioner(s)	Concrete repair and waterproofing contractors.
Description of Main Features	AV-202, AV-330, and AV-333 multigrouts are polymer solutions that cure when reacted with water. It reacts freely with water to form a strong film, gel, or foam of PU. Its intended use would be to prevent water infiltration into sub-grade structures and pipes.
Main Benefits Claimed	• Durable elastic foam or gel • Used for heavy or light flow conditions, as well as under water • Nonflammable
Main Limitations Cited	• Bypass pumping required • Requires man-entry
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Dams and Reservoirs
II. Technology Parameters	
Service Application	Spot Repair with Chemical Grout
Service Connections	Not applicable
Structural Rating Claimed	Not-structural
Materials of Composition	Prepolymer urethane resin grout
Diameter Range	• 1 in. and up (externally) • 24 in. and up (internally)
Thickness Range	Not Available
Pressure Capacity, psi	Not Available
Temperature Range, ^{o}F	40°F to 200°F
Renewal Length, feet	Spot repair technology, can be used in as many locations as needed
Other Notes	The primary difference in the two products is the viscosity, with AV-202 having a viscosity of approximately 2,500 cps and AV-333 having a viscosity of approximately 450 cps. The more viscous material would be used in larger cracks.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 approved by UL (not listed on the NSF website)
Design Standards	ASTM D-93 and ASTM D-3574
Design Life Range	25 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• Clean the crack or joint to be sealed of any loose foreign material. • Cut oakum in sizes to meet the requirements of the cracks and holes. • Place the oakum in a heavy-duty plastic bag or pail.

Technology/Method	**Avanti AV-202, AV-330 and AV-333/Chemical Grouting**
	• Pour the product into the plastic bag or pail. Pour enough to cover the oakum. Let the oakum soak long enough to get thoroughly saturated with the chemical grout. The appropriate protective equipment and ventilation should be used. • Take the saturated oakum out of the container and submerse in water for approximately 5 to 10 seconds. Then hold the oakum out of water until the grout starts to foam (approximately 5 to 10 seconds). • Place the oakum into the leaking crack, joint, or hole. Use a blunt instrument, such as a screwdriver, to drive the oakum further into the leaking area (joint). The water in the joint will continue to activate the grout that has been absorbed by the oakum.
QA/QC	Manufacturer's QA/QC procedures plus UL certification each year.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Grout and equipment • Mobilization • Entry access pits • Cleaning • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.avantigrout.com/202sum.html • Email correspondence with Jim Gentry

Datasheet A-5. Belzona® 5811DW Epoxy Coating

Technology/Method	**Belzona® 5811DW/Spray-On Epoxy Coating**
I. Technology Background	
Status	Emerging
Date of Introduction	2007
Utilization Rates	Not Available
Vendor Name(s)	**Belzona, Inc.** 2000 N.W. 88th Court Miami, FL 33172 Phone: (305) 594-4994 Fax: (305) 599-1140 Toll Free: (800) 238-3280 Email: belzona@belzona.com Web: www.belzona.com
Practitioner(s)	Not Available
Description of Main Features	Belzona® 5811DW 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	• Provides protection from the effects of salt water, acid, alkali, alcohol, hydrocarbon, and the environment • Long lasting and economically sound system • Repair and seal pipe expansion bellows • Repair existing linings • Repair leaking pipes
Main Limitations Cited	• Requires up to 5 days for full cure • Requires man-entry
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Not Applicable
II. Technology Parameters	
Service Application	Spot Repair Coating of Water Mains
Service Connections	Connections may have to be plugged or handled separately.
Structural Rating Claimed	Not Available
Materials of Composition	2 Component, Solvent-Free Epoxy
Diameter Range	36 in. and up
Thickness Range	20 mils (maximum film thickness)
Pressure Capacity, psi	Not Available
Temperature Range, °F	• 50°F (use within 2 hrs) • 77°F (use within 1 hr) • 86°F (use within 30 mins)
Renewal Length, feet	Limited by length of hose if spray applied
Other Notes	Final curing time is 5 days and at 68°F temperature. A re-coat cure time is for 6 to 8 hrs at 68°F temperature for a maximum of 72 hrs.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	ASTM D-695, ASTM D-790, ASTM D-1002, ASTM D-2240, ASTM D-4541, and NACE TM0174-2002
Design Life Range	Not Available
Installation Standards	As per manufactures' guidelines

Technology/Method	Belzona® 5811DW/Spray-On Epoxy Coating
Installation Methodology	The epoxy coating is applied by spraying 2 coats, each having a mix ratio of Part A to Part B at 3 to 1 by volume.
QA/QC	As per manufacturers' guidelines
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection as per AWWA standards when used in potable water pipes.
Repair Requirements for Rehabilitated Sections	The coating can be reapplied over rehabilitated sections.
V. Costs	
Key Cost Factors	• Epoxy materials • Entry and exit access pits • Duration of cure time
Case Study Costs	Not Available
VI. Data Sources	
References	• www.belzona.com/prod5k.aspx • Belzona Press Release: "Belzona, Inc. Coating NSF Approved for Drinking Water System Components" • Product Flyer: Belzona® 5811DW

Datasheet A-6. CarbonWrap™ Pipe Wrapping

Technology/Method	**CarbonWrap™/Pipe Wrapping**
I. Technology Background	
Status	Conventional
Date of Introduction	Invented in 1987, available in the market since 1994.
Utilization Rates	Over 100,000 lf of pipe have been wrapped.
Vendor Name(s)	**CarbonWrap™ Solutions LLC** 2820 E. Fort Lowell Rd. Tucson, Arizona 85716 Phone: (520) 292-3109 Fax: (520) 408-5274 Toll Free: (866) 380-1269 Email: info@carbonwrapsolutions.com Web: www.carbonwrapsolutions.com
Practitioner(s)	• Strengthening of underground concrete pipes in Phoenix, AZ • Strengthening of underground concrete pipes in Tucson, AZ
Description of Main Features	CarbonWrap™ is an effective and economical application for strengthening buried pipes. Concrete and steel pipes can be strengthened to take pressures even greater than that of their original design value.
Main Benefits Claimed	• Requires no excavation • Increases pipe strength to higher than its original pressure rating • Creates a smooth surface and improves pipe flow • Requires no heavy equipment for installation
Main Limitations Cited	• Requires man-entry if used internally • Requires excavation if used externally
Applicability (Underline those that apply)	Force Main <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Spot Repair of Water Mains
Service Connections	Can be cut to fit around services
Structural Rating Claimed	Structural material
Materials of Composition	Epoxy and carbon
Diameter Range	36 in. and up if used internally and any size if used externally
Thickness Range	1/8 in. thick
Pressure Capacity, psi	Increases pipe strength to higher than original pressure rating (claimed)
Temperature Range, °F	Application in humid temperature is not recommended
Renewal Length, feet	No limitation, limited by access only
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Meets NSF/ANSI Standard 61 (not listed on the NSF website)
Design Standards	ASTM D-638, ASTM D-3039, and ACI 440
Design Life Range	Minimum 25 years
Installation Standards	As per manufacturer guidelines
Installation Methodology	In the case of 3 ft and larger diameter pipes operations are conducted internally. If the pipe can be accessed from the outside, the wrapping can be installed 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	

Technology/Method	**CarbonWrap™/Pipe Wrapping**
O&M Needs	Regular cleaning is required. Maintenance strategies should include condition assessment measures.
Repair Requirements for Rehabilitated Sections	Relining may be done.
V. Costs	
Key Cost Factors	• The composite material is generally the key governing factor • Site accessibility and pipe condition determine the amounts
Case Study Costs	Material cost at $10 to $15/sf
VI. Data Sources	
References	• www.carbonwrapsolutions.com/PDFinfo/Brochure.pdf • Phone and email correspondence with Dr. Hamid Saadatmanesh. • Email correspondence with Faro Mehr.

Datasheet A-7. Cement Mortar Lining

Technology/Method	**Cleaning and Cement Mortar Lining**
I. Technology Background	
Status	Conventional
Date of Introduction	1930s
Utilization Rates	Thousands of miles in the U.S.
Vendor Name(s)	**J. Fletcher Creamer & Son, Inc.** 101 East Broadway Hackensack, New Jersey 07601 Phone: (201) 488-9800 Fax: (201) 488-2901 Email: info@jfcson.com Web: www.jfcson.com **Mainlining Service, Inc.** P.O. Box 96 Elma, New York 14059 Phone: (716) 652-3700 Email: rehab@mainlining.com Web: www.mainlining.com
Practitioner(s)	• Macon-Bibb Water Authority, Macon , Georgia Lined over 200,000 lf of 6 in. to 36 in. CI pipe at various locations. • Los Angeles Department of Water and Power, California Cleaned and lined over 3,000,000 lf of 4 in. to 60 in. CI and steel water mains on numerous projects. • New Jersey American Water, Haddon Heights, New Jersey Cleaned and lined over 250,000 lf of 4 in. to 20 in. water lines.
Description of Main Features	In-place cleaning and cement mortar lining restores flow, eliminates red water complaints, and it's all done without removing the pipe from the ground and without interruption of water service to the customer. There are large excavations and no disruption of traffic or business operations.
Main Benefits Claimed	• Less local area inconvenience • Savings in pumping costs • Extends system life • Eliminates red water • Increases pressure and fire flow • Improves water quality
Main Limitations Cited	• Surfaces must be very clean • Cannot negotiate sharp bends
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main (underlined) Service Lines Other: Storm Water Lines (underlined)
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	Need to be free of debris and mortar or reinstatement is required
Structural Rating Claimed	Not a structural solution
Materials of Composition	1:1 mixture of Portland cement, well-graded silica sand, and water added
Diameter Range	4 in. and up
Thickness Range	6 mm to 13 mm
Pressure Capacity, psi	Depends in the diameter

Technology/Method	**Cleaning and Cement Mortar Lining**
Temperature Range, °F	Not Available
Renewal Length	Up to 750 ft, limited by the length of the spray hose
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	AWWA C104
Design Life Range	50 years
Installation Standards	AWWA C602
Installation Methodology	• While excavations are being made to prepare for cleaning and lining operations, temporary bypass pipe is installed along the curb line on both sides of the street. • Before lining, the pipe interior must be cleaned either hydraulically (a steel frame with protruding metal scraper blades is propelled through the pipeline by water pressure) or mechanically (the cleaning scrapers are pulled through the pipe by a winch and water is used to flush debris out of the pipe opening). • The premixed cement mortar lining is centrifugally applied to the pipe wall interior using mortar application equipment. As the mortar lining is applied, a flexible troweling device follows behind to produce a smooth, hydraulically efficient surface.
QA/QC	AWWA C602
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Coating can be resprayed over the problem area.
V. Costs	
Key Cost Factors	• Cement mortar materials • Entry and exit access pits • Bypass system • Cleaning and inspection • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.jfcson.com • www.mainlining.com • www.epa.gov/nrmrl/pubs/600ja02406/600ja02406.pdf

Datasheet A-8. Clock Spring® Pipe Sleeve

Technology/Method	**Clock Spring®/Pipe Sleeve**
I. Technology Background	
Status	Conventional
Date of Introduction	1993
Utilization Rates	Over 250,000 units installed in over 75 countries
Vendor Name(s)	**Clock Spring Company, L.P.** 14107 Interdrive West Houston, TX 77032 Phone: (281) 590-8491 Fax: (281) 590-9528 Email: sales@clockspring.com Web: www.clockspring.com
Practitioner(s)	• Conoco Phillips • British Petroleum • Enterprise Products • Koch • Duke Energy
Description of Main Features	Clock Spring® is an economical repair alternative for pipelines. The repair is comprised of 8 wraps of composite, a high-strength filler material, and the adhesive. The individual wraps of the repair are bonded together, and to the pipe surface to restore serviceability. It can be used to permanently repair external blunt metal loss defects with a depth of less than 80% of the nominal wall thickness.
Main Benefits Claimed	• High strength and corrosion resistant • Fast repairs • No release of greenhouse gases • No waste disposal issues
Main Limitations Cited	• Only used for external repairs • Requires excavation for installation
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas</u>
II. Technology Parameters	
Service Application	Spot Repair with External Pipe Sleeve
Service Connections	Not applicable
Structural Rating Claimed	Not-structural
Materials of Composition	• E-glass and polyester resin composite sleeve • Adhesive and filler
Diameter Range	4 in. to 56 in.
Thickness Range	½ in.
Pressure Capacity, psi	Shares the load with the host pipe
Temperature Range, ^{o}F	• 0°F to 170°F (-18°C to 77°C) for application • -20°F to 170°F (-29°C to 77°C) for service
Renewal Length	Spot repair technology, sleeve width of 11.5 +/- 0.5 in.
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not NSF/ANSI Standard 61 Certified
Design Standards	Long-term accelerated laboratory testing and evaluations of long-term field installations results in the aged material properties.

Technology/Method	**Clock Spring®/Pipe Sleeve**
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• The missing or damaged wall is replaced by filling the volume with a proprietary compound that transfers the structural load from the defect to the glass fibers reinforcement. • The sleeve is then wrapped around the pipe while applying the viscous adhesive between each layer. • During installation, the adhesive acts as a lubricant between the composite layers, allowing them to be cinched tightly to the pipe. • During cinching, the excess adhesive/filler is distributed, filling voids and tented areas – and is squeezed out the sides of the composite.
QA/QC	Documentation of the system is in the form of a controlled QA Manual and controlled work instructions/procedures providing sufficient detail to demonstrate compliance to requirements and allow evaluation of results.
IV. Operation and Maintenance Requirements	
O&M Needs	Allowable repairs based on specific codes, such as ASME B31.4 or B31.8.
Repair Requirements for Rehabilitated Sections	NACE 3 surface preparation
V. Costs	
Key Cost Factors	• Sleeves and equipment • Mobilization • Access pits • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.clockspring.com/PDF/ClockSpringpiperepairsystempdf.pdf • Email correspondence with Buddy Powers

Datasheet A-9. Freyssinet Frey-CWRAP® Pipe Wrapping

Technology/Method	**Freyssinet Frey-CWRAP®/Pipe Wrapping**
I. Technology Background	
Status	Innovative
Date of Introduction	Product is ready to be commercialized
Utilization Rates	Not Applicable
Vendor Name(s)	**Freyssinet LLC.** 44880 Falcon Place, Suite 100 Sterling, VA, 20166 Phone: (703) 378-2500 Fax: (703) 378-2700 Email: freyssinet@freyssinetusa.com Web: www.freyssinetusa.com
Practitioner(s)	• 96 in. diameter pipe repair in Potomac, MD • 84 in. diameter pipe repair in Tucson, AZ
Description of Main Features	Reinforcement by CFRP lining is a promising technology for pipe repair and Freyssinet has developed FREY-CWRAP®: a carbon fiber/epoxy resin composite specifically designed for application on PCCP surfaces.
Main Benefits Claimed	Used to ensure 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 FREY-CWRAP® robot making it an industrialized and automated pipe relining.
Main Limitations Cited	• Limited to sectional repairs • Requires man-entry
Applicability (Underline those that apply)	Force Main <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Mainly PCCP pipes</u>
II. Technology Parameters	
Service Application	Composite Lining/Spot Repair of Water Mains
Service Connections	Need to be plugged.
Structural Rating Claimed	Not Available
Materials of Composition	Carbon Fiber Reinforced Polymer
Diameter Range, inches	60 in. to 120 in.
Thickness Range	20 to 27 mils
Pressure Capacity, psi	290 psi
Temperature Range, °F	3°C above dew-point, generally ambient temperature is acceptable.
Renewal Length, feet	Full length or spot repair (joints can be bridged by NSF approved glass-fiber based products
Other Notes	• Freyssinet has also developed a PCCP external durable pre-grouted PT system called DURALOOP®. • Based on the use of the patented 2MX15 anchorage and special indented strand centering external HDPE/PP sheathing to achieve a fully encapsulated and durable post-tensioning system. • Pre-grouting of the centralized strands prior to stressing provides uniform support of the unbonded monostrands, thus ensuring that the corrosion protection system remains intact.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification

Technology/Method	Freyssinet Frey-CWRAP®/Pipe Wrapping
Design Standards	ASTM D-3039
Design Life Range	50 years
Installation Standards	As per manufacturer's installation manual
Installation Methodology	• Pipeline is dewatered. • Defects and delaminated concrete surfaces repaired with Foreva. • Inner surface is dried. • Robot is introduced in the pipeline through normal entry points. • It is assembled and loaded with carbon fabric rolls and resin barrels. • 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. • Curing time is done at ambient temperature within 2 hours. • 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 2 MPa. • Ensure a minimum overlapping of 600 mm.
IV. Operation and Maintenance Requirements	
O&M Needs	The system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Distance from repair location to surface access • Wrapping materials • Quantity of lineal feet to be rehabilitate • Cleaning and inspection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.freyssinetusa.com/pdfs/brochures/WATER%20CIVIL%20ENGINEERING%20STRUCTURES%20-%20Foreva.pdf • www.freyssinetusa.com/projects.html#pipe Brochure provided by Freyssinet USA • Email correspondence with Dominique Deschamps and Gregoire Jeanson

Datasheet A-10. HOBAS® Segmental Sliplining

Technology/Method	**HOBAS®/Segmental Sliplining**
I. Technology Background	
Status	Conventional
Date of Introduction	NSF/ANSI Standard 61 potable water approval in 1998
Utilization Rates	• Sliplining (all applications) ~1,200,000 ft since 1987 • Less than 5,000 ft for potable water
Vendor Name(s)	**Hobas Pipe USA, Inc.** 1413 Richey Rd. Houston, Texas 77073 Phone: (281) 821-2200 Fax: (281) 821-7715 Toll Free: (800) 856-7473 Email: info@hobaspipe.com Website: www.hobaspipe.com
Practitioner(s)	• New Orleans, Louisiana, Boh Brothers Construction Sliplining of 1,000 ft of 36 in., 125 psi pressure, 46 psi stiffness class pipe into a 48 in. CI main that was nearly 100 years old. • McAllen-Miller International Airport, McAllen, Texas Sliplining of 1,090 ft of 63 in. pipe in concrete pipe under a runway.
Description of Main Features	HOBAS pipes are centrifugally cast, fiberglass reinforced, polymer mortar (CCFRPM). They are strong, light, and inherently corrosion resistant with consistent dimensions, smooth surfaces and high stiffness.
Main Benefits Claimed	• Long, maintenance-free life and corrosion resistance. • Leak-free, quick assembly, gasket-sealed, push-together joints • Low head loss experienced from the smooth inner surface • 20 ft sections and push-together joints (no welding or chemicals). • Field length adjustments with gasket-sealed coupling joints that seal anywhere along the natural pipe OD surface with no calibration.
Main Limitations Cited	• Cannot push through bends over: 3° (for 18 in.), 2° (for 27 in.), 1.5° (for 36 in.), and 1° (for 54 in.) (elbows required at these locations). • Requires excavation at each service for reinstatement • Reduces the inner diameter (ID) although the smooth wall typically improves flow
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Culverts</u>
II. Technology Parameters	
Service Application	Sliplining Rehabilitation of Water Mains
Service Connections	Reinstate with excavation
Structural Rating Claimed	Fully structural with grouted annulus
Materials of Composition	• Centrifugal cast fiberglass reinforced polymer mortar wall • Final interior layer is epoxy resin in addition to the normal polyester layer (for potable water applications only)
Diameter Range, inches	18 in. to 110 in.
Thickness Range	0.35 in. to 4 in.
Pressure Capacity, psi	50 psi to 250 psi
Temperature Range, ^{o}F	Up to 150°F suitable (NSF potable water approval for cold water only)
Renewal Length, feet	Typical length up to 1,000 ft
Other Notes	Stiffness Classes - 36, 46, and 72 psi standard, although others, in-

Technology/Method	HOBAS®/Segmental Sliplining
	between and higher, are available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• NSF/ANSI Standard 61 Certification • AWWA C950, Fiberglass Pressure Pipe Standard
Design Standards	• Chapter 5 of the AWWA Fiberglass Pipe Design Manual, M45 • ASTM D-638, ASTM D-790, ASTM D-1599, ASTM D-2290, ASTM D-2412, ASTM D-2583, ASTM D-2584, ASTM D-2992, ASTM D-3567, and ASTM D-3681
Design Life Range	100 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• Liner pipes are pushed into the existing pipe with the pipes being inserted spigot end first with the bell end trailing. • Sometimes the leading pipe spigot end is protected by a nose piece designed to ride-up and over off-set joints and other minor inconsistencies or debris in the invert. • The pushing force must be applied to the pipe wall end inside of the bell (do not apply the pushing load to the end of the bell and assure that safe jacking loads are not exceeded). • Laterals may be typically reconnected to the new liner pipe using "Inserta Tees" or similar accessories. • Grout the annular space between the OD of the liner pipe and the ID of the existing pipe with a cement or chemical based grout. • During grout placement, assure that the safe grouting pressure is not exceeded and that the grout density and lift heights are coordinated to control the liner pipe flotation and deformation to within allowable limits.
QA/QC	Standard quality control tests are defined in AWWA C950. However, it is not standard to factory hydrotest HOBAS pressure pipes due to their seamless, solid wall, non-porous, monolithic cast construction.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Cut out and replace with pipe of the same OD, using repair clamps and all standard fittings.
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry and exit access pits • Cleaning and inspection • Service reconnection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.hobaspipe.com • Email correspondence with Rick Turkopp

Datasheet A-11. HydraTech HydraTite® Joint Seal

Technology/Method	**HydraTech HydraTite®/Internal Joint Seal**
I. Technology Background	
Status	Conventional
Date of Introduction	1995
Utilization Rates	Over 7,500 seals installed
Vendor Name(s)	**HrdraTech Engineered Products, LLC** 10448 Chester Rd. Cincinnati, Ohio 45215 Phone: (513) 827-9169 Fax (513) 827-9171 Email: info@hydratechllc.com Web: www.hydratechllc.com
Practitioner(s)	Various municipalities and DOT's. Installed by a network of certified contractors specializing in trenchless technology repairs.
Description of Main Features	HydraTite® is an internal sealing system that offers customized mechanical remediation for pipe joint repairs without excavation featuring rapid installation and return-to-service.
Main Benefits Claimed	• A mechanical, trenchless remediation for repair of pipe joints • Each seal is designed and custom made for each application to ensure complete compliance with project specifications • Low profile ensures minimal flow loss • Patented interlocking design for lining long lengths of pipe. • Non-corrosive components
Main Limitations Cited	• Bypass pumping required • Applicable for accessible pipes only • Smaller pipes down to 18 in. are subject to location of repair with respect to access point. • Installed by fully trained application specialists • Pipes must be in a condition to accommodate pressures exerted during expansion of retaining bands.
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas and Power</u>
II. Technology Parameters	
Service Application	Spot Repair with Internal Joint Seals
Service Connections	Not applicable
Structural Rating Claimed	Not-structural
Materials of Composition	• Proprietary rubber seal (EPDM for water) • Stainless steel retaining bands
Diameter Range, inches	18 in. to 218 in.
Thickness Range	• EPDM rubber is 0.6 in. (non-compressed state) • Retaining bands range from 1/8 in. to 3/8 in. depending on pipe size
Pressure Capacity, psi	Up to 300 psi
Temperature Range, °F	Up to 250°F
Renewal Length, feet	Spot repair technology, although seals can be interlocked to any length
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	AWWA M28, ASTM D-395, ASTM D-412, ASTM D-573, and AWS

Technology/Method	**HydraTech HydraTite®/Internal Joint Seal**
	D1.1
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• The system consists of a proprietary rubber seal that spans the joint and is held in place by stainless steel retaining bands in either side of the joint, which must be repaired and cleaned. • These retaining bands are expanded and locked in place using a wedge lock design which forms an air tight clamp around the joint eliminating all infiltration and exfiltration.
QA/QC	In order to guarantee an optimal installation it is necessary pressure test the seals to check for leaks.
IV. Operation and Maintenance Requirements	
O&M Needs	Maintenance free
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Seals and equipment • Mobilization • Entry access pits • Cleaning • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.nsf.org • www.hydratechllc.com/hydratite.html • www.hydratechllc.com/tds/hydratite_tds2.html • Email correspondence with Mike Fox

Datasheet A-12. HydraTech WaterLine Epoxy Lining

Technology/Method	**HydraTech WaterLine/Spray-On Epoxy Lining**
I. Technology Background	
Status	Innovative
Date of Introduction	1993 in the U.K.
Utilization Rates	More than 500,000 lf (95 miles) since 2005 (reported by one contractor)
Vendor Name(s)	**HrdraTech Engineered Products, LLC** 10448 Chester Rd. Cincinnati, Ohio 45215 Phone: (513) 827-9169 Fax (513) 827-9171 Email: info@hydratechllc.com Web: www.hydratechllc.com
Practitioner(s)	• AMEC Utilities, UK • Heitkamp Inc. • Atlantic Underground Services Ltd.
Description of Main Features	WaterLine can be remotely applied in small diameter pipe or installed in potable water vessels. This remote installation allows for the trenchless remediation of pipe down to 4 in. in diameter with minimal out of service time.
Main Benefits Claimed	• A high-build, fat-curing, solvent free epoxy lining system. • Compatible with a variety of substrates. • Return to service in 16 hours
Main Limitations Cited	• Surfaces must be sound and free from grease, dust and all moisture • Requires fully trained application specialists.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Storage Tanks
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	Need to be plugged
Structural Rating Claimed	• Tensile Strength (MPa) 22.26 • Elongation at Yield (%) 1.18 • Young's Modulus (MPa) 1,814 • Compressive Yield Strength (MPa) 118.67 • Flexural Strength (MPa) 38.21 • Coating to Concrete Bond Strength (N) 3,316 • Coating to Metal Bond Strength (N) 2,808
Materials of Composition	Epoxy: 2 parts Base , 1 Part Hardener by volume
Diameter Range, inches	4 in. and up
Thickness Range	Wet and dry film thickness of 40 mils
Pressure Capacity, psi	Depends on hole size, from 70 up to 650 psi (5 to 45 bar, burst pressure)
Temperature Range, °F	• Minimum application temperature 40°F (3°C) • Flash point above 212°F (100° C)
Renewal Length, feet	Limited by the length of the spray hose
Other Notes	• Storage life 12 months when stored in original sealed containers, between 50-77°F (10°-25°C)
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	AWWA M28 and Deb et al., 2006

Technology/Method	**HydraTech WaterLine/Spray-On Epoxy Lining**
Design Life Range	50 years
Installation Standards	In accordance with manufacturer's recommendations
Installation Methodology	• All surfaces must be clean, dry and sound. • Coating should not take place if: (1) the temperature is below 40°F (3°C); (2) the relative humidity exceeds 85%; (3) on steel substrate temperature is less than 5°F (3°C) above the dew point; (4) on concrete the substrate has a moisture content greater than 50% • During application, regular wet film thickness readings must be taken to ensure the required dry film is obtained. • Due to the chemical cure of the materials, they must be thoroughly mixed. The system must be allowed to cure for 16 hours prior to being placed back in service or commissioned.
QA/QC	A clear spark test is recommended on conductive substrates.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Allow a minimum of 6 hours (maximum 48 hrs) before over coating if patch repair is required.
V. Costs	
Key Cost Factors	• Epoxy materials • Entry and exit access pits • Cleaning and inspection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.nsf.org • www.hydratechllc.com/waterline.html • Email correspondence with Mike Fox • Waterline epoxy pressure data

Datasheet A-13. Insituform InsituGuard® Close-Fit Lining

Technology/Method	**Insituform InsituGuard®/Fold and Form/Reduced Diameter Pipe**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced in the U.S. is 2001
Utilization Rates	Approximately 6 miles for potable water applications
Vendor Name(s)	**Insituform Technologies, Inc.** 17999 Edison Avenue Chesterfield, MO 63005 Phone: (636) 530-8000 Fax: (636) 519-8744 Email: drosenberg@insituform.com Web: www.insituform.com
Practitioner(s)	• 1,000 ft of 19 in. to 24 in. Steven Tusler, City of Colorado Springs, (719) 668-8537 • 19,000 ft of 30 in. Dick Fett, IMC Agrico Company, Mulberry, Florida, (863) 648-9990 • 3,700 ft of 36 in. Howard Wellspring, City of Baytown, TX, (713) 424-5508 • 10,000 ft of 48 in. Madison Ave., City of New York
Description of Main Features	Inserted into an existing pipeline, the PE liner is continuous, and installed with a close-fit against the inner wall of the host pipe. The liner isolates the flow stream from the host pipe wall, eliminating internal corrosion. The liner stops leaks, and can provide a fully structural solution and increases flow capacity in some cases. Can be installed via the fold and form process or symmetrically reduced diameter process.
Main Benefits Claimed	• 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)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Fold and Form or Reduced Diameter Pipe Rehabilitation of Water Mains
Service Connections	Service Connections have to be excavated.
Structural Rating Claimed	Class III or IV depending upon diameter, pressure, and pipe condition.
Materials of Composition	4710 (PE 100) is preferred.
Diameter Range, inches	12 in. to 48 in. Folded or 6 in. to 10 in. Flexed
Thickness Range	Dimension ratio (DR) 17 or thinner
Pressure Capacity, psi	• Up to 150 psi for Class III • Class IV dependent upon DR.
Temperature Range, °F	140°F
Renewal Length, feet	Up to 2,000 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	

Technology/Method	Insituform InsituGuard®/Fold and Form/Reduced Diameter Pipe
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	• Class IV design based on AWWA/PPI design standards. • Class III interactive design based on industry accepted design.
Design Life Range	50 years
Installation Methodology	• Excavations are made for access and removal of existing fittings. • Sections of PE pipe are fused 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. • The fused pipe is pushed through the folding machine or roller box, which alters the shape of the pipe, resulting in a diameter reduction of up to 40% of the cross-sectional area which is maintained by banding the folded pipe. • The liner is inserted into the host pipe. • Once the liner is in place, it is pressurized with water to break the bands and re-round the liner. • The liner is cut to length and all end and intermediate connections are installed using fused or mechanical fittings. • The completed line is pressure tested, disinfected and returned to service. Access points are backfilled and reinstated.
QA/QC	• Prior to installation, CCTV inspection of the main is needed to locate any obstructions, protrusion, changes in diameter or in-line valves that could affect the liner. • After installation, the liner is inspected again visually with CCTV, and any abnormalities are noted. • For the post-installation pressure test, an internal pressure equal to twice the known operating pressure, or operating pressure plus 50 psi, whichever is less is applied to the liner. • 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	The system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Excavate, remove the damaged portion of the liner 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	• Pipe Material • Installation Equipment • Entry and exit access pits
Case Study Costs	Not Available
VI. Data Sources	
References	• www.insituform.com/mm/files/InsituGuard-UK.pdf • www.insituform.com/content/309/insituguard---pressure-pipe.aspx • Email correspondence with David Rosenberg

Datasheet A-14. Insituform InsituMain® CIPP Lining

Technology/Method	**Insituform InsituMain®/CIPP**
I. Technology Background	
Status	Innovative
Date of Introduction	Introduced in the U.S. in early 2009
Utilization Rates	Approximately 25,000 ft installed for potable water
Vendor Name(s)	**Insituform Technologies, Inc.** 17999 Edison Avenue Chesterfield, MO 63005 Phone: (636) 530-8000 Fax: (636) 519-8010 Email: drosenberg@insituform.com Web: www.insituform.com
Practitioner(s)	• City of Rochester, Minnesota • Missouri American Water, St. Louis, Missouri • Kansas City, Missouri • Naperville, Illinois
Description of Main Features	• AWWA Class IV fully structural pressure rated CIPP technology. • Applicable for both distribution and transmission water mains. • No risk of disrupting or damaging nearby utilities or other underground infrastructure systems.
Main Benefits Claimed	• Has a PE layer on the inside pipe surface that increases smoothness, reduces surface friction, and provides an additional corrosion barrier • 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 • Cannot negotiate 90° bends
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Industrial Pressure and Fire</u>
II. Technology Parameters	
Service Application	CIPP Lining Rehabilitation of Water Mains
Service Connections	• No specialty fittings required. • In 6 in. and larger pipes service connections can be made by robotic remote access using mechanical sealing apparatus.
Structural Rating Claimed	Exceeds ASTM F-1216 and ASTM F-1743 standards
Materials of Composition	Epoxy composite layer reinforced with glass and polyester fiber materials
Diameter Range, inches	6 in. to 60 in.
Thickness Range	¼ in. (7.5 mm)
Pressure Capacity, psi	150 psi
Temperature Range, °F	Up to 120°F
Renewal Length, feet	200 ft to 400 ft (typically)
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	ASTM F-1216 and ASTM F-1743
Design Life Range	50 years

Technology/Method	**Insituform InsituMain®/CIPP**
Installation Standards	In accordance with manufacturer's operation manual.
Installation Methodology	• Composite materials are saturated with a thermosetting epoxy resin either on the job-site or in an authorized Insituform wet out facility. • Using water or air pressure, the tube is then inserted into the host pipe by either a pull-in or inversion method. • Following installation, hot water or steam is used to cure the thermosetting resin. • 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 putting it back into 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	• Materials: liner and epoxy resin, fittings, valves and hydrants • Mobilization • Bypass system • Entry and exit access pits • Cleaning and inspection • Service plugging and reinstatement • Site restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.insituform.com/mm/files/InsituMain%20Brochure.pdf • www.insituform.com/content/579/insitumain-technical-envelope.aspx • Email and phone correspondence with David Rosenberg

Datasheet A-15. Insituform PPL® CIPP Lining

Technology/Method	**Insituform PPL®/CIPP**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced in the early 1990s
Utilization Rates	Not Available
Vendor Name(s)	**Insituform Technologies, Inc.** 17999 Edison Avenue Chesterfield, MO 63005 Phone: (636) 530-8000 Fax: (636) 519-8010 Email: drosenberg@insituform.com Web: www.insituform.com
Practitioner(s)	• City of Albuquerque, NM • City of Greely, CO • City of Detroit, MI • City of Saskatoon, Saskatchewan, Canada
Description of Main Features	• Custom-engineered product designed to eliminate leakage and prevent internal corrosion and/or erosion in structurally sound pressure pipe. • Designed with the flexibility to expand up to and transfer internal pressure loading to the host pipe while maintaining the ability to span any small holes, pits or open joints that may exist in the host pipe. • Design assumes that the host pipe is currently structurally sound and will continue to carry the internal pressure loading for the life of the piping system.
Main Benefits Claimed	• Suitable for CI, DI, steel, AC, RCP, and thermoplastic pipes • Thin wall and close fit minimizes reduction in flow cross section • Flexibility to negotiate horizontal and vertical bends up to 90° • Small site footprint required for installation • Installed inside the existing main so there is no risk of damage or disturbance to adjacent utilities or infrastructure • Trenchless installation of CIPP reduces traffic and commercial disruption, site noise, pollution and safety concerns as well as the need for imported backfill and pavement reinstatement
Main Limitations Cited	• Bypass required • Limited to structurally sound host pipes
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Industrial Pressure and Fire</u>
II. Technology Parameters	
Service Application	CIPP Lining Rehabilitation of Water Mains
Service Connections	No specialty fittings required
Structural Rating Claimed	Not a structural solution
Materials of Composition	• The CIPP tubes have a construction similar to that of standard Insituform CIPP tubes, but special glass reinforcement is included to address specific service conditions found in pressure applications. • Resin system is either a vinyl ester or epoxy, depending on the application.

Technology/Method	Insituform PPL®/CIPP
	• For drinking water applications, a special epoxy resin system is used.
Diameter Range, inches	8 in. to 60 in.
Thickness Range	Not Available
Pressure Capacity, psi	Up to 200 psi
Temperature Range, °F	Up to 120°F
Renewal Length, feet	200 ft to 1,000 ft (Typically)
Other Notes	pH range of 0.5 to 12
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	ASTM F-1216
Design Life Range	50 years
Installation Standards	In accordance with manufacturer's operation manual.
Installation Methodology	• The reinforced felt tube is saturated with a thermosetting resin, then carefully packaged for transport. • The tube is positioned in the pipeline using water pressure to turn the tube inside out via the inversion process. • The continuous hydrostatic pressure of the inversion process results in a close fit with the host pipe. • Following inversion, the thermosetting resin is cured by circulating hot water throughout the tube. Once cured, the pipe is cooled, ends are cut and sealed, and the pipe is returned to service.
QA/QC	• Samples tested in accordance with ASTM D-790 and ASTM D-638. • The lined section is tested under pressure to check for water tightness.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of the system before putting it back into 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	• Materials: liner and resin • Bypass system • Entry and exit access pits • Cleaning and inspection
Case Study Costs	Not Applicable
VI. Data Sources	
References	• www.insituform.com/content/345/about_insituform_ppl.aspx • www.insituform.com/content/207/how_insituform_ppl_is_installed.aspx • Insituform PPL Specification for Potable Applications • Email and phone correspondence with David Rosenberg

Datasheet A-16. Insituform Thermopipe® Hose Lining

Technology/Method	**Insituform Thermopipe®/Hose Liner**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced in the U.S. in 1997
Utilization Rates	Over 800,000 ft. installed worldwide
Vendor Name(s)	**Insituform Technologies, Inc.** 17999 Edison Avenue Chesterfield, MO 63005 Phone: (636) 530-8000 Fax: (636) 519-8010 Email: drosenberg@insituform.com Web: www.insituform.com
Practitioner(s)	• 1,550 ft of 12 in. Water Main Dennis Pay, City of South Salt Lake 195 W. Oakland Avenue, South Salt Lake, UT 84115 (801) 483-6038 • 1,400 ft of 8 in. Terry Hodnik, NIES Engineering Hammond, IN (219) 844-8680 • 1,000 ft of 8 in. George Fanous, City of Grand Prairie, TX (972) 237-8143
Description of Main Features	• A thin reinforced polyethylene liner that is ideally suited for rehabilitation of distribution water mains and other pressurized piping systems. • Supplied as a factory-folded "C" shape liner, the PE liner is winched into the host pipe from a reel and reverted with steam. • Once inflated and heated, the liner forms a close-fit within the host pipe, creating a joint less, leak-free lining system able to independently carry the full system internal design pressure. • Can usually be completed within an 8-hour time period.
Main Benefits Claimed	• The fully structural PE 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 • Cannot negotiate bends greater than 45°
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Industrial and Fire applications
II. Technology Parameters	
Service Application	Hose Lining Rehabilitation of Water Mains
Service Connections	In pipe 6 in. in diameter and greater, service reconnections up to 10 in. diameter can be made to the lined pipe by remote internal connection of a mechanical sealing apparatus.

Technology/Method	**Insituform Thermopipe®/Hose Liner**
Structural Rating Claimed	Independent structural lining, AWWA Class IV
Materials of Composition	Polyester Reinforced Polyethylene
Diameter Range, inches	2.75 in. to 12 in.
Thickness Range	0.08 in. to 0.20 in.
Pressure Capacity, psi	170 psi (up to 230 psi for 4 in., 6 in., and 8 in. diameters)
Temperature Range, °F	140°F
Renewal Length, feet	1,600 ft (for 4 in. to 8 in.) and 700 ft (for 10 in. to 12 in.)
Other Notes	Can negotiate bends up to 45°.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	Manufacturer supplied internal pressure rating
Design Life Range	50 years
Installation Standards	In accordance with manufacturer's recommendations
Installation Methodology	• The pipe is dewatered and reasonably free of incoming water. • The liner is winched in through an appropriate pipe opening. • The liner is inflated using compressed air, then heated with steam. • The liner is then cooled and adequate air pressure shall be maintained during the cooling process to ensure a tight fit between the liner and the host pipe when pressure is removed. • After installation, the liner shall be cut to appropriate length to allow fitting of end couplers capable of maintaining a leak proof seal at the system design pressure.
QA/QC	• Prior to installation, CCTV inspection of the main is needed to locate any obstructions, protrusion, changes in diameter or in-line valves. • After installation, the liner is inspected again visually with CCTV, and any abnormalities are noted. • Pressure testing is carried out after cooling to the original ambient ground temperature. The liner 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. Make-up water to maintain pressure is limited to 20 gallons per inch diameter per mile of pipe per day.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into 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	• Materials: fittings and liner • Bypass system • Entry and exit access pits • Cleaning and inspection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.insituform.com/mm/files/IBLU%20A4%20Therm%20Sheet.pdf • Email correspondence with Lynn Osborn and David Rosenberg

Datasheet A-17. LINK-PIPE Hydro-Seal™ Mechanical Sleeve

Technology/Method	**LINK-PIPE Hydro-Seal™/Mechanical Sleeve**
I. Technology Background	
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	**LINK-PIPE Inc.** 27 West Beaver Creek Road, Unit #2 Richmond Hill, ON L4B 1M8 Phone: (800) 265-5696 Fax: (905) 886-7323 Email: info@linkpipe.com Web: www.linkpipe.com
Practitioner(s)	Not Available
Description of Main Features	Hydro-Seal™ is an internal repair method, designed for joint rehabilitation of water mains, repair of pin-holes, cracks, and areas of corrosion.
Main Benefits Claimed	• Provides long-term seal of leaks using mechanically locked stainless steel sleeves and aquatic resin sealers • Seals leaking and separated, misaligned, and offset joints • Seals pinholes
Main Limitations Cited	Only used for spot repairs up to 3 ft long
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Not Applicable
II. Technology Parameters	
Service Application	Spot Repair by Mechanical Sleeve
Service Connections	Need to address separately. Punching holes in the sleeve is not recommended.
Structural Rating Claimed	Not structural
Materials of Composition	• The sleeve core is made of stainless steel SST-316. • Outside gasket is saturated with resin.
Diameter Range, inches	4 in. to 54 in.
Thickness Range	Less than 3/8 in.
Pressure Capacity, psi	Tested up to 560 psi (37 bar) for ultimate pressure over a 3/8 in. (10 mm.) 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 in., 18 in., 24 in., and 36 in. are available.
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	ASTM A-240
Design Life Range	More than 50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• For repairs, the main must be taken out of service. • The prospective work site in the pipe should then be pre-inspected using a CCTV camera to determine the internal condition of the host pipe and the location of the intended installation. • Prior to an installation, the main must be thoroughly cleaned of any

Technology/Method	**LINK-PIPE Hydro-Seal™/Mechanical Sleeve**
	deposits exposing the pipe wall to bare metal over the repair area. • A second CCTV inspection should be made following the cleaning to verify that the pipe is ready for the repairs. • In preparation for the installation the plug must be calibrated. Calibration pressure is the pressure required to inflate the plug rubber to make contact with inside wall of the host pipe. • Sleeve preparation: Supplied resin is mixed and worked into the felt gasket. The gasket is then wrapped around the sleeve and tied so as to hold it on the sleeve. The prepared sleeve is then mounted on the air plug specified for installation. Slight pressure is applied to the plug to hold the sleeve in place while the assembly travels in the pipe. A camera is attached in front of the plug/sleeve assembly looking back on the sleeve to monitor sleeve transportation and installation of the sleeve. • When the sleeve arrives to the repair site, it is positioned while being observed by the CCTV camera. • Installation is complete when all locks are engaged. Engaging of the locks is often announced by clicking sounds that can be heard coming from the pipe. As soon as the locks are engaged, the plug must be deflated. The resin must be left to cure undisturbed. • Before removing the Plug from the pipe, or moving on to another installation site, the sleeve must be re-inspected to make sure all locks are engaged. Equipment is then retrieved.
QA/QC	Manufactured 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	• Stainless steel sleeves • Resins materials • Pits for access to the main
Case Study Costs	Not Available
VI. Data Sources	
References	www.linkpipe.com/applications.htm www.linkpipe.com/PDF/hs_specifications_internet.pdf

Datasheet A-18. MainSaver™ Composite Lining

Technology/Method	**MainSaver™/Cement-Polyethylene Composite Liner**
I. Technology Background	
Status	Innovative
Date of Introduction	UK market in 1999 and U.S. market in 2006
Utilization Rates	Approximately 7,000 ft installed in the U.S.
Vendor Name(s)	**MainSaver™** 14062 Denver West Parkway, Suite 110, Building 52 Golden, CO 80401 Phone: (303) 277-8603 Fax: (303) 277-0042 Toll Free: (866) 594-8345 Email: info@mainsaverworld.com Website: www.mainsaverworld.com
Practitioner(s)	• City of Thornton 12450 Washington Street Thornton, CO 80241-2405 Jason Pierce, (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. Air pressure is used to move a swab along the length of the liner, which progressively expands the tube and distributes the grout against the interior surface of the host pipe. Used to renew pipes with holes, displaced joints, and leaking joints.
Main Benefits Claimed	• Suitable for use with ferrous, AC, reinforced concrete, and PCCP • PE tube ensures water quality, prevents leakage and restores hydraulic capacity • Service connections can be reinstated robotically to reduce excavation requirements
Main Limitations Cited	• Designed for pressure pipes only • Unsuitable for lining PVC, PE, or PE/PU/bituminous coated pipe • Unsuitable for lining through diameter changes • Cannot negotiate bends greater than 11.25° elbows
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Cement-Polyethylene Composite Lining Rehabilitation of Water Mains
Service Connections	Uses a RoboTap™ method for remote robotic service connection reinstatement after the composite has been installed.
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 in. to 12 in.
Thickness Range	Up to 3 mm, however, grout will often be thicker where it is filling pipe defects.
Pressure Capacity, psi	Maximum hole size of 1 in. with pressure up to 294 psi (20 bar)
Temperature Range, °F	37°F and up (ideally between 40°F and 80°F during installation)
Renewal Length, feet	Up to 500 ft

Technology/Method	**MainSaver™/Cement-Polyethylene Composite Liner**
Other Notes	Cathodic protection can be restored to ferrous pipes to retard external corrosion.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	Not Available
Design Life Range	50 years
Installation Standards	As per manufacturers guidelines
Installation Methodology	• Main must be thoroughly cleaned and CCTV inspected. • Robotically plug any open service connections where unwanted grout may migrate. • The liner is winched in and at the end where grout is to be introduced; a grout injection fitting is fixed to the 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 16 hours. • Once the grout is hydrated, the lining is inspected using CCTV and Infrared thermography. • Services are remotely reinstated and PE end seals are installed to protect the liner while it's being returned to service. • The pipe is disinfected before being put back into service.
QA/QC	• The Quality Management System is certified to ISO 9001:2000 for the Custom Manufacture of NSF/ANSI Standard 61 Extruded Tape and Insitu Remediation of Potable Water Lines. • 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.
Repair Requirements for Rehabilitated Sections	The liner can be cut out with the damaged pipe section and conventionally patched with a spool piece.
V. Costs	
Key Cost Factors	• Liner material and equipment • Mobilization • Entry and exit access pits • Surface restoration • Cleaning and inspection • Traffic control requirements
Case Study Costs	Not available
VI. Data Sources	
References	• www.mainsaverworld.com/about • Email correspondence with Dan Cohen and Bruce Butler.

Datasheet A-19. Miller Pipeline Weko-Seal® Joint Seal

Technology/Method	**Miller Pipeline Weko-Seal®/Internal Joint Seal**
I. Technology Background	
Status	Conventional
Date of Introduction	1980
Utilization Rates	Over 285,000 installations to date.
Vendor Name(s)	**Miller Pipeline Corp.** 8850 Crawfordsville Rd. Indianapolis, Indiana 46234 Phone: (317) 293-0278 Fax: (317) 293-8502 Email: terry.bell@millerpipeline.com Web: www.millerpipeline.com
Practitioner(s)	• Denver Water • City of Dallas, Water Department • Ft. Worth Water • City of Milwaukee, Milwaukee Water Works • Santa Clara Valley Water Department • City of Des Moines Water • Marietta Water Authority • DC Water and Sewer Authority
Description of Main Features	The Weko-Seal® is flexible rubber leak clamp that ensures a non-corrodible, bottle-tight seal around the full inside circumference of the joint area. Its design incorporates a series of proprietary lip seals that create a leak proof fit on either side of the joint. Installed internally with up to 2,000 feet between access points, the seal can be utilized in square, rectangular, round or elliptical pipes, including transitions, fittings, and vertical offsets or specialty configurations. In nuclear and fossil fuel power plant applications, the WEKO-SEAL® is used for sealing leaks in both fresh and seawater cooling and circulation lines.
Main Benefits Claimed	• Non-corrodible seal with minimal reduction of internal diameter • Accommodates normal pipe movement from ground shifting, thermal expansion or contraction, and vibration • Test valves standard in all seals • Minimum surface disturbance • Access openings can be in excess of 2,000 feet apart
Main Limitations Cited	• Bypass pumping required • Applicable for accessible pipes only or end of non-accessible pipes
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Natural Gas, Industrial, and Nuclear</u>
II. Technology Parameters	
Service Application	Spot Repair with Internal Joint Seals
Service Connections	Not applicable
Structural Rating Claimed	Non-structural
Materials of Composition	• Cement mortar • Stainless steel retaining bands • EPDM rubber
Diameter Range, inches	16 in. to 216 in.
Thickness Range	Approximately 1 in. diameter reduction after installation.

Technology/Method	**Miller Pipeline Weko-Seal®/Internal Joint Seal**
Pressure Capacity, psi	Up to 300 psi
Temperature Range, °F	0°F to 305°F
Renewal Length, feet	• Spot repair technology, seals vary from 11 in. to 18 in. long. • Extended coverage can be achieved through sleeve/seal concept.
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Classified by UL for NSF/ANSI Standard 61 (not listed on the NSF website)
Design Standards	ASTM D-3568 and ASTM D-3900
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	Selected seal straddles the leaking joint and is held firmly in position by hydraulically expanded stainless steel retaining bands.
QA/QC	• Seals are tested to provide a 100% positive leak-proof barrier through the test port located within each seal. • Installations typically performed by manufacturer's trained installation personnel.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Dewatering, lock-out/tag-out, access and means for ventilation.
V. Costs	
Key Cost Factors	• Seals and equipment • Mobilization • Entry access pits • Cleaning • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.millerpipeline.com/weko-seal.html • Email correspondence with Terry Bell

Datasheet A-20. NordiTube NordiPipe™ CIPP Lining

Technology/Method	**NordiTube NordiPipe™/CIPP**
I. Technology Background	
Status	Innovative
Date of Introduction	Introduced in 2002 in Sweden, 2004 in Canada, 2009 in the U.S.
Utilization Rates	Approximately 34 miles installed annually in North America
Vendor Name(s)	**Sekisui NordiTube Inc.** 501 N. El Camino Real, Suite 224 San Clemente, CA 92672 Phone: (714) 267-1030 Email: jaykeating@cox.net Web: www.sekisuispr.com/public/spr/en
Practitioner(s)	• Jean Lemire, City of Cornwall 1225 Ontario Street Cornwall, Ontario, Canada K6H 5T9 Phone : (613) 930-2787 Email: jelemire@cornwall.ca • Tony Di Fruscia, City of Montreal 13301 Sherbrooke St. E., Suite 209 Montreal, Quebec, Canada H1A 1C2 Phone : (514) 872-6678 Email: tonydifruscia@ville.montreal.qc.ca • Annie Fortier, City of Dorval 60 Martin Ave. Dorval, Quebec, Canada H9S 3R4 Phone: (514) 633-4244 Email: afortier@ville.dorval.qc.ca
Description of Main Features	NordiPipe™ is a CIPP system that incorporates a glass fiber reinforced layer(s) between two polyester felt layers, impregnated with epoxy resin. A PE coating is on the interior of the liner.
Main Benefits Claimed	• Fully-structural, no support of the host pipe required for internal or external loads • High pressure resistance • Can negotiate bends up to 45°
Main Limitations Cited	• Not recommended for low ground temperature when using epoxy • Bypass required • Cannot negotiate bends greater than 45°
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	CIPP Lining Rehabilitation of Water Mains
Service Connections	Internally reinstated robotically or externally by excavation
Structural Rating Claimed	AWWA Type IV – Fully-structural
Materials of Composition	• Polyethylene coating in contact with potable water • Non-woven felt and glass fiber woven mat • Epoxy or vinyl ester resin
Diameter Range, inches	6 in. to 48 in. (150 mm to 1200 mm)
Thickness Range	0.18 in. to 0.94 in. (4.6 mm – 24 mm)
Pressure Capacity, psi	6 in. to 250 psi and 48 in. to 60 psi

Technology/Method	**NordiTube NordiPipe™/CIPP**
Temperature Range, °F	100°F with epoxy and 160°F with vinyl ester
Renewal Length, feet	800 ft to 1,000 ft
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	ASTM F-1216
Design Life Range	50 years
Installation Standards	Not Available
Installation Methodology	• The liner is either air inverted with air/steam cure, or water column inverted with circulated water cure. • Service reinstatement is performed internally with robotics or externally with saddles.
QA/QC	• Resin yield check for impregnation • 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 couplings/fittings • Link-Pipe ring repair
V. Costs	
Key Cost Factors	• Materials: liner, resin, fittings, valves and hydrants • Mobilization • Bypass system • Entry and exit access pits • Cleaning and inspection • Service plugging and reinstatement • Site restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• www.sekisuispr.com/public/spr/en/technology/schlauchlining/nordipipe.html • Email correspondence with Steve Leffler and Jay Keating • Norditube brochure

Datasheet A-21. NordiTube Tubetex™ CIPP Lining

Technology/Method	**NordiTube Tubetex™/CIPP**
	I. Technology Background
Status	Conventional
Date of Introduction	Introduced in 1986 in Europe
Utilization Rates	Several kilometers for gas and water
Vendor Name(s)	**Sekisui NordiTube Inc.** 501 N. El Camino Real, Suite 224 San Clemente, CA 92672 Phone: (714) 267-1030 Email: jaykeating@cox.net Web: www.sekisuispr.com
Practitioner(s)	Not Available
Description of Main Features	This type of liner was developed in Japan to rehabilitate pipes in earthquake areas. It has a unique coating which combines with the round, woven fabric pipe; TUBETEX™ can cope with many gas and water-related problems.
Main Benefits Claimed	• Adheres to the old pipe but remains extremely flexible • Approved for host pipes up to PN 32 • Can negotiate bends up to 90° • Support service offered by experts every step of the way
Main Limitations Cited	• Bypass required • Not available currently in the U.S.
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas</u>
	II. Technology Parameters
Service Application	CIPP Lining Rehabilitation of Water Mains
Service Connections	Internally reinstated robotically or externally by excavation
Structural Rating Claimed	Not Available
Materials of Composition	• PE coating in contact with potable water • High modulus polyester yarn tube • Epoxy resin
Diameter Range, inches	4 in. to 40 in. (100 mm to 1000 mm)
Thickness Range	Not Available
Pressure Capacity, psi	Up to 460 psi (32 bar)
Temperature Range, °F	Not Available
Renewal Length, feet	Up to 1,970 ft (600 m)
Other Notes	Not Available
	III. Technology Design, Installation, and QA/QC Information
Product Standards	• Not NSF/ANSI Standard 61 Certified • Approved for potable water in various countries
Design Standards	Not Available
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• The liner is inverting with a pressure drum and cured with steam. • Service reinstatement is performed internally with robotics or externally with saddles.
QA/QC	• Manufactured in accordance with ISO 9001
	IV. Operation and Maintenance Requirements

Technology/Method	NordiTube Tubetex™/CIPP
O&M Needs	Protection of the PE coating during inspection or cleaning
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Materials: liner, resin, fittings, valves and hydrants • Mobilization • Bypass system • Entry and exit access pits • Cleaning and inspection • Service plugging and reinstatement • Site restoration
Case Study Costs	Not Available
VI. Data Sources	
References	www.sekisuispr.com/public/spr/en/technology/schlauchlining/tubetex.html

Datasheet A-22. Nu Flow Epoxy Coating

Technology/Method	**Nu Flow Epoxy/Forced Air Epoxy Coating**
I. Technology Background	
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	**Nu Flow Technologies Inc.** 1010 Thornton Rd. South Oshawa, Ontario L1J 7E2 Phone: (800) 834-9597 Fax: (905) 433-9687 Email: info@nuflowtech.com Web: www.nuflowtech.com
Practitioner(s)	• MetLife Building, New York City , NY • Bonner Hospital, Sandpoint, ID
Description of Main Features	Streamlines restoration in a quick, cost-effective way. Nu Flow's non-invasive epoxy pipe lining process can resolve 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	• Limited to diameters less than 10 in. • Not applicable for water mains
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main <u>Service Lines</u> Other: <u>Industrial pressure lines</u>
II. Technology Parameters	
Service Application	Coating Repair of Water Services
Service Connections	Valves and couplings are refitted after curing
Structural Rating Claimed	Not Available
Materials of Composition	Epoxy
Diameter Range, inches	½ in. to 10 in.
Thickness Range	12 mils
Pressure Capacity, psi	Not Available
Temperature Range, °F	Not Available
Renewal Length, feet	10 ft to 1,000 ft
Other Notes	The process can be used on a variety of piping materials including galvanized steel, copper, CI, black iron, and lead pipe. The abrading agent is EPA-approved sand for open and closed blasting locations. The cured epoxy product is durable and impervious to the corrosive action of acids, alkalis, and petroleum.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 approved by Underwriters Laboratories, Inc. (not listed on the NSF website)
Design Standards	• Potable Water Part A #700 • Potable Water Part B #720
Design Life Range	35 to 50 years under normal use (has exhibited a potential useful life up to 80 years in accelerated laboratory mechanical testing).
Installation Standards	Not Available
Installation Methodology	• System diagnosis begins with mapping the internal plumbing system

Technology/Method	Nu Flow Epoxy/Forced Air Epoxy Coating
	and inspecting it for integrity and spot repairs are made to excessively worn joints and fittings. Temporary bypass water piping may be installed. The system is drained and air-dried. After testing for leaks, the pipes are prepared for cleaning. • Pipes are dried with heated, compressed air. A safe abrading agent is blown through the pipe system, removing rust and corrosion by-products that are collected in a holding unit for disposal. Compressed air is applied once again to remove fine particles. • Optimal internal pipe surface temperature is created prior to epoxy coating. Another air pressure leak test is performed. Conditioned air is then introduced into the pipe to uniformly distribute the epoxy coating throughout the pipe segment. Following the coating application, continuous controlled air flows through the piping to facilitate epoxy curing. • After curing, valves and couplings are refitted. A final leak test and inspection confirms lining integrity.
QA/QC	Water quality, volume, and flow tests confirm system functionality.
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Epoxy materials • Forced air equipment • Access to the service • Duration of cure, entire process takes 2 to 3 days
Case Study Costs	Not Available
VI. Data Sources	
References	• www.nuflowtech.com/Products/EPOXYLINING.aspx • Nu Flow Technical Specifications • Phone conversation with Cameron Manners

Datasheet A-23. Pipe Wrap A+ Wrap™ Pipe Wrapping

Technology/Method	**Pipe Wrap A+ Wrap™/Pipe Wrapping**
I. Technology Background	
Status	Innovative
Date of Introduction	October 2006
Utilization Rates	Not Available
Vendor Name(s)	Pipe Wrap LLC P.O. Box 270190 Houston, TX 77277 **Phone:** (713) 365.0881 **Fax:** (713) 463.4459 Web: www.piperepair.net E-mail: info@piperepair.net
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.
Main Benefits Claimed	• Conformable high strength piping remediation wrap consisting of proprietary glass fiber reinforcement fabric that is factory impregnated with durable, moisture cured polyurethane resins • Offers non-intrusive piping remediation, repair, reinforcement, and/or complete hoop strength replacement to any size, material, shape or configuration including elbows, manifolds, tees, or bends • Efficient and economical • Chemically resistant, nonconductive, and temperature resistant
Main Limitations Cited	• Only used externally • Requires excavation
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Oil and Gas lines</u>
II. Technology Parameters	
Service Application	Spot Repair of Water Mains
Service Connections	Service connections have to be done separately if required.
Structural Rating Claimed	• Shear Modulus 185,000 psi as per ASTM D-5379 • Tensile Modulus 3.01 x 10^6 psi as per ASTM D-3039 • Tensile Strength 51,800 psi as per ASTM D-3039 • Flexural Modulus 1.9 x 10^6 psi as per ASTM D-790 • Thermal Expansion 10.2 (um/m/C^o) as per ASTM E-831
Materials of Composition	Resin impregnated woven fiberglass
Diameter Range, inches	½ in. and up
Thickness Range	Ply thickness 0.022 in. (22 mils)
Pressure Capacity, psi	No pressure limit (design of the systems are based on the maximum working stress of steel pipe). All pipelines are designed in accordance with the basic formula, where the maximum allowable wall stress is a constant regardless of pressure.
Temperature Range, ^{o}F	176°F (80°C)
Renewal Length, feet	No limitation, limited by access only

Technology/Method	**Pipe Wrap A+ Wrap™/Pipe Wrapping**
Other Notes	Setting Time of 1 hr and a curing time of 24 hrs to achieve 100% operational use.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• Allowed for DOT 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. • Meets NSF/ANSI Standard 61 2007a, Section 6 (not listed on the NSF website), tested in May 2008 by IAPMO R&T Lab, Project No. 14177, results available upon request.
Design Standards	• ASTM D-790, ASTM D-3039, ASTM D-5379, and ASTM E-831
Design Life Range	20 years
Installation Standards	• As per manufacturer's guidelines
Installation Methodology	• The anchor pattern and cleanliness requirement shall meet the minimum standard of NACE #3 or SA 2 ½ (NACE #1 is preferred) finish or equivalent for pipe surface preparation prior to installation. • Solvent wipe blasted surfaces. • In the event that the repair zone of the pipe cannot be sandblasted, a hand grinder with disc (24 to 80 grit) may be used to create a clean anchor patterned surface. Solvent wipe surface (as applicable). • Prepare pipe by abrasive blast to produce a uniform 2.5 to 4 mil profile. Disk grinding, wire brush or wire wheel can be used as alternatives in some situations. • Apply accompanying undercoating, according to directions, over prepared area. Wrap 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	In-house procedure as per ISO 9001
IV. Operation and Maintenance Requirements	
O&M Needs	The system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Wrap materials • Access to the main • Surface restoration
Case Study Costs	Available on request
VI. Data Sources	
References	• www.piperepair.net/apluswrap.html • E-mail correspondence with Jim Souza and Gen Withers

Datasheet A-24. Powercrete® PW Epoxy Coating

Technology/Method	**Powercrete® PW/Spray-On Epoxy Coating**
I. Technology Background	
Status	Conventional
Date of Introduction	Not Available
Utilization Rates	Not Available
Vendor Name(s)	**Protection Engineering** 2201 Harbor St., Unit C Pittsburg, California 94565 Phone: (925) 427-6200 Fax: (925) 427-6202 Web: http://powercrete.corrosioncoatings.com/index.htm Email: info@corrosioncoatings.com
Practitioner(s)	Not Available
Description of Main Features	Powercrete® PW is a liquid epoxy polymer coating designed for use on potable and wastewater pipes and storage tanks. The coating is effective for slurries and abrasive applications and offers protection from corrosion as it provides high adhesion to bare steel and ductile iron along with abrasion resistance.
Main Benefits Claimed	• Same formula can be hand or spray applied • Flexibility in difficult to coat field conditions • Adhesive to, cathodic disbondment and soil stress resistance on bare steel
Main Limitations Cited	• Requires man-entry for internal use • Not a structural solution
Applicability (Underline those that apply)	Force Main <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Storage Tanks</u>
II. Technology Parameters	
Service Application	Spot Repair Coating of Water Mains
Service Connections	Need to be plugged or done in a second phase.
Structural Rating Claimed	ASTM C-109, ASTM D-2240, and ASTM D-3289
Materials of Composition	100% Solids Liquid Epoxy, no VOCs or isocyanates
Diameter Range, inches	8 in. and up
Thickness Range	0.02 in. (20 mils)
Pressure Capacity, psi	Not Applicable
Temperature Range, ^{o}F	Maximum operating temperature is 140°F
Renewal Length, feet	Limited by length of hose if spray applied
Other Notes	Mix ratio A:B is 100:5.5 by weight.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• NSF/ANSI Standard 61 Certification • WRc-NSF, UK BS: 6920 Standard Certified
Design Standards	ASTM C-581, ASTM D-149, ASTM D-570, ASTM D-4060, ASTM D-4541, ASTM G-14, ASTM G-95, and NACE RP0394-2002
Design Life Range	Not Available
Installation Standards	If the surface to be coated is below 10°C (50°F), preheating of the substrate is recommended. Preheat temperatures should not exceed 82°C (180°F) prior to the application.
Installation Methodology	The coating is applied by spraying 1 coat, roughly 20 mils thick. Curing takes 24 hrs at 25°C (72°F) and 10 days at 43°C (104°F) +/- 3°C.

Technology/Method	Powercrete® PW/Spray-On Epoxy Coating
QA/QC	Disinfection as per AWWA standards when used in potable water pipes.
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	The coating can be reapplied over rehabilitated sections.
V. Costs	
Key Cost Factors	• Epoxy materials • Entry and exit access pits • Duration of cure time
Case Study Costs	Not Available
VI. Data Sources	
References	• www.berrycpg.com/index.asp?marca=004 • http://powercrete.corrosioncoatings.com/powercrete-pw.html

Datasheet A-25. QuakeWrap™ Pipe Wrapping

Technology/Method	**QuakeWrap™/Pipe Wrapping**
I. Technology Background	
Status	Conventional
Date of Introduction	Mid-1990s
Utilization Rates	More than 6,500 lf of pipe
Vendor Name(s)	**QuakeWrap, Inc** 2055 E. 17th St. Tucson, Arizona 85719 Phone: (520) 791-7000 Fax: (520) 791-0600 Toll Free: (800) 782-5397 Email: engineering@quakewrap.com Web: www.quakewrap.com
Practitioner(s)	• FRP Construction, Tucson, Arizona San Juan Generating Station, 700 ft of 10 in. PCCP San Juan Generating Station, sections of 4 ft and 10 ft steel El Encanto Pipeline, Costa Rica, 5700 ft of 7 ft concrete pipe • Nuclear Power Plant, 11,500 ft^2 on 9 ft diameter PCCP
Description of Main Features	QuakeWrap™ VU18C is a high-strength unidirectional carbon fabric. The fabric is impregnated in the field using QuakeBond™ J300SR saturating resin to form a CFRP used to strengthen structural elements.
Main Benefits Claimed	• Strong and lightweight fabric ideal for confined spaces • Used for flexure and shear strengthening as well as confinement • Can be wrapped around complex shapes • Non-corrosive and alkali resistant
Main Limitations Cited	• Requires man-entry if used internally • Requires excavation if used externally • Not to be used on concrete pipes in freeze thaw areas
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Water Tanks</u>
II. Technology Parameters	
Service Application	Spot Repair of Water Mains
Service Connections	Can be cut to fit around services
Structural Rating Claimed	• Nominal tensile strength is 4.1 kips/linear inch of width of FRP strip. • For multiple layered FRP with all carbon fibers running in the same direction, the total force is 98 kips by the number of layers.
Materials of Composition	Epoxy resin and carbon fabric
Diameter Range, inches	36 in. and up if used internally and any size if used externally
Thickness Range	1/8 in. (90 mils)
Pressure Capacity, psi	Depends on the diameter of the pipe and the number of layers considered. The formula to calculate the nominal pressure capacity is P = 2nT/D; where P is the nominal internal pressure capacity provided by the FRP liner, n is the number of layers, T is the nominal tensile strength of the laminated FRP and D is the diameter of the pipe. For example, if you are retrofitting a 24 in. pipe with 2 layers of VU18C, the nominal increase in the internal pressure capacity of the pipe will be P = 2(2 layers)(4100 psi)/24 in. = 683.33 psi.
Temperature Range, ^{o}F	32°F to 140°F (0°C to 60°C)

Technology/Method	**QuakeWrap™/Pipe Wrapping**
Renewal Length, feet	Limited by access only
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	ASTM D-2584 and ASTM D-3039
Design Life Range	Up to 50 years
Installation Standards	The manufacturer specification addresses proper prep work, installation and curing procedures.
Installation Methodology	• A tack coat is applied at a ratio of 2:1 by volume up to 40 mils. • The second layer involves applying a coat of saturating resin to the carbon fabric at a ratio of 2:1 by volume (to a maximum 50% by volume of resin to fabric) to 50 mils.
QA/QC	• Provided in the FRP installation specification. • In general, QA/QC involves testing of the pipe substrate pull off strength, FRP pull off strength and FRP tensile strength. • FRP installation quality is addressed by establishing repair measures as a function of the size and dispersion of blisters. Such blisters develop due to entrapped air bubbles or delaminations of the FRP.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Repair procedures during FRP installation are addressed in the QA/QC sections of the specifications.
V. Costs	
Key Cost Factors	• Materials: Carbon fabric and saturating resin • Mobilization • Bypass system • Entry and exit access pits • Cleaning and inspection • Site restoration
Case Study Costs	Unit prices for retrofit of pipelines in US power plants have a practical range of \$30/sf to \$40/sf of CFRP liner. This price includes engineering, installation supervision, materials, and installation labor. For the Costa Rica pipeline, a glass FRP liner was installed. The unit price was around \$8/sf and included materials, engineering, and installation supervision, but excluded installation labor (provided by the prime).
VI. Data Sources	
References	• www.nsf.org • www.quakewrap.com/pipes.php • Phone and email correspondence with Carlos Pena

Datasheet A-26. Radlinger Primus Line ® Hose Lining

Technology/Method	**Radlinger Primus Line®/Hose Liner**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced in the Germany in 2001
Utilization Rates	Not Available
Vendor Name(s)	**Radlinger Primus Line GmbH** Kammerdorfer Strasse 16 Cham, Germany 93413 Phone: +49 (0) 9971 400-3100 Fax: +49 (0) 9971 400-3123 Email: primusline@raedlinger.com Web: www.raedlinger.com
Practitioner(s)	• Gemeindeverwaltung Grünwald – Wasserwerke 85 m of 6 in. and 8 in. drinking water pipe up to 232 psi • Berliner Wasserbetriebe, Berlin, Germany 60 m of 6 in. siphon underneath a canal • ENI Neapel, Italy 2300 m. of 8 in. drinking water pipe
Description of Main Features	Primus Line® is a new technology of flexible high-pressure pipes for the transport of gases and liquids in large diameters. It is used in the renovation of high-pressure pipes, as bypass-pipe during maintenance and in other fields of application.
Main Benefits Claimed	• Renovation of high-pressure pipes • Able to negotiate bends in big lengths • Close fit liner limits the loss of diameter
Main Limitations Cited	• Bypass required • Cannot negotiate 90° bends
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas, Oil, and Bypass pipes</u>
II. Technology Parameters	
Service Application	Hose Lining Rehabilitation of Water Mains
Service Connections	Must be excavated and reconnected
Structural Rating Claimed	Not-structural
Materials of Composition	Seamless woven aramid fiber embedded in high-performance plastic
Diameter Range, inches	6 in. to 18 in.
Thickness Range	Up to 6 mm
Pressure Capacity, psi	Up to 1,000 psi (double layer design for a 6 in. pipe)
Temperature Range, ^{o}F	Not Available
Renewal Length, feet	Up to 6,000 ft
Other Notes	The liner is winched into the host at a rate of 1,200 ft/hr.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• Not NSF/ANSI Standard 61 Certified • DVGW German Technical and Scientific Assoc. for Gas and Water • Meets the certification of KTW and W270
Design Standards	Not Available
Design Life Range	Not Available
Installation Standards	In accordance with manufacturer's recommendations
Installation Methodology	• The existing pipe is dewatered, the condition of the host is inspected

Technology/Method	**Radlinger Primus Line®/Hose Liner**
	with a camera which pulls in a rope and the pipe is cleaned. • The liner is winched in through the entry access pit. • The liner is fixed to the existing system with specialty couplings that are based on an inner sleeve and an outer sleeve. The inner sleeve is put into the inliner; the outer sleeve is slid over the inliner. • A deformable steel jacket is welded on the inside of the outer sleeve to form a casing. • A resin is pressed into this casing and forces both the steel jacket and the inliner to move into the contours of the inner sleeve. • After curing of the resin the coupling serves as a durable and save joint. The inner sleeve of the coupling can be welded on the existing pipe. T-iron or other special pipe components can be fixed by common welding engineering. • The flexible tube is then pressurized and the coupling is slid into place.
QA/QC	• Pressure testing is carried out after installation • Manufacturing certified to ISO 9001:2000 and ISO 14001:2004
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Excavate, remove the damaged portion, install end couplers and bridge the previously damaged location with new pipe and couplers.
V. Costs	
Key Cost Factors	• Materials: liner plus specialty couplings and fittings • Bypass system • Entry and exit access pits • Cleaning and inspection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.primusline.com/en/technology/medium-high-pressure-system/system/

Datasheet A-27. RLS Solutions AquataPoxy® Epoxy Lining

Technology/Method	**AquataPoxy®/Spray-On Epoxy Lining**
I. Technology Background	
Status	Conventional
Date of Introduction	Used in North America over the past 10 years
Utilization Rates	Over 360,000 ft in water pipe
Vendor Name(s)	**RLS Solutions Inc.** 13105 East 61st Street, Suite A Broken Arrow, Oklahoma 74012 Phone: (800) 324-2810 Fax: (918) 615-0140 Email: henkej@rlssolutions.com Web: www.rlssolutions.com
Practitioner(s)	New York Aqueduct, 700 mi. of 8 in. to 20 in. diameter multi-material 125 year-old pipes
Description of Main Features	AquataPoxy® can be applied using the CuraFlo Spincast System™, 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+ mm. 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	• Unable to negotiate 90° bends
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Tanks, Reservoirs, and Basins</u>
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	Must be drilled robotically if plugged during lining
Structural Rating Claimed	Not Available
Materials of Composition	100% solids epoxy
Diameter Range, inches	3 in. to 36 in.
Thickness Range	1 to 5+ mm
Pressure Capacity, psi	Not Available
Temperature Range, °F	Approved for use in pipes with water temperatures up to 180°F
Renewal Length, feet	Up to 500 ft segments
Other Notes	Not Applicable
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	Not Available
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
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 lining is applied, potable water pipes are inspected to ensure water quality.
QA/QC	Disinfection as per AWWA standards

Technology/Method	**AquataPoxy®/Spray-On Epoxy Lining**
IV. Operation and Maintenance Requirements	
O&M Needs	Not Available
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Epoxy Materials • Spraying equipment • Entry and exit access Pits • Cleaning and inspection
Case Study Costs	Not Available
VI. Data Sources	
References	• http://ravenlining.com/ServiceOfferings/PipeRestoration.aspx • http://ravenlining.com/ServiceOfferings/ProductsServices.aspx • http://curaflo.com/EpoxyPipeLining/WaterSafetyCertified.aspx • New York Restoration: Case No. 58

Datasheet A-28. Sanexen Aqua-Pipe® CIPP Lining

Technology/Method	**Sanexen Aqua-Pipe®/CIPP**
I. Technology Background	
Status	Innovative
Date of Introduction	2000 in Canada and 2005 in U.S.
Utilization Rates	Over 800,000 ft installed since 2000 in Eastern Canada and the U.S.
Vendor Name(s)	**Sanexen Environmental Services Inc.** 1471 Lionel-Boulet Blvd., Suite 32 Varennes, Québec J3X 1P7 Phone: (450) 652-9990 Toll Free: (800) 263-7870 Fax: (450)652-2290 Email: aqua-pipe@sanexen.com Web: www.aqua-pipe.com
Practitioner(s)	• John Vose, City of Naperville, (630) 420-6741 1200 W. Ogden Naperville, IL 60563 • Kevin Bainbridge, City of Hamilton (905) 546-2424, ext. 5677 320-77 James St. North Hamilton, ON L8R 2K3 • Kamran Sarrami, City of Toronto, (416) 395-6370 North York Civic Center, 2nd Floor Toronto, ON M2N 5V7
Description of Main Features	Sanexen, in collaboration with the NRC Canada developed a new structural liner for the structural rehabilitation of drinking water mains. Aqua-Pipe® is an economical and viable alternative to the water main problems where, in the past, dig and replace was the only choice. The line 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	• Installation of 2,500+ ft per week and negotiates bends up to 45° • Corrosion resistance and no effect on water quality • Economic considerations include small carbon footprint
Main Limitations Cited	• Bypass required • Cannot negotiate 90° bends due to limitations of the robot
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	CIPP Lining Rehabilitation of Water Mains
Service Connections	• Service connections are reinstated from within the lined pipe using a remote controlled mechanical robot. • CCTV 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.
Structural Rating Claimed	Class IV (AWWA M28 Manual) fully structural independent liner
Materials of Composition	• Composed of two concentric, tubular, plain woven seamless polyester jackets and a polymeric membrane bonded to the interior to ensure water tightness. • The liner is impregnated with a thermoset epoxy resin that allows a

Technology/Method	Sanexen Aqua-Pipe®/CIPP
	tight bond between the liner and the host pipe.
Diameter Range, inches	6 in. to 12 in.
Thickness Range	3 to 6 mm
Pressure Capacity, psi	Up to 150 psi (operating pressure)
Temperature Range, °F	35°F to 100°F
Renewal Length, feet	100 ft to 500 ft between access pits (typical 350 ft)
Other Notes	Hazen-Williams coefficient of up to 120 or more
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• NSF/ANSI Standard 61 Certification • BNQ Standard 3660-950
Design Standards	ASTM F-1216 and ASTM F-1743
Design Life Range	50 years
Installation Standards	In accordance with manufacturer's operation manual.
Installation Methodology	• Precisely aligned with the host pipe's point of entry and pulled through to the exit point. • Shaping is achieved by pushing a pig through the hose using water pressure. Circulating hot water ensures the curing process. • Day 1: Cure 1.5 hrs 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 hrs 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	The lined section is tested under pressure to check for water tightness.
IV. Operation and Maintenance Requirements	
O&M Needs	• Pressure or dry taps for future service connections can be easily carried out with no special equipment. • Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	• Typically need to cut out defective pipe and replace with new pipe.
V. Costs	
Key Cost Factors	• Materials: liner, resin, fittings, valves and hydrants • Mobilization • Bypass system • Entry and exit access pits • Cleaning and inspection • Service plugging and reinstatement • Site restoration
Case Study Costs	• Hamilton = $133/ft • Toronto = $137/ft • Naperville = $186/ft
VI. Data Sources	
References	• www.sanexen.com/en/aquapipe/tech_info_product.htm • Communication with Valerie Belisle, Michael Davison, and Joseph Loiacono

Datasheet A-29. Sprayroq SprayShield Green® I Polyurethane Coating

Technology/Method	**Sprayroq SprayShield Green® I/Spray-On Polyurethane Coating**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced in January 2007 in the U.S.
Utilization Rates	Over 5,000+ Structures repaired/rehabilitated to date
Vendor Name(s)	**Sprayroq, Inc.** 248 Cahaba Valley Parkway Pelham, AL 35124 Toll Free: (800) 634-0504 Phone: (205) 957-0020 Fax: (205) 957-0021 Email: info@sprayroq.com Web: www.sprayroq.net
Practitioner(s)	• Wayne Schutz, Assistant Manager Derry Township, PA Email: wschutz@dtma.com Office: (717) 566-3237, x312, Cell: (717) 497-8026 • Rodney Jones, Construction Program Manager County of Sarasota, FL Email: rjones@scgov.net Cell: (941) 232-8295
Description of Main Features	SprayShield Green® I is an elastomeric, 100% solids polyurethane coating which provides chemical resistance for concrete, steel, masonry, fiberglass pipes and has a quick curing time which allows the pipe to be returned to service immediately.
Main Benefits Claimed	• Fast installation and high corrosion resistance • Provides chemical resistance against all elements that eat away at underground structures
Main Limitations Cited	• Requires man-entry
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> <u>Manholes</u> Appurtenances <u>Water Main</u> Other: <u>Tanks, Lift Stations, or any exposed surfaces</u>
II. Technology Parameters	
Service Application	Spot Repair of Water Mains
Service Connections	Connections need to be plugged during installation.
Physicals Claimed	• Tensile Strength > 2,780 psi • Tear Strength > 580 pli • Biobased • Elongation > 115% • Manning's "n" = 0.01
Materials of Composition	100 % solids - polyurethane
Diameter Range, inches	36 in. and greater on pipes and unlimited on man entry structures
Thickness Range	Up to ½ in. (13 mm) or greater in special applications
Pressure Capacity, psi	Not Available
Temperature Range, °F	Operating temperature up to 140°F
Renewal Length, feet	Limited by length of the spray hose
Other Notes	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 SprayShield Green® I,

Technology/Method	Sprayroq SprayShield Green® I/Spray-On Polyurethane Coating
	require a clean and dry substrate for optimal performance.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	See website for complete list
Design Life Range	50 year design life
Installation Standards	Per Manufacturer's Guidelines
Installation Methodology	After the A and B components are mixed, the polyurethane begins to gel in about 8 to 12 seconds, with a tack free condition after one minute. Within 30 to 60 minutes, the initial cure is completed and the structure is capable of accepting flow while the complete curing continues for the next 4 to 6 hours.
QA/QC	Licensed Installers (Sprayroq Certified Partners) 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	• Polyurethane materials • Entry and exit access points • Amount of surface preparation
Case Study Costs	Corrosion only $200-300/vertical ft; Structural $300-500+/vertical ft
VI. Data Sources	
References	• www.sprayroq.net/index.php/en/products/sprayshield-green-i-elastomeric-polyurethane • E-mail correspondence with Jerry Gordon and Chip Johnson

Datasheet A-30. Sprayroq SprayWall® Polyurethane Coating

Technology/Method	**Sprayroq SprayWall®/Spray-On Polyurethane Coating**
I. Technology Background	
Status	Conventional
Date of Introduction	Introduced in January 1990 in the U.S.
Utilization Rates	Over 200,000+ structures repaired/rehabilitated to date (number of water mains unknown)
Vendor Name(s)	**Sprayroq, Inc.** 248 Cahaba Valley Parkway Pelham, AL 35214 Toll Free: (800) 634-0504 Phone: (205) 957-0020 Fax: (205) 957-0021 Email: info@sprayroq.com Web: www.sprayroq.net
Practitioner(s)	• Wayne Schutz, Assistant Manager Derry Township, PA Email: wschutz@dtma.com Office: (717) 566-3237, x312, Cell: (717) 497-8026 • Rodney Jones, Construction Program Manager County of Sarasota, FL Email: rjones@scgov.net Cell: (941) 232-8295
Description of Main Features	SprayWall® is a durable, spray-applied 100% VOC-free polyurethane coating that provides both structural reconstruction and chemical resistance against all elements that eat away at underground structures.
Main Benefits Claimed	• Fast installation and high corrosion resistance • Provides chemical resistance against all elements that eat away at underground structures
Main Limitations Cited	• Requires man-entry
Applicability (Underline those that apply)	Force Main Gravity Sewer Manholes Appurtenances Water Main Other: Tanks, Lift stations, or any exposed surfaces
II. Technology Parameters	
Service Application	Spot Repair of Water Mains
Service Connections	Connections need to be plugged during installation.
Structural Rating Claimed	• Tensile Strength 7,450 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" = 0.0009
Materials of Composition	100 % solids - polyurethane
Diameter Range, inches	36 in. and greater on pipes and unlimited on man entry structures
Thickness Range	Up to 1 in. (25.4 mm) or greater in special applications
Pressure Capacity, psi	400 psi @ 250 mils (per LA Tech 2009 study)
Temperature Range, °F	Operating temperature up to 140°F
Renewal Length, feet	Limited by length of the spray hose
Other Notes	Complete capability to handle hydrostatic loading if required. Solvent Cleaning (SSPC-SP1) may be necessary for steel. Surfaces to be treated

Technology/Method	**Sprayroq SprayWall®/Spray-On Polyurethane Coating**
	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/ANSI Standard 61 Certification
Design Standards	Thickness Design for Structural ASTM F-1216 Appendix X1
Design Life Range	50 year design life retaining 72% of Flex Modulus
Installation Standards	Per Manufacturer's Guidelines
Installation Methodology	After the A and B components are mixed, the polyurethane begins to gel in about 8 to 12 seconds, with a tack free condition after one minute. Within 30 to 60 minutes, the initial cure is completed and the structure is capable of accepting flow while the complete curing continues for the next 4 to 6 hours.
QA/QC	Licensed Installers (Sprayroq Certified Partners) 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	• Polyurethane materials • Entry and exit access pits • Amount of surface preparation
Case Study Costs	Corrosion only $200-300/vertical ft; Structural $300-500+/vertical ft
VI. Data Sources	
References	• www.sprayroq.net/index.php/en/products/structural-spraywall • E-mail correspondence with Jerry Gordon and Chip Johnson • ASCE Pipelines Paper (Steward et al., 2009)

Datasheet A-31. Starline® CIPP Lining

Technology/Method	**Starline® 1000/HPL-W/CIPP**
I. Technology Background	
Status	Conventional
Date of Introduction	For water, 1998 in Europe and 2010 in the U.S.
Utilization Rates	400 miles installed for water and gas
Vendor Name(s)	**Starline Trenchless Technology, LLC** 1700 South Mount Prospect Rd. Des Plaines, IL 60018-1804 Phone: (847) 544-3428 Cell Phone: (847) 222-3493 Email: mattson@gastechnology.org Web: www.starlinett.com
Practitioner(s)	Progressive Pipeline Management, Red Bank, New Jersey
Description of Main Features	Capable of rehabilitating drinking water transmission mains.
Main Benefits Claimed	• Structural solution • Can negotiate 45° bends depending on diameter, locations and the number of bends • Withstands circumferential pipe fractures • Bridges corrosion holes up to 2 in.
Main Limitations Cited	• Bypass required • Cannot negotiate bends greater than 45° • Relies on overall structural integrity of the host pipe
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas</u>
II. Technology Parameters	
Service Application	CIPP Rehabilitation of Water Mains
Service Connections	Reinstated from inside the pipe
Structural Rating Claimed	Semi-structural solution
Materials of Composition	• Polyester woven liner • Epoxy resin
Diameter Range, inches	4 in. to 24 in.
Thickness Range	1 mm to 3 mm
Pressure Capacity, psi	Up to 150 psi (250 psi for gas)
Temperature Range, °F	Up to 78°F
Renewal Length, feet	Up to 1,800 ft (depending on installation equipment)
Other Notes	Same day reconnection for force mains is possible
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• Meets KTW and DVGW W270 Compliant in Germany • NSF/ANSI Standard 61 Certification Applied For
Design Standards	• ASTM F-2207, DIN 30658-1, DVGW VP 404, and DVGW W 330(E)
Design Life Range	50 years
Installation Standards	• DVGW G 478 and DVGW GW 327(E)
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. The liner is then cured via hot water.

Technology/Method	**Starline® 1000/HPL-W/CIPP**
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	No welding on potable water steel pipelines
V. Costs	
Key Cost Factors	• Materials: liner, resin, fittings, valves and hydrants • Mobilization • Bypass system • Entry and exit access pits • Cleaning and inspection • Site restoration
Case Study Costs	Article in Underground Construction Magazine (Hüttemann and Mattson, 2009)
VI. Data Sources	
References	• www.starlinett.com/products/index.html • Email correspondence with Brian Mattson

Datasheet A-32. Subterra ELC 257-91 Epoxy Lining

Technology/Method	**Subterra ELC 257-91/Spray-On Epoxy Lining**
I. Technology Background	
Status	Conventional
Date of Introduction	Late 1990s in North America, Early 1990s in the UK
Utilization Rates	More than 250,000 gallons (850,000 liters) supplied
Vendor Name(s)	**Daniel Contractors Limited (Subterra Division)** Lyncastle Way, Appleton Thorn Warrington, Cheshire WA4 4ST Phone +44 0 (192) 586-0666 Fax: +44 0 (192) 586-0504 Email: info@subterra.co.uk Web: www.subterra.co.uk/subterra.php?page=home
Practitioner(s)	• Bucks County W&S Authority, Philadelphia, PA • City of Pierrefonds, Canada • City of Minneapolis, MN • City of Halton, ON, CN • Montreal North, Quebec, CN • Peterborough, ON, CA
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	• Unable to negotiate 45° bends
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Not Applicable
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	Need to be inspected after lining to ensure they have not been plugged.
Structural Rating Claimed	Non-structural (for pipeline internal corrosion protection)
Materials of Composition	Solvent free epoxy resin base, with added hardener technology
Diameter Range, inches	4 in. to 24 in.
Thickness Range	0.039 in. to 0.059 in., depending on diameter
Pressure Capacity, psi	Not Applicable
Temperature Range, °F	37°F to 100°F (3°C to 40°C)
Renewal Length, feet	Up to 650 ft (200 m)
Other Notes	Not Applicable
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not NSF/ANSI Standard 61 Certified
Design Standards	Complies fully with Water UK's "In-situ Resin Spray Lining - Operational Requirements and Code of Practice"
Design Life Range	30 to 50 years
Installation Standards	Contractors must carry out a lining trial supervised by an authorized independent assessor.
Installation Methodology	The mixed resin is applied by a centrifugal spray lining machine. The

Technology/Method	**Subterra ELC 257-91/Spray-On Epoxy Lining**
	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	Soft swab to remove sediment/deposits arising from supply, as required.
Repair Requirements for Rehabilitated Sections	Lined pipe can be drilled and tapped using conventional tools with sharp bits. Cut lined pipe preferably with disc cutter. If necessary, repair any lining damage using ELC 257/91 patch repair kits.
V. Costs	
Key Cost Factors	• Epoxy resin materials • Spraying equipment • Entry and exit access pits • Cleaning equipment
Case Study Costs	$17/ft on 4 in. to 6 in. mains in large-scale lining programs
VI. Data Sources	
References	• www.subterra.co.uk/subterra.php?page=Polyurethane and Epoxy Resins • NASTT No-Dig Article (Hoffman and Warren, 1999) • Email correspondence with John De Rosa and Norman Howell

Datasheet A-33. Subterra Fast-Line Plus™ Polyurethane Lining

Technology/Method	**Subterra Fast-Line Plus™/Spray-On Polyurethane Lining**
I. Technology Background	
Status	Emerging
Date of Introduction	2004
Utilization Rates	15,000 ft (4,500 m) low-build lining 30,000 ft (9,000 m) high-build lining
Vendor Name(s)	**Daniel Contractors Limited (Subterra Division)** Lyncastle Way, Appleton Thorn Warrington, Cheshire WA4 4ST Phone +44 0 (192) 586-0666 Fax: +44 0 (192) 586-0504 Email: info@subterra.co.uk Web: www.subterra.co.uk
Practitioner(s)	• Municipality of Dijon/Axeo, France • Vicany Water Company/Combin, Slovakia • Scottish Water, UK • South East Water • Wessex Water, UK
Description of Main Features	Fast-Line Plus™ is a rapid-setting polyurethane resin that has been formulated specifically for the in-situ lining of drinking water mains by centrifugal application. It can be applied equally as a low-build lining, to solve water quality problems in distribution, as well as a high-build lining, which can help reduce leakage from corrosion holes and deteriorated joints. It can be applied from conventional resin spray lining machines, suitably adapted to store and handle the product. Provides a durable, corrosion-resistant barrier layer over the surface to be protected.
Main Benefits Claimed	• Low-build (non-structural) and high-build (semi-structural) linings can be applied from the same resin spray lining machine without machine modification or change of material. • Touch dry in 30 minutes and can be returned to service in 2 hours • Negligible shrinkage on curing • Coating provides a corrosion-resistant barrier layer • 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	• Unable to negotiate 45° bends
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Lining Rehabilitation of Water Mains
Service Connections	Need to be inspected after lining to ensure they have not been plugged.
Structural Rating Claimed	Non-structural or Semi-structural
Materials of Composition	Solvent-free isocyanate, and a blend of solvent-free polyols
Diameter Range, inches	3 in. to 60 in. (75 mm to 1500 mm)
Thickness Range	0.039 in. to 0.276 in. (1 mm to 7 mm) depending on diameter
Pressure Capacity, psi	• Non-Structural – not applicable • Semi-structural – depends on lining thickness, pipeline pressure and

Technology/Method	Subterra Fast-Line Plus™/Spray-On Polyurethane Lining
	size of corrosion holes, etc.
Temperature Range, °F	37°F to 100°F (3°C to 40°C)
Renewal Length, feet	Up to 650 ft (200 m.)
Other Notes	Not Applicable
III. Technology Design, Installation, and QA/QC Information	
Product Standards	Not NSF/ANSI Standard 61 Certified
Design Standards	Complies fully with Water UK's "In-situ Resin Spray Lining - Operational Requirements and Code of Practice"
Design Life Range	30 to 50 years
Installation Standards	Contractors must carry out a lining trial supervised by an authorized independent assessor.
Installation Methodology	The mixed resin is 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 two components 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; high-build linings can also seal corrosion holes/leaking joints.
QA/QC	Manufactured under a quality assurance system registered to EN ISO 9002.
IV. Operation and Maintenance Requirements	
O&M Needs	Soft swab to remove sediment/deposits arising from supply, as required.
Repair Requirements for Rehabilitated Sections	Lined pipe can be drilled and tapped using conventional tools with sharp bits. Cut lined pipe preferably with disc cutter. If necessary, repair any lining damage using ELC epoxy patch repair kits.
V. Costs	
Key Cost Factors	• Polyurethane resin materials • Cleaning equipment • Spraying equipment • Entry and exit access pits
Case Study Costs	$17/ft on 4 in. to 6 in. mains in large-scale lining programs
VI. Data Sources	
References	• www.subterra.co.uk/subterra.php?page=Polyurethane and Epoxy Resins • ISTT No-Dig Article (Howell and De Rose, 2000) • Email correspondence with Norman Howell

Datasheet A-34. Subterra Rolldown Process

Technology/Method	**Subterra Rolldown/Reduced Diameter Pipe**
I. Technology Background	
Status	Conventional
Date of Introduction	1986
Utilization Rates	Over 280 miles (450 km) installed worldwide
Vendor Name(s)	**Daniel Contractors Ltd. (Subterra Division)** Lyncastle Way, Appleton Thorn Warrington, Cheshire WA4 4ST Phone +44 0 (192) 586-0666 Fax: +44 0 (192) 586-0504 Email: info@subterra.co.uk Web: www.subterra.co.uk/subterra.php?page=home
Practitioner(s)	• Client: Aziend Mediterranea Gas Acqua (AMGA) Site: Via Gramsci, Genoa, Italy • Consolidated Edison/PIM Corporation, NJ • LILCO/PIM Corporation, NJ
Description of Main Features	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 maximized.
Main Benefits Claimed	• Ambient temperature process – no heat required • Low winching loads and reversion procedure minimize the residual stresses in the liner after installation • Close-fit of lining maximizes carrying capacity • Smooth bore of PE liner pipe minimizes friction • Solves pipeline leakage and water quality problems arising from internal pipeline corrosion
Main Limitations Cited	• Bypass required • Cannot negotiate bends greater than 11.25°
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas and Industrial</u>
II. Technology Parameters	
Service Application	Reduced Diameter Pipe Rehabilitation of Water Mains
Service Connections	Service connections have to be excavated.
Structural Rating Claimed	Fully-structural
Materials of Composition	PE 80 or PE 100
Diameter Range, inches	4 in. to 20 in. (100 mm to 500 mm)
Thickness Range	SDR 11 to 33
Pressure Capacity, psi	Up to 230 psi (16 bar)
Temperature Range, °F	As per PE guidelines
Renewal Length, feet	1,000 ft to 4,000 ft (300 m to 1200 m) between excavations
Other Notes	• Pipe is reduced in diameter up to 10% before installation. • Use insert stiffeners to bring liner pipe OD to standard size for termination with standard electrofusion couplers.
III. Technology Design, Installation, and QA/QC Information	

Technology/Method	Subterra Rolldown/Reduced Diameter Pipe
Product Standards	PE 80/PE 100 has NSF/ANSI Standard 61 Certification (overall product is not listed on the website)
Design Standards	As suggested by PE 80 or PE 100 market guidelines
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• In the Rolldown process, standard grade PE 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-sectional area and maximizing capacity.
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Replacement with standard PE pipe sections and appropriate fittings.
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry and exit access pits • Cleaning and inspection • Service reconnection
Case Study Costs	Project costs are dependent on pipe dimensions, length of main to be rehabilitated, pressure rating of the liner pipe and overall site conditions. Budget rates for cleaning existing pipeline, PE liner welding, processing and installation only are as follows: • Installation > 150 mm but <= 300 mm $55/lf • Installation > 300 mm but <= 450 mm $90/lf • Installation > 450 mm but <= 500 mm $110/lf
VI. Data Sources	
References	• ConEdison Website • www.subterra.co.uk/subterra.php?page=Close Fit and PE Lining Systems • Email correspondence with Norman Howell

Datasheet A-35. Subterra Subcoil Hose Lining

Technology/Method	**Subterra Subcoil/Hose Liner**
I. Technology Background	
Status	Conventional
Date of Introduction	1999
Utilization Rates	Over 60 miles (100 km) installed worldwide
Vendor Name(s)	**Daniel Contractors Limited (Subterra Division)** Lyncastle Way, Appleton Thorn Warrington, Cheshire WA4 4ST Phone +44 0 (192) 586-0666 Fax: +44 0 (192) 586-0504 Email: info@subterra.co.uk Web: www.subterra.co.uk/subterra.php?page=home
Practitioner(s)	• Consolidated Edison Inc. NY/PIM Corporation • Abu Dhabi Distribution Company/Kurtec, Abu Dhabi • Anglian Water, UK • Bournemouth & West Hampshire Water, UK
Description of Main Features	Subcoil is specifically designed as a low cost rehabilitation system for distribution mains and small trunk mains. It uses a 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	• 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 • Thin wall liner and smooth bore maximizes flow capacity • Solves pipeline water quality and leakage problems arising from internal pipeline corrosion
Main Limitations Cited	• Bypass required • Cannot negotiate bends greater than 22.5°
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas</u>
II. Technology Parameters	
Service Application	Hose Lining Rehabilitation of Water Mains
Service Connections	Service Connections have to be excavated.
Structural Rating Claimed	Structural or Semi-Structural
Materials of Composition	Polyethylene, PE 80 or PE 100
Diameter Range, inches	3 in. to 10 in. (75 mm to 250 mm)
Thickness Range	SDR 26 and greater
Pressure Capacity, psi	Up to 90 psi (6 bar)
Temperature Range, °F	As per PE guidelines
Renewal Length, feet	Up to 4,200 ft (1,300 m) in a single insertion
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	PE 80/PE 100 has NSF/ANSI Standard 61 Certification (overall product is not listed on the NSF website)
Design Standards	As suggested by PE 80 or PE 100 market guidelines

Technology/Method	**Subterra Subcoil/Hose Liner**
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• The PE liner pipe is supplied in coils on a drum. • The product is dispensed from a small site drum trailer unit. • The liner pipe is inserted into the pre-cleaned main and then reverted to a round profile by pressurization with air or water according to the liner size and application. • The lining is completed by fitting liner end terminations and customer service connections designed specifically for this use.
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	• Structural: Replacement with standard PE pipe sections and appropriate fittings. • Semi-structural: Cut out damaged section, re-terminate liner ends with proprietary fittings, complete repair with standard PE pipe sections and appropriate fittings.
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry and exit access pits • Cleaning and inspection • Service reconnection
Case Study Costs	Project costs are dependent on pipe dimensions, length of main to be rehabilitated, pressure rating of the liner pipe and overall site conditions. Budget rates for cleaning existing pipeline, PE liner welding, processing and installation only are as follows: • Installation > 75 mm but <= 100 mm $25/lf • Installation > 100 mm but <= 150 mm $30/lf • Installation > 150 mm but <= 225 mm $45/lf
VI. Data Sources	
References	• ConEdison Website • www.subterra.co.uk/subterra.php?page=Close Fit and PE Lining Systems • Email correspondence with Norman Howell

Datasheet A-36. Subterra Subline Fold and Form

Technology/Method	**Subterra Subline/Fold and Form**
I. Technology Background	
Status	Conventional
Date of Introduction	1986
Utilization Rates	Over 150 miles (250 km) installed worldwide
Vendor Name(s)	**Daniel Contractors Limited (Subterra Division)** Lyncastle Way, Appleton Thorn Warrington, Cheshire WA4 4ST Phone +44 0 (192) 586-0666 Fax: +44 0 (192) 586-0504 Email: info@subterra.co.uk Web: www.subterra.co.uk/subterra.php?page=home
Practitioner(s)	• Annarundel, MD/ PIM Corporation • Cinnaminson, NJ/PIM Corporation • Detroit Water, MI • Middlesex County Water, NJ/PIM Corporation • New York City-DEP/PIM Corporation
Description of Main Features	Subline is a close-fit PE lining technique, developed by Subterra, which is specifically designed for thin wall application.
Main Benefits Claimed	• Ambient temperature process – no heat required • Folded cross section reduces friction and winching loads, facilitates the negotiation of existing pipeline bends, minimizes liner residual stresses after installation • Close-fit of lining maximizes carrying capacity • Smooth bore of PE liner pipe minimizes friction • Stops water quality problems from internal corrosion
Main Limitations Cited	• Bypass required • Cannot negotiate bends greater than 22.5°
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Gas and Industrial
II. Technology Parameters	
Service Application	Fold and Form Rehabilitation of Water Mains
Service Connections	Service connections have to be excavated.
Structural Rating Claimed	Structural or Semi-Structural
Materials of Composition	Polyethylene, PE 80 or PE 100
Diameter Range, inches	3 in. to 60 in. (75 mm to 1500 mm)
Thickness Range	SDR 26 to 61
Pressure Capacity, psi	Up to 90 psi (6 Bar)
Temperature Range, ^{o}F	As per PE guidelines
Renewal Length, feet	Up to 3,000 ft (900 m) in a single insertion
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	PE 80/PE 100 has NSF/ANSI Standard 61 Certification (overall product is not listed on the NSF website)
Design Standards	As suggested by PE 80 or PE 100 market guidelines
Design Life Range	50 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• Lengths of the PE liner pipe are butt fused into strings of the

Technology/Method	Subterra Subline/Fold and Form
	appropriate length. • The liner is then folded cold into a heart shape by pushing it through the former machine on site, secured with temporary restraining strap bands and inserted into the precleaned main. • The liner is pressurized with cold water to revert it back to its circular form, which breaks the temporary restraining bands. • The liner end terminations and other connections are then completed according to requirements using commercially available fittings.
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Cut out damaged section, re-terminate liner ends with proprietary fittings, complete repair with standard PE pipe sections and appropriate fittings.
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry and exit access pits • Cleaning and inspection • Service reconnection
Case Study Costs	Project costs are dependent on pipe dimensions, length of main to be rehabilitated, pressure rating of the liner pipe and overall site conditions. Budget rates for cleaning existing pipeline, PE liner welding, processing and installation only are as follows: • Installation > 150 mm but <= 300 mm $60/lf • Installation > 300 mm but <= 450 mm $95/lf • Installation > 450 mm but <= 600 mm $120/lf • Installation > 600 mm but <= 1000 mm $150/lf • Over 1000 mm costs are generated on a specific project basis
VI. Data Sources	
References	• ConEdison website • www.subterra.co.uk/subterra.php?page=Close Fit and PE Lining Systems • Email correspondence with Norman Howell

Datasheet A-37. Swagelining™ Reduced Diameter Pipe

Technology/Method	**Swagelining™/Reduced Diameter Pipe**
I. Technology Background	
Status	Conventional
Date of Introduction	1986
Utilization Rates	Around 1,500 miles installed to date for water worldwide.
Vendor Name(s)	**Swagelining Limited** 1 Aurora Ave. Queens Quay, Clydesbank Glasgow G81 1BF Phone: +44 (0) 845-180-3444 Email: enquiries@swagelining.com Web: www.swagelining.com
Practitioner(s)	• Licenser: Murphy Pipeline Contractors, Inc Contact: Andy Mayer 11243-4 St. Johns Industrial Parkway South Jacksonville, FL 32246 Phone: (904) 620-9702 Fax: (904) 620-9703 Email: andym@murphypipelines.com
Description of Main Features	A polymer liner that can provide an effective barrier against further corrosion and deliver a significant life extension to the existing pipeline. This is a low risk operation in terms of proven technology that also minimizes pipeline system downtime and usually eliminates the extensive process of gaining regulatory approvals to build a replacement pipeline.
Main Benefits Claimed	• 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 in CI, DI, steel, and AC pipelines • There is no shrinkage or curing, and no field chemistry or heating is required. PE is flexible and highly resistant to chemical attack
Main Limitations Cited	• Bypass required • Limited to 22.5° bends, dependent on length of the bend
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Gas and Mining Slurry</u>
II. Technology Parameters	
Service Application	Reduced Diameter Pipe Rehabilitation of Water Mains
Service Connections	Service connections have to be excavated.
Structural Rating Claimed	Structural and Semi-structural, as per PE pipe rating guidelines
Materials of Composition	Polyethylene
Diameter Range, inches	2 in. to 60 in.
Thickness Range	Any thickness of PE
Pressure Capacity, psi	As per PE pipe rating guidelines

Technology/Method	**Swagelining™/Reduced Diameter Pipe**
Temperature Range, °F	As per PE pipe rating guidelines
Renewal Length, feet	Up to 3,000 ft between excavations.
Other Notes	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.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	PE pipe has NSF/ANSI Standard 61 Certification (overall product is not listed on the website)
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	• 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.
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Replacement with standard PE pipe sections.
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry and exit access pits • Cleaning and inspection • Service reconnection
Case Study Costs	Not Available
VI. Data Sources	
References	• http://swagelining.com/index1.html • Communication with Richard Hempson and David Whittle.

Datasheet A-38. Tyfo® FibrWrap® Pipe Wrapping

Technology/Method	**Tyfo® FibrWrap®/Pipe Wrapping**
I. Technology Background	
Status	Conventional
Date of Introduction	In use since 1980s, pipe rehabilitation system since 1999
Utilization Rates	100s of pipes since 1999
Vendor Name(s)	**Fyfe Company, LLC** 8380 Miralani Dr. San Diego, CA 92126 Phone: (858) 642-0694 Fax: (858) 444-2982 Email: info@fyfeco.com Web: www.fyfeco.com
Practitioner(s)	• Gary Schult, Kiewit Western Company, (602) 437-7841 For 60 in. through 96 in. PCCP pipes • John Galleher, San Diego County Water Authority, (760) 488-1991 For two 24 ft sections of 96 in. pipe • Don Lieu, Chief and Robert Diaz, Engineering Project Manager Utility Design Division, DPW, 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 internal repair, strengthening and retrofit of corrosion-damaged and distressed large diameter PCCP, RCP, and steel pressure pipelines used in municipal, industrial and other applications.
Main Benefits Claimed	• Allows for trenchless emergency repair of pipelines • Accommodates rehabilitation of non-uniform geometry • Restoration of pipelines to original hydrostatic pressure • Accommodation of increased internal pressure requirements • Re-establishment of flexural loading capabilities • Restoration of original external load bearing capacity • Non-metallic material ensures that corrosion-related damages do not recur in rehabilitated pipe segments
Main Limitations Cited	• Requires highly trained technicians for appropriate installation • Requires extensive polymer durability studies to predict lifecycle • Requires dewatering to allow for man-entry for internal repair • Minimal compression strength added in comparison to tensile
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main Service Lines Other: Tunnels
II. Technology Parameters	
Service Application	Spot Repair of Water Mains
Service Connections	Can be cut to fit around services (design must be taken into account)
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	24 in. and up
Thickness Range	0.1 in. to 0.5 in.
Pressure Capacity, psi	-14 psi (vacuum pressure) to 350 psi.

Technology/Method	Tyfo® FibrWrap®/Pipe Wrapping
Temperature Range, °F	220°F
Renewal Length, feet	4 ft and up
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	NSF/ANSI Standard 61 Certification
Design Standards	• 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, ASTM D-695, and ASTM D-3039.
Design Life Range	50 to 75 years
Installation Standards	ICC Pmg Report and Fyfe Co. QA/QC Manual
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	Manufacturer's manual 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. • Periodic visual inspections.
Repair Requirements for Rehabilitated Sections	Top coat renewal.
V. Costs	
Key Cost Factors	• Distance from repair location to surface access • Quantity of lineal feet contracted • Lead time for crews mobilization • Allotted time for onsite completion of project
Case Study Costs	• $1,000/lf to $6,000/lf (varies based on design requirements and project conditions). • Typically, a 54 in. pipe operating at 150 psi with 12 ft of cover would be $3,000/lf.
VI. Data Sources	
References	• www.fibrwrapconstruction.com/pipeline-repairs-rehabilitation.html • Correspondence via email and a binder provided by Heath Carr. • Email and phone correspondence with Anna Pridmore.

Datasheet A-39. Underground Solutions Duraliner™

Technology/Method	**Underground Solutions Duraliner™/Expandable PVC**
I. Technology Background	
Status	Conventional
Date of Introduction	2003
Utilization Rates	Not Available
Vendor Name(s)	**Underground Solutions, Inc.** 13135 Danielson St., Suite 201 Poway, CA 92064 Phone: (858) 679-9551 Fax: (858) 679-9555 Email: info@undergroundsolutions.com Website: www.undergroundsolutions.com
Practitioners	• Rogers St., Billerica, MA 100 lf of 6 in. DR18 Duraliner UGSI Contact: Martin Barrette - (724) 622-4475 • Cleveland, OH Water Main Replacement Project 600 lf of 12 in. DR18 Duraliner UGSI Contact: Chet Allen - (724) 321-1514 • City of Lima, OH 2,000 lf of Duraliner
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. The PVC pipe provides a design life of 100+ years.
Main Benefits Claimed	• 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	• Cannot negotiate bends greater than 45° • Requires excavation at each service for reinstatement
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> <u>Laterals</u> Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Fire protection systems and Industrial</u>
II. Technology Parameters	
Service Application	Sliplining Rehabilitation of Water Mains with Expandable PVC
Service Connections	• Services are tapped with standard fittings and procedures. • May be tapped with the same saddles used on conventional PVC.
Structural Rating Claimed	Fully-structural stand-alone system
Materials of Composition	100% PVC
Diameter Range, inches	4 in. to 16 in.
Thickness Range	Similar to C900 and C905 PVC pipe
Pressure Capacity, psi	Up to 150 psi
Temperature Range, °F	As per PVC guidelines
Renewal Length, feet	Up to 500 ft
Other Notes	The improved coefficient of friction can offset the reduction in internal area to maintain or improve flow.
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• NSF/ANSI Standard 61 Certification • Products meet all of the same current performance standards and

Technology/Method	Underground Solutions Duraliner™/Expandable PVC
	health/safety issues as AWWA C900 and C905 PVC pipe
Design Standards	• Conforms to cell classification 12454 as defined in ASTM D-1784 • Meets AWWA C900 or AWWA C905
Design Life Range	100 years
Installation Standards	Uni-Bell PVC Pipe Manual
Installation Methodology	• Excavations are performed at entry, exit and service locations. • The OD of the starting stock is smaller than the ID of the host pipe. • The pipe is fused to length for the project. • The fused pipe is inserted into a cleaned, inspected host pipe. • The pipe is expanded tightly against the interior walls of the host pipe after insertion. • Exposed ends of the liner are expanded to standard fitting sizes. • The new liner is cut to length and reconnected to system.
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Replacement with standard pipe sections and appropriate fittings.
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry and exit access pits • Cleaning and inspection • Service reconnection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.undergroundsolutions.com/duraliner.php • Business Wire Article (Business Wire, 2003)

Datasheet A-40. Underground Solutions Fusible PVC Continuous Sliplining

Technology/Method	**Fusible C900®, C905®, FPVC®/Cont. Sliplining**
I. Technology Background	
Status	Emerging
Date of Introduction	Introduced in 2004
Utilization Rates	Over 3.5 million linear feet installed since 2004
Vendor Name(s)	**Underground Solutions, Inc.** 13135 Danielson St., Suite 201 Poway, CA 92064 Phone: (858) 679-9551 Fax: (858) 679-9555 Email: info@undergroundsolutions.com Website: www.undergroundsolutions.com
Practitioner(s)	• Zaragosa Boulevard Water Line, El Paso, TX Sliplining of 16,300 lf of 24 in. DR25 using Fusible C905 UGSI Contact: Marty Scanlan - (858)-774-8887 • Homestead Road Water Line, City of Sunnyvale, CA Sliplining of 1,000 lf of 20 in. DR18 using Fusible C905 UGSI Contact: Rob Craw - (925) 577-7566 • Carrolton Pump Station Water Main, New Orleans, LA Sliplining of 24 in. DR25 using Fusible C905 UGSI Contact: Dan Huffaker - (713) 545-4789
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.
Main Benefits Claimed	• Corrosion and 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 • Requires excavation at each service for reinstatement
Applicability (Underline those that apply)	<u>Force Main</u> <u>Gravity Sewer</u> Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Culverts</u>
II. Technology Parameters	
Service Application	Sliplining Rehabilitation of Water Mains with Fusible PVC
Service Connections	• Reinstate with excavation. • Tapping procedure per Uni-bell standards.
Structural Rating Claimed	• Fully structural (Class IV)
Materials of Composition	• 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 in. to 12 in. (C900®) and 14 in. to 36 in. (C905®) • 4 in. to 36 in. (FPVC® potable water pipe other than C900®/C905®)
Thickness Range	• Fusible C900®: DR 14 - 25 and Fusible C905®: DR 14 - 51

Technology/Method	Fusible C900®, C905®, FPVC®/Cont. Sliplining
	• FPVC®: DR 14, 18, 21, 25, 26, 32.5, 41, 51, Sch 40, Sch 80
Pressure Capacity, psi	165 psi – 305 psi (C900®) and 80 psi – 235 psi (C905®)
Temperature Range, °F	Up to 140°F (above 73°F, standard internal pressure de-rating factors apply for long term elevated temperature exposure)
Renewal Length, feet	Up to 1,000 ft typically (3,500 ft in a single pull has been completed)
Other Notes	High C-factor at 150
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	AWWA C900, AWWA C905, ASTM, D-1785, ASTM D-2241, ASTM D-3034, and ASTM F-679
Design Life Range	100 years
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• For sliplining, host pipe is cleaned and CCTV. • Depending on logistics, the pipes can be strung out and the joints butt fused above grade prior to insertion, or butt fused in the ditch. • 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 data logger. Additional parameters such as the heat plate temperature are also recorded.
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
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	• Pipe material and equipment • Mobilization • Long access pits to accommodate required bend radius • Service reconnection
Case Study Costs	Fusible PVC™ 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	• www.undergroundsolutions.com/fusible-pvc.php • Correspondence with Tom Marti, Gary Shepherd, and Chet Allen

Datasheet A-41. United Pipeline Tite Liner® Reduced Diameter Pipe

Technology/Method	**United Pipeline Tite Liner®/Reduced Diameter Pipe**
I. Technology Background	
Status	Conventional
Date of Introduction	Introduced in 1985
Utilization Rates	Over 8,500 miles worldwide for oil, gas and water
Vendor Name(s)	**United Pipeline Systems** 135 Turner Dr. Durango, CO 81303 Phone: (970) 259-0354 Toll Free: (800) 938-6483 Fax: (970) 259-0356 Cell: (303) 506-5230 Email: jhawn@insituform.com Web: www.unitedpipeline.com
Practitioner(s)	• 5,000 ft of 48 in. along Madison Ave. in New York City • 30 in. in Austin, Texas • Decatur, Illinois
Description of Main Features	United's HDPE pipe lining system spans holes and gaps in the leaking host pipes, resulting in a continuous HDPE interactive lining system. The smooth inner surface coupled with the thin, close-fitting HDPE lining often result in increased flow capacity.
Main Benefits Claimed	• Minimizes disruption • Fully structural in some situations • Corrosion resistant
Main Limitations Cited	• Bypass required • Cannot go through sharp tees or 90° bends (unless sweeping)
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Oil and Gas</u>
II. Technology Parameters	
Service Application	Reduced Diameter Pipe Rehabilitation of Water Mains
Service Connections	Service connections have to be excavated.
Structural Rating Claimed	In some cases, the HDPE system can act as a fully structural solution where the host pipe is considered fully deteriorated.
Materials of Composition	HDPE
Diameter Range, inches	2 in. to 52 in.
Thickness Range	DR 35 to DR 44
Pressure Capacity, psi	No pressure rating (pressure must be contained by the host-pipe)
Temperature Range, °F	192°F (highest to date)
Renewal Length, feet	Up to 2,500 ft depending on winching capacity
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	NSF/ANSI Standard 61 Certification
Design Standards	Not Available
Design Life Range	50 years
Installation Methodology	• The PE pipe lining has a larger outside diameter than the inside diameter of the steel pipe it protects. The steel pipeline is cut into sections that allow for the insertion of the pipe lining system. Depending on diameter, bends, terrain, and condition of the steel, the

Technology/Method	United Pipeline Tite Liner®/Reduced Diameter Pipe
	maximum section length (pull-length) can be up to a mile. • A wire line cable is sent through a section of pipeline and is then attached to the liner pipe. The wire line pulls the internal pipe lining system through the roller reduction box which is positioned at the insertion end of the pipeline section. • The liner pipe is compressed radially as it passes through the roller reduction box. This temporary reduction provides sufficient clearance between the steel pipe and the liner pipe to allow insertion. • Until the pulling is complete, the liner is under tension, causing it to remain at a reduced diameter. When the tension is released, the liner pipe expands and creates a tight fit against the internal wall of the steel pipe. • Following relaxation of the inner pipe, the polyethylene flange-fittings are attached and the line is ready for bolt-up and testing.
QA/QC	After installation the liner is tested under pressure.
IV. Operation and Maintenance Requirements	
O&M Needs	Before returning to service, the system shall be disinfected in accordance with local standards.
Repair Requirements for Rehabilitated Sections	Minor damage is repaired by stretching the liner and fusing it together within a flange.
V. Costs	
Key Cost Factors	• Liner material • Installation equipment • Entry and exit access pits • Service reconnection
Case Study Costs	Not Available
VI. Data Sources	
References	• www.unitedpipeline.com/content/111/municipal.aspx • www.unitedpipeline.com/content/148/about-tite-liner.aspx • Email and phone correspondence with Jordan Hawn

Datasheet A-42. Wavin Neofit Service Lining

Technology/Method	**Wavin Neofit Process/Close-Fit Pipe Lining**
I. Technology Background	
Status	Conventional
Date of Introduction	1998 in Europe
Utilization Rates	More than 50 installation companies worldwide
Vendor Name(s)	**Flow-Liner System, Ltd.** 4830 North Pointe Drive Zanesville, Ohio 43701 Phone: (800) 348-0020 International: (740) 453-9387 Web: www.flow-liner.com
Practitioner(s)	• North America (Louisville, KY; Calgary, AB; and Ohio) • Australia South East Water • France
Description of Main Features	The Neofit process is suitable where alternative solutions prove to be disruptive, such as long side service connections involving road crossings, congested ground and customer service pipes under drives, fencing, gardens, etc. An effective barrier is created between water supply and pipe material. The thin lining provides leak tightness in bridging socket gaps and holes in the wall, without affecting the performance of the service. The max hole spanning capability is about 1.5 times the liner diameter (i.e., 15 mm holes to be covered with a 10 mm tube).
Main Benefits Claimed	• A typical planned pipe relining from preparation to completion is about 2-3 hours with 'water off' time reduced to about 1 hr • Apart from an access pit at the main connection point, no disturbance to the environmental surroundings takes place • Minimal effect on flow rates
Main Limitations Cited	• Water off is required • Not applicable for water mains
Applicability (Underline those that apply)	Force Main Gravity Sewer Laterals Manholes Appurtenances Water Main <u>Service Lines</u> Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Close-Fit Pipe Lining of Service Lines
Service Connections	Not applicable
Structural Rating Claimed	Not-structural
Materials of Composition	Polyethylene terephthalate
Diameter Range, inches	½ in. to 1.5 in. (7 mm to 45 mm)
Thickness Range	0.006 in. to 0.016 in. (0.15 mm to 0.40 mm)
Pressure Capacity, psi	• Installed in services with pressures 87 psi to 116 psi • Has been exposed to pressures up to 290 psi
Temperature Range, ^{o}F	Cold water applications only
Renewal Length, feet	Up to 110 ft
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	
Product Standards	• NSF/ANSI Standard 61-G Certification, EN 14409 and ISO 11298, Australian WSAA, Dutch KIWA, and French LHRSP
Design Standards	Not Available
Design Life Range	50 years

Technology/Method	**Wavin Neofit Process/Close-Fit Pipe Lining**
Installation Standards	As per manufacturer's guidelines
Installation Methodology	• A small flexible tube made of PET material is inserted into the pipe • Then 85° to 87°C water is run through the lined pipe to inflate it up to 2.2 times the original size to form a close fitting thin walled liner. • Once the pipe has expanded, compressed air is run through pipes until the temperature drops to 50°C. • The cycle is completed in approximately 30 minutes.
QA/QC	As per manufacturer's guidelines
IV. Operation and Maintenance Requirements	
O&M Needs	Disinfection of system before putting it back into service.
Repair Requirements for Rehabilitated Sections	Not Available
V. Costs	
Key Cost Factors	• Pipe material and equipment • Mobilization • Entry point access pits • Surface restoration
Case Study Costs	Not Available
VI. Data Sources	
References	• http://overseas.wavin.com/overseas/Wavin_Neofit.html • www.nsf.org • www.flow-liner.com/water_lining.html • Phone and email correspondence with Mike Gonder • International Article (Elzink, 2006)

Datasheet A-43. Aqualiner Melt-in-Place Pipe Lining

Technology/Method	**Aqualiner/Melt-in-Place Pipe Lining**
I. Technology Background	
Status	Emerging
Date of Introduction	2008 – development trials in Europe
Utilization Rates	Limited, still in development stage
Vendor Name(s)	**Aqualiner Ltd** Unit 10, Charnwood Business Park, North Road, Loughborough, Leicestershire, LE11 1QJ, United Kingdom Phone: +44 (0) 150-921-0027 Email: info@aqualiner.co.uk Website: www.aqualiner.co.uk
Practitioner(s)	Three field trials undertaken by Wessex Water Contact Julian Britton, Manager – Critical Sewers Team Kingston Seymour STW, Back Lane Clevedon UK BS21 6UY Phone: +44 (0) 127-587-5157
Description of Main Features	Aqualiner involves inserting a glass fiber reinforced polypropylene sock into a deteriorated pipe. Once the composite sock has been inserted into the host pipe, a silicone rubber inflation tube pushes a heated pig through the composite melting the thermoplastic sock against the pipe. The inversion bag presses the molten thermoplastic composite sock against the pipe wall where it cools to form a solid glass reinforced thermoplastic liner.
Main Benefits Claimed	• No mixing of chemicals – long shelf life • Environmentally safe – no releases • Structural – capable of withstanding internal and external pressure • Minimizes any loss of capacity since the liner is thin • Minimizes excavation and disruptions
Main Limitations Cited	• Bypass required • Still in incubation – not commercially released yet • Not NSF/ANSI 61 certified
Applicability (Underline those that apply)	<u>Force Main</u> Gravity Sewer Laterals Manholes Appurtenances <u>Water Main</u> Service Lines Other: <u>Not Applicable</u>
II. Technology Parameters	
Service Application	Melt-in-Place Pipe Lining Rehabilitation of Water Mains
Service Connections	Open cut or robotically reinstate. Fusion couplings under development
Structural Rating Claimed	• Class IV (AWWA M28 Manual) fully structural independent liner • Will conform to the strain corrosion requirements for a GRP sewer pipe as contained in Table 6 of EN 13566-4:2002 (similar to those in ASTM D-3262).
Materials of Composition	Chopped glass fiber and polypropylene
Diameter Range, inches	6 in. to 12 in.
Thickness Range	3 to 6 mm
Pressure Capacity, psi	Up to 145 psi
Temperature Range, °F	23°F to 104°F (-5°C to 40°C)
Renewal Length, feet	500 ft for 12 in. pipes
Other Notes	Not Available
III. Technology Design, Installation, and QA/QC Information	

Technology/Method	**Aqualiner/Melt-in-Place Pipe Lining**
Product Standards	None at this time. Closest applicable standard might be EN ISO 15874 – Polypropylene for hot and cold water installations
Design Standards	None at this time. Closest applicable standard might be EN 13566-4:2002, Plastic piping systems for renovation of underground sewerage networks (CIPP).
Design Life Range	50 years
Installation Standards	None at this time.
Installation Methodology	• The host pipe is first cleaned and then CCTV inspected for location of laterals and fittings. • The liner can be installed through a bend of up to 45 degrees. • A pig is inserted into the thermoplastic composite sock. The pig heats the polypropylene until it melts. • An inversion drum deploys a silicone rubber inflation tube which pushes the pig through the pipe. Application rate is 1.5 ft/min. • The inversion bag also presses the molten thermoplastic composite sock against the pipe wall where it cools to form a solid homogeneous thermoplastic composite liner. Pressure in the inversion bag is kept at 45 psi (3 bar). • The inversion bag is deflated and removed after the liner cools.
QA/QC	• After installation, CCTV inspection should be performed on the liner. The internal surface is to be smooth, clean, and free from scoring, cavities, wrinkling, and other surface defects. • Samples of the formed liner should be checked for thickness, short-term flexural modulus, and tensile strength, but as yet no design values have been provided.
IV. Operation and Maintenance Requirements	
O&M Needs	None identified yet.
Repair Requirements for Rehabilitated Sections	Remove host pipe and Aqualiner and replace with new pipe section and tie back to existing host pipe with repair clamps.
V. Costs	
Key Cost Factors	• Mobilization one fully equipped installation truck, compressor, and generator. • Cleaning and inspection • Materials: liner tuber, resin, and fittings • Bypass system • Entry and exit access pits • Service reinstatement • Site restoration
Case Study Costs	Estimated Cost ~ $35-$40/ft
VI. Data Sources	
References	• www.aqualiner.co.uk • ISTT No-Dig Paper (Boyce and Downey, 2010) • Aqualiner Product Specification Issue 3 (Aug. 12, 2007)