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WEB-BASED DATABASE ON RENEWAL TECHNOLOGIES



Office of Research and Development
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by

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DISCLAIMER

The U.S. Environmental Protection Agency (EPA), through its Office of Research and Development, funded and managed the research described herein under Task Order (TO) 01 of Contract No. EP-C-11-038 to Battelle. It has been subjected to the Agency's peer and administrative review and has been approved for publication. Any opinions expressed in this report are those of the authors and do not necessarily reflect the views of the Agency, therefore, no official endorsement should be inferred. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use. Case study data was collected from publically available information. The quality of the case study information and secondary data referenced in this document was not independently evaluated by EPA and Battelle.

ABSTRACT

As U.S. utilities continue to shore up their aging infrastructure, renewal needs now represent over 43% of annual expenditures compared to new construction for drinking water distribution and wastewater collection systems (Underground Construction [UC], 2016). An increased understanding of renewal options will ultimately assist drinking water utilities in reducing water loss and help wastewater utilities to address infiltration and inflow issues in a cost-effective manner. It will also help to extend the service lives of both drinking water and wastewater mains. This research effort involved collecting case studies on the use of various trenchless pipeline renewal methods and providing the information in an online searchable database. The overall objective was to further support technology transfer and information sharing regarding emerging and innovative renewal technologies for water and wastewater mains. The result of this research is a Web-based, searchable database that utility personnel can use to obtain technology performance and cost data, as well as case study references. The renewal case studies include: technologies used; the conditions under which the technology was implemented; costs; lessons learned; and utility contact information. The online database also features a data mining tool for automated review of the technologies selected and cost data. Based on a review of the case study results and industry data, several findings are presented on trends in the water and wastewater renewal market and opportunities for future improvements. The database can be accessed at: http://138.47.78.37/Retrospective.

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This report has been prepared with input from the research team, which includes Battelle and the Trenchless Technology Center (TTC) at Louisiana Tech University, and Dr. Ray Sterling. The technical direction and coordination for this project were provided by Dr. Ariamalar Selvakumar, the EPA Task Order Manager. The project team would like to thank the water and wastewater utilities and technology vendors that provided case study information.

EXECUTIVE SUMMARY

As U.S. utilities continue to shore up their aging water and wastewater infrastructure, renewal needs now represent over 43% of annual expenditures compared to new construction (Underground Construction [UC], 2016). New trenchless renewal technologies continue to come to market and improvements in existing technologies are ongoing. An increased understanding of these new renewal options will ultimately assist drinking water utilities to optimize their choices for reducing water loss and help wastewater utilities to optimize their choices for addressing infiltration and inflow issues in a cost-effective manner. To support information sharing, the U.S. Environmental Protection Agency (EPA) supported this research effort for the collection of case studies on the use of trenchless pipeline renewal methods. This task also created a Web-based, searchable database that utility personnel can use to obtain technology performance and cost data. Several findings are also presented on trends in the water and wastewater renewal market and opportunities for future technology improvements based on a review of the case study results.

For water main renewal, 107 case studies were collected. Spray-on lining, cured-in-place pipe (CIPP), and close-fit lining were identified as the most prevalent methods from the case study collection efforts. Lessons learned and the needs for future improvements for each of these renewal technologies are summarized. Overall, the use of water main renewal technologies was highest in the northeast (18%) followed by the southwest (16%) and north central (16%) U.S. regions. At the same time, a large number of water main renewal case studies were identified in Canada or outside of North America (29%) indicating that the use of these technologies may be more prevalent outside the U.S. This suggests there is room for growth in the U.S. market as the demand for water main renewal services increases over time.

For wastewater main renewal, 82 case studies were collected. CIPP is by far the dominant technology. The case study results focus on innovations identified in ultraviolet-cured and reinforced CIPP liners, spiral wound lining, and spray-on lining for sewer mains. After conventional CIPP, these technologies were identified as the next most prevalent methods used for sewer main renewal from the case study collection efforts. Lessons learned and the needs for future improvements for each of these technologies are summarized. The most wastewater main renewal case studies were identified in the north central region at 25%. This was followed by the northeast (19%) and southwest (19%) regions. In contrast to water main renewal, only 9% of the case studies identified were located in Canada or outside North America. This reflects the stronger domestic market for wastewater main renewal due to enhanced regulatory drivers.

A data mining algorithm was also developed to extract and normalize cost data from the case studies and to plot the data for ease of review. To serve as a benchmark, bid cost data were collected for conventional renewal technologies including cement mortar lining (CML) for water mains and sliplining for sewer mains for comparison to the innovative technology costs. CML and sliplining technologies were chosen to benchmark costs because of their well-established and long-term history of use nationwide. Costs can vary widely based on site-specific conditions such as cleaning needs, dewatering needs, the need for night work to avoid traffic disruption, and other factors. Cost curves are provided in the online tool to view unit costs from the case studies.

The Web-based, searchable tool created as part of this research project can be used to review: the renewal technologies used; the conditions under which the technology was implemented; costs; lessons learned; and utility contact information. Utilities are encouraged to review the case studies for relevance to their own system and to support future expansion of the online database through the addition of their own case study information.

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ABBREVIATIONS AND ACRONYMS

AC	asbestos cement
EPA	U.S. Environmental Protection Agency
CCTV	closed-circuit television
CI	cast iron
CIPP	cured-in-place pipe
CML	cement mortar lining
DI	ductile iron
HDPE	high density polyethylene
PCCP	pre-stressed concrete cylinder pipe
PE	polyethylene
psi	pound per square inch
PVC	polyvinyl chloride
RCP	reinforced concrete pipe
RCCP	reinforced concrete cylinder pipe
SOT	state-of-technology
TO	task order
TTC	Trenchless Technology Center
QA	quality assurance
QC	quality control
UC	Underground Construction
VCP	vitrified clay pipe
WERF	Water Environment Research Foundation

Section 1.0: INTRODUCTION

1.1 Objective of this Study

As U.S. utilities continue to shore up their aging water and wastewater infrastructure, renewal needs now represent over 43% of annual expenditures compared to new construction. Approximately 33% of projects overall are reported to utilize some form of trenchless technology (Underground Construction [UC], 2016). New trenchless renewal technologies continue to come to market and improvements in existing technologies are ongoing. Despite the growing use and acceptance of trenchless technologies nationwide, many water and wastewater utilities remain unaware of the full range and capabilities of available technologies. An increased understanding of these renewal options will ultimately assist drinking water utilities in reducing water loss and help wastewater utilities to address infiltration and inflow issues in a cost-effective manner. For the purposes of this report, renewal technologies are considered to cover the repair, rehabilitation, and replacement of pipes via trenchless means (e.g. excluding open cut approaches). This research effort involved the collection of case studies on the use of various pipeline renewal methods and provides the information in an online searchable database. The overall objective was to further support technology transfer and information sharing regarding emerging and innovative renewal technologies for water and wastewater mains.

1.2 Study Background

Water and wastewater utilities have shown great interest in having access to renewal case study information. Therefore, this Web-based database fulfills a need in the industry to document and share lessons learned from real-world projects with varying host pipe and site conditions. The database contains both quantitative parameters on host pipe condition and technology specifications, along with lessons learned from technology applications. This research builds upon previous work to document the state-of-technology for water main renewal (Environmental Protection Agency [EPA], 2013) and wastewater main renewal (2010), to demonstrate innovative renewal technologies in the field (EPA, 2012a; EPA, 2012b; EPA, 2014a, EPA, 2016a), and to review available technology selection decision-support tools (EPA, 2011).

Decision support tools do exist for the selection of renewal technologies, but several gaps remain in these tools (EPA, 2011). These tools are capable of performing critical decision functions (i.e., processing condition assessment data; screening multiple technologies based on various technical parameters; performing cost analysis; and ranking applicable technologies). However, most tools lack other crucial information including: access to more alternative renewal options and data; access to regional cost data; access to technology case histories, specifically for new methods; and access to utility users that have used the technology for further information about applicability and lessons learned. Further guidance on tools used to select renewal technologies is provided in EPA (2011).

This task created a Web-based, searchable tool that utility personnel can use to obtain technology performance and cost data, as well as case study references. The renewal case studies include: technologies used; the conditions under which the technology was implemented; costs; lessons learned; and utility contact information.

1.3 Organization of the Report

The remainder of the report is organized into the following sections:

- **Section 2 Database Development Approach.** Section 2 describes the development of the database for storing renewal technology data, its user interface, and data mining approaches.

- **Section 3 Water Main Renewal Market and Innovations.** Section 3 describes the current state of the water main renewal market and recent innovations. Water main renewal case studies are organized by technology type and cover characteristics related to host pipe types, pipe sizes, and regional distribution, along with findings on lessons learned.
- **Section 4 Wastewater Main Renewal Market and Innovations.** Section 4 describes the current state of the wastewater main renewal market and recent innovations. Wastewater main renewal case studies are organized by technology type and cover characteristics related to host pipe types, pipe sizes, and regional distribution, along with findings on lessons learned.
- **Section 5 Conclusions.** Section 5 provides the conclusions from the current work and recommendations to further advance the use of innovative and cost-effective renewal technologies.

Section 2.0: DATABASE DEVELOPMENT APPROACH

This section describes the overall approach to the online database development and provides an overview of the features and capabilities of the user interface. The data mining methods deployed to analyze the renewal case study information are also discussed.

2.1 Database Need and Value

The Web-based renewal technology case study database provides a vehicle to share case studies for different trenchless technologies installed in locations nationwide. The database contains key technology parameters, as well as lessons learned from utilities on the installation, quality assurance/quality control (QA/QC), and operation and maintenance of renewal technologies. The primary focus was on emerging and innovative renewal technologies suitable for water and wastewater mains from each of the six regions of the U.S. (i.e., northeast, southeast, north central, south central, northwest, and southwest). Additional case studies were collected from Canada, Mexico, Europe, and other locations in situations where the numbers of domestic case studies were limited. More than 180 case studies were identified for water main and wastewater renewal technologies. The case studies were collected from EPA sponsored field studies, journal articles, conference proceedings, trade magazines, and vendor-supplied information.

2.2 Database Location and Accessibility

The database is currently being maintained and housed on a server at the Louisiana Tech University Trenchless Technology Center (TTC). It is accessible through the following Web link: http://138.47.78.37/Retrospective. The database is available online through a Web site constructed using *Microsoft ASP.Net technology* with *C#.Net* and the database software is *MySQL*.

2.3 Database Overview

2.3.1 Login Page. The *Login* page requires the following account information: username, password, and role. Two roles are specified in the dropdown menu including User and Administration. For the first time user, there is an option to register and the administrator is alerted by an e-mail notification to authorize access. An e-mail will then follow from the administrator to the new user once the request for an account has been approved. Once logged in, the user can access the Web pages and *RehabAnalytics* tool described below. The Web site is a free database with no charge to access the content, but an account is requested for security and access purposes.

2.3.2 Background Pages. After successful login, the user is directed to the *Home* page where a brief description of the project is given. As shown in Figure 2-1, the Web site housing the database consists of the following Web pages:

- Home Page,
- Research Page,
- Team Page,
- Methods Page,
- Case Studies Page,
- RehabAnalytics,
- Submit, and
- Account Profile/Login.

Figure 2-1. Home Page of the Database Web Site

Under the *Research* Web page, the overall research objectives are explained, along with information about the database. This Web site houses both a wastewater retrospective case study database (EPA, 2014b) and the renewal case study database described in this report. The Web site describes the objectives for both research efforts. The retrospective case study database was focused on the collection of case study information from trenchless projects that had been installed decades ago, along with physical pipe specimens to assess the long-term performance of well-established trenchless technologies. The renewal case study database was focused on the collection of case study information with a primary focus on more recent emerging and innovative trenchless technology applications. The participants on the research team from Battelle and TTC are presented under the *Team* Web page, along with acknowledgments.

2.3.3 Methods Page. Separate tabs for *Wastewater* and *Water* technologies are provided under the *Methods* Web page (see Figures 2-2 and 2-3). The main focus of the database is on the rehabilitation methods listed below, although spot repair case studies are also addressed in the renewal database. Under the *Wastewater* tab, various sewer main rehabilitation methods are outlined that are included as part of the database structure. Under the *Water* tab, various water main rehabilitation methods are outlined that are included as part of the database structure. This serves as a reference for the general categories of available technologies and links are provided to the relevant state-of-technology (SOT) reports for more detailed information (EPA, 2013; EPA, 2010).

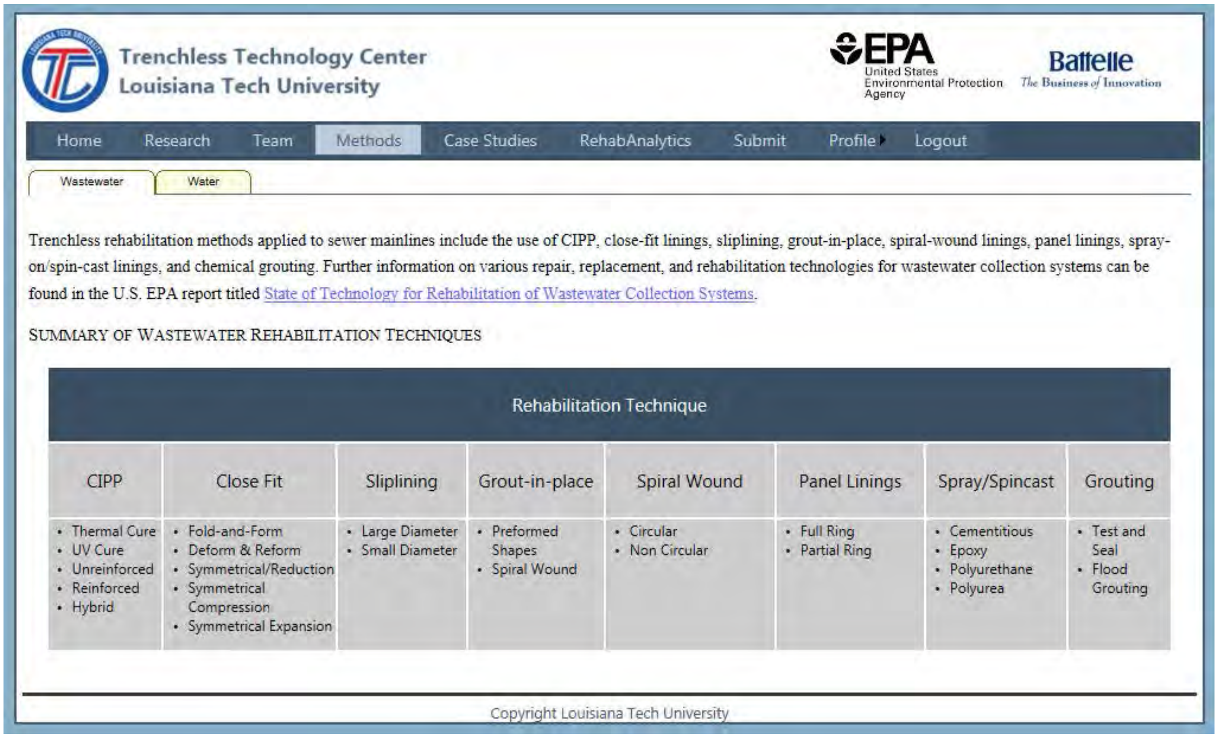

Figure 2-2. Wastewater Main Rehabilitation Techniques

Figure 2-3. Water Main Rehabilitation Techniques

2.3.4 Case Studies. This page has three subtabs including *Wastewater (Retro)*, *Wastewater*, and *Water*. The *Wastewater (Retro)* tab provides access to the retrospective rehabilitation technology performance information collected as part of a companion study to this research effort as documented in EPA (2014b). The information provided in the retrospective portion of the Web site is described in detail in EPA (2014b). Under the *Wastewater* and *Water* tabs, the renewal case studies of conventional, innovative, and emerging technologies collected as part of the current research effort can be accessed. The case studies are searchable through either a dropdown menu of key parameters and/or an interactive map. The *Water* tab is shown here as an example in Figure 2-4. The *Wastewater* tab contains similar information with the dropdown menu choices tailored to that specific application. Case studies are searchable by: region, renewal method, pipe material, and pipe diameter. The user can also select "all" in each dropdown box to view the complete contents of the case study database. Upon selection of the search criteria, the user can download the case study information into a Microsoft® Excel database that can be viewed online or saved to their desktop. An example case study for a water main cured-in-place pipe (CIPP) study is provided in Table 2-1 to illustrate the nature of the information collected. The data collected include utility information, host pipe information, technology application information, cost, lessons learned, and references for more details.

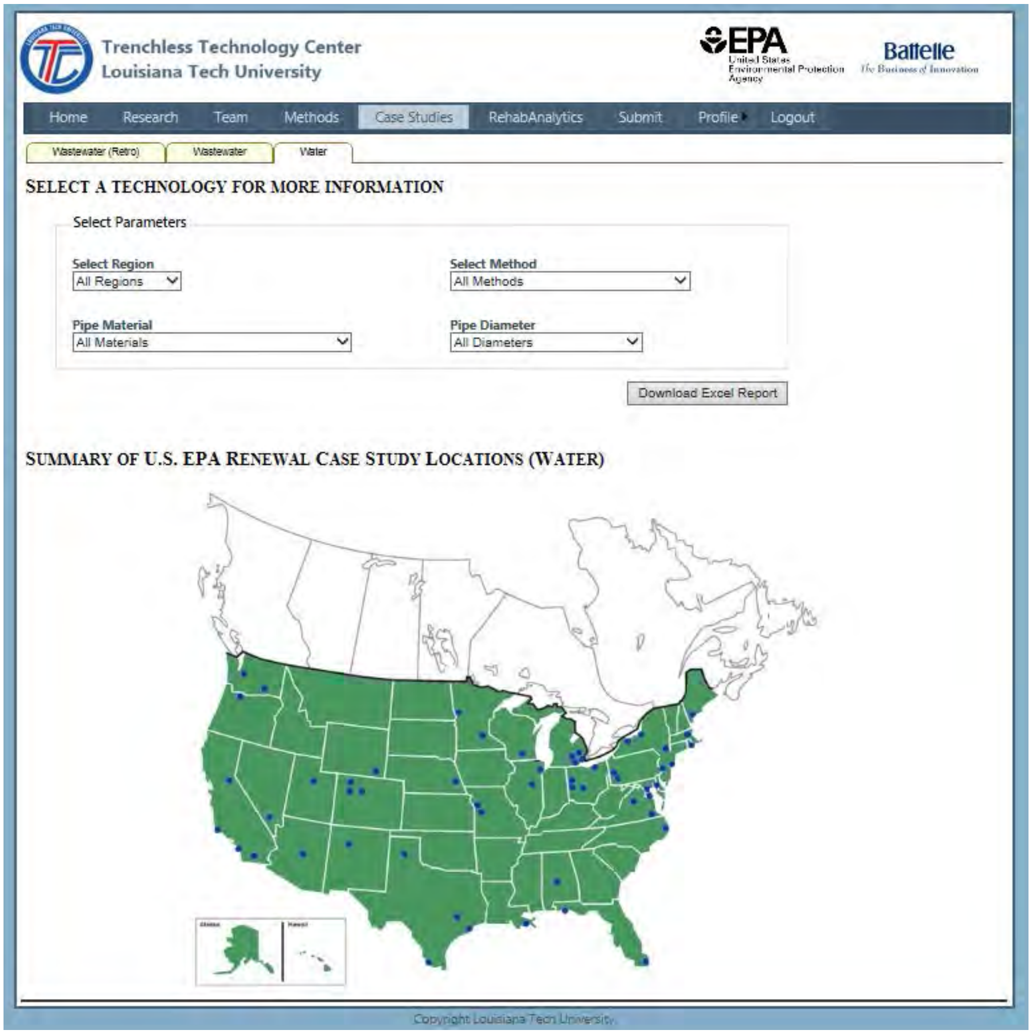

Figure 2-4. Water Main Renewal Case Study Locations

Table 2-1. Example Water Main CIPP Case Study

Utility Information	
Agency	City of Cleveland Water Division, Cleveland, OH
Region	North Central
Primary Contact	Greg Sattler, Water Utility Technical Lead, (216) 664-2444, gregory_sattler@clevelandwater.com
System Type	Water Distribution
System Size	5,200 miles of water mains
Host Pipe Data	
Host Pipe Location	Ferncliffe Avenue between West 190th and Rock River Drive, Cleveland, OH
Host Pipe Installation Date	1914 and 1949
Host Pipe Material	Cast Iron (CI)
Host Pipe Shape	Circular
Host Pipe Diameter (in)	6
Host Pipe Length	1,996 ft Long
Host Pipe Burial Depth and Water Table	6 ft Deep Pipe; Groundwater Table Below the Pipe
Condition Assessment History	CCTV Inspection Prior to Lining
Problem in the Host Pipe	Cracking, Corrosion, Debris, Tuberculation
Technology Data	
Technology Type	Cured-in-Place Pipe (CIPP)
Technology Name	Sanexen Aqua-Pipe®
Date Installed	September 10-18, 2010
Technology Design	2.5 mm Liner Thickness per ASTM F1216
Technology Installer/Vendor	Terrace Construction/Sanexen
Cleaning Method Used	Hydraulic Jet Cleaning, Scraping, and Swabbing
Technology QA/QC Data	Post-Lining CCTV, Lining Thickness, Flow Test, Pressure Testing, and Structural Material Testing
Cost Data ($/LF)	$187.38
Cost Notes	Lining Cost Only
Lessons Learned	
Construction Problems	Had to reinstate 27% of the services externally, which is well above the typically reported 5-10%
Technology Performance Problems	None reported
Adjustments Made	N/A
Continued Use of the Technology	Multiple utilities have expressed their willingness to use this technology again
Reference	EPA. (2012). Performance Evaluation of Innovative Water Main Rehabilitation CIPP Lining Product in Cleveland, OH. EPA/600/R-12/012, U.S. EPA, ORD, NRMRL, Edison, NJ, Feb., 117 pp.

2.3.5 RehabAnalytics. Data analytics provides a powerful tool for the automated analysis and correlation of datasets. The *RehabAnalytics* tool was created by TTC using Visual Studio 2010 to provide data mining and Web-based data analyses for the renewal case studies. Trends are analyzed and displayed based upon the frequency of use of renewal technologies nationwide. Cost data curves were also incorporated based on bid cost data analyses for various innovative and conventional renewal technologies. The *RehabAnalytics* Web page allows access to this data mining component to automatically query and display aggregated data and trends across multiple case study sites from the database.

RehabAnalytics displays case study frequency counts and cost data plots for wastewater and water main renewal technologies. For example, the *Frequency Plot* subtab under the *Water* tab runs a query to display the total number of case studies by water main renewal method (see Figure 2-5). A similar plot is available online for the wastewater main renewal case studies. This plot is actively generated from the database, so it has the ability to automatically update as new case studies are added.

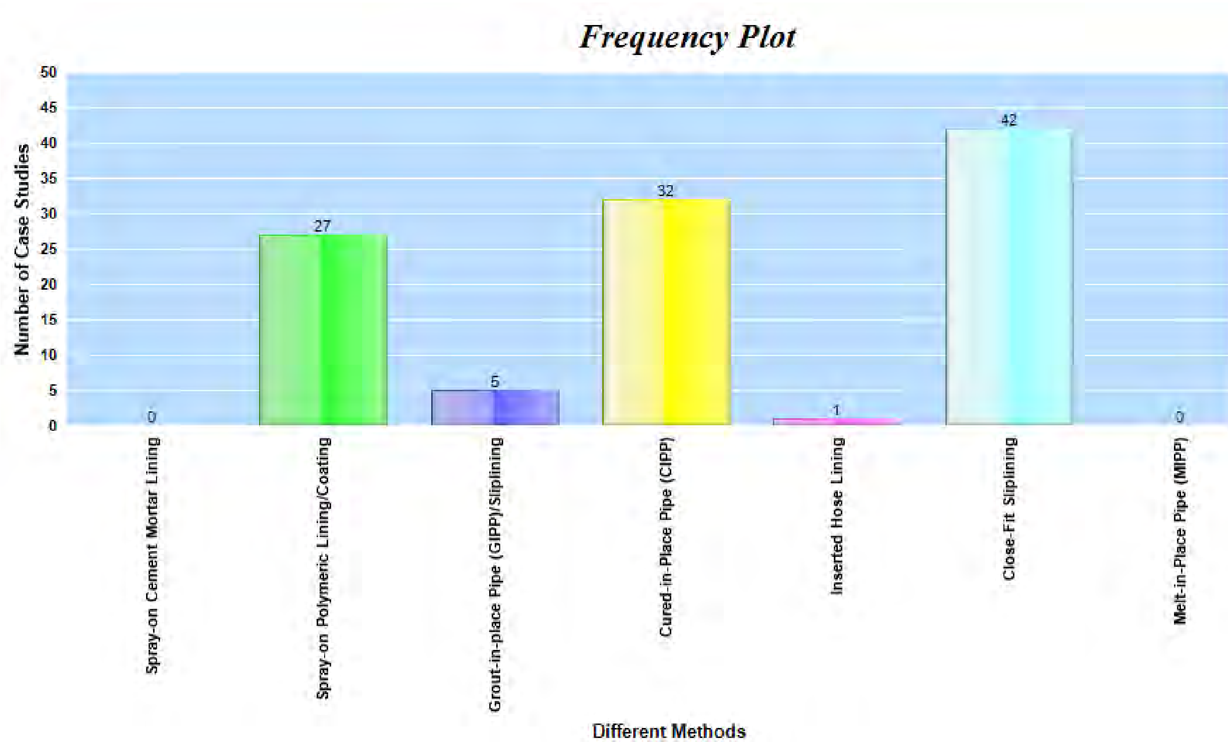

Figure 2-5. RehabAnalytics Total Count Summary for Water Main Case Studies

RehabAnalytics also provides a feature to retrieve unit cost data from the case studies and compare them to bid costs for conventional renewal technologies. The major cost components are also summarized in the case studies under "cost notes" to describe what cost factors are included or excluded from the cost estimate. The *Cost Plot* subtab is shown in Figure 2-6 for the water main case studies where the user can select the renewal method of interest from the dropdown box. An example plot is provided in Figure 2-7 of unit water main CIPP costs versus conventional cement mortar lining (CML) costs as normalized by diameter. This plot is provided to benchmark the unit costs versus a conventional technology that is familiar to water utilities. A curve fitting function is also provided.

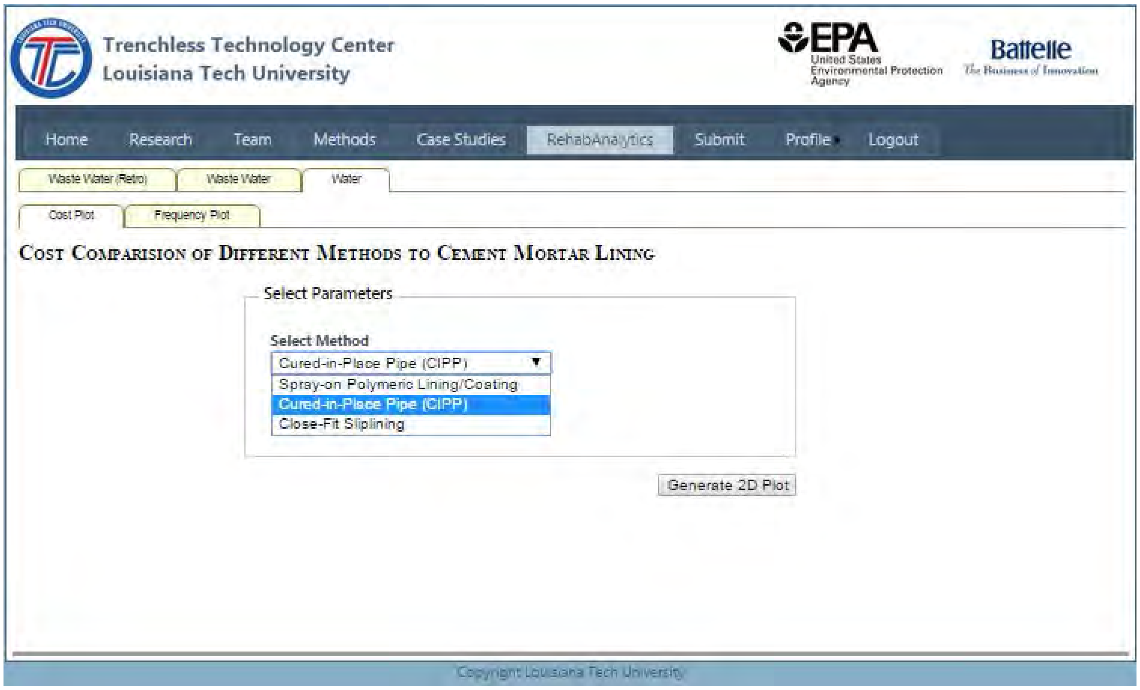

Figure 2-6. RehabAnalytics for Water Main Case Studies

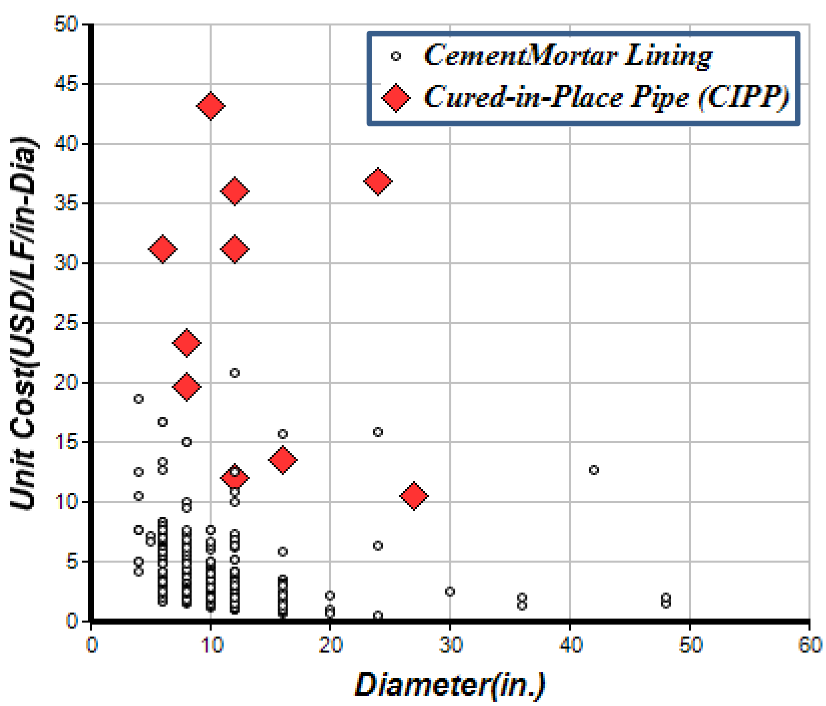

Figure 2-7. RehabAnalytics Water Main Renewal Comparison Cost Plot

Section 3.0: WATER MAIN RENEWAL MARKET AND INNOVATIONS

The adoption of trenchless technologies for potable water applications has been slower than wastewater applications, but it is becoming more prevalent over time. Over the past 18 years, total U.S. municipal spending on drinking water distribution systems has more than doubled from $2.6 to $6.3 billion (see Figure 3-1). In that same timeframe, the expenditures on water main renewal has more than tripled from $0.6 billion in 1998 to $2.2 billion in 2016. Water main renewal is also a growing proportion of the total expenditures compared to new construction, reaching 35% in 2016 (UC, 2016). This section reviews the overall status of the water main renewal market based on the collected case studies and relevant industry information. Available water main renewal technologies are presented, along with a summary of the case studies identified including total case study counts, pipe sizes, pipe material types, regional distribution, and any findings on lessons learned. The technologies are categorized as shown in Figure 3-2 with a focus on spray-on linings, CIPP, and close-fit lining, which were identified as the most prevalent methods used for water main renewal from the case study review.

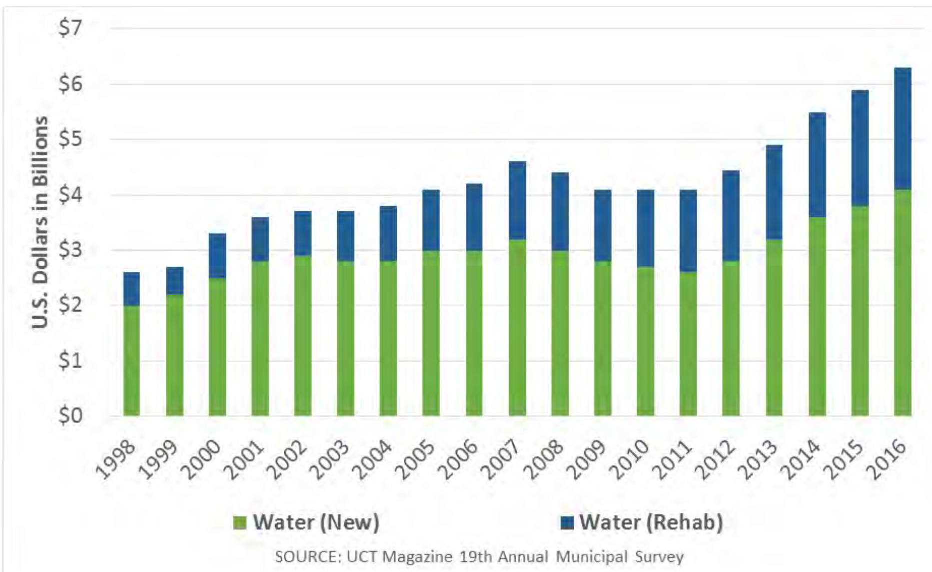

Figure 3-1. Expenditures on Water Pipeline Infrastructure (UC, 1998 to UC, 2016)

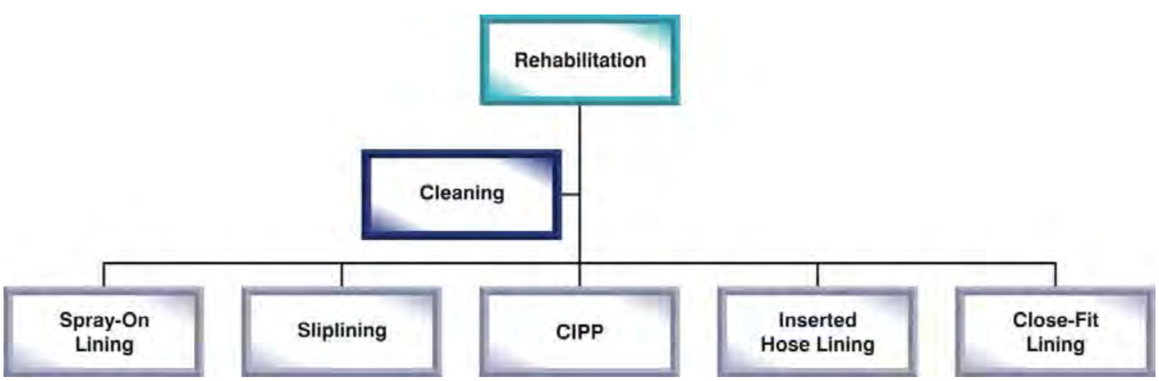

Figure 3-2. Rehabilitation Approaches for Water Mains (EPA, 2013)

3.1 Spray-On Lining for Water Mains Case Study Findings

Spray-on linings include either cementitious or polymer-based linings. They can be applied using conventional spray applications or spin-cast, projectile, or centrifugal applications. CML has been widely used for water main rehabilitation when corrosion protection of the interior surface is needed. Because the use of CML for water mains is well established, it is not further addressed in this report. The report does address a growing trend in the use of innovative polymeric linings that have been designed to provide for structural rehabilitation in addition to corrosion protection. More detailed information on spray-on linings can be found in Ellison et al. (2010). Over 19 spray-on lining products have been NSF 61 approved as coatings suitable for potable water main rehabilitation. Table 3-1 summarizes the 27 spray-on polymeric lining case studies for water mains identified as part of the case study collection efforts.

Table 3-1. Summary of Spray-on Polymeric Lining Case Studies for Water Mains

Company Information					Case Study Information			
Vendor	Technology Name	Headquarters Location	Annual Sales ($M)	No. of Staff	No. of Case Studies	Regions	Pipe Size Range (in)	Pipe Materials
3M	Scotchkote™ Pipe Renewal Liner 2400	St. Paul, MN	$31,821	89,800	5	NE, CA, NNA	6 - 10	CI
Acuro	Polymeric Resin Lining	Montreal, Quebec, Canada	NA	NA	9	CA	4 - 10	CI, DI
Nu Flow	Epoxy Coating	Oshawa, Ontario, Canada	$2.9	31	8	NE, SE, NNA	1 - 4	CU
Quest Inspar	Pipe Armor 150S W	Kent, WA	$8.8	46	1	NW	58	SP
Radius Systems (Subterra)	Fast-Line Plus™ Polyurethane Lining	Alfreton, Derbyshire, England	$106	449	3	NNA	6 - 32	CI
Warren Environmental	Epoxy and Pressure Infusion Lining System	Middleboro, MA	$2.9	8	1	SW	42	PCCP

Note:
Regions: NE (North East), SE (South East), NC (North Central), SC (South Central), NW (North West), SW (South West), CA (Canada), NNA (Non-North America)
Pipe Materials: CI (Cast Iron), CIL (Cast Iron, Lined), DI (Ductile Iron), DIL (Ductile Iron, Lined), SP (Steel Pipe), SPL (Steel Pipe, Lined), PVC (Polyvinyl Chloride), HDPE (High-Density Polyethylene), PCCP (Prestressed Concrete Cylinder Pipe), RCP (Reinforced Concrete Pipe), AC (Asbestos Cement), CU (Copper Pipe), RCCP (Reinforced Concrete Cylinder Pipe), U (Unknown)

The majority of case studies identified were located in Canada and Europe suggesting that there is still room for additional growth in the application of spray-on lining technologies within the U.S. Water main pipe sizes requiring renewal ranged from 4 to 58 inches with the host pipes consisting primarily of ferrous pipes, but also steel and pre-stressed concrete cylinder pipe (PCCP). The host pipe condition issues addressed included reduced structural integrity, breaks, leaking joints, tuberculation, corrosion, discolored water, low flow, and low pressure. One technology (Nu Flow) was applied primarily for copper service lines ranging in size from 1 to 4 inches to address pinhole leaks and discolored water. One hybrid technology was installed on a 42-inch water main in Mesa, Arizona that combined a spray-applied epoxy from Warren Environmental with a carbon fiber lining to provide for an innovative structural repair.

No major issues were noted with spray-on lining products available on the market. Surface preparation is an important first step in the spray-on lining process and a variety of cleaning methods were used including abrasive blasting, rack-feed boring, scraping, and water jetting. The types of QA/QC activities included post-lining closed-circuit television (CCTV), lining thickness verification, hydraulic pressure testing, and flow tests. One large-scale installation with a man-entry pipe (58 inches in diameter) included visual inspection for QA/QC. Across the case studies, minor construction issues were noted with blisters, small areas of lining discontinuity at joints, and some equipment downtime (e.g., liner gun and thickness gauge). Future technology refinement is needed to ensure minimum thicknesses are met in a consistent manner throughout the installation. Thickness verification is suggested as a QA/QC measure for all installations and a standardized approach to post-lining QA/QC processes could be adopted for spray-on applications. The consistent application of spray-on linings is an important issue for further research.

3.2 CIPP for Water Mains Case Study Findings

CIPP lining involves the insertion of a resin-saturated tube into the host pipe. The tube is first placed by air or water inversion (or a winch) and then expanded against the host pipe using air or water pressure. The resin is cured using steam or hot water to form a structurally sound pipe liner within the deteriorated host pipe. A recent innovation is an ultraviolet-cured application suitable for water mains (SAERTEX-Liner® H2O). For potable water main applications, the resins are certified as safe for use through NSF 61. Currently, ten CIPP products are certified for water main rehabilitation within the U.S. Of these 10 CIPP products, two are steam cured, one is ultraviolet-cured, and the remaining seven are hot water cured. Most require an additional ambient cure time ranging from 2 to 7 days before returning to service. More information on CIPP for water mains can be found in EPA (2013). Table 3-2 summarizes the 32 CIPP case studies for water mains identified as part of the case study collection efforts.

Table 3-2. Summary of CIPP Case Studies for Water Mains

Company Information					Case Study Information			
Vendor	Technology Name	Headquarters Location	Annual Sales ($M)	No. of Staff	No. of Case Studies	Regions	Pipe Size Range (in)	Pipe Materials
Ashimori	PALTEM	Osaka, Japan	$453.5	2,146	1	NNA	32	DIL
Insituform	InsituMain® CIPP Lining	Chesterfield, MO	$276.9	3,280	7	NC, SC, SW	10 - 24	CI, DI, DIL, SP, SPL
Insituform	PPL® CIPP Lining	Chesterfield, MO	$276.9	3,280	1	SW	27	SP
Karl Weiss Technologies	Starline HPL-W	Berlin, Germany	$22.9	185	1	NNA	20	CI
LiquiForce	CIPP	Kingsville, Ontario, Canada	$2.8	45	2	NC, CA	12 - 48	CI, U
Sekisui Norditube, Inc.	NordiPipe™ CIPP Lining	San Clemente, CA	$0.5	5	5	NE, NW, NNA	12 - 36	AC, CI, DI, SP
Sanexen	Aqua-Pipe® CIPP Lining	Brossard, Quebec, Canada	$112.2	240	15	NE, NC, SE, SW, CA	6 - 12	AC, CI, DI

Note:
Regions: NE (North East), SE (South East), NC (North Central), SC (South Central), NW (North West), SW (South West), CA (Canada), NNA (Non-North America)
Pipe Materials: CI (Cast Iron), CIL (Cast Iron, Lined), DI (Ductile Iron), DIL (Ductile Iron, Lined), SP (Steel Pipe), SPL (Steel Pipe, Lined), PVC (Polyvinyl Chloride), HDPE (High-Density Polyethylene), PCCP (Prestressed Concrete Cylinder Pipe), RCP (Reinforced Concrete Pipe), AC (Asbestos Cement), CU (Copper Pipe), RCCP (Reinforced Concrete Cylinder Pipe), U (Unknown)

The majority of the case studies identified were located within the north central U.S. likely due to their proximity to the main CIPP vendors for water main applications. Water main pipe sizes requiring renewal ranged from 6 to 48 inches with the host pipes consisting of asbestos cement (AC), cast iron (CI), ductile iron (DI), and steel pipe types. The host pipe condition issues addressed included large cracks, joint leaks, known leaks identified from pipe inspections, construction damage, and external corrosion. It was noted that many of the CIPP installations for water mains were located in high consequence areas such as under highways, railways, airport facilities, water treatment plant facilities, schools, and congested downtown locations (e.g., Madison Avenue in New York City). This suggests that CIPP may be selected at challenging sites where there is a high need for improving structural integrity through use of a technology with an established track record.

Across the CIPP case studies, no major issues were noted with products available on the market. QA/QC measures included hydraulic pressure testing, liner thickness measurements, mechanical testing, and post-lining CCTV inspection. Some challenging site-specific conditions were noted such as a congested subsurface that limited pit excavation locations and challenges related to bends in pipelines. For example, the CIPP at one location could only be rated for 30 pounds per square inch (psi) versus the 50 psi design because of an unanticipated 45 degree bend. The installation was still accepted by the owner as the water distribution system operating pressure was around 15 psi at that location. Minor construction issues were noted with the need to reinstate service lines manually through excavation for a higher percentage of locations than expected at 20%, 27%, and 89% for three case studies. Future technology refinement may be needed to improve the ability to reconnect service lines without the need for excavations. A case study from an EPA field demonstration project of an innovative CIPP rehabilitation of a water main is highlighted below (EPA, 2012b).

INNOVATIVE CIPP PRODUCT FOR WATER MAINS IN CLEVELAND, OHIO

Under a related research effort, EPA performed an evaluation of an innovative CIPP lining product for water main rehabilitation in Cleveland, Ohio. The project evaluated the technology maturity, feasibility, complexity, performance, cost, and environmental impact. This case study is included in the Web-based renewal database (see Table 2-1). The full results are reported in EPA (2012b) for more information.

The field demonstration of the Sanexen Aqua-Pipe® CIPP liner in Cleveland provided valuable information on the design, installation, and QA/QC of CIPP used to rehabilitate water mains. The field demonstration involved the CIPP lining of approximately 2,000 ft of a 6-inch cast iron water main pipeline that had been installed in 1914 and 1949. The testing results showed that the CIPP as installed exceeded the applicable requirements of ASTM F-1216 to provide for a Class IV fully-structural liner. Findings from the study included the need to improve the cleaning process in order to avoid damaging or deforming corporation stops and to address other issues contributing to the need to excavate and externally reinstate 17 of the 63 service connections (27%). A more typical external reinstatement rate was reported to be 5% to 10% by the vendor (EPA, 2012b). Case study results from the water main renewal database suggest that fully internal reinstatement of service lines can be a challenge for several water main CIPP technologies depending on site conditions.

3.3 Close-Fit Lining for Water Mains Case Study Findings

Close-fit lining involves the use of a thermoplastic liner for insertion into a deteriorated host pipe. The liner materials typically consist of polyethylene (PE) or polyvinyl chloride (PVC). The thermoplastic liner is temporarily deformed to reduce its cross section before insertion. The liner can be deformed either in the field or at the manufacturer's facility. Once the liner shape is restored, it forms a close-fit within the host pipe. The close-fit lining technique helps to overcome issues caused by conventional sliplining, which can result in a significant reduction in the pipe cross section and a large annular space between the liner and host pipe that must be grouted. A close-fit liner can serve as a semi-structural solution for spanning holes and gaps or as a fully structural liner depending upon its standard dimension ratio and the operating pressure of the host pipe (EPA, 2013). Table 3-3 summarizes the 42 close-fit lining case studies for water mains identified as part of the case study collection efforts.

Table 3-3. Summary of Close-Fit Lining Case Studies for Water Mains

Company Information					Case Study Information			
Vendor	Technology Name	Headquarters Location	Annual Sales ($M)	No. of Staff	No. of Case Studies	Regions	Pipe Size Range (in)	Pipe Materials
Insituform	InsituGuard® Close-Fit Lining	Chesterfield, MO	$276.9	3,280	1	NE	48	CI
Insituform	Thermopipe®	Chesterfield, MO	$276.9	3,280	5	SW, NNA	6 - 12	AC, CI, SP
Radius Systems (Subterra)	PE Structural (Rolldown Process)	Alfreton, Derbyshire, England	$106.2	449	1	NNA	12	CI
Radius Systems (Subterra)	Subcoil Polyethylene Liner	Alfreton, Derbyshire, England	$106.2	449	2	NNA	9 - 42	CI, RCP
Radius Systems (Subterra)	Subline Fold and Form	Alfreton, Derbyshire, England	$106.2	449	6	NE, NNA	30 - 59	CI, PCCP
Swagelining	Reduced Diameter Pipe	Clydebank, Dunbartonshire, Scotland	NA	4	12	SC, SW, NNA	16 - 39	CI, SP, SPL, PCCP, RCP, RCCP
Underground Solutions, Inc.	Duraliner™	Poway, CA	$6.9	49	6	NE, NC, SE	6 - 20	AC, CI, DI
Underground Solutions, Inc.	Fusible PVC Continuous Sliplining	Poway, CA	$6.9	49	9	NC, NE, NW, SE, SW, SC	6 - 36	CI, DI, SP, SPL, HDPE

Note:
Regions: NE (North East), SE (South East), NC (North Central), SC (South Central), NW (North West), SW (South West), CA (Canada), NNA (Non-North America)
Pipe Materials: CI (Cast Iron), CIL (Cast Iron, Lined), DI (Ductile Iron), DIL (Ductile Iron, Lined), SP (Steel Pipe), SPL (Steel Pipe, Lined), PVC (Polyvinyl Chloride), HDPE (High-Density Polyethylene), PCCP (Prestressed Concrete Cylinder Pipe), RCP (Reinforced Concrete Pipe), AC (Asbestos Cement), CU (Copper Pipe), RCCP (Reinforced Concrete Cylinder Pipe), U (Unknown)

Most of the close-fit lining case studies identified were located within the northeastern and southwestern U.S. Water main pipe sizes requiring renewal ranged from 6 to 59 inches with the host pipes consisting of AC, CI, DI, steel pipe types, along with reinforced concrete pipe (RCP), reinforced concrete cylinder pipe (RCCP), and PCCP. The host pipe condition issues addressed included breaks, leaks, leaking joint seals, tuberculation, discolored water, root ingress, internal pitting, and external corrosion. Other mechanical issues with the host pipes included pipe displacement under a river bed, deflected joints, leaks from gasket failures, and the corrosion of bolts holding mechanical joints together. Site considerations that drove the need for renewal by close-fit lining included the weight of a highway expansion, redevelopment of the area requiring renewal, and the conversion of a sewer pipe into a water transmission main.

Across the close-fit lining case studies, no major issues were noted with products available on the market. QA/QC measures included primarily post-lining hydraulic pressure testing at pressures ranging from 150 to 200 psi. Some challenging site-specific conditions were noted such as root ingress causing the need for manual cutting of root masses in the host pipe to facilitate the close-fit lining insertion. Minor construction issues were noted including issues with the deformation process, pipe breakage, and pull head. Due to extreme cold at one site, the high density polyethylene (HDPE) pipe had to be warmed up to room temperature prior to being reduced. This same site experienced a few weld breaks while pulling in the close-fit liner and the exact cause of the breakages was not determined. At another site one pipe break occurred after pulling 210 meters, which was caused by the lack of coherence of the weld. Two sites noted issues with the pull head. At one site, the pull head broke away from the pipe string during the initial pulling activities. A different pull head was brought to the site and fused to the pipe string and no other issues were encountered. At another site it was found that a longer pull head was needed to prevent breaking the pipe. Another issue noted in the technology selection considerations was the need for custom made connections from HDPE to steel pipe.

3.4 RehabAnalytics Data Review for Water Mains

The *RehabAnalytics* page contains summary information on case studies for water main renewal including total case study counts (see Section 2, Figure 2-5) and an automated plotting of normalized cost data. The largest number of case studies collected was for close-fit lining (42), followed by CIPP (32), and spray-on polymeric lining (27). Bid cost data were also collected for water main renewal by CML to benchmark the innovative technology costs. Although it is not a structural repair, CML is a widely-used renewal method and utilities will be familiar with typical costs for their region for this conventional technology. The trenchless technology cost data collected were normalized to the host pipe footage and diameter for the project as shown in Figures 3-3 to 3-5 for spray-on polymeric lining, CIPP, and close-fit lining, respectively, for water mains. The spray-on polymeric lining normalized costs for water mains ranged from $3 to $35 per linear foot per inch diameter (Figure 3-3). Ellison et al. (2010) has suggested that detailed pipe wall inspections could save costs for spray-on lining applications by lining only where it is needed at the appropriate thickness (e.g., for non-, semi-, full-structural applications). However, this is an area of future research. The CIPP normalized costs for water mains ranged from approximately $10 to $45 per linear foot per inch diameter (Figure 3-4). The close-fit lining normalized costs for water mains ranged from $3 to $21 per linear foot per inch diameter (Figure 3-5). In the future, the use of trenchless water main renewal techniques could grow as they become more cost competitive with open trench replacement and as the capabilities to internally re-connect service lines improves.

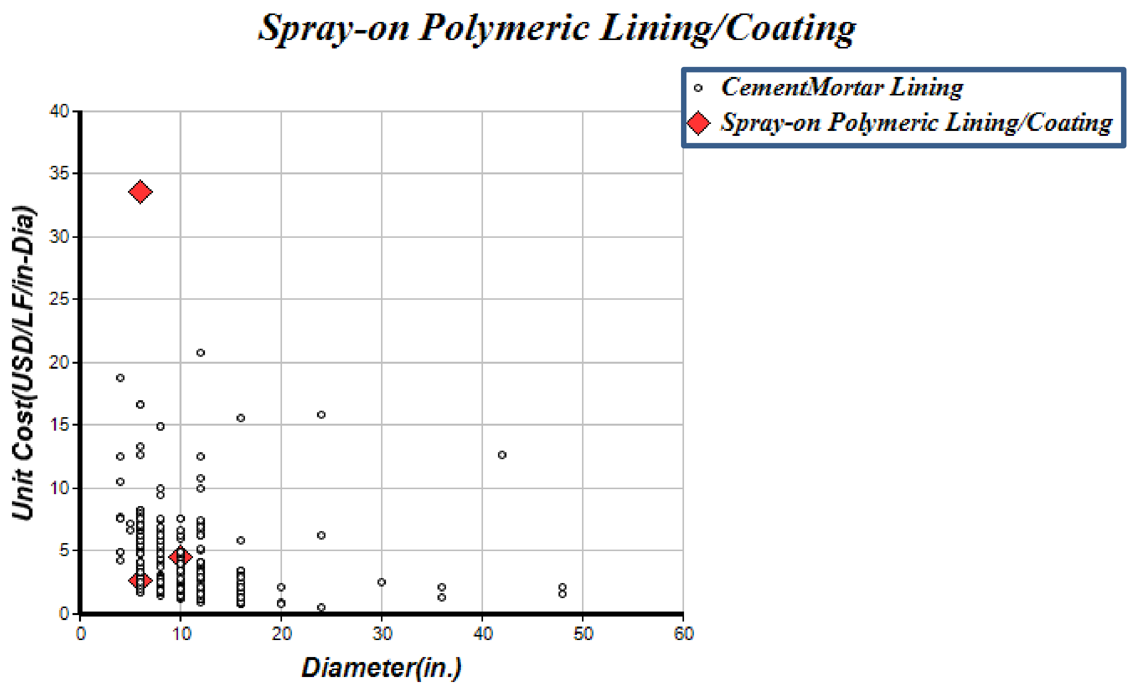

Figure 3-3. RehabAnalytics Normalized Cost Data for Spray-On Polymeric Lining of Water Mains

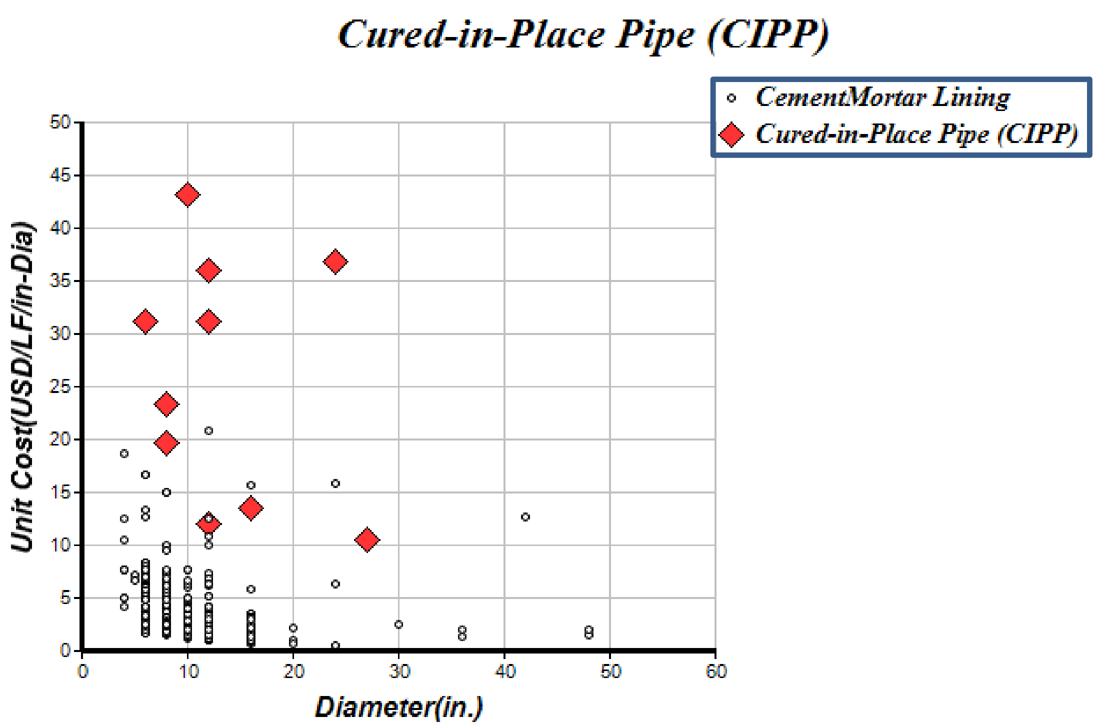

Figure 3-4. RehabAnalytics Normalized Cost Data for CIPP of Water Mains

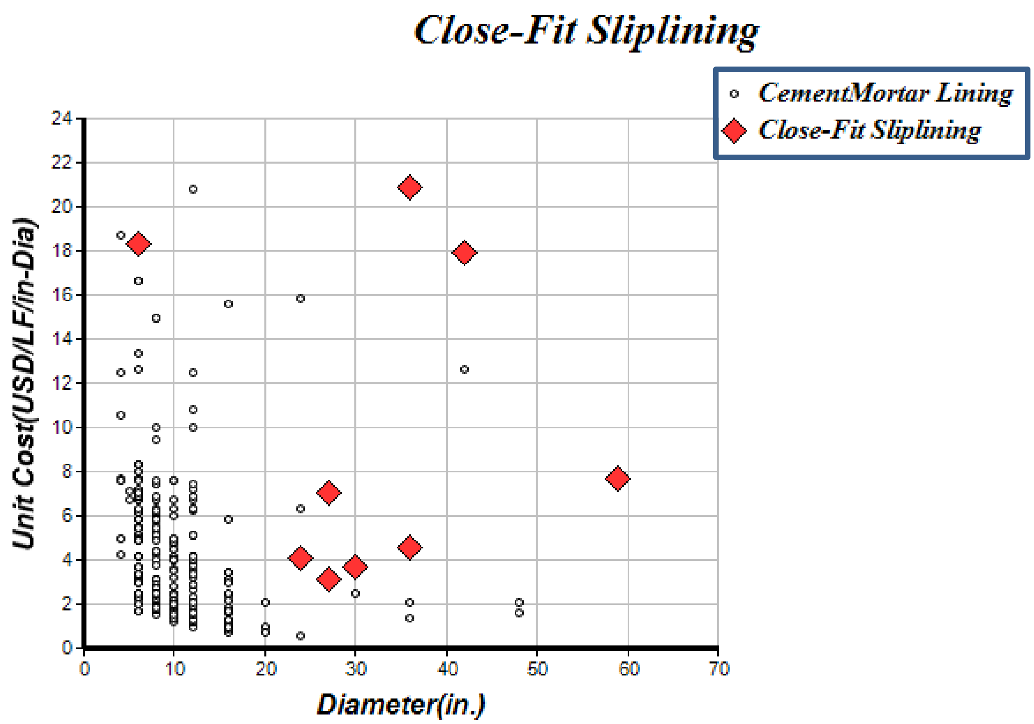

Figure 3-5. RehabAnalytics Normalized Cost Data for Close-Fit Sliplining of Water Mains

Section 4.0: WASTEWATER MAIN RENEWAL MARKET AND INNOVATIONS

A survey recently released by EPA indicates that over $271 billion in total funding is required to address aging infrastructure needs at publically-owned wastewater utilities (EPA, 2016b). Approximately 53% of this funding is needed to correct issues with wastewater collection systems including $51.2 billion for sewer main renewal, $44.5 billion for new sewer main installation, and $48 billion to correct combined sewer overflow conditions (EPA, 2016b). As shown in Figure 4-1, the annual municipal expenditures on wastewater main renewal is more than double that for water mains (e.g., at $5 billion versus $2.2 billion as of 2016). Sewer main renewal is also approximately on par with new sewer main construction at 48% of the total expenditures with an increasing trend over time (UC, 2016).

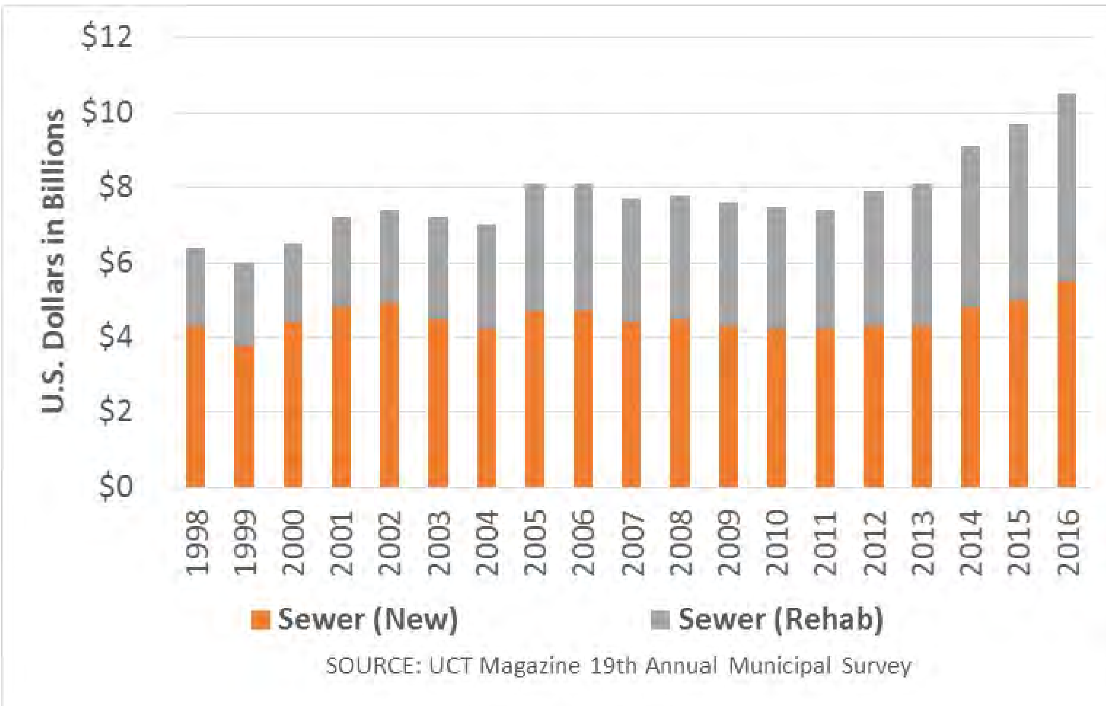

Figure 4-1. Expenditures on Wastewater Pipeline Infrastructure (UC, 1998 to UC, 2016)

This section reviews the overall status of the wastewater main renewal market based on the collected case studies and relevant industry information. Available wastewater main renewal technologies are presented, along with a summary of the case studies identified including total case study counts, pipe sizes, pipe material types, regional distribution, and any findings on lessons learned. CIPP is by far the dominant trenchless technology used in wastewater rehabilitation applications. For this reason, this report is focused on the use of more recent innovations to CIPP including ultraviolet-cured CIPP and glass fiber reinforced CIPP liners suitable for larger diameter sewer mains. The renewal database also does not focus on pipe replacement methods such as pipe bursting, but does include several trenchless repair and rehabilitation technologies. The rehabilitation technologies for wastewater mains are categorized in the database as shown in Figure 4-2. The discussion in this section is focused on case study results from ultraviolet-cured and glass fiber reinforced CIPP liners, spiral wound, and spray-on linings for sewer mains. After conventional CIPP which is a well-established technology, these technologies were identified as the next most prevalent methods used for sewer main renewal from the case study collection efforts.

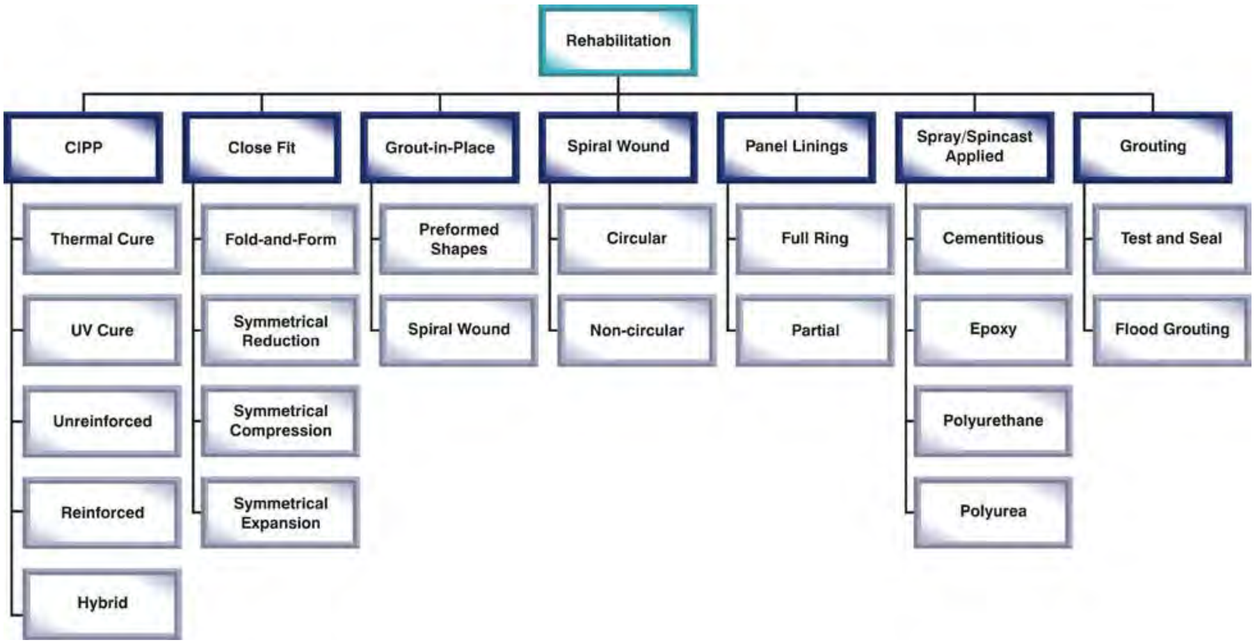

Figure 4-2. Rehabilitation Approaches for Wastewater Mains (EPA, 2010)

4.1 CIPP for Wastewater Mains Case Study Findings

Conventional CIPP technologies dominate today's wastewater main renewal market, but innovations are still ongoing. CIPP technologies can vary based upon tube construction, method of installation, curing method, and type of resin. After the original CIPP patent expired, a number of new technology variations came to market for wastewater main rehabilitation. However, most were still similar to the original CIPP product of a needled felt tube saturated with a polyester resin and cured using hot water or steam (EPA, 2010). Under a related research effort, a comprehensive study was undertaken of the long-term performance of conventional CIPP for wastewater main rehabilitation. The retrospective study concluded that CIPP liners with up to 34 years in service showed little evidence of deterioration and that properly designed and installed CIPP liners should meet and likely exceed the typical 50-year expected design life (EPA, 2014b). These 25 conventional CIPP case studies are available in the online database. This report focuses on a review of the case studies involving CIPP innovations including the growing use of ultraviolet-cured CIPP (as shown in Table 4-1) and glass fiber reinforced CIPP liners developed for larger diameter sewer mains.

Ultraviolet cured liners were first developed in Germany and began to be promoted more widely for use worldwide in the 2000s. Several vendors now offer ultraviolet-cured CIPP products within the U.S. Ultraviolet-cured CIPP involves the use of a glass fiber or polyester fiber tube that is impregnated with polyester or vinylester resin. The resin-saturated liner is pulled into place by a winch and then the tube is inflated against the host pipe using compressed air. Curing is then accomplished with an ultraviolet light train. The liner typically has an inner film and outer film used to contain the resin prior to curing. The inner film allows for the passage of ultraviolet light and is removed after curing is accomplished. The outer film is resistant to ultraviolet light and prevents the resin from entering cracks or service laterals. Among the advantages of ultraviolet-cured CIPP include the minimization of styrene emissions and process wastewater that are generated from steam or hot water curing (EPA, 2010). As shown in Table 4-1, five different vendors were identified with 15 ultraviolet-cured CIPP case studies. All of the U.S. installations occurred relatively recently from 2008 to 2014.

Table 4-1. Summary of Ultraviolet CIPP Case Studies for Wastewater Mains

Company Information					Case Study Information			
Vendor	Technology Name	Headquarters Location	Annual Sales ($M)	No. of Staff	No. of Case Studies	Regions	Pipe Size Range (in)	Pipe Materials
AOC/Insituform	CIPP with Vipel® Isophthalic Polyester	Guelph, Ontario, Canada	$10.73	95	3	NC	8 - 24	Concrete, VCP
BKP Berolina	Berolina-Liner®	Velten, Germany	$6.77	59	1	NNA	12	Concrete
Reline America	Blue-Tek™	Saltville, VA	$8.72	32	6	NE, SC	8 - 10	VCP
Saertex	Saertex-Liner®	Saerbeck, Nordrhein-Westfalen Germany	$229.1	1,200	1	SW	6	CI
LightStream LP	StreamLiner UV™	La Jolla, CA	$0.420	4	4	SW	6 - 18	AC

Note:
Regions: NE (North East), SE (South East), NC (North Central), SC (South Central), NW (North West), SW (South West), CA (Canada), NNA (Non-North America)
Pipe Materials: Brick, Vitrified Clay Pipe (VCP), Concrete, Prestressed Concrete Cylinder Pipe (PCCP), Reinforced Concrete Pipe (RCP), Ductile Iron (DI), Steel, Polyvinyl Chloride (PVC), Polyethylene (PE), Fiberglass Reinforced Plastic Pipe (FRP), Unknown (U), Cast Iron (CI), Asbestos Cement (AC)

The majority of the ultraviolet-cured case studies identified were located within the northeastern and southwestern U.S. Wastewater main pipe sizes requiring renewal ranged from 6 to 24 inches with the host pipes consisting of AC, concrete, CI, and vitrified clay pipe (VCP). The host pipe condition issues addressed included cracks, collapsed sections, root damage, heavy tuberculation, deteriorated o-rings on VCP, and hydrogen sulfide corrosion on AC pipe. At one site, the ultraviolet-cured CIPP method was selected to minimize emissions and odor from the resin curing because the project was located in tunnels beneath an airport terminal.

Across the ultra-violet cured CIPP case studies, no major issues were noted with products available on the market. There is no current ASTM design standard specific to ultraviolet-cured CIPP. Instead, the design standard relied upon is ASTM F1216 (2009) *Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube*. QA/QC measures may include hydraulic pressure testing, lining thickness measurement by calipers, tensile strength (ASTM D638), flexural strength and modulus (ASTM D790), and a post-lining CCTV inspection. In addition, curing parameters such as temperature and duration of the ultraviolet cure are typically monitored.

From the collected ultra-violet cured case studies, a few challenging site-specific conditions were noted such as a host pipe with varying inner diameter and another site with tight access to manholes requiring excavation in a dry creek bed. Minor construction issues were noted with heavy rains softening soil and causing access issues for the heavy equipment vehicles used for the ultraviolet-cured CIPP installation. Minor technology issues reported included wrinkles caused by varied host pipe diameter and/or tears in the inner film, but these defects were not expected to significantly impact performance. Future technology refinement may be needed to provide for a tear-resistant inner film. A case study is highlighted below from an EPA-funded Water Environment Research Foundation (WERF) field demonstration project of an innovative ultraviolet-cured CIPP rehabilitation of a wastewater main (Matthews, 2014).

INNOVATIVE ULTRAVIOLET CURED CIPP IN FRISCO, TEXAS

EPA funded a field demonstration conducted by WERF of the rehabilitation of 888 ft of 10-inch VCP using Reline America's Blue-Tek™ product. This case study is also included in the Web-based renewal database to share lessons learned on the use of new wastewater main renewal technologies. This ultra-violet cured CIPP demonstration provided valuable information on the design, installation, and QA/QC of this innovative technology. The project documented site preparation activities including temporary bypass, pre-lining inspection with CCTV, and the cleaning process. The installation steps were then observed including winching in of the liner, inflation via compressed air, and completion of the ultraviolet curing process. The installation for 888 ft of ultraviolet-cured CIPP took place over 3 days. The liner insertion was completed at a rate of approximately 18 ft/min, while inflation took 35 minutes per run. The ultraviolet curing was completed in approximately 3.8 ft/min per run. The QA/QC process was observed and samples taken for laboratory testing. The main challenges noted at the site were the varied inner diameter of the host pipe. In addition, certain sections of the liner were reported to be wrinkled due to a tear on the inner film. However, the minor defects noted did not compromise the overall strength. The mechanical testing showed that the liner's flexural strength and modulus exceeded the design requirements. As a result of the demonstration, the vendor later modified the technology design for use of a more tear resistant inner film (Matthews, 2014).

Another innovation noted in the case studies collected was CIPP suitable for large-diameter applications. CIPP is generally available in diameters of 4 to 120 inches. However, large diameter installations can be challenging because of the increased thickness of the liner needed to meet design requirements. Another new variant on the CIPP technology uses glass fiber reinforced CIPP liners. The additional strength and stiffness provided by these reinforcing layers allow the liner's overall thickness to be reduced to ease handling and installation. Two case studies were identified using the Insituform iPlus® Composite, which is an example of this CIPP innovation suitable for medium to large-diameter pipes from 24 to 97 inches. The case studies included rehabilitation of a 97-inch RCP sewer main in Texas and a 96-inch concrete sewer main in California. The composite liner thickness ranged from 32 to 35 millimeters (1.25 to 1.38 inches) for these case studies. The technology was successfully installed at both sites with no construction or technology performance issues noted.

4.2 Spiral Wound Linings for Wastewater Mains Case Study Findings

Spiral wound liners are installed in the field from a continuous plastic strip (typically PVC or HDPE). The strips are joined together onsite via a mechanical inter-locking system activated by a spiral winding machine or by hand. Grout is typically used to help to seal the annulus and increase the structural stability of the liner. The strips can also be reinforced with steel for non-circular and larger diameter applications. A mobile winding machine has been developed for large-scale applications that travels inside the existing pipe allowing the spiral wound liner to adjust to changes in the host pipe's shape and diameter. Spiral wound liners can be installed without grout for small, circular pipes and a hot melt adhesive used to hold the liner at a constant diameter (EPA, 2010). Table 4-2 summarizes the 12 spiral wound lining case studies for wastewater mains identified as part of the case study collection efforts.

Table 4-2. Summary of Spiral Wound Lining Case Studies for Wastewater Mains

Company Information					Case Study Information			
Vendor	Technology Name	Headquarters Location	Annual Sales ($M)	No. of Staff	No. of Case Studies	Regions	Pipe Size Range (in)	Pipe Materials
Danby	Danby Panel Lok (PVC)	Houston, TX	$0.180	2	5	NE, SE	42 - 96	Brick, RCP
Sekisui RibLoc Australia	Ribline (HDPE)	Gepps Cross, South Australia	$10.66	73	1	SW	36	RCP
Sekisui SPR Americas	SPR™ (PVC)	Atlanta, GA	$5.4	20	3	NC, SE	48 - 90	Brick, Concrete
Sekisui SPR Americas	SPR EX™ (PVC)	Atlanta, GA	$5.4	20	3	SW	8 - 12	VCP, Concrete

Note:
Regions: NE (North East), SE (South East), NC (North Central), SC (South Central), NW (North West), SW (South West), CA (Canada), NNA (Non-North America)
Pipe Materials: Brick, Vitrified Clay Pipe (VCP), Concrete, Prestressed Concrete Cylinder Pipe (PCCP), Reinforced Concrete Pipe (RCP), Ductile Iron (DI), Steel, Polyvinyl Chloride (PVC), Polyethylene (PE), Fiberglass Reinforced Plastic Pipe (FRP), Unknown (U), Cast Iron (CI), Asbestos Cement (AC)

Most of the spiral wound case studies were located in the southeastern and southwestern U.S. Nine of the case studies are for larger diameter applications on 36 to 96-inch sewer mains. Three of the case studies are for smaller diameter applications on 8 to 12-inch sewer mains. The types of host pipes rehabilitated included brick, concrete, RCP, and VCP. The host pipe condition issues addressed included defects in pipe joints, deteriorating mortar in brick pipes, severe corrosion, hydrogen sulfide corrosion, root intrusion, excessive infiltration, and new construction over the brick sewer requiring improved structural performance.

Across the spiral wound case studies, no major issues were noted with products available on the market. The QA/QC measures specifically employed at the sites were not reported in the case studies. However, several of these products follow ASTM standards for the material and installation specifications (e.g., ASTM F1735, ASTM F1697, ASTM F1698, and ASTM F1741). Site-specific construction challenges were noted such as the need for debris removal by hand and heavy rains and excessive infiltration from groundwater and/or a nearby wetland causing the need for bypass pumping and groundwater de-watering. One large-diameter site experienced grout setting issues and the affected sections had to be removed and replaced with grout from a new supplier. This demonstrates how critical grout placement is to the quality of the finished installation. Future improvements could include taking compressive strength samples of the grout at regular intervals and soundings of the finished liner to test for voids in grouted sections.

4.3 Spray-On Linings for Wastewater Mains Case Study Findings

Spray-on linings used for sewer main rehabilitation consist of either cementitious or polymer-based materials. Table 4-3 summarizes the 10 spray-on lining case studies for wastewater mains identified as part of the case study collection efforts. This includes case studies for Geospray™, which is a fiber reinforced geopolymer spray-applied mortar that is manufactured from a sustainable green material derived from recycled industrial byproducts. Also, case studies were identified for Permacast®, which is a specially formulated fiber reinforced cement designed for structural sewer rehabilitation.

The case studies identified were located in the north central and south central U.S. Wastewater main pipe sizes requiring renewal ranged from 36 to 108 inches with the host pipes consisting primarily of brick, concrete, and RCP. The host pipe condition issues addressed included a fully deteriorated host pipe, section collapses, need for invert repair, excessive leakage, and hydrogen sulfide corrosion.

Table 4-3. Summary of Spray-on Lining Case Studies for Wastewater Mains

Company Information					Case Study Information			
Vendor	**Technology Name**	**Headquarters Location**	**Annual Sales ($M)**	**No. of Staff**	**No. of Case Studies**	**Regions**	**Pipe Size Range (in)**	**Pipe Materials**
Milliken Infrastructure Solutions, LLC	GeoSpray™ geopolymer mortar	Spartansburg, SC	$0.967	13	8	NC, SC	36 - 108	Brick, RCP
AP/M Permaform	Permacast® structural liner	Johnston, IA	$0.660	5	2	NC	36 - 60	Concrete

Note:
Regions: NE (North East), SE (South East), NC (North Central), SC (South Central), NW (North West), SW (South West), CA (Canada), NNA (Non-North America)
Pipe Materials: Brick, Vitrified Clay Pipe (VCP), Concrete, Prestressed Concrete Cylinder Pipe (PCCP), Reinforced Concrete Pipe (RCP), Ductile Iron (DI), Steel, Polyvinyl Chloride (PVC), Polyethylene (PE), Fiberglass Reinforced Plastic Pipe (FRP), Unknown (U), Cast Iron (CI), Asbestos Cement (AC)

No major issues were noted with spray-on lining products available on the market. Surface preparation is an important first step in the spray-on lining process. Pressure washing was used in all cases for cleaning and supplemented at some sites with high pressure air. The design thickness of the spray-on liners ranged from approximately 1.5 to 2.0 inches for the Geospray™ product and 0.5 inch for the Permacast® product. The types of QA/QC activities included compressive strength testing (ASTM C109), depth gauges, and post-lining CCTV. As described below, one site experienced excessive infiltration issues which required the lining to be manually sprayed versus the automated sled application. Positive experiences were reported for use of the technology with odd shaped pipes and pipes where minimal capacity reduction was desired. A case study from an EPA field demonstration project of an innovative geopolymer spray-applied mortar rehabilitation of a sewer main is highlighted below (EPA, 2014a).

INNOVATIVE SPRAY-APPLIED GEOPOLYMER MORTAR IN HOUSTON, TEXAS

EPA performed an evaluation of an innovative geopolymer spray-applied mortar for wastewater main rehabilitation in Houston, Texas. This case study is also included in the Web-based renewal database. The GeoSpray™ product was used to rehabilitate a 60-inch RCP sewer main leading to the wastewater treatment plant where the 25-ft depth of the pipe and the need to rapidly return to service precluded open cut excavation. The RCP host pipe was severely deteriorated with corroded and exposed steel reinforcements and had several locations of heavy infiltration. The heavy infiltration conditions eventually led to the product being manually spray applied by hand rather than using a sled. The material was successfully installed manually and the post-lining CCTV inspection showed the rehabilitated pipe to be infiltration free, with no signs of exposed rebar or cracking, and with no significant defects. A lining thickness of approximately 3.3 inches was sprayed in the pipe, which is more than the minimum design value of 1.9 inch. The third-party test results for compressive strength averaged 8,635 psi at 28 days and passed the required criteria. Recommendations were made related to improving QA/QC through measuring the "as installed" lining thickness, bond strength testing, and the use of shaker tables to minimize voids in samples (EPA, 2014a).

4.4 RehabAnalytics Data Review for Wastewater Mains

The *RehabAnalytics* page contains summary information on case studies for wastewater main renewal including total case study counts and an automated plotting of normalized cost data. As shown in Figure 4-3, the largest number of case studies collected was for CIPP (27), followed by ultraviolet-cured CIPP (15), spiral wound lining (12), and spray-on lining (10).

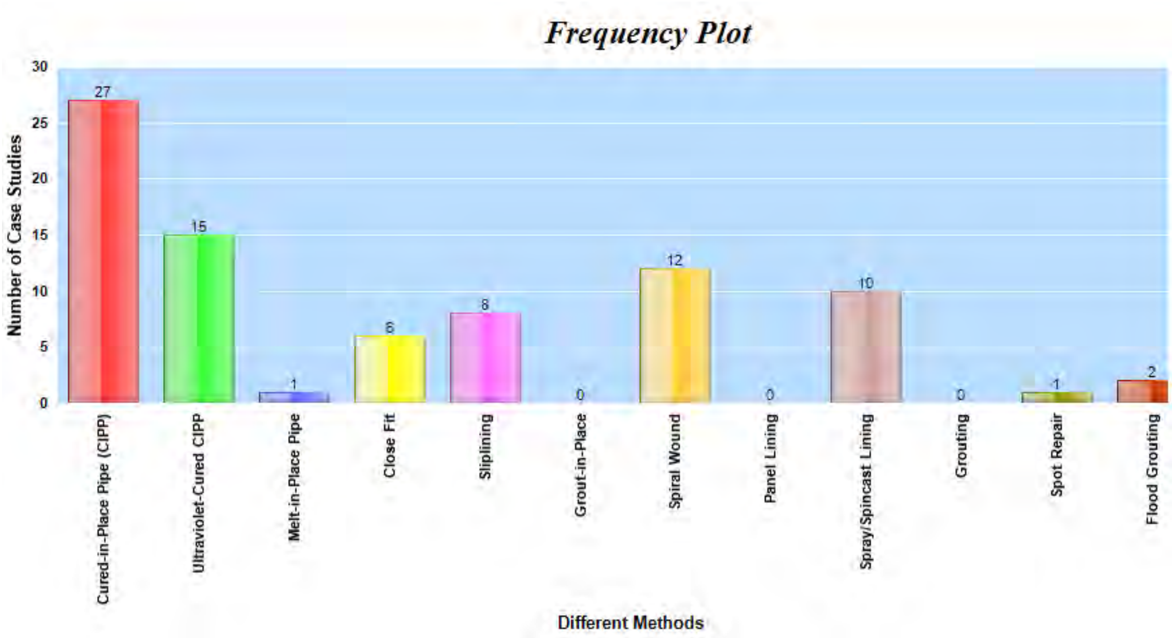

Figure 4-3. RehabAnalytics Total Count Summary for Wastewater Case Studies

Bid cost data were also collected for wastewater main renewal by sliplining to benchmark the innovative technology costs. The trenchless technology cost data collected were normalized to the host pipe footage and diameter for the project as shown in the examples in Figures 4-4 and 4-5. Cost plots for additional trenchless technologies can be viewed on the *RehabAnalytics* page. Cost was obtained for only one sewer main project for the ultraviolet-cured CIPP at $7 per linear foot per inch diameter. The spiral wound lining normalized costs for sewer mains ranged from $2 to $12 per linear foot per inch diameter (Figure 4-4). The spray-on lining normalized costs for sewer mains ranged from $3 to $9 per linear foot per inch diameter (Figure 4-5).

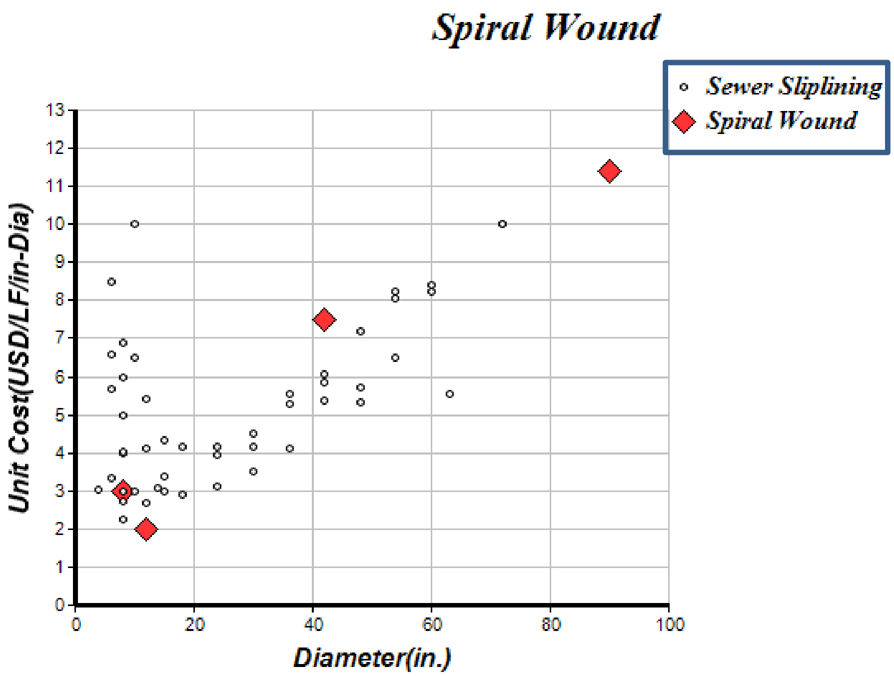

Figure 4-4. RehabAnalytics Normalized Costs Data for Spiral Wound Lining of Sewer Mains

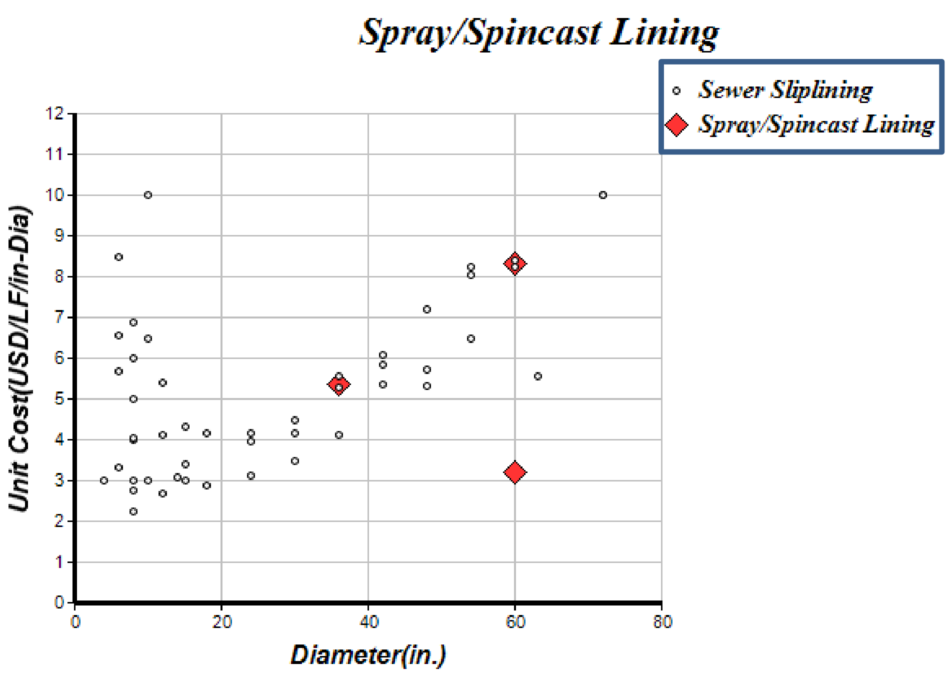

Figure 4-5. RehabAnalytics Normalized Costs Data for Spray-On Lining of Sewer Mains

Section 5.0: CONCLUSIONS

An increased understanding of various renewal options will help utilities to select the most viable and cost-effective technologies to shore up their aging water infrastructure and extend its useful life. This research effort involved the collection of case studies on the use of various pipeline renewal methods and provides the information in an online searchable database. The conclusions and recommendations to further advance the use of innovative and cost-effective renewal technologies are as follows:

- Renewal case studies were developed for both water and sewer mains that included the technologies used; the conditions under which the technology was implemented; costs; lessons learned; and utility contact information. More than 180 case studies were collected. The case studies were categorized by several geographic regions including northeast, southeast, north central, south central, northwest, and southwest, Canada, and non-North American. The following trends were noted related to the regional distribution of innovative renewal technology case studies.
    - The most water main renewal technology case studies were identified in the northeast (18%). This was closely followed by the southwest (16%) and north central (16%) U.S. regions. A large number of water main renewal case studies were identified in Canada or outside North America (29%) suggesting that the use of these technologies may be more prevalent outside the U.S. and that there is room for growth in the U.S. market as the demand for water main renewal services increases over time.
    - The most wastewater main renewal case studies were identified in the north central U.S. region at 25%. This was followed by the northeast (19%) and southwest (19%) U.S. regions. In contrast to water main renewal, only 9% of the case studies identified were located in Canada or outside North America. This reflects the stronger domestic market for wastewater main renewal due to enhanced regulatory drivers.
- For water main renewal, spray-on lining, CIPP, and close-fit lining were identified as the most prevalent methods from the case study collection efforts. Lessons learned and the needs for future improvements for each of these renewal technologies were summarized in Section 3.0. Future technology refinement needs included ensuring minimum thicknesses are met throughout an installation for spray-on linings. Adjusting cleaning methods to avoid damage to corporation stops and improvements in robotic reinstatement of service lines may help to reduce the need for excavations to reinstate service on water main CIPP projects. In addition, close attention is needed to avoid weld and pull head breakage issues at close-fit lining applications for water mains.
- For wastewater main renewal, conventional CIPP is by far the dominant technology. The case study results were focused on a discussion of innovations identified in ultraviolet-cured CIPP and reinforced CIPP liners, spiral wound lining, and spray-on lining for sewer mains. After conventional CIPP, these four technologies were identified as the next most prevalent methods used for sewer main renewal from the case study collection efforts. Lessons learned and the needs for future improvements for each of these technologies were summarized in Section 4.0. A recommended future technology refinement is a tear-resistant inner film for ultraviolet-cured CIPP applications. Lessons learned include the importance of grouting to a successful spiral wound lining installation, and the need for compressive strength testing and soundings of the grout. For spray-on lining products, similar to findings for water main applications, QA/QC measures could be improved to ensure that the "as installed" lining thickness is measured and a uniform thickness achieved throughout the installation.

- Cost data curves were incorporated into the *RehabAnalytics* tool based on bid cost data collected for conventional technologies such as CML for water mains and sliplining for sewer mains. A data mining algorithm was then deployed to extract and normalize the cost data from the case studies and to plot for ease of review. In general, cost data was challenging to collect for this study as vendors may not disclose this information and utilities do not always track the individual costs for a single innovative technology project if it is part of a larger contract. Costs can also vary widely based on site-specific conditions such as cleaning needs, dewatering needs, the need for night work to avoid traffic disruption, and other factors. The following trends were noted in the cost of innovative renewal technology case studies:
    - For water main renewal, the spray-on polymeric lining normalized costs ranged from $3 to $35 per linear foot per inch diameter. The water main CIPP normalized costs ranged from $10 to $45 per linear foot per inch diameter. The close-fit lining normalized costs for water mains ranged from $3 to $21 per linear foot per inch diameter.
    - For sewer main renewal, the cost was obtained for only one project for the ultraviolet-cured CIPP at $7 per linear foot per inch diameter. The spiral wound lining normalized costs for sewer mains ranged from $2 to $12 per linear foot per inch diameter. The spray-on lining normalized costs for sewer mains ranged from $3 to $9 per linear foot per inch.

The Web-based, searchable tool created as part of this research project can be used by utility personnel to review the technology performance and cost data described above, as well as case study references. The database can be accessed at: http://138.47.78.37/Retrospective. The database will be publicized to the water infrastructure community through release of this report on the EPA Web site. Utilities are encouraged to review the case studies and to support future expansion of the online database through the addition of their own case study information.

Section 6.0: REFERENCES

Ellison, D., F. Sever, P. Oram, W. Lovins, A. Romer, S. Duranceau, and G. Bell. 2010. "Global Review of Spray-On Structural Lining Technologies." Water Research Foundation Project No. 4095, Denver, CO, http://www.waterrf.org/PublicReportLibrary/4095.pdf

EPA. 2010. *State of Technology for Rehabilitation of Wastewater Collection Systems.* EPA/600/R-10/078, U.S. EPA, Office of Research and Development, Cincinnati, OH, Jul., 325 pp., http://nepis.epa.gov/Adobe/PDF/P1008C45.pdf.

EPA. 2011. *Decision Support for Renewal of Wastewater Collection and Water Distribution Systems*. EPA/600/R-11/077, U.S. EPA, Office of Research and Development. Cincinnati, OH, Jul., 70 pp., http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100BWUR.TXT

EPA. 2012a. *Performance Evaluation of Innovative Water Main Rehabilitation Spray-On Lining Product in Somerville, NJ*. EPA/600/R-12/009, U.S. EPA, Office of Research and Development, Cincinnati, OH, Feb., 212 pp., http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100GDZH.TXT

EPA. 2012b. *Performance Evaluation of Innovative Water Main Rehabilitation Cured-in-Place Pipe Lining Product in Cleveland*. EPA/600/R-12/012, U.S. EPA, Office of Research and Development, Cincinnati, OH, Feb., 63 pp., http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100LHXY.TXT

EPA. 2013. *State of Technology for Rehabilitation of Water Distribution Systems.* EPA/600/R-13/036. U.S. EPA, Office of Research and Development, Cincinnati, OH, Mar., 212 pp., http://nepis.epa.gov/Adobe/PDF/P100GDZH.pdf.

EPA. 2014a. *Performance Evaluation of an Innovative Fiber Reinforced Geopolymer Spray-Applied Mortar for Large-Diameter Wastewater Main Rehabilitation in Houston, Texas*. EPA/600/R-14/443. U.S. EPA, Office of Research and Development, Cincinnati, OH, Dec., 63 pp., http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100LHXY.TXT

EPA. 2014b. *National Database Structure for Life Cycle Performance Assessment of Water and Wastewater Rehabilitation Technologies (Retrospective Evaluation)*. EPA/600/R-14/251, U.S. EPA, Office of Research and Development, Cincinnati, OH, Sept, 247 pp., http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100LDG0.txt

EPA. 2016a. *Testing and Performance Evaluation of an Innovative Internal Pipe Sealing System for Wastewater Main Rehabilitation*. EPA/600/R-15/326., U.S. EPA, Office of Research and Development, Cincinnati, OH, Jan., 38 pp., http://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100O12N.TXT

EPA. 2016b. Clean Watersheds Needs Survey 2012 Report to Congress. EPA/830/R-15005. U.S. EPA, Office of Wastewater Management, Washington, D.C., Jan., 41 pp., https://www.epa.gov/sites/production/files/2015-12/documents/cwns_2012_report_to_congress-508-opt.pdf

Matthews, J. 2014. Demonstration and Evaluation of Innovative Wastewater Main Rehabilitation Technologies. Project Number INFR4R11. Water Environment Research Foundation (WERF). Alexandria, VA, Jun, 61 pp., https://www.werf.org/a/ka/Search/ResearchProfile.aspx?ReportId=INFR4R11

UC. 2016. “Underground Construction 19th Annual Municipal Survey.” Underground Construction. Feb., Vol. 71, No. 2, https://ucononline.com/2016/02/17/underground-construction-19th-annual-municipal-survey/