



PVC PIPE LONGEVITY REPORT

Affordability & The 100+ Year Benchmark Standard

A Comprehensive Study on
PVC Pipe Excavations, Testing, & Life Cycle Analysis

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INTRODUCTION >>>

In the United States and Canada, underground water infrastructure was installed during three main time periods because of population growth in the 1800s, 1900–1945, and post 1945. Pipes made of iron constructed in each of these three eras will all start to fail at nearly the same time over the next couple of decades due to the corrosion of the iron pipes. Additionally, the life span of the materials used since the 1960's has changed. Grey cast iron pipes are no longer manufactured and the new ductile iron material has been made thinner to reduce costs, but as a result, the pipe life expectancy has become shorter with each new investment cycle (1). In 2013, the American Society of Civil Engineers issued a USA Infrastructure Report Card and gave an overall "D" grade to drinking water and wastewater infrastructure which included the piping infrastructure.

In an update to the "Dawn of the Replacement Era," (2) AWWA has published "Buried No Longer" which states "More than a million miles of pipes are nearing the end of its useful life and approaching the age at which it needs to be replaced." (3) These water pipe replacement costs combined with projected expansion costs will cost over \$1 trillion over the next couple of decades. The cost of underground pipe infrastructure is 60% of the US water industry's total funding requirement. In addition, sewer and storm drain funding needs also drive up the cost burden on rate payers. Municipalities continue to struggle with balancing water service affordability against the rise in service interruptions from water main breaks. With the introduction of piping materials such as PVC, utilities were able to address the issue of iron pipe degradation due to corrosion. To gain the full benefits of reliability and longevity, asset management financial practices need to be applied.

Infrastructure asset management is an approach which can help utilities bring together the concepts, tools, and techniques to manage assets at an acceptable service level at the lowest life-cycle cost. Asset management practices applied to underground infrastructure help utilities understand the timing and costs associated with replacement activities. The knowledge gained from these efforts also helps in the development of effective pipe material selection through comparative financial analysis called "life cycle costing" as part of the replacement strategies and funding plans. Understanding the longevity of a pipe improves the ability for management to make better infrastructure investment decisions with improved affordability results for customers.

The water industry has seen many types of academic surveys and studies on water main replacement programs and the benefits of asset management and prioritization. However, many utilities have not historically tracked all of the elements of pipe failure. As this trend changes, more data and analysis will be available to the industry to improve water distribution system repair and replacement decision making. This comprehensive study provides the next body of evidence supporting the ability of utilities to address the failing infrastructure and the affordability dilemma.

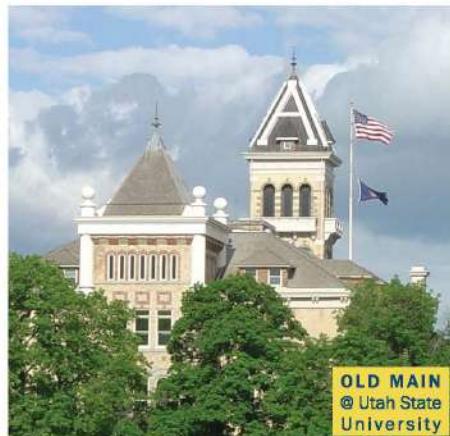


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THE PRIMARY RESEARCHER

DR. STEVEN FOLKMAN

Dr. Steven Folkman is a registered Professional Engineer, a member of American Society for Testing and Materials (ASTM) F17 Plastic Piping Systems, a member of AWWA and a member of the Transportation Research Board Committee on Culverts and Hydraulic Structures, and has oversight of the prestigious Utah State University's (USU) Buried Structures Laboratory. The Buried Structures Laboratory at USU has been involved in analysis and testing of all kinds of pipe and associated structures for over 50 years. Previous directors include Dr. Reynold Watkins and Dr. Al Moser who are internationally recognized experts. Dr. Moser and Dr. Folkman are coauthors of the widely used text *Buried Pipe Design* (McGraw Hill, 3rd Edition). Dr. Folkman's expertise includes structural dynamics, linear and nonlinear finite element analysis utilizing soil/structure interaction, and testing. The USU buried structures laboratory is recognized as one of the laboratories in the United States capable of performing large scale tests on buried pipes. It is from this expertise and background that the excavation reports were reviewed and additional quality control testing was conducted in 2012 and 2013 to complete this comprehensive study.



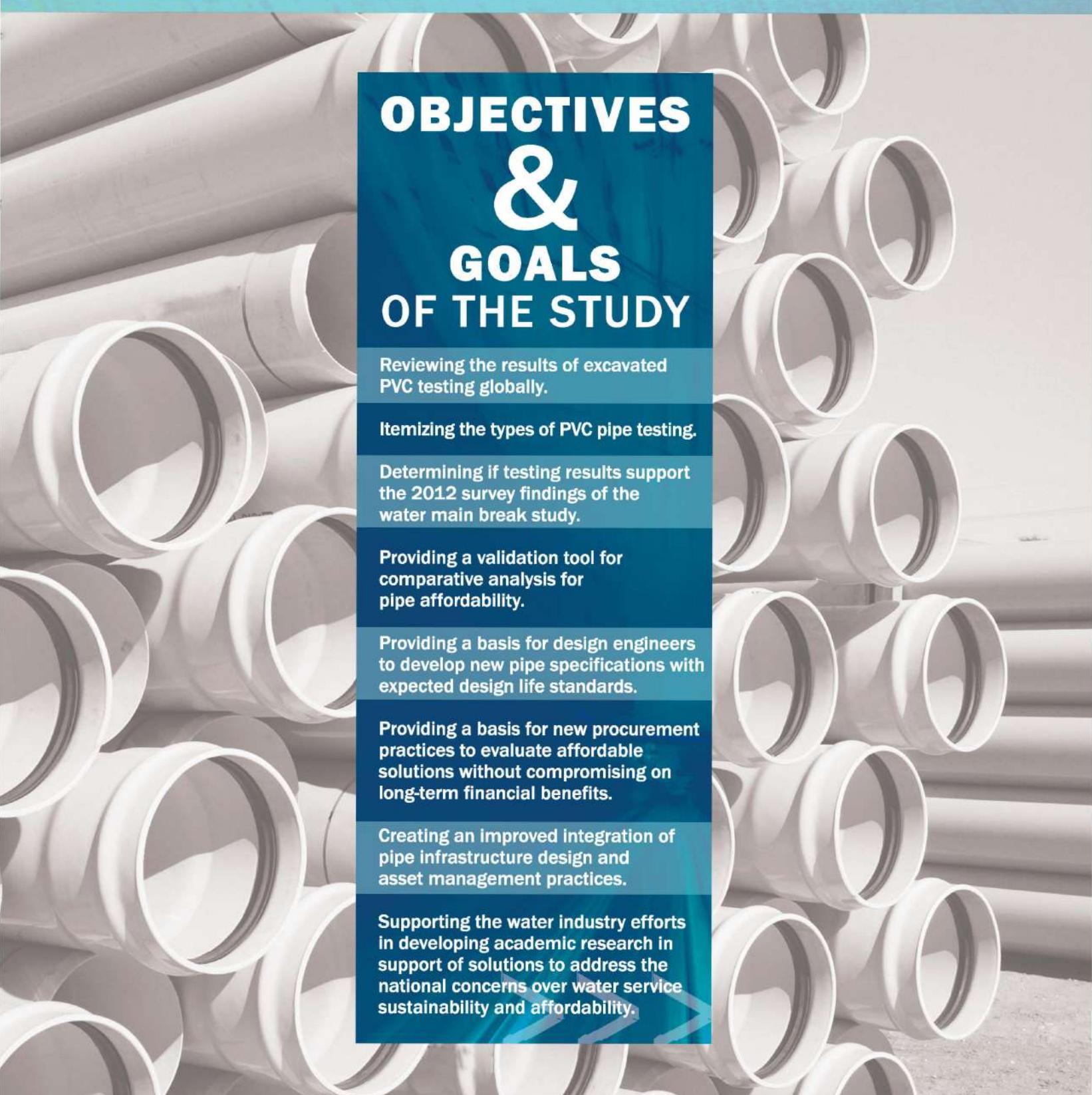
EXECUTIVE SUMMARY >

In 2012, The Utah State University's Buried Structures Laboratory published a comprehensive study based on statistical results of water main breaks in the US and Canada. The findings of the research demonstrated that PVC pipe has the lowest rate of main breaks of pipe materials considered in the study, which included ductile iron, cast iron, steel, concrete, and asbestos cement.

This study continues to explore the elements of PVC reliability and longevity through the comprehensive research on PVC pipe testing results. Pipe experts from around the world have contributed to the documented evidence of PVC pipe longevity through excavations and testing. These dig-up or pipe excavation reports are from "in service" pipes with operational conditions. Non-operational pipe dig-up testing offers very limited performance data.

This comprehensive study reviews past PVC dig-up reports and presents new quality control testing results that continue to validate the performance and longevity of PVC pipe used in water networks. A second component to this research addresses the fundamental challenge of affordability for utilities facing the difficult process of replacing the buried infrastructure which is at the end of its service life.

Life cycle cost analysis is presented as a financial decision tool for pipe replacement selection by applying the findings of reliability and longevity research and testing. This combination of pipe examination and testing data in conjunction with previous pipe break studies supports PVC as a sustainable pipe material, confirming a 100+ year benchmark as an industry standard.



OBJECTIVES & GOALS OF THE STUDY

Reviewing the results of excavated PVC testing globally.

Itemizing the types of PVC pipe testing.

Determining if testing results support the 2012 survey findings of the water main break study.

Providing a validation tool for comparative analysis for pipe affordability.

Providing a basis for design engineers to develop new pipe specifications with expected design life standards.

Providing a basis for new procurement practices to evaluate affordable solutions without compromising on long-term financial benefits.

Creating an improved integration of pipe infrastructure design and asset management practices.

Supporting the water industry efforts in developing academic research in support of solutions to address the national concerns over water service sustainability and affordability.

MAJOR FINDINGS

The comprehensive nature of this study has provided several national recommendations and rules of thumb which utilities can use for benchmarking and procurement purposes.

- 1** Dig-up test results in the U.S. and around the world indicate that PVC pipe can be expected to provide reliable service in excess of 100 years.
- 2** The average water main is failing at 47 years. Corrosion is the major cause.
- 3** Utilities using non-corrodible pipe materials are able to reduce the number of water main breaks.
- 4** Many utilities still have the ability to reduce water main breaks and to reduce O&M costs by utilizing non-corrodible pipes in their replacement and procurement strategies.
- 5** Internationally, PVC dig-up reports support the previous findings of PVC having the lowest water main break-rate.
- 6** Improved installation and inspection practices have been shown to contribute to lower failure rates and increased pipe longevity and affordability.
- 7** Dig-up studies on PVC pipe materials around the world report no degradation after decades of operational service.
- 8** Recently excavated PVC pipes, some nearly 50 years old, were tested by Utah State University and met all applicable standards. They are expected to easily exceed 100 years of service life.
- 9** PVC pipes offer a high degree of resilience in freezing conditions and after 25 years meet virtually all new pipe requirements.
- 10** PVC pressure pipes exhumed after being in operation for almost 30 years have not suffered any loss of strength. All tested pipes would be expected to exceed a 100 year life under normal operating conditions.
- 11** After over 35 years of operation, PVC pipes have virtually no change in mechanical properties due to ageing. Both ductility and resistance to internal pressure are still on the same level as new pipes.
- 12** Based on stress regression, slow crack growth and fatigue testing, the service life of PVC pressure pipe should exceed 100 years.
- 13** The Water Research Foundation reported that 100 years is a conservative estimate for a properly designed and installed PVC pipe.
- 14** Life cycle costing provides a basis to financially evaluate pipe selection over a 100 year period.
- 15** Including the realistic costs of corrosion control mitigation* for ductile iron pipes over the 100 year period for all pipe sizes is critical in developing a comparable evaluation of PVC pipe costs and ductile iron pipe costs.

* Corrosion mitigation methods approved by the National Association of Corrosion Engineers

THE AFFORDABILITY ISSUE >>>

Traditionally, there has been a lack of analysis that combines both underground pipe performance and affordability. Existing practices tended to ignore the effect of environmental conditions on different pipe materials. Engineers understand how the complexity of underground infrastructure has increased along with the array of pipe material and installation choices. The ability to change old habits and consider new materials requires additional analysis, and improved design and installation practices requires more work. This additional "reevaluation work" is required in this new generation of sustainability and striving to make critical decisions in the core infrastructure enabling a healthy and productive life for communities. This enhanced work analysis of pipe design, selection and installation sets forth the longevity and life-cycle costs critically influencing water service affordability for the next 100-200 years.

There have been many studies on water main failure rates in the US, Canada, Australia, and Europe over the last three decades. These studies mainly compared the number of pipe breaks by general pipe type and by length. While these studies have been very helpful to the water industry, the new driver has been concern with the ability to make underground pipe decisions to improve the repair and replacement costs in an effort to address the affordability of water services to customers. This new level of fiscal accountability and demand for transparent utility management back to their owners and stakeholders has increased the need for additional evidence to demonstrate the improved decision making. Dig-up reports and pipe performance and longevity studies form the next body of evidence needed to collaborate water main break surveys and studies.

The simple formula in a life cycle cost framework is essentially that "a pipe which has a long life at a low cost is the most affordable." Engineers are to make available every alternative which would answer the simple question of longevity and cost at each relevant point within the underground network providing service.

The analysis of pipe breakage is incomplete without the assessment of why the pipe failed. This knowledge is then applied to the cost analysis of repairing and replacing the pipe. Once again, analysis would dictate that if a pipe is failing in less than 100 years then one or more of the following factors should be considered; a) the pipe has an identified manufacturing defect, b) the recommended installation procedures were not followed, c) the design process did not correctly address the actual operating conditions, d) the system was not properly maintained, e) the pipe material originally selected needs to be changed, and/or f) efforts need to be made to increase the pipe's longevity and performance as compared to an alternative option based on cost. The 2013 United States Conference of Mayor's report on *Municipal Procurement* (4) highlighted the importance of such procurement policies and also in the appendix demonstrated a simple cost comparison methodology for affordable pipe options for utilities.

WATER MAIN BREAK STUDIES

Water main break studies over the last 30 years demonstrate the changing trends based on the use of various pipe types.

1981

Kirby (5) published an early study of water main failure rates in England. Kirby noticed that first PVC installations in 1965 suffered from higher failure rates than cast iron pipes. Most of these failures were related to improper installation procedures. By 1979, the failure rates of PVC had dropped to well below that of cast iron due to improved pipe installation procedures.

2005

Bjorklund (6) looked at water main failure rates in Sweden. He noted the improved performance of PVC pipes.

2012

Burn, et. al. (7) conducted a small survey of water utilities in Australia, Canada, and US. Important observations include the low overall failure rate of PVC relative to other pipe materials. Variability in survey data indicated that early failures were very likely attributed to installation practices.

2013

US Water Main Breaks Study by Folkman, et. al. (8) reported results of a survey of 188 utilities across the US and Canada. That survey demonstrated that PVC pipe has the lowest overall failure rate when compared to cast iron, ductile iron, concrete, steel and asbestos cement pipes. Corrosion was indicated as the primary cause of failure. PVC currently represents 23%-27% of the total length of pipe installed in US water systems. PVC dominates the rural water systems and the sewer underground infrastructure. The report also found that 8.4% of water mains are described as beyond their useful life.

THE DIG-UP REPORTS

EVIDENCE OF PERFORMANCE & LONGEVITY

Dig-up reports have occurred globally, but mainly in Australia, Europe, Canada and the United States. In these studies, the pipes were subjected to a range of mechanical tests in order to assess whether there had been any deterioration during their service. PVC pressure pipes have been used in Australia for over thirty years. A presentation in 2001 by Stahmer (10) on the long-term performance of these pipes explained that quantifying how long a pipe will remain serviceable is sometimes complicated by misunderstandings surrounding the characteristics of PVC pipes. An excerpt includes:

PVC exhibits time dependent properties under stress. Unfortunately this time dependency is sometimes interpreted as age dependency. For example, the downward slope of the traditional pipe hoop-stress regression curve is often interpreted as a loss of strength with age. In fact the downward slope simply reflects the ability of the viscoelastic material to support lower stresses for longer periods than it can support higher stresses. Hucks demonstrated the burst strength of PVC pipes was not diminished by long term exposure to lower stresses. The burst strength was shown to be higher for pipe aged in the laboratory for 10 years than it was for the same pipe at the time of manufacture.

AUSTRALIAN TESTING DEMONSTRATES NO PIPE DEGRADATION AFTER 30 YEARS

The testing methodology used by Stahmer (10) takes into consideration the field performance of the PVC pressure pipes as well as the actual testing based on the Australian Standards. The pipes which were exhumed in 1996 after 25 years of operation were subjected to the following tests:

- 1 Resistance to flattening was carried out by placing short sections of pipe between parallel plates and deflecting to 40% of the original diameter. The sections were then inspected for any damage or fracture. Test Method: Australian Standard AS 1462.2
- 2 Resistance to impact was performed using a weight falling 2 m. A failure is recorded if there was any fracture evident in the specimen at the conclusion of the test. The size of the weight varies with the size of the pipe in the manner described in the product standard. Test Method: Australian Standard AS 1462.3
- 3 The dispersion of the resin in the pipes was assessed on samples approximately 0.02 mm thick under low power magnification.
- 4 Tensile properties of the PVC were determined on four pipe samples, using the average of five determinations for each. Test Method: ASTM D638M.
- 5 The fracture toughness of the pipes was determined using the notched C-ring method. For each of the pipes tested, a series of C-rings was prepared and tested under a range of applied stresses. The stress and time-to-failure were recorded for each and the fracture toughness versus the time-to-failure was plotted. Test Method: Australian Standard Draft No. 2570.

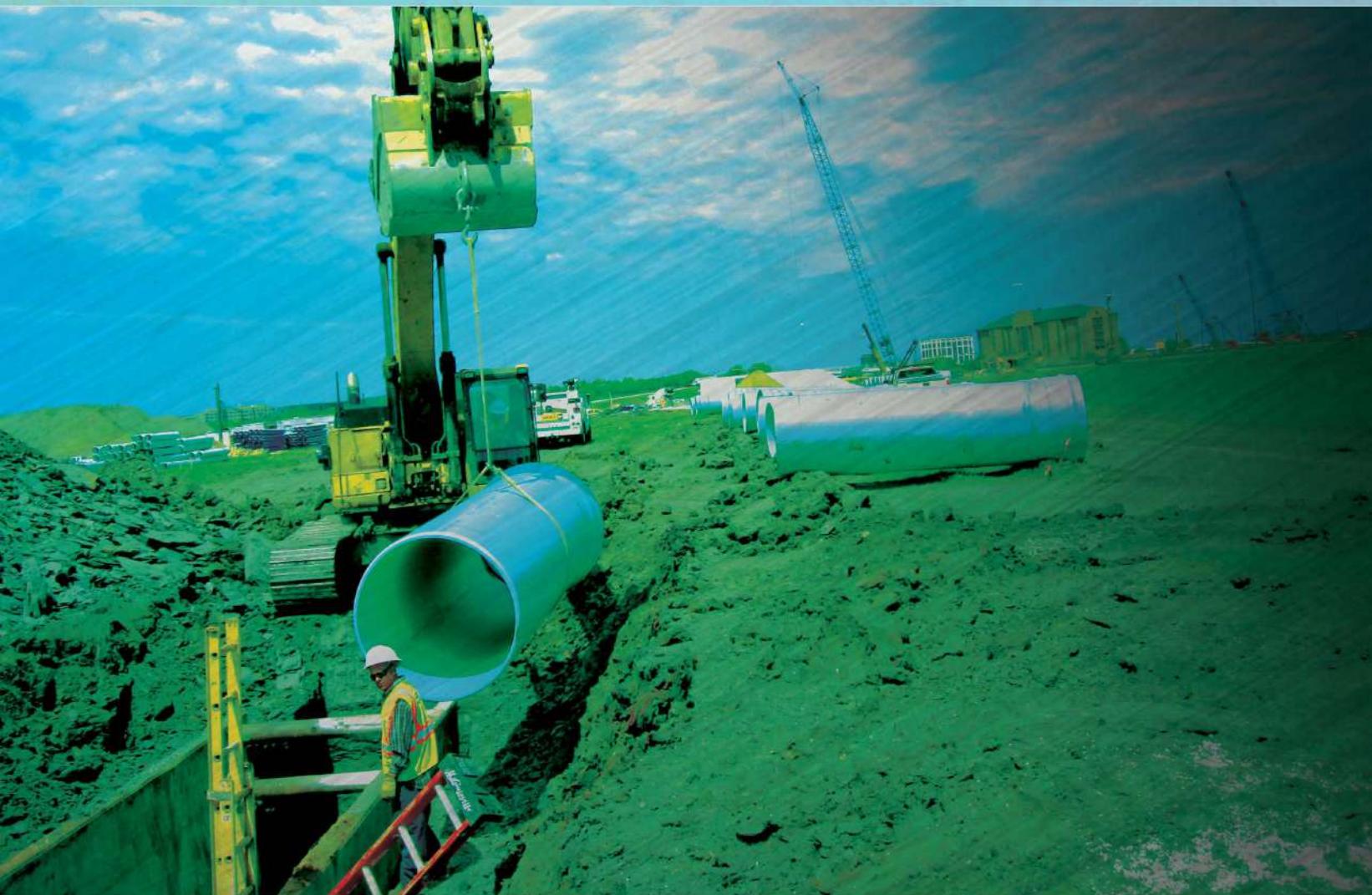
It was reported that these PVC pressure pipes were installed in a variety of terrains including sandy soil and solid limestone. The performance was reported to have been satisfactory in all situations. In addition, the pipes in the system traverse both roads and rail lines. In neither instance was the pressure class of the pipe upgraded to accommodate the dynamic loads imposed by passing road traffic or trains. Nevertheless, no failures have been reported as a consequence of dynamic loading.

The long-term performance of the system has been clearly dependent upon the initial pipe quality, handling and installation. *Degradation of the PVC material has not occurred.* For the four pipes tested, both the tensile strength at yield and elongation-at-break were essentially the same. Moreover, the results are the same as expected for contemporary pipes tested at the time of manufacture. Thus it can be concluded there has been *no degradation in the strength or elongation characteristics of the PVC during the service life of the pipes. The exhumed pipes have not suffered any loss of strength as a consequence of operating under pressure for almost 30 years.*

These results showed there was no deterioration in the fracture toughness during a service life approaching 30 years. A number of studies have been made of exhumed PVC pipes in order to test the premise that material degradation is neither occurring nor adversely affecting potential service life. The findings of the Australian pipe testing support the earlier works by Lancashire (11), Bauer (12) and Alferink et al (13).

Numerous studies on the fatigue failure characteristics of PVC pipe have been conducted. In 2005 Whittle and Teo (14) summarized previous research and conducted rotating beam experiments with notched PVC specimens and were able to match fatigue failure test results from pressure cycling PVC pipes. Their results show that an endurance limit exists in PVC-U pipes such that stress amplitudes less than 2.5 MPa (362 psi) would have negligible effect on the life of a pipe. This stress range is well below that expected in a typical municipal water system.

The Water Research Foundation funded a study published in 2005 titled "Long-Term Performance Predictions for PVC Pipes," Burn, et. al. (7). This report has a comprehensive review of methods to analyze the expected life of PVC pipe. *They report that 100 years is a conservative estimate for a "properly designed and installed pipe."* A detailed survey was sent out to 44 water utilities in Australia, Canada, and the USA. Of the 44 participants, 17 water utilities provided detailed data. This provided a benchmark for failure models developed. Fracture mechanics-based models were produced to predict the conditions under which pipe failure will occur in service. These models were calibrated against failure rates recorded in a number of North American and Australian utilities.



UNITED KINGDOM & EUROPEAN STUDIES RESULT IN PIPE LIFE IN EXCESS OF 100 YEARS

In 1985, Lancashire [11] investigated whether the performance of PVC-U pipe is affected by time in service. Lancashire studied PVC water pipes exhumed after 4 to 16 years' service and concluded that ageing was not a significant factor influencing the performance of the pipes. Material quality, particularly good gelation and small size of inclusions, was found to have the overwhelming influence on performance. The pipes were 4 inch, Class C (operating pressure 9 bar) from a single manufacturer. They performed stress regression testing and concluded that initial pipe quality is the overriding influence in determining pipe performance. *All of the pipes tested would be expected to exceed a 100 year life under normal operating conditions.*

In 1996, Alferink et al (13) tested exhumed PVC pressure pipes ranging up to 37 years of age. It was concluded there was virtually no change in the mechanical properties of the pipes due to ageing. The report summarized results of testing a total of 19 pipe samples. The tensile tests showed that the material modulus does not decrease with pipe age. There did not appear to be any changes in tensile strength and impact strength with pipe age. Stress regression testing showed that PVC pipes after 35 years of service still were meeting CEN stress regression requirements. They concluded that "old PVC water pressure pipes still fulfill the most important functional requirements. *Ductility and resistance to internal pressure have been virtually unaffected by ageing, and are still on the same level as for new pipes.*"

Hülsmann (15) in 2004 reported tests on some of the first PVC pipes installed in Germany. One set of tests examined 15 pipe specimens exhumed after being in use for 23 years. They ranged in diameter from 20-48 mm (0.787-1.890 in) and were subjected to long term hydrostatic pressure testing. The testing was completed at 60°C and then the Arrhenius equation was used to scale the results back to 20°C. The extrapolation of the stress regression data was taken out to 10^6 hours (114 years). Hülsmann concluded that under realistic conditions in the Bitterfeld location and at 4-5 bar (58-83 psi) water pressure, it may be assumed that another 100 years of safe operation could be expected. An additional nine pipe specimens, 4 coming from a 32.5 mm (1.28 in) pipe and 5 coming from a 25.2 mm (1.0 in) pipe, were in operation as potable water pipes for 53 years at 4-5 bar (58-83 psi) operation pressure.

The 9 samples were subjected to long term hydrostatic pressure tests at 60°C. An extrapolation of the stress regression data was to 10^6 hours (114 years). They concluded these pipes would last another 100 years of operation even at 7 bar (102 psi) and 60°C (140°F) operating conditions.

If the temperature is between 20-40°C (68-104°F) and the operating pressure is doubled to 8-10 bar (116-145 psi), *the pipe would easily operate for 100 years as a potable water pipe with a safety factor of 1.5.*

The following year in 2005, Boersma and Breen (16) examined chemical and physical ageing of PVC pressure pipe. They defined chemical ageing by a change in the chemical structure of a polymer and physical ageing as a change in the physical structure. He notes that "Chemical ageing at 15°C seems not to have a significant influence on the quality of PVC water distribution pipes." Physical ageing was investigated by examining the free volume relaxation by measuring yield stress. Accelerated aging of PVC pipe at 60°C leads to an increase in yield stress and thus yield stress is an indication of the pipe age. However, measured yield strength of pipes in service up to 30 years does not show any trends indicating changes in yield strength with pipe age. They concluded that "Physical ageing at 15°C seems not to have a significant influence on the quality of water distribution pipes." They also tested PVC pipes for stress regression, slow crack growth, and fatigue and concluded *that the service life of high quality PVC should exceed 100 years.*

In 2006, Breen (17) studied five excavated pressure pipe specimens produced between 1959 and 1997 with pipe diameters between 160 and 400 mm (6.3 and 15.7 inch). He performed chemical and physical ageing tests on the PVC along with tensile, burst test, slow crack growth, impact test, and fatigue measurements. He concluded that the "existing PVC tap water pipe systems in the Netherlands will operate for at least 100 years provided that the internal and external loads do not result in hoop stresses which will exceed 12.5 MPa and that no micro-crack and mechanical damages are present in the PVC pipes."

NORTH AMERICAN STUDIES STATE THAT 100 YEARS IS A CONSERVATIVE ESTIMATE

Moser and Kellogg in 1994 (18) published an AWWARF funded survey of water utilities and performed impact and acetone immersion tests on 59 PVC pipe samples from 16 different utilities that were being installed in 1992. The samples provided came from ten different PVC pipe manufacturers. All of the samples passed the acetone immersion test and only four samples failed the impact tests. The survey results found some evidence of early PVC pipe failure but these problems usually occurred in the first year of operation and were usually attributed to improper pipe installation.

Moser and Folkman (19) reviewed previous studies of fatigue failure in PVC pipe and guidelines to prevent failures. They also conducted numerous pressure cycling tests of 6-inch PVC pipe and combined their results with previously reported data. Their results are currently the design guidelines presented in the AWWA C900 standard in Appendix B.

In 2013, Folkman and Barfuss (20) reported on quality control tests on PVC pipe that had been in use for a number of years. The pipes tested are summarized in Table 1 and had been in continuous use for between 20 and 49 years. Note that sample #1 was manufactured under an early commercial standard CS 256. In 1964, the CS 256 standard became ASTM D2241. The tests included pipe dimensions, acetone immersion, and pressure tests. The burst pressure test was used for samples #1 and #2 that were manufactured to CS 256 and ASTM D2241 standards and the hydrostatic integrity test was applied to sample #3 which was made to the AWWA C905 standard. Table 2 lists the specifications used for these quality control tests. All three samples passed all of the quality control tests. Figure 1 is a photograph of Sample #3 prior to the hydrostatic integrity test.



FIGURE 1 :
PHOTO OF
SAMPLE #3
PRIOR TO
STRUCTURAL
INTEGRITY
TESTING

TABLE 1 : Description of PVC Pipe Tested at USU

	SAMPLE #1	SAMPLE #2	SAMPLE #3
SIZE, DR	4 INCH, SDR21	4 INCH, SDR21	24 INCH, DR18
USAGE	WATER MAIN	WATER MAIN	SEWER FORCEMAIN
MANUFACTURING STANDARD	CS 256	ASTM D2241	AWWA C905
YEAR INSTALLED AGE	1964	1987	EARLY 1990'S
YEAR EXCAVATED	2012	2012	2012
YEARS IN SERVICE	49 YEARS	26 YEARS	~20 YEARS

TABLE 2 : Quality Control Test Specifications

TEST	TEST CONDITIONS	APPLICABLE STANDARDS
PIPE DIMENSIONS	6 SPECIMENS @ 8 POINTS	AWWA C905 & ASTM D2122
ACETONE IMMERSION	8 SAMPLES	ASTM D2152
BURST PRESSURE	1 SPECIMEN, 630 PSI IN 60 SEC	ASTM D2241 & D1599
HYDROSTATIC INTEGRITY	1 SPECIMEN, 470 PSI IN 60 SEC	AWWA C905 & ASTM D1599

DIG-UP TEST RESULTS SUMMARY >>>

Accelerated ageing studies all indicate that PVC pressure pipe can be expected to provide reliable service in excess of 100 years. Accelerated ageing tests provide the best estimates a laboratory can provide for longevity. Validation of PVC expected long-term performance with exhumed samples provides confidence to the end user. With many installations of PVC pipe reaching 50 years with no indication of loss of capacity, this provides further validation of PVC pipe's long life.

Examples can be found of PVC pipe failures with very short life spans. When an early PVC failure occurs, it has been the experience of the author that there will be two possible causes. The failure could be due to a defective pipe usually caused by incomplete gelation of the PVC. Quality control tests by manufacturers on each lot of pipe should prevent this occurrence. The primary cause of early PVC pipe failure is improper installation procedures. Regardless of the pipe material chosen, a quality installation procedure will provide enhanced pipe life.



SEWER PIPE STUDIES >>>

Bauer (22) tested PVC sewer pipe exhumed after 15 years of service and in 1990 reported on tests that no measurable degradation of the material occurred in this period. In particular it was reported that there was *no embrittlement and no decrease in modulus or pipe stiffness*.

Meerman (23) in 2008 conducted inspections of sewer pipe up to 25 years old. A number of pipes were recovered from their service sites and subjected to a range of visual, microscopic and other test to assess their condition. The tests included: visual and microscopic inspections, geometrical analysis and deformations, and surface roughness and degradation. He concluded that the existing PVC sewer pipe systems will operate for at least 100 years.



**UNDERGROUND PVC PIPE
INFRASTRUCTURE CONTRIBUTES
TO WATER SERVICE AFFORDABILITY:
PIPE LIFE CYCLE COST ANALYSIS**

LIFE CYCLE COST ANALYSIS >>>

Life cycle cost analysis (LCCA) is an evaluation technique applicable for the consideration of certain water and wastewater infrastructure investment decisions. Specifically, when it has been decided that a project will be implemented, LCCA will assist in determining the best—the lowest-cost—way to accomplish the project. The LCCA approach (24) enables the total cost comparison of competing design (or preservation) alternatives, each of which is appropriate for implementation of underground pipe projects. All of the relevant costs that occur throughout the life of an alternative, not simply the original expenditures, are included. Also, the effects of the utility's construction and maintenance activities and the direct costs to the utility are included.

LCCA is reasonably straightforward to understand and perform. It incorporates both the utility's institutional knowledge and the application of sound economic analysis techniques. In brief, the LCCA process begins with the development of alternatives to accomplish the structural and performance objectives for a project. The analyst then defines the schedule of initial and future activities involved in implementing each project design alternative. Next, the costs of these activities are estimated. Best-practice LCCA calls for including not only direct agency expenditures (for example, construction or maintenance activities) but other related costs. Using an economic technique known as "discounting," these costs are converted into present dollars and summed for each alternative. The analyst can then determine which alternative is the most cost-effective. It is important to note that the lowest LCCA option may not necessarily be implemented when other considerations such as risk, available budgets, and political and environmental concerns are taken into account. LCCA provides critical information to the overall decision-making process, but not the final answer.

- 1 ESTABLISH DESIGN ALTERNATIVES
- 2 DETERMINE ACTIVITY TIMING
- 3 ESTIMATE COSTS
- 4 COMPUTE LIFE-CYCLE COSTS
- 5 ANALYZE THE RESULTS

The EPA's 10 step process (25) for asset management programs supports the activity of life cycle costing.

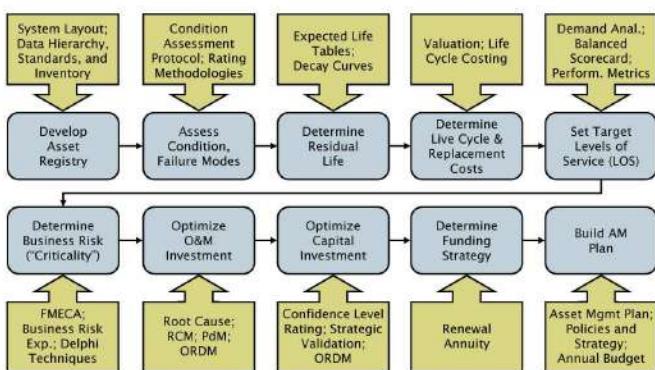


FIGURE 2 : EPA's Life Cycle Steps

In summary, LCCA (24) is a cost-centric business approach used to select the most cost-effective alternative that accomplishes a preselected project at a specific level of benefits that is assumed to be equal among project alternatives being considered. Underground pipe infrastructure is a perfect application of life cycle cost analysis.



LIFE CYCLE COST ANALYSIS

CONTINUED

The life cycle costs according to the EPA include the total cost of an item throughout its life, including costs of planning, design, acquisition, operations, maintenance, and disposal, less any residual value, or the total cost of providing, owning and maintaining an asset over a predetermined evaluation period. The EPA asset management training charts (25) below in Figures 3 and 4 illustrate this concept.

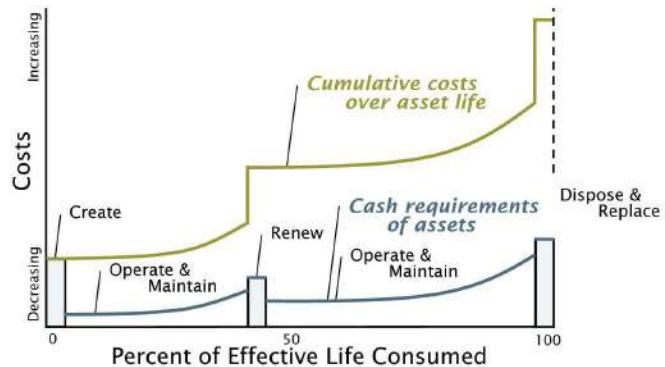


FIGURE 3 : . EPA Costs Over Lifetime

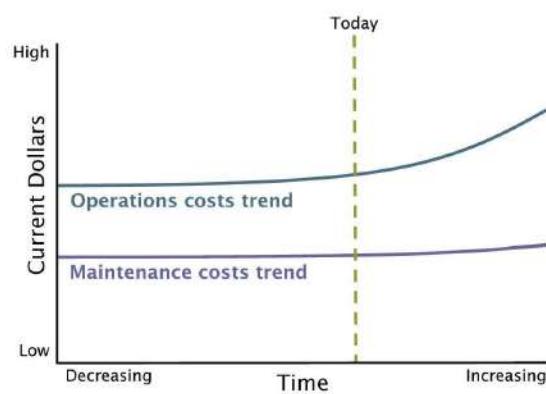


FIGURE 4 : . EPA Replacement Timing

The timing of rehabilitation activities as shown in Figure 4 should be based on existing performance records such as those available from a utilities work order management system or CMMS (computerized maintenance management system). This information may be supplemented with findings from outside research such as national water main break studies, national database repositories of pipe condition assessment data like WaterID (waterid.org) and dig-up studies. When actual data are unavailable or not applicable, the judgment of experienced engineers may be particularly useful for both planned activities and costs to monitor, rehab or replace underground infrastructure.

The national database of WaterID offers various cost synthesis data (26) on water and sewer pipe costs including estimated and reported costs for various types of condition assessment and rehabilitation.

In 2014, a North Carolina city published (27) in a local newspaper article “Saluda estimates costs of repairing infrastructure” the initial price comparisons for replacing two current lines with PVC pipe versus iron pipe.

Costs for Replacing Waterlines A:

Eight-inch PVC Pipe
1,600 feet - \$29,587.72

Eight-inch Ductile Iron Pipe
1,600 feet - \$42,352.32

Costs for Replacing Waterlines B:

Six-inch PVC Pipe
1,500 feet - \$20,125.20

Six-inch Ductile Iron Pipe
1,500 feet - \$40,110.30

The focus of this study is not to produce a price list of pipes, condition assessment and corrosion control activities but to recommend that these types of costs be included in a life cycle costing analysis. Life cycle costing as a pipe selection evaluation tool becomes very valuable in comparing underground pipe replacement cost for pipe projects. These tools and recommendations should become standards in the procurement process of utilities in order to support sustainability and affordability goals and policies. This same methodology can be applied to other infrastructure categories such as valves and manholes.

Underground infrastructure projects have a number of different types of costs beyond the initial pipe price as demonstrated in Figure 5 from a Water ID synthesis report (26) on pipe costs and considerations.

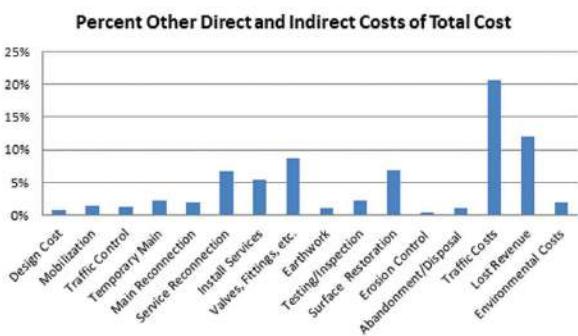
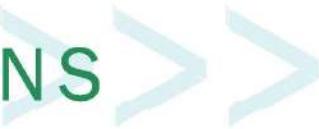


FIGURE 5 : WaterID Synthesis Report Example of Costs

CONCLUSIONS AND RECOMMENDATIONS



Our water and sewer underground infrastructure is now in decline after decades of service. The signs of distress surface daily as water mains break, creating floods and sink holes. The loss of service is more than an inconvenience, causing significant social and economic disruptions at ever increasing costs. The downturn of the economy has also given rise to new issues on the affordability of water services when the total price tag of regulatory issues and replacement costs are considered. These issues create a more complex environment for utility management, including an increased amount of public awareness and a greater demand for transparency and accountability. In an effort to provide solutions to these new utility business requirements, additional processes and tools are needed as part of the underground pipe infrastructure evaluation and selection process. This effort requires the attention of elected officials, the support of utility management and the involvement of engineering, financial and procurement resources to develop a new program for sustainability and affordability.

The first phase of gathering evidence of new solutions involved a study of pipes to quantify the occurrences of failing underground pipe networks namely water main break rates. Water main break rates are calculated for all pipe materials used in the transport of water to create a measurement to judge pipe performance and durability. Water main break rates can vary year to year and by utility. However, in aggregate, break rates produce a compelling story which can aid our prudent decision making as it relates to repairing and replacing our underground pipes.

The second phase to further support the water main break evidence involves reports and studies on "in service," excavated pipe testing. These results further the development of a case for performance and longevity review as well as contributing to financial costs analysis tools. Within the framework of this collective data including life cycle costs and asset management practices, many new standards of pipe evaluation selection can be performed. This methodology provides for greater understanding and acceptance of alternative materials to be used in the underground networks necessary to withstand corrosion and other environmental challenges facing every utility to some degree. Many utilities have fallen short in producing appropriate cost and life cycle comparison of pipe performance. This has occurred when insignificant statistical sampling is used, poor installation practices are assumed as local standards, modeling activities do not take into consideration the difference in material mechanics, and cost analysis omits the operational and maintenance cost of corrosion control programs both internal and external to the pipe.

As these recommendations continue to become accepted best practices for effectively managed utilities in both private and public operations, the nation as a whole can rebuild its basic water and sewer infrastructure and stand as a national treasure of innovation and industry with performance and longevity to extend beyond the next 100 years. This process can be achieved by applying correct tools and methodologies which can quantify the costs and demonstrate efforts towards achieving more affordable infrastructure choices without sacrificing quality or performance. The combination of research, testing, and analysis results in confirming a 100+ year benchmark standard for PVC pipes.

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