

# PVC Pipe has Lowest Break Rate according to Utah State University Buried Structures Laboratory Researcher

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USU researcher Steven Folkman recently concluded a study finding PVC pipe has the lowest overall failure rate when compared to cast iron, ductile iron, concrete, steel and asbestos cement pipes. Also, corrosion is a major cause of water main breaks.

The Utah State University Buried Structures Laboratory has published a comprehensive study on “*Water Main Break Rates for the United States and Canada.*” The Buried Structures Laboratory is one of two locations in the United States that has a large-scale testing facility for pipe materials and structures.

Steven Folkman, a USU professor of mechanical and aerospace engineering, has completed a pipe materials study that involved 188 utilities representing approximately 10 percent of the nation’s installed water main pipe network. Water main break rates are calculated for all pipe materials used in the transport of water to create a measurement and to judge pipe performance and durability. The study will help prudent decision-making as it relates to repairing and replacing underground pipes.

A major finding of the study is that PVC pipe has the lowest overall failure rate when compared to cast iron, ductile iron, concrete, steel and asbestos cement pipes. Another major finding is that corrosion is a major cause of water main breaks.

“Nearly 75 percent of all utilities have corrosive soil conditions and combined with a high portion of old cast iron and ductile iron pipes, corrosion is ranked the second-highest reason for water main pipe failure in the United States,” said Folkman. “When comparing older cast iron and newer ductile iron, thinner-walled ductile iron is experiencing failures more rapidly.”

Other findings include a new national metric of 264 people per 1 mile of pipe connections regardless of utility size. The average age of the failing water mains is 47-years old and 22 percent of all water mains are over 50-years old. The study also found that eight percent of all installed water mains are beyond their useful life and that the use of trenchless technologies will continue to increase with directional drilling as the most widely accepted technology with a higher satisfaction rating. In fact, 74 percent of utilities are considering directional drilling in the near future, said Folkman.

Folkman’s study contributes to the continuing efforts of the EPA’s Aging Water Infrastructure research and the American Water Works Association (AWWA). The study can be found on the [web](#).

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. He has oversight of USU's Buried Structures Laboratory which been involved in analysis and testing of all kinds of pipe and associated structures for more than 50 years and is recognized as one of two laboratories in the United States for performing large scale tests on buried pipes. Folkman's expertise includes structural dynamics, linear and nonlinear finite element analysis utilizing soil/structure interaction and testing.

USU is also home to the Utah Water Research Laboratory that has significantly contributed to water and wastewater research internationally for the last 50 years.

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See full report below.....

# ***Water Main Break Rates In the USA and Canada: A Comprehensive Study April 2012***



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Utah State University  
Buried Structures Laboratory

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Steven Folkman, Ph.D., P.E.





## EXECUTIVE SUMMARY

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Modern societies base their economic prosperity on a standard of living which includes a complex network of infrastructure, both above and below ground. Quality drinking water brought to the tap through elaborate underground distribution systems is a critical component to our public health and economic well-being. In the USA and Canada, it has been the hallmark of our industry and cooperation.

### EVIDENCE OF DECLINE

Our water 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 water service is more than an inconvenience, since it causes significant social and economic disruptions and jeopardizes public health.

### THE MEASUREMENT

One factor used to quantify the occurrences of failing underground pipe networks is **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.

### PURPOSE AND HIGHLIGHTS

This Comprehensive Water Main Break Rate Study for the USA and Canada compiles the collective experience of 188 utilities which can be used for making future critical pipe replacement decisions. It is the desire of the researchers and participants to offer data and analysis that utility managers and elected officials can apply to the circumstances of their own operations. Highlights of the Comprehensive Water Main Break Study include a new national metric for citizens served per one mile of pipe, aggregate data on pipe material break rates, analysis of age and corrosion in failure modes, and related observations on pressure, temperature and trenchless technology practices.



## INTRODUCTION

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In the United States and Canada, underground water infrastructure was installed during three main time periods because of the population growth in the 1800s, 1900–1945, and post 1945. Pipes constructed in each of these three eras will all start to fail at nearly the same time over the next couple of decades for a number of reasons ranging from age and corrosion to inadequate design and poor installation. Additionally, the life span of the materials used has become shorter with each new investment cycle (WIN, 2002). In 2009, the American Society of Civil Engineers issued a USA Infrastructure Report Card and gave a D- to drinking water and wastewater infrastructure (ASCE, 2009).

In 2001, an AWWA study called “Dawn of Replacement” pointed out: *The oldest cast iron pipes—dating to the late 1800s—have an average useful life of about 120 years. This means that, as a group, these pipes will last anywhere from 90 to 150 years before they need to be replaced, but on average they need to be replaced after they have been in the ground about 120 years. Because manufacturing techniques and materials changed, the roaring ‘20s vintage of cast-iron pipes has an average life of about 100 years. And because techniques and materials continued to evolve, pipes laid down in the Post-World War II boom have an average life of 75 years, more or less. Using these average life estimates and counting the years since the original installations shows that these water utilities will face significant needs for pipe replacement over the next few decades. Replacement of pipes installed from the late 1800s to the 1950s is now hard upon us, and replacement of pipes installed in the latter half of the 20th Century will dominate the remainder of the 21st. We believe that we stand today at the dawn of a new era—the replacement era—for water utilities.* (AWWA, 2001) In an update to the “Dawn of Replacement”, 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.”* (AWWA 2012) These replacement costs combined with projected expansion costs will cost more than \$1 trillion over the next couple of decades.



Over 54,000 community water systems face the inevitable cost of pipe repair and replacement. The United States EPA states that nearly 60% of the total system costs are found in the distribution and transmission pipe lines. 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 pipe material selection criteria as part of the replacement strategies and funding plans.

### AGING WATER INFRASTRUCTURE

The EPA's Aging Water Infrastructure research program (<http://www.epa.gov/awi/>) is working toward the goal of making our nation's water infrastructure sustainable by supporting research and by promoting strategic asset management. This comprehensive water main break study is part of the continuing credible, analysis-based effort to support the EPA's program goals including:

- Reduced life-cycle costs for water infrastructure management
- Extended service life of existing infrastructure
- Reduced high-risk water main breaks
- Improved condition assessment and decision-making capabilities
- Reduced potable water leakage and intrusion potential
- Increased use of performance and cost data for decision support, and the adoption of asset management
- Increased adoption of innovative technologies

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 water main break data. 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 report based on statistically significant experiences from 188 utilities also draws from other relevant studies to be the most complete study on water main break data.

### THE PRIMARY RESEARCHER

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 (Mc Graw Hill, 3rd Edition). Dr. Folkman's research assistant for this project was Ammon Sorensen. 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 two laboratories in the United States for performing large scale tests on buried pipes. It is from this expertise and background that the surveys of water main breaks were developed and analyzed to complete this comprehensive study.



## THE METHODOLOGY

During 2011, Utah State University conducted a study of utilities across the USA and Canada to obtain data on water main failures of municipal and private water supply systems. The study was comprised of two parts: a basic survey and a more detailed survey. The focus of the basic survey was to examine the number of failures utilities were experiencing and how those failures related to the pipe materials used. This effort focused on water supply mains (sewer and force main pipes were excluded). A variety of pipe materials are used in water supply systems and over the past 100 years the materials have evolved with different manufacturing technologies. As a result, pipe performance has changed. A goal of the more detailed level of analysis was to look at which materials were performing best at a snapshot in time and to track how pipe age affects failure rates.

A total of 1,051 surveys were mailed out to USA and Canadian water utilities in May and June of 2011. The participants were asked for data from a previous 12 month time period and thus the results represent a time period that mostly coincides with the year 2010. A total of 188 utilities responded and completed the basic survey with 47 of these also responding to the detailed survey. 117,603 miles of pipe are represented in this comprehensive study. The USA and Canada were divided into nine regions and the 188 survey respondents were categorized according to the region and the size of the utility based on amount of pipe. This comprehensive study documents the results from both surveys and draws from other relevant industry sources.

## OBJECTIVES AND GOALS OF THE STUDY

There were many objectives of the surveys. These objectives include:

- Understanding the age and pipe size distribution of pipe in the respondent's system
- Reviewing delivery and fluctuations of water pressure
- Itemizing pipe failures over a time period with the data broken down by material type
- Identifying the most common pipe failure modes and materials as identified by the utility
- Determining whether corrosive soils are present and whether corrosion prevention methods were used
- Highlighting pipe replacement plans, expected pipe life of new pipe and leak detection methods
- Considering contractor selection based on contractor experience and which pipe materials are allowed
- Quantifying experience with pipe relining, pipe bursting, and directional drilling to examine future directions of pipe repair and installation.



## MAJOR FINDINGS

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

### 1. This Survey Achieved Wide Participation

A total of 117,603 miles of pipe were reported by the 188 survey participants. This represents approximately 10% of the total length of water mains in the USA. This is one of the largest surveys conducted on water mains failures and the results give an accurate representation water main behavior in the USA and Canada.

### 2. Nationwide One Mile of Installed Water Main Serves 264 People

While in urban areas the industry has assumed 325 people are served for 1 mile of distribution system pipe, this survey suggests a new national metric of 264 people served per 1 mile of pipe regardless of utility size. Also, 66% of all water mains are 8" or less in diameter and the range of 10" to 14" make up another 18% of all installed water mains.

### 3. Most Utilities Use Several Kinds of Pipe Materials

80% of the installed water mains utilize a combination of Cast Iron (CI) at 28%, Ductile Iron (DI) at 28% and PVC pipe at 23%. This fact is supported by a relative low amount (13%) of utilities which avoid DI due to corrosion concerns.

### 4. Pipe Material Use Differs by Region

Water main pipe material usage varies significantly over geographic regions (see Figure 9). The Northeast and North Central region of the USA (Regions 6 and 8 as illustrated in Figure 1) uses either CI or DI pipe for approximately 90% of its length. In Region 9, Canada, PVC pipe makes up 43% of the total.

### 5. There is Considerable Scatter in Pipe Failure Rate Data

The water main break experiences of one utility may not represent another. Factors such as climate, installation practices, and soil corrosivity can greatly affect failure rates. Every utility should properly install pipe - regardless of material. In order to have an accurate water main break survey, a large number of respondents are required.

### 6. PVC Pipe Has the Lowest Overall Failure Rate

When failure rates of Cast Iron, Ductile Iron, PVC, Concrete, Steel, and Asbestos Cement pipes were compared, PVC is shown to have the lowest overall failure rate.

### 7. Corrosion is a Major Cause of Water Main Breaks

75% of all utilities have corrosive soil conditions and combined with a high portion of CI and DI pipes, one in four main breaks is caused by corrosion which is ranked the second highest reason for water main pipe failure. Northeast and North Central USA utilities (Region 6 and 8) will experience a higher percentage of corrosion breaks due to a higher concentration of CI and DI pipes (90%) installed.

### 8. The Average Age of Failing Water Mains is 47 years old

43% of water mains are between 20 and 50 years old and 22% of all mains are over 50 years old. While pipe life can be estimated at over 100 years, actual life is affected by soil corrosivity and installation practices. Based on the detailed survey, the average expected life of pipe being put in the ground today is 79 years. For example, non-corrosive materials like PVC have an estimated life over 110 years (Burn, 2006). Regardless of the pipe material selected, installation practices will affect the actual life that can be achieved.

### 9. The Average Supply Pressure is 77 psi with Pressure Fluctuations less than 20 psi.

Pressure events can contribute to water main breaks for pipes that have internal corrosion (tuberculation) or weakened areas due to external corrosion. Pressure is an important component to pipe design and material selection. A well-controlled system operated below design limits will lead to extended pipe life.

### 10. The Use of Trenchless Technologies will continue to Increase

While 57% of utilities use some form of leak detection, fewer utilities have engaged in trenchless technologies like pipe relining, pipe bursting and directional drilling. Over 40% are considering pipe relining and pipe bursting in the future. Directional drilling is more widely accepted and has a higher satisfaction rating and as a result, 74% of utilities are considering it in the future.

### 11. Over 8% of Installed Water Mains are Beyond Their Useful Life

This figure corresponds well with an EPA study (EPA, 2002) that shows the amount of pipe needing immediate replacement is growing rapidly. Improved asset management will be essential to all utilities to survive this trend.



## SURVEY REGIONS

In total, 188 utilities participated in the surveys and are representative of the nine survey regions in the United States and Canada.

Figure 1. Regions used to report survey results.



The regions defined in the study are used here to indicate the wide geographical distribution of the respondents. Table 1 lists the number of respondents in the basic and detailed surveys from each region, and Figure 1 illustrates the locations of the nine different regions used in this report. The provinces in Canada with a white color did not have respondents to the survey. Figure 2 illustrates the miles of water main pipe that were reported in the basic survey on a regional basis. Similarly, Figure 3 illustrates the miles of water main pipe on a regional basis from the detailed survey. A total of 32,130 miles of pipe was reported by respondents in the detailed survey. It is noted that the respondents were distributed across a large survey area, but this study is still more comprehensive than other studies to date.

Table 1. Number of Survey Respondents by region.

REGION	NUMBER OF RESPONDENTS	
	BASIC SURVEY	DETAILED SURVEY
1	19	7
2	20	4
3	26	5
4	22	6
5	18	3
6	28	11
7	23	2
8	20	4
9	12	5

Figure 2. Length of pipe from each region that responded to the basic survey.

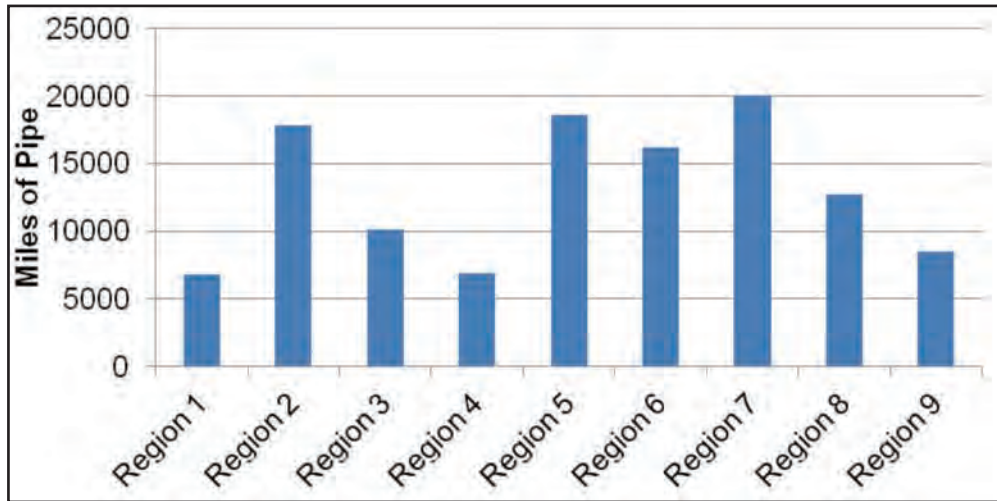
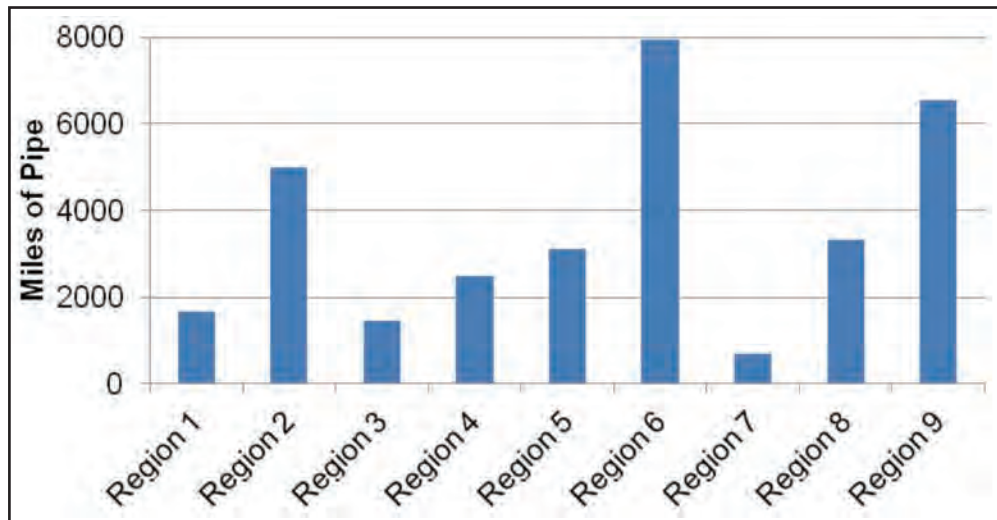


Figure 3. Length of pipe from each region that responded to the detailed survey.



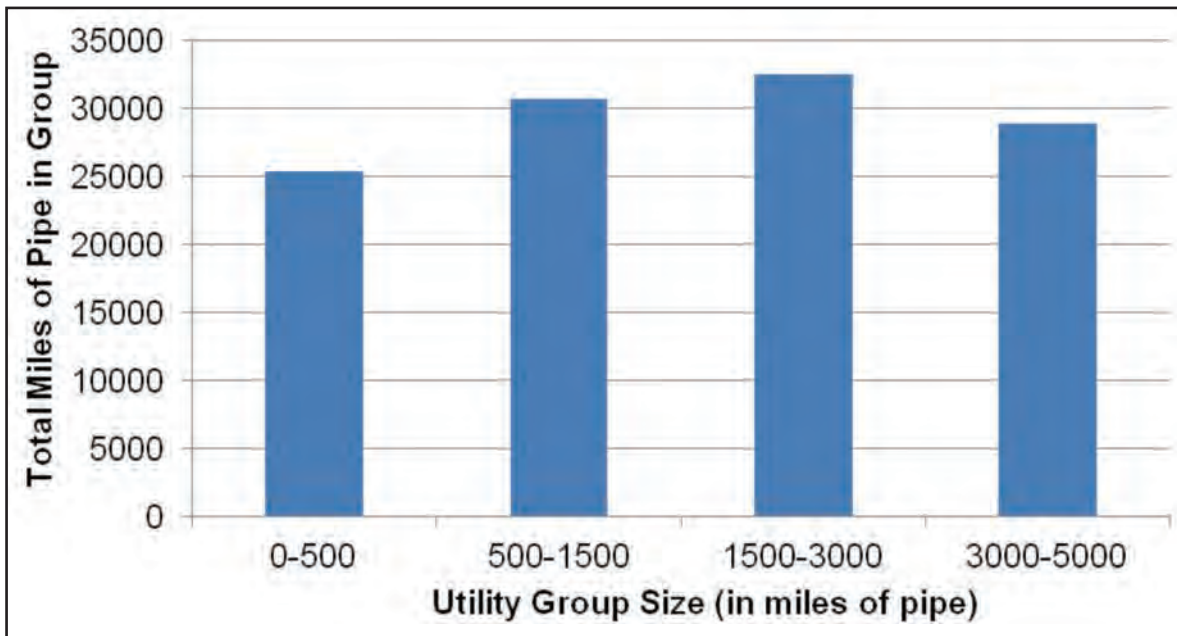
### SIZE OF SURVEY PARTICIPANTS

Four categories were established as shown in Table 2 and each survey participant was allocated to one of the categories. Figure 4 shows the distribution of total miles from the basic survey based on these categories. Respondents covered the range from very small to very large with each group from Table 2 well represented.

Table 2. Grouping of utility size.

DESCRIPTION	MILES OF PIPE INSTALLED
Small Utility/City	0 to 500 miles
Medium Utility/City	500 to 1000 miles
Large Utility/City	1000 to 3000 miles
Very Large Utility/City	3000 to 5000 miles

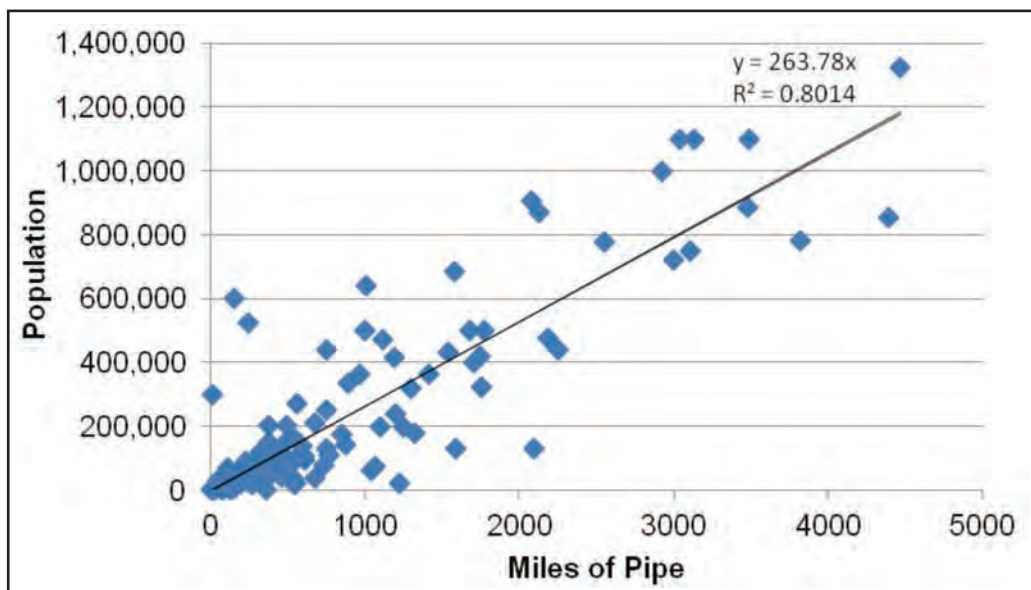
Figure 4. Total miles of pipe in each size group defined in Table 2 based on the basic survey respondents.



### MILES OF PIPE VS. POPULATION

Figure 5 illustrates the relationship between the population served by the utilities participating in the basic survey and the number of miles of water main pipe. The trend line and equation are a best fit to the data. The slope of this line indicates that there are on average 264 people served for each mile of water main installed.

Figure 5. Population served relative to total pipe line miles from the basic survey.



## SURVEY SAMPLE SIZE: 10% OF INSTALLED WATER MAIN PIPE IN THE US

The total length of water main pipe reported by the 188 basic survey participants was 117,603 miles (the survey did not include sewer or force mains). The average utility surveyed had 626 miles of water main with the largest having 4,468 miles and the smallest having 2 miles. Based on an EPA report (EPA, 2007), there are approximately 880,000 miles of distribution pipe in the USA. Another EPA report (EPA, 2008) estimates the amount of installed water main pipe in the USA at over 1,000,000 miles. The current population of the USA is 312 million (US Census, 2011). Using the estimate from the previous section of 264 people served per mile of water main, one can estimate the length of water mains as  $(312 \text{ million people}) / (264 \text{ people/mile}) = 1.18 \text{ million miles}$  of water main pipe. Using this last estimate, the total length of pipe in the survey would represent approximately 10% of the installed water main pipe in the USA. Thus, the survey sample size is significant in size and therefore provides reliable results. Note that the Canadian provinces provided 8,423 miles of pipe to this survey or 7.4% of the total.

## PIPE MATERIALS

Table 3 lists the pipe materials and their abbreviation used in this report. Many pipe products have evolved over the years of use, and most pipe products could be broken down into subcategories based on pipe manufacturing and surface treatments. These changes along with new installation techniques should affect life expectancy of the pipe. Both the basic and detailed surveys were intended to be relatively simple to complete and, thus, encourage wide scale participation of the water utilities. Most utilities have limited records as to which specific pipe materials were installed decades ago and what corrosion protection measures were used. Therefore, tracking subcategories of material types was not completed as part of this study. The results reported represent generic pipe material behavior but may not represent a specific product material on the market today.

**Table 3. Material abbreviations.**

ABBREVIATION	DESCRIPTION
CI	Cast Iron
DI	Ductile Iron
PVC	Polyvinyl Chloride
CPP	Concrete Pressure Pipe
Steel	Steel
AC	Asbestos Cement

Figure 6 illustrates the length of pipe reported in the basic survey broken down by pipe material. The “Other” category in Figure 6 includes materials such as HDPE, galvanized steel, and copper. Figure 7 illustrates the length of pipe reported in the detailed survey broken down by pipe material. Figure 8 illustrates the pipe material distribution as a percentage of the total length from both the basic and detailed surveys. The distribution of miles of pipe is quite similar in Figure 8 indicating that the detailed survey with a smaller number of respondents still gives similar results.

**Figure 6. Length of pipe broken down by material type from the basic survey.**

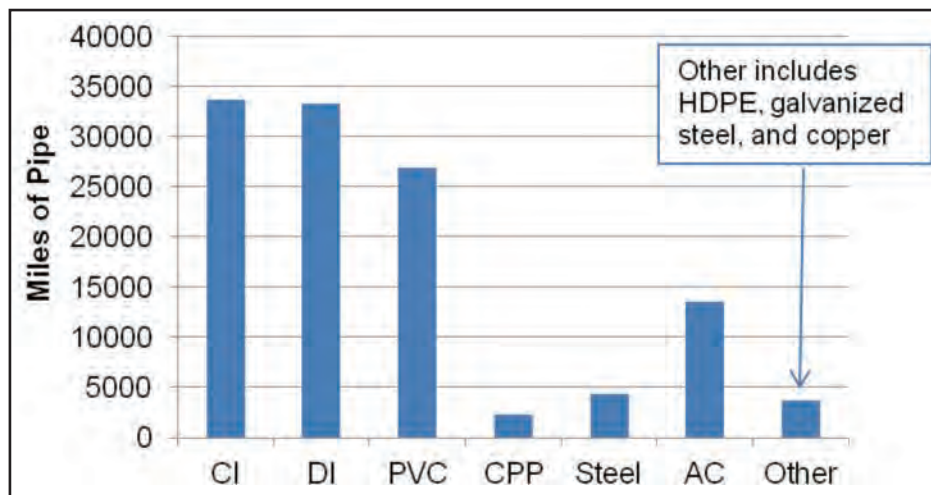




Figure 7. Length of pipe broken down by material type from the detailed survey.

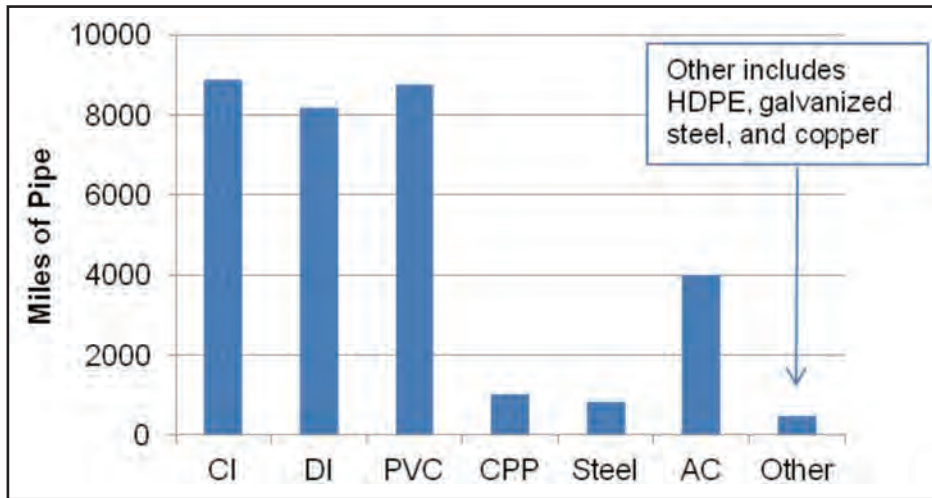


Figure 8. Percentage of total length of pipe by material type from both the basic and detailed surveys.

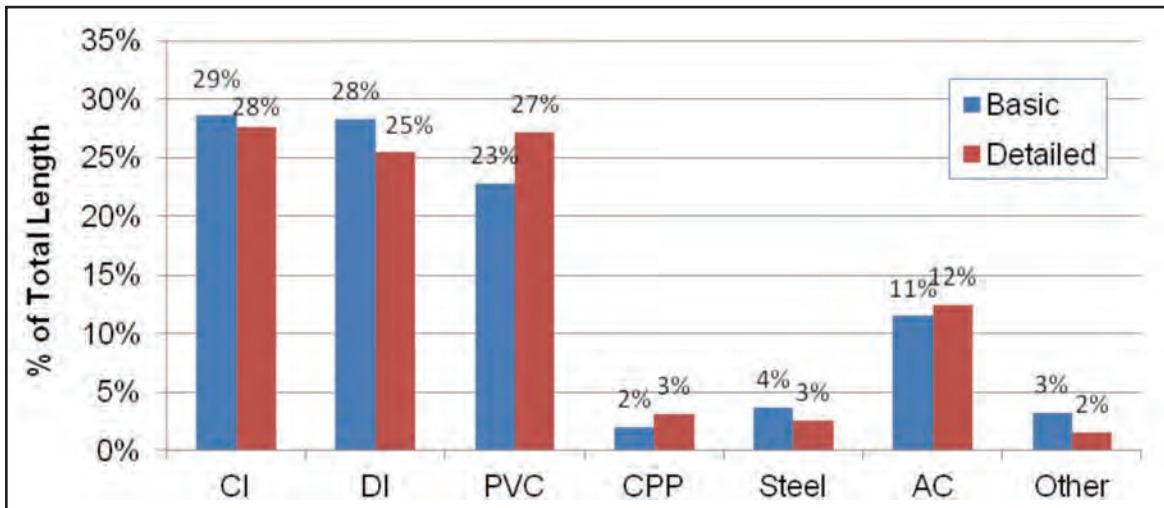
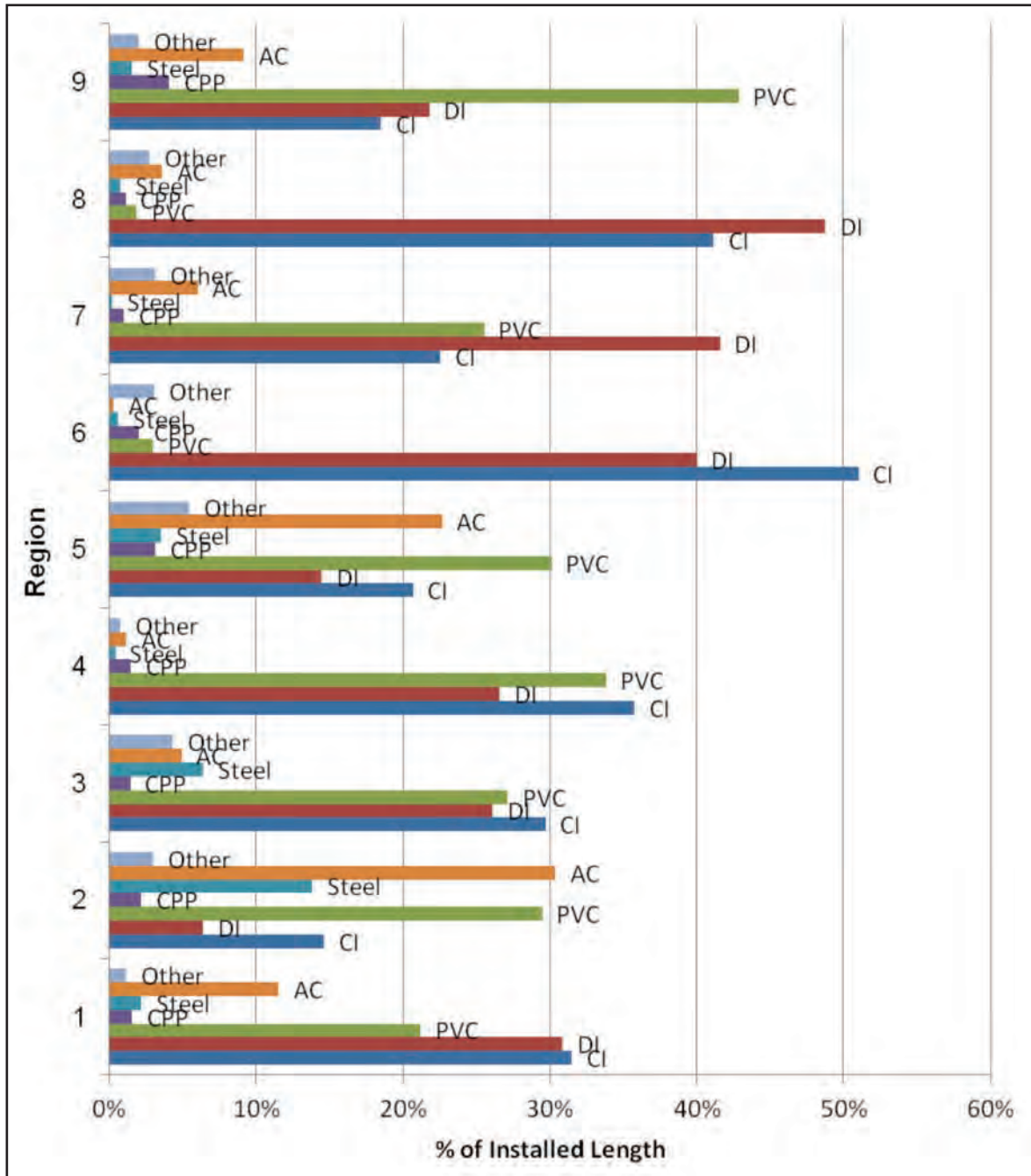




Figure 9 illustrates the regional distribution of pipe material usage as a percentage of the total length in that region. It is interesting to note the significant differences in regional pipe material utilization. Cast and Ductile Iron represent approximately 90% of the pipe in regions 6 and 8. PVC has a dominant role in region 9 and is well established in regions 2, 3, 4, 5, and 7.

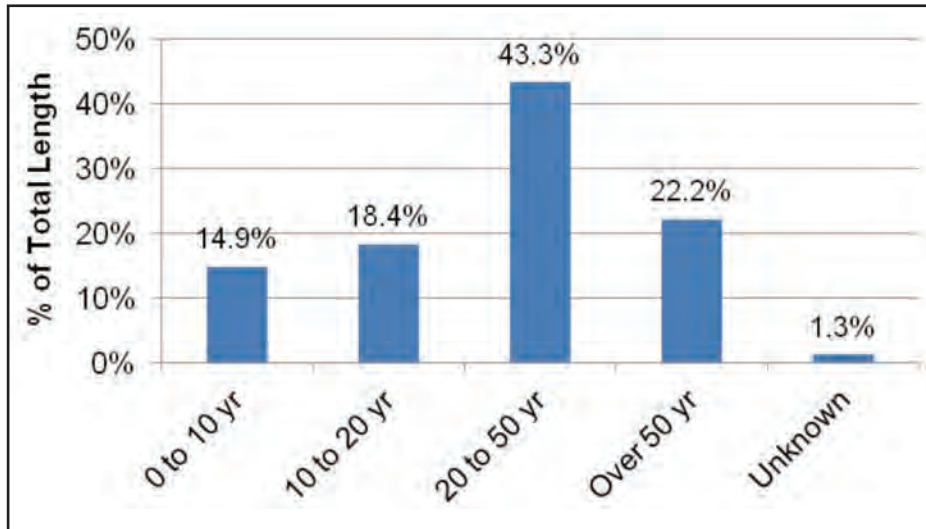
**Figure 9. Regional percentage of length of pipe by material type from the basic survey.**



## PIPE AGE AND DIAMETER

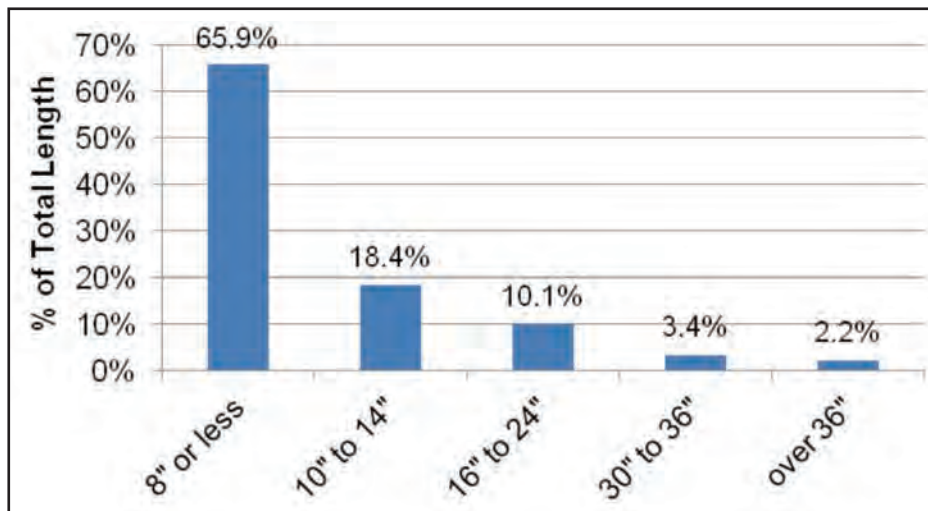
The detailed survey asked respondents to provide the distribution of installed pipe by age. Four age groups were provided; zero to 10 years, 10 to 20 years, 20 to 50 years, and over 50 years. Figure 10 lists the percentage of water main length that fits in each age category. Figure 10 indicates that approximately 43% of installed pipe are in the 20 to 50 year age category and 22% are over 50 years of age. This finding is consistent with other industry sources.

**Figure 10. Percent of length of pipe by age from the detailed survey.**



The respondents were also asked to break down the fraction of total installed pipe length by five pipe diameter categories. Figure 11 illustrates the percentage of water main that fit into each size range. Figure 11 indicates that approximately 66% of the installed pipe is 8 inches or less in diameter.

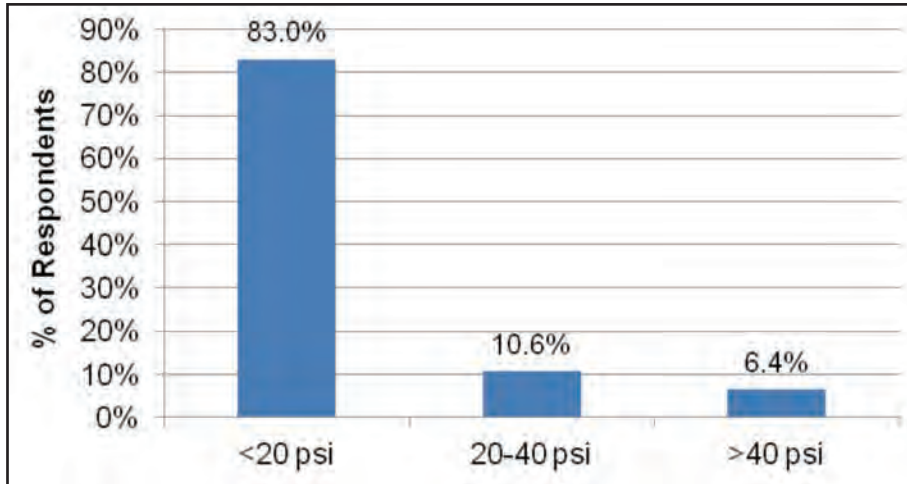
**Figure 11. Percent of length of pipe by pipe diameter from the detailed survey.**



## DELIVERY PRESSURE

Based on the detailed survey, the average delivery pressure is 77 psi. The range of values reported for average delivery pressure was 45 to 150 psi. The detailed survey also asked how much does the water pressure fluctuate at any given point in their system during a typical day. The respondents were asked to select one of three ranges. Figure 12 illustrates the percentage of respondents that fit into each pressure range. About 83% are able to limit pressure fluctuations to be less than 20 psi.

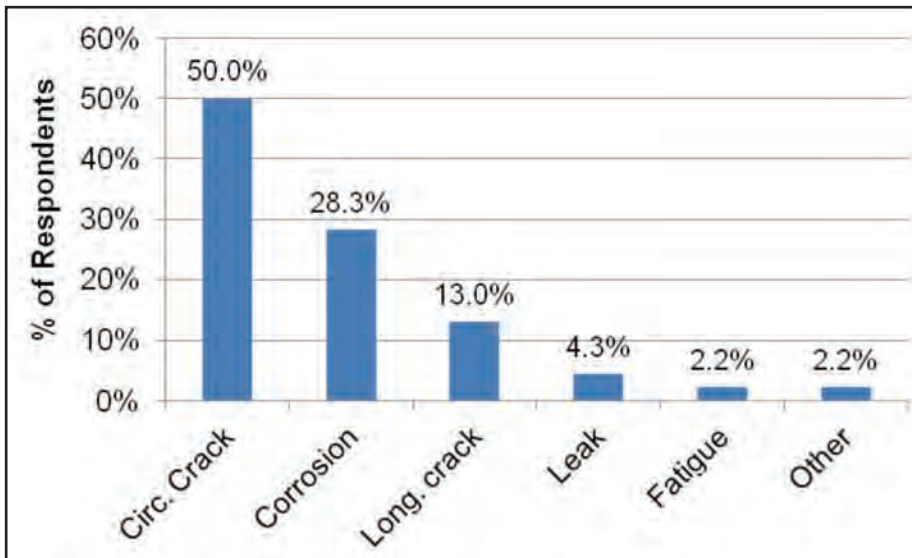
Figure 12. Percentage of respondents with one of three pressure fluctuation ranges.



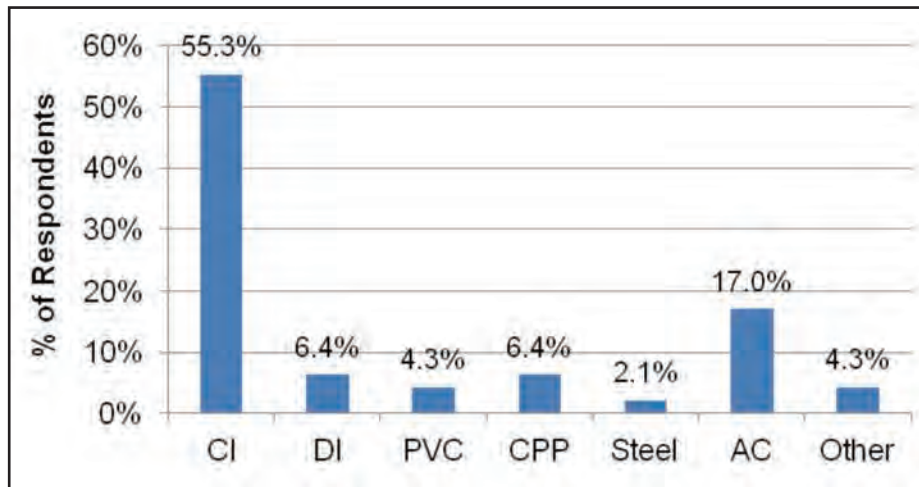
## MOST COMMON FAILURE MODE, MATERIAL, AND AGE

The detailed survey asked the respondents to identify the most common failure mode by selecting from one of the following; corrosion, circumferential crack, longitudinal crack, leakage at joints, fatigue, or other. Figure 13 identifies a circumferential crack as the most common failure mode followed by corrosion. The detailed survey also asked respondents to identify the pipe material that was failing most often. Figure 14 shows that 55.3% of respondents identified Cast Iron as the most common failing pipe material followed by Asbestos Cement at 17.0%. The respondents also reported the typical age of a failing water main. The average result was 47 years with a range of values from 20 to 86 years. The survey also asked what the expected life should be when installing new pipe. The average expected life of new pipe was 79 years with a range of responses from 30 to 200 years.

Figure 13. Percent of respondents selecting a most common failure.



**Figure 14. Percent of respondents selecting a most common failure material.**



### COMPUTING WATER MAIN FAILURE RATES

Both the basic and detailed surveys asked respondents to consider a water main failure as one where leakage was detected and repairs were made. However, they were requested to not report failures due to joint leakage, construction damage, or tapping of service lines. The goal was to examine how installed pipe performs.

Utilities reported the number of failures over a recent 12 month period for each pipe material and the installed length of each pipe material. The failure rate was computed by dividing the total number of failures from all utilities for a particular pipe material by the total length of that pipe material.

For example, the survey reported a total of 12,963 failures of water mains during a recent 12 month period for all pipe materials. The total installed water main length from the survey was 117,603 miles (or 1176.03 hundreds of miles). Thus the overall failure rate is  $12,963/1176.03 = 11.0$  failures/(100 miles)/year.

This simple method for computing failure rates was used because it discourages biases toward large or small utilities. It is noted that utilities experience widely different failure rates for the same pipe material. Several significant variables affect the results including pipe age, soil types (corrosive or noncorrosive), different corrosion prevention techniques, different installation practices, and climate.

### FAILURE RATES FOR EACH PIPE MATERIAL

The survey measured pipe failures over a recent 12 month period, broken down by material type. Table 4 lists the total length of pipe by material type, the number of failures over a recent 12 month period, and the failure rate for each pipe material. Figure 15 illustrates the failure rates as a function of material type. If one assumes a utility had equal lengths of each material installed, then Figure 16 would illustrate the percentage of failures as a function of pipe material. Figure 17 gives the failure rates broken down by material type and by respondents from the USA and Canada.

**Table 4. Summary of failure data from the basic survey over a 12 month period.**

PIPE MATERIAL	LENGTH MILES	NUMBER OF FAILURES	FAILURE RATE #/(100mi)/(year)
CI	33611.0	8204	24.4
DI	33238.7	1620	4.9
PVC	26840.3	689	2.6
CPP	2355.3	128	5.4
Steel	4300.1	581	13.5
AC	13502.8	954	7.1
Other	3755.3	787	21.0
<b>TOTAL</b>	<b>117603.4</b>	<b>12963</b>	<b>11.0</b>

Figure 15. Failure rates of each pipe material from the basic survey.

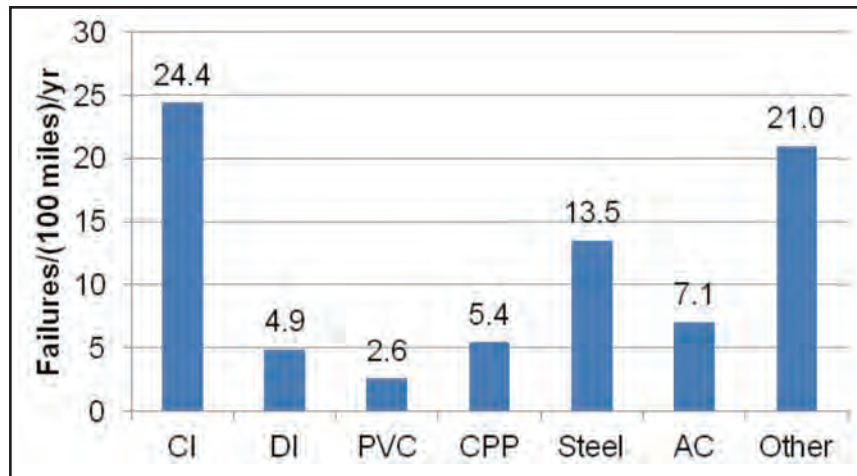


Figure 16. Percentage of failures attributed to each pipe material assuming equal lengths of material were installed.

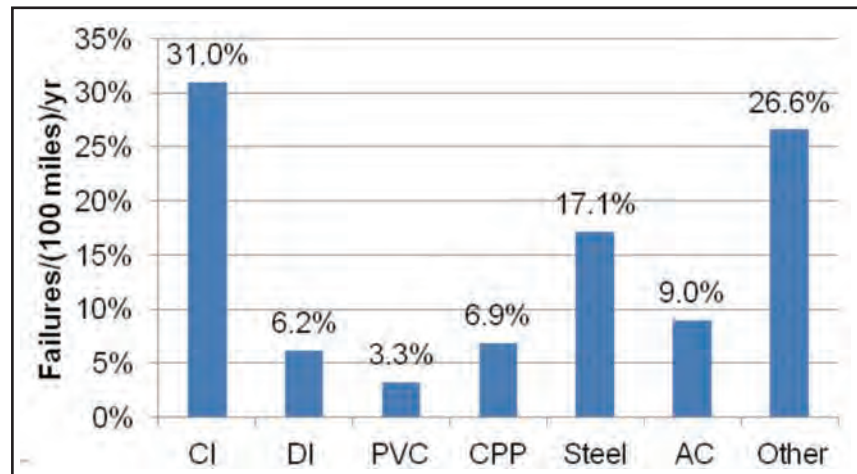
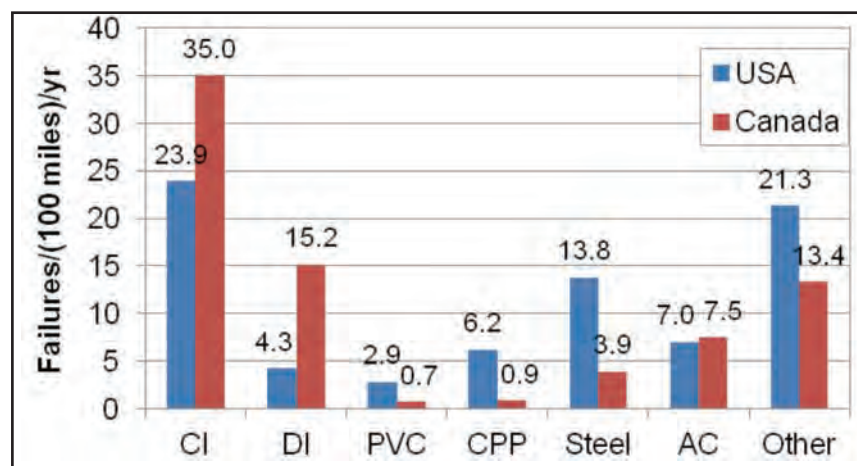


Figure 17. Comparison of failure rates from USA and Canada.





## FAILURE RATES OVER FIVE YEARS

The detailed survey requested the respondents to list the number of failures per year for five years, broken down by material type. The desired focus was to examine the year to year variations by pipe material. A single utility might have large year to year variations, but if the number of utilities sampled is sufficient, the year to year variation should be small. Figure 18 shows the failure rates from the detailed survey from each of the five years covered by the survey. Respondents that did not have five years of data were not included in these results.

**Figure 18. Pipe failure rates over a five year period as a function of pipe material.**

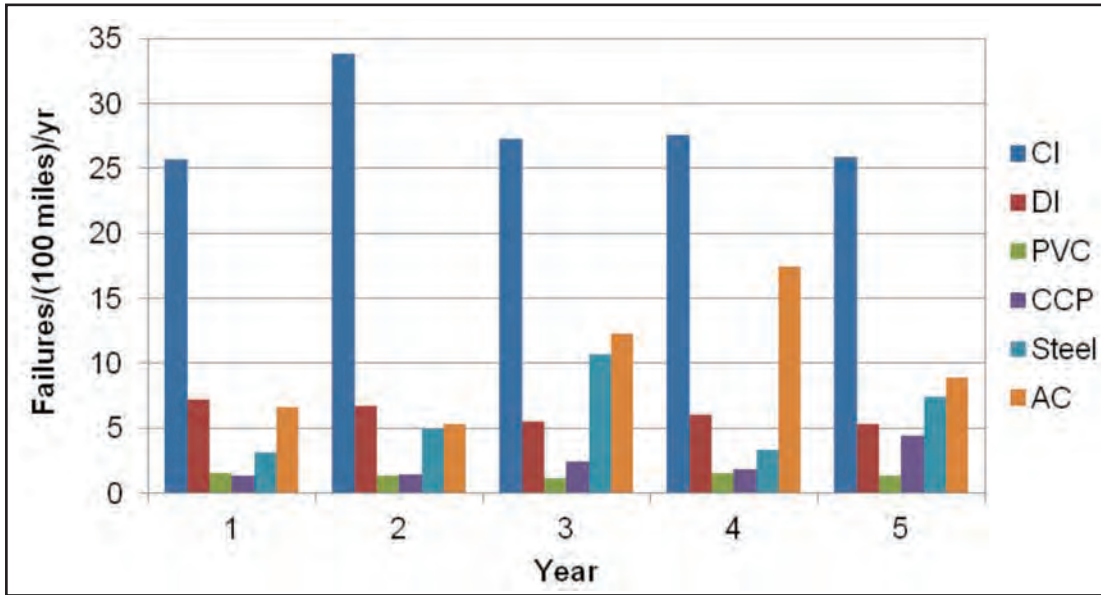


Table 5 lists the average of the failure rates over the five year period along with the standard deviation and the coefficients of variation (the standard deviation divided by the average). The coefficients of variations for CI, DI, and PVC are similar indicating they have approximately the same variability. The widest variation in rates was associated with CPP, steel and AC pipe. The length of pipe in the detailed survey for these materials was small and more respondents could likely reduce the variability.

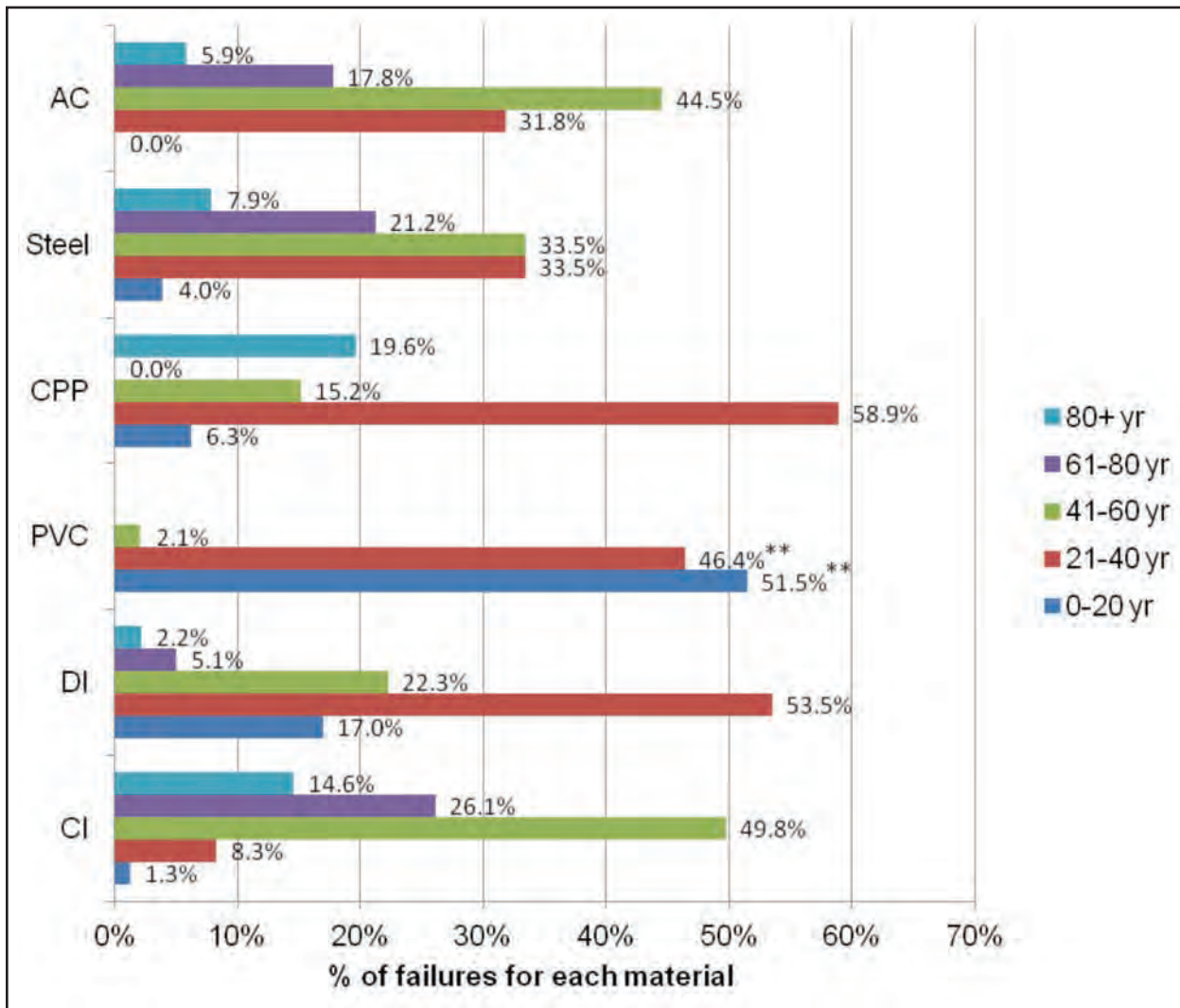
**Table 5. Statistical summary of the five year failure rate data.**

	CI	DI	PVC	CPP	Steel	AC
Average (failures/(100 mi)/yr)	28.03	6.15	1.38	2.25	5.90	10.10
Standard Deviation	3.34	0.79	0.16	1.27	3.18	4.88
Coefficient of Variation	0.12	0.13	0.12	0.56	0.54	0.48

## EFFECTS OF AGE

Clearly, pipe age will affect failure rates. The basic survey asked respondents to break down the failures into five different pipe age categories. It is noted that some of the respondents did not know the age of the failed pipes, and they were not included in the results below. For each material type, the fraction of failures in each age group is examined in Figure 19 based on the basic survey results. For example, 49.8% of the reported cast iron failures occurred with a pipe age between 41 and 60 years. Note that the largest percentage of failures is not in the oldest pipes, which has several possible causes. First, the older pipe is being replaced, and, thus, there is less available to fail.

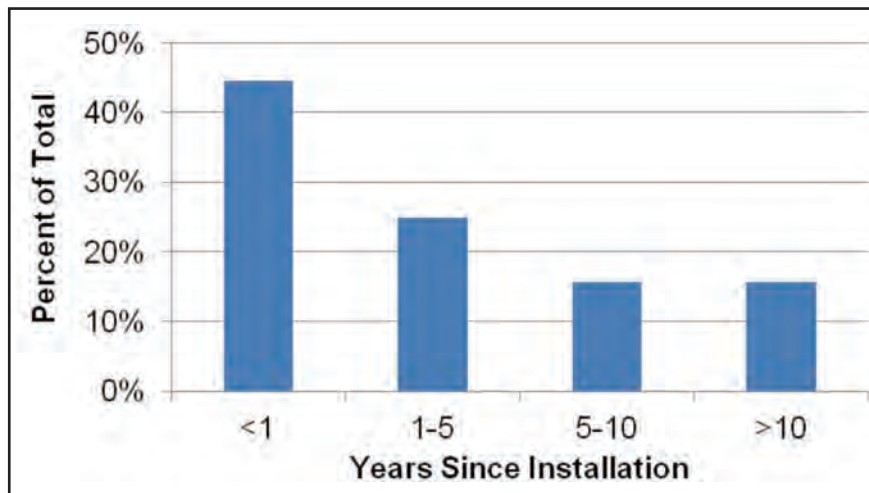
Figure 19. Percent of failures as a function of age and pipe material.



The results in Figure 19 are related to when a pipe material was introduced or removed from the market. Asbestos Cement pipe has not been installed in the USA and Canada in the past 20 years, and, thus, all AC pipe failures exceed 20 years of age. Widespread DI and PVC pipe production in the USA did not start until about 1970, so we should expect to see a small failure percentage for both DI and PVC in the 41 to 60 year age group and none for the 61 to 80 and 80+ age groups. PVC follows that trend in Figure 19. Figure 19 shows the majority of DI pipe failures occur at an age between 21 and 40 years. The DI results in Figure 19 for the 61 to 80 and the 80+ age groups are possibly caused by incorrect records on the age of those failed pipes.

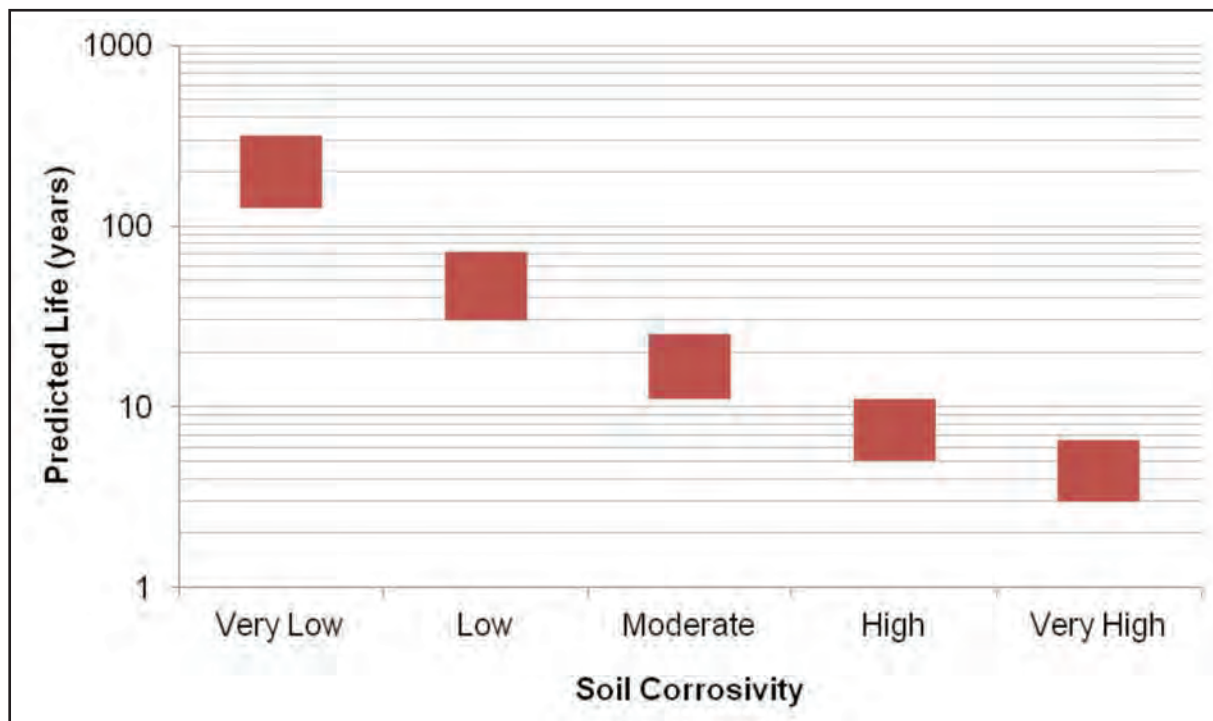
It is of interest that Figure 19 shows a greater percentage of PVC pipes fail in the first 20 years of use than in the next 20 years\*\*. This was investigated in a previous survey funded by AWWARF (Moser, 1994). Figure 20 illustrates the percent of failures as a function of time for AWWA rated PVC pipe. As shown below, over 40% of the reported failures occurred in the first year. Often the cause of these failures in PVC pipe is related to improper installation practices and not a defect in the pipe. The city of Calgary has been able to achieve remarkably small PVC failure rates due to enforced construction standards (Brander, 2004). In addition, Calgary requires new subdivision infrastructure to remain the property of the private developer for a period of two years. During this two year period, most construction related problems will occur. An AWWARF study (Burn, 2006) estimates the design life of PVC to be in excess of 110 years.

Figure 20. PVC failures as a function of time (adapted from Moser, 1994).



The expected life in years of an unprotected DI pipe was estimated in a recent Water Research Foundation study (Rajani, 2011). Figure 21 illustrates the published results as a function of a relative scale of soil corrosivity. Figure 19 indicates that the majority of DI pipe failures occur at an age between 21 and 40 years. A 21 to 40 year life in Figure 21 would correspond to a low to moderate soil corrosivity for an unprotected pipe. This would indicate that corrosion is a significant problem in all regions of this study. When a comparison is made between Cast Iron and Ductile Iron, thinner-walled Ductile Iron is experiencing failures more rapidly (21-40 year period) than the thicker-walled cast iron (41-60 year period). Concrete Pressure Pipe also shows failures rates that are impacted by corrosion in the 21-40 year period. The study also notes that “aging or deterioration of ductile iron pipes can vary significantly from one geographical region to another within a city, let alone from city to city.”

Figure 21. Predicted life of unprotected class 350 DI pipe (from Rajani, 2011).



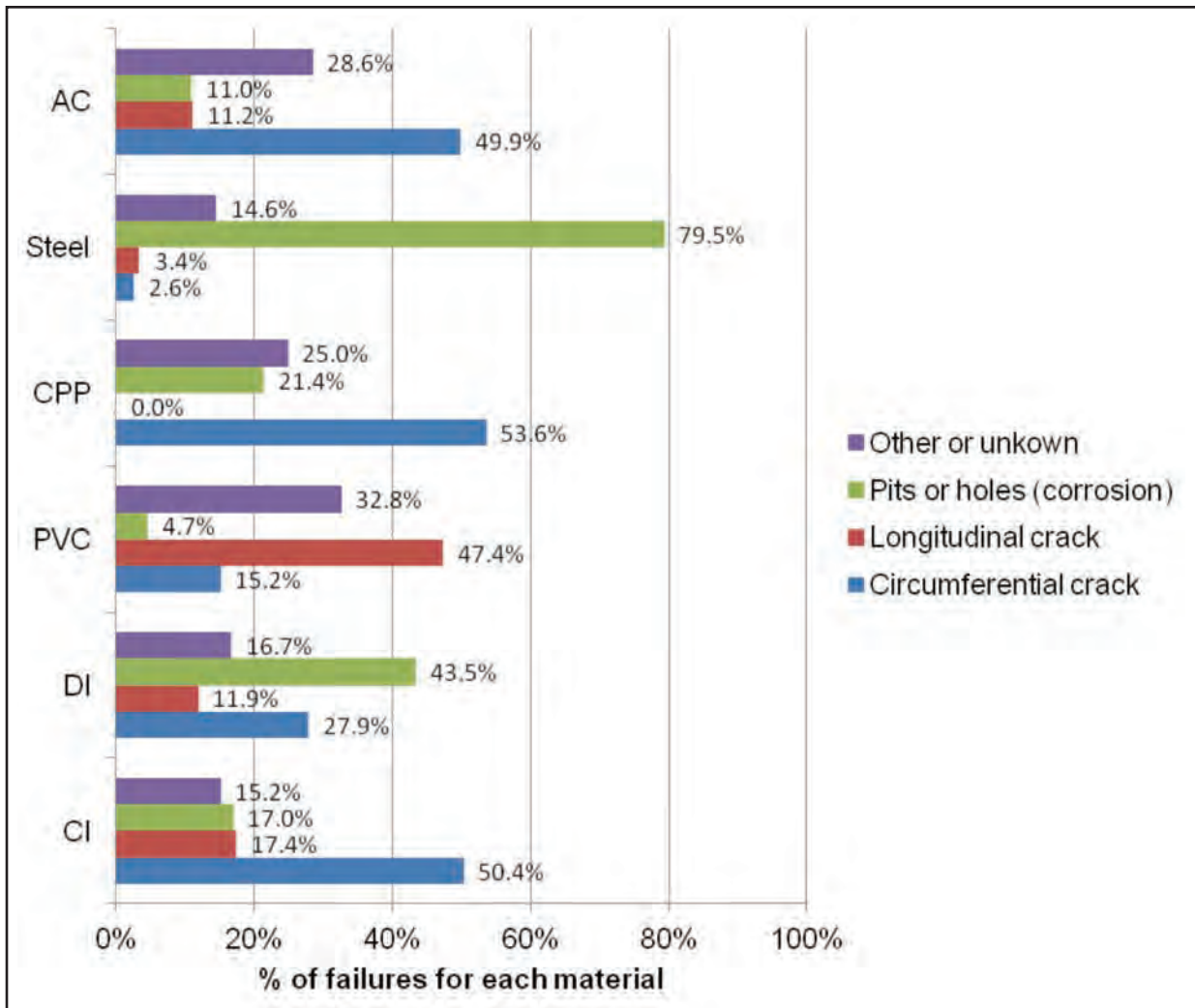
## DESCRIPTION OF FAILURES

Respondents to the basic survey were asked to describe the type of failures observed by picking from the following list:

- Circumferential crack or fracture
- Longitudinal crack or split
- Pits or holes (corrosion)
- Other or Unknown

Figure 22 summarizes the percentage of failures that were reported to fit in each description. A circumferential crack is the primary failure mode for Cast Iron, Concrete and Asbestos Cement pipe. Corrosion is the primary failure mode of Ductile Iron and Steel pipe. A longitudinal crack is the primary failure mode of PVC.

**Figure 22. Description of failure for each pipe material.**

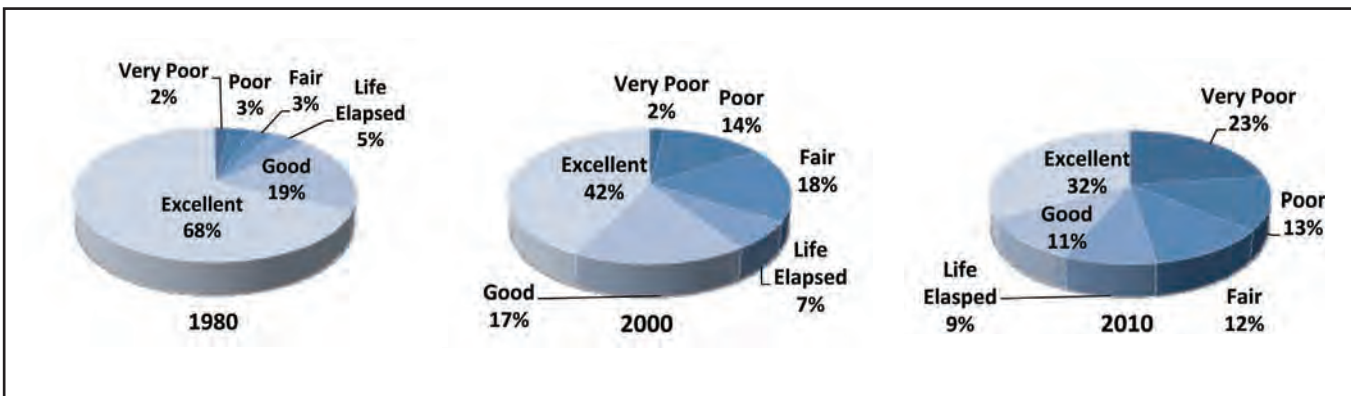


## PLANS FOR REPLACING WATER MAINS

The detailed survey asked if the respondents had a plan for regular replacement of water mains that are nearing their end of useful life. Over 77% reported they do have a replacement plan. The survey also asked what percentage of water mains are beyond their useful life but have yet to be repaired/replaced due to a lack of funds. The survey results showed a range of answers from zero to 75% of their pipe was beyond its useful life and the average of all respondents was that 8.4% of the pipe is beyond its useful life.

It is of interest to compare these results with a study done by the EPA (EPA, 2002). This study classified water main pipe condition into six categories; Excellent, Good, Fair, Poor, Very Poor, and Life Elapsed. The study examined data for years 1980 and 2000 and forecasted data for 2020. Figure 23 below is reproduced from their report and shows that the above mentioned survey average response of 8.4% of pipe are beyond their useful life would correspond well with the “Life Elapsed” category in Figure 23. It is very important to note the projected growth in the “Very Poor” condition category in Figure 23. The rate of growth in that category will make it much more difficult for utilities to get that pipe replaced before it reaches the “Life Elapsed” category. An AWWA study (AWWA, 2012) echoes this trend as illustrated in Table 6. Table 6 shows aggregate costs to cover both replacement and growth in water mains in the USA.

**Figure 23. Assessment of pipe condition with time (from EPA, 2002).**



*Percentage of Pipe by Classification*

**Table 6. Aggregate needs for investment in water mains through 2035 and 2050 by region of the United States (from AWWA, 2012).**

2011–2035 TOTALS			
(2010 \$M)	REPLACEMENT	GROWTH	TOTAL
Northeast	\$92,218	\$16,525	\$108,744
Midwest	\$146,997	\$25,222	\$172,219
South	\$204,357	\$302,782	\$507,139
West	\$82,866	\$153,756	\$236,622
<b>TOTAL</b>	<b>\$526,438</b>	<b>\$498,285</b>	<b>\$1,024,724</b>
2011–2050 TOTALS			
(2010 \$M)	REPLACEMENT	GROWTH	TOTAL
Northeast	\$155,101	\$23,200	\$178,301
Midwest	\$242,487	\$36,755	\$279,242
South	\$394,219	\$492,493	\$886,712
West	\$159,476	\$249,794	\$409,270
<b>TOTAL</b>	<b>\$951,283</b>	<b>\$802,242</b>	<b>\$1,753,525</b>



## CONTRACTOR EXPERIENCE

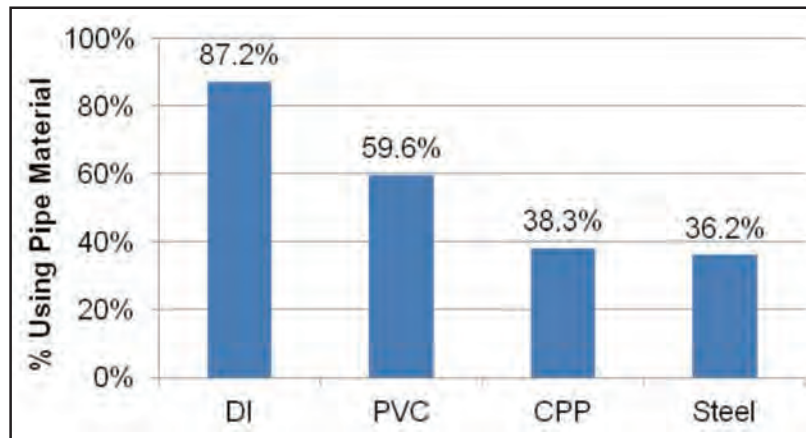
Proper installation is very important to getting the maximum life out of a water main. The detailed survey asked if their utility utilized contractor experience used as a weighting factor when selecting a contractor. There are 66% of the respondents that do consider contractor experience. Many of those who do not consider contractor experience reported that state or local laws prevented them from doing so.



## ALLOWED PIPE MATERIALS

The detailed survey also asked what water main pipe materials are currently excluded from being installed at their utility. Figure 24 illustrates the percentage of respondents that allow a particular pipe material to be installed. The reasons used for excluding a pipe material were also requested in the survey. Table 7 summarizes the most common comments made for exclusion of a pipe material.

**Figure 24. Percent of respondents that will allow installation of these water main pipe materials.**



**Table 7. Typical comments for exclusion.**

MATERIAL	COMMENTS
DI	Corrosion
PVC	Strength, tapping difficulties, bedding concerns
CPP	Difficult to install, tapping difficulties, difficult to repair
Steel	Corrosion

## LEAK DETECTION METHODS

The detailed survey asked if regular leak detection methods were utilized at their utility and 57% of the respondents indicated that they did. The methods of leak detection that were used included acoustic leak detectors, visual inspection of lines, digital correlation sensors, and eddy current detectors.

## CORROSIVE SOILS AND CORROSION PREVENTION TREATMENTS

The detailed survey asked respondents if they have one or more regions in their service area with soils that tend to be corrosive. A total of 75% of the respondents reported that they do have at least one area with corrosive soils. The survey also asked what kind of corrosion treatments they are utilizing for DI, CPP, and Steel pipes. The typical results are summarized in Table 8.

**Table 8. Typical corrosion prevention treatments.**

MATERIAL	TREATMENT
DI	Polywrap and installation of magnesium anodes
CPP	Bedding improvements, type 50 concrete, coatings, and anodes
Steel	Impressed current, anodes, and protective coatings

## EFFECT OF AMBIENT TEMPERATURE ON FAILURES

The detailed survey asked if the utility observed an increase in water main failures with extreme ambient temperatures, either warm or cold. The results of the survey indicated that 72% of the respondents did note an increase in pipe failures with extreme cold ambient temperatures and only 13% reported a correlation with warm temperatures. Clearly this result would be dependent on the climate at each utility. The average depth of burial was also reported. An effort was made to see if there is a correlation between temperatures extremes and burial depths. For each utility the temperature extremes were derived from average monthly temperatures. The highest average monthly temperature in the summer and the lowest average monthly temperature during the winter were recorded for each utility location.

Figure 25 plots the lowest average minimum monthly temperature during the year for each respondent versus their reported average burial depth. The utilities with the blue symbols indicated they are not sensitive to cold ambient temperatures and the red colored symbols are sensitive. It was thought that with sufficient burial depth, the low temperature sensitivity might be reduced, but the data in Figure 25 does not support that conjecture.

**Figure 25. Correlation of the lowest average minimum monthly temperature during the year and burial depth. Red symbols note locations where failures increase with low ambient temperatures.**

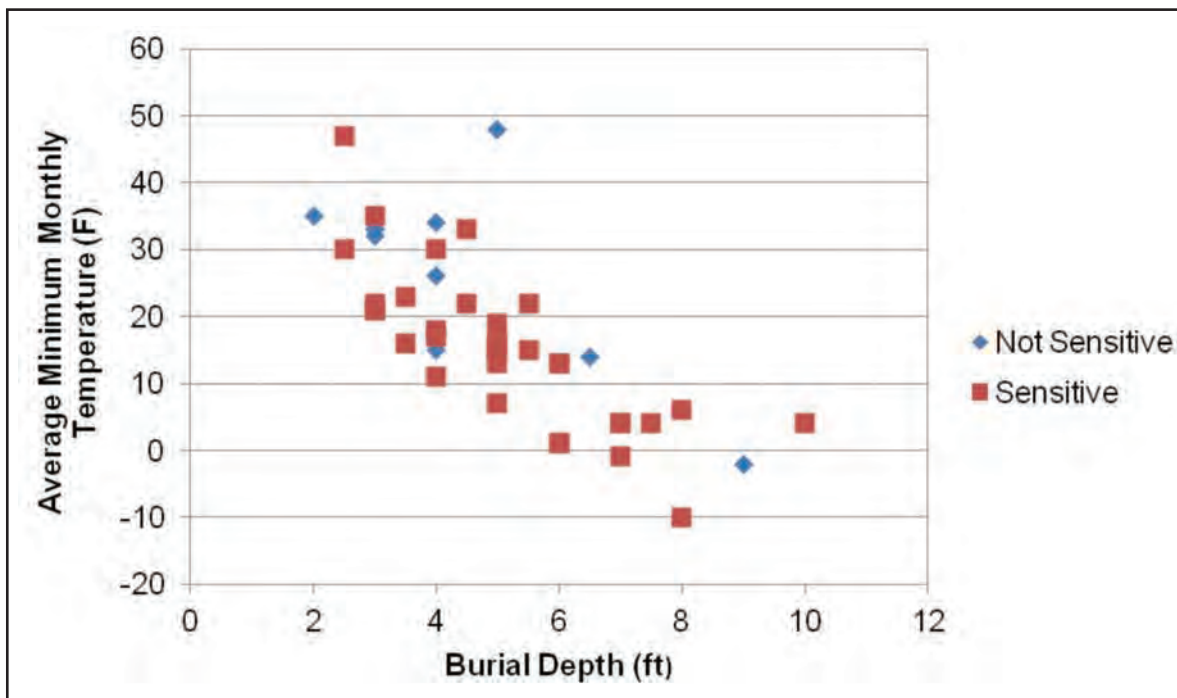
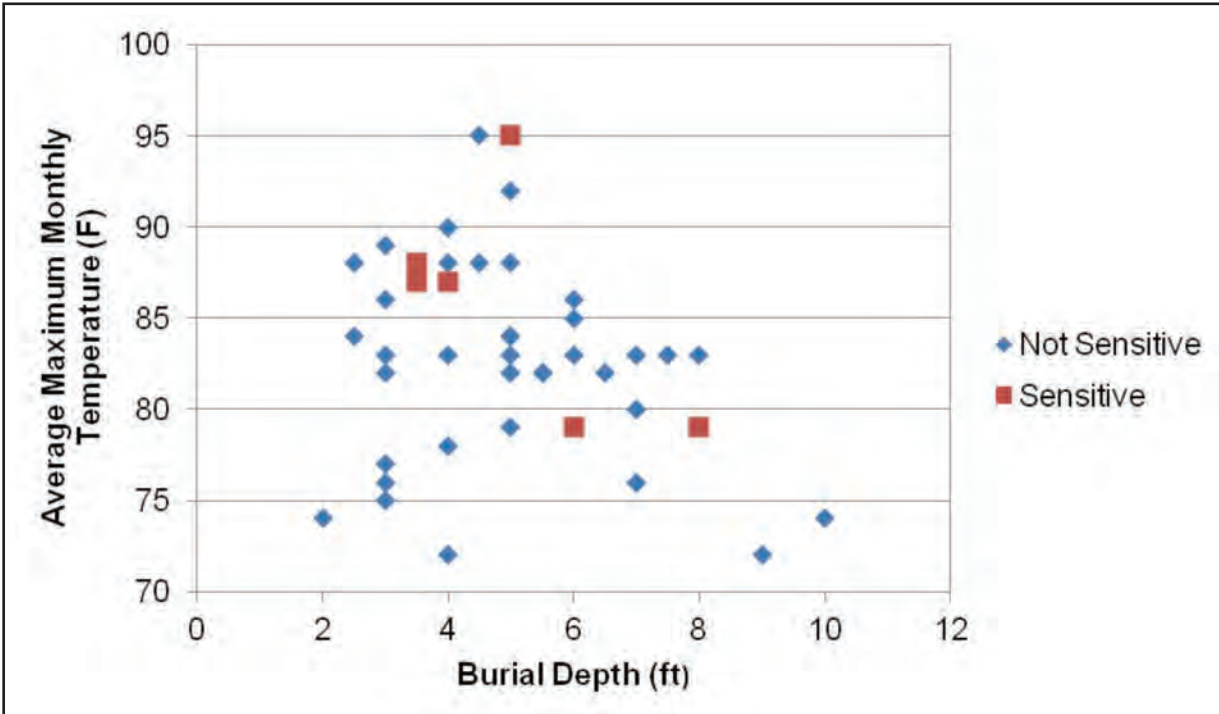


Figure 26 plots the highest average maximum monthly temperature during the year for each respondent versus their reported average burial depth. Again, the color of the symbol indicates whether that utility reported to be sensitive to high ambient temperatures. Again, no correlation was observed.

It is noted that one respondent reported that failures increase when large and rapid ambient temperature changes occurred, but not necessarily reaching extreme temperatures.

**Figure 26. Correlation of the highest average maximum monthly temperature during the year and burial depth. Red symbols note locations where failures increase with high ambient temperatures.**



## TRENCHLESS TECHNOLOGY USE

The detailed survey asked respondents about experiences with three techniques of repairing, replacing, and installing water main pipes. They were relining deteriorated pipes, replacing pipes with a pipe bursting technique, and installation of new pipes using directional drilling. Table 9 summarizes their responses. The rating scale in Table 9 is from 1 to 5 with 1 being “Not Satisfied” to 5 being “Very Satisfied”. Not many respondents have utilized pipe bursting, but an increasing number are looking at using both pipe relining and pipe bursting techniques. A majority of respondents have utilized directional drilling and are very happy with the results.

**Table 9. Summary of responses for relining, bursting, and directional drilling.**

	PIPE RELINING	PIPE BURSTING	DIRECTIONAL DRILLING
% of respondents that have used this technique	32%	17%	62%
Average Rating 1 to 5	3.9	3.8	4.4
% of respondents that will use this technique in the future	43%	40%	74%
Comments	High cost, several will consider use in future	High cost, useful in some situations	Worked well particularly for river and street crossings, Happy with most contractors

## CONCLUSION

This Comprehensive Water Main Break Study surveyed a statistically significant amount of utilities that have collected data on their underground infrastructure. This survey was focused on material usage in water mains across the USA and Canada. This effort was successful in getting 188 participants to respond to a basic survey and 47 of those to respond to a more detailed survey. Significant results from this study include:

- A correlation of people served per mile
- Current pipe material usage with a regional breakdown
- Pipe age and size distribution
- Average operation and fluctuation pressures
- Most common pipe failure mode and materials
- Pipe failure rates for six mostly commonly used pipe materials
- The distribution of pipe failures with pipe age for each material
- The distribution of pipe failure modes for each material
- Percentage of utilities that allow installation of certain pipe materials
- Percentage of utilities with corrosive soils and prevention techniques
- Effects of ambient temperature swings on failures
- Attitudes about use of pipe relining, pipe bursting, and directional drilling.

It is hoped that these results would be helpful to utility managers in comparing their experiences with these survey results and thereby make better decisions regarding possible changes in their management practices. Through understanding more about the issues surrounding the performance of our underground water infrastructure, utilities will be able to successfully make cost-effective pipe replacement decisions.

## ACKNOWLEDGEMENTS

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