During 2011, Utah State University conducted a basic survey of utilities across the United States and Canada to obtain data on water main failures of municipal and private water supply systems. Surveys were mailed to a total of 1,051 US and Canadian water utilities in May and June of 2011. Those that responded to the basic survey were also invited to participate in a more detailed survey. A total of 188 utilities responded and completed the basic survey, with 47 also responding to a detailed survey. A total of 117,603 mi of pipe were represented in the basic survey and 32,130 mi in the detailed survey. This article documents some of the results from both surveys.

One of the primary goals of this survey was to obtain data on current pipe inventories and failure rates of different pipe materials during a previous 12-month period. Most of the responses to the survey were received in the middle of 2011; thus, the survey estimates behavior during the 2010 and 2011 calendar years. The detailed survey allowed collection of a wider variety of data relating to operating parameters, installation practices, and pipe material preferences.
SURVEY REGIONS
To show participation as a function of geography, the areas covered by the basic survey were broken down into nine regions as shown in the map on page 71. The number of respondents to the basic survey are listed, followed by the number of respondents to the detailed survey in parentheses.
- Region 1—19 (7)
- Region 2—20 (4)
- Region 3—26 (5)
- Region 4—22 (6)
- Region 5—18 (3)
- Region 6—28 (11)
- Region 7—23 (2)
- Region 8—20 (4)
- Region 9—12 (5)

No responses were obtained from the Canadian provinces of New Brunswick, Newfoundland, Nova Scotia, Prince Edward Island, or Quebec. Figure 1 shows the miles of water main pipe that were reported in the basic and detailed surveys according to region.

MILES OF PIPE VERSUS POPULATION
Figure 2 shows the relationship between the population served by the utilities participating in the basic survey and the number of miles of water main pipe represented by those utilities. The trend line and equation are a best fit to the data with a zero intercept. The slope of this line indicates that on average there are 264 people served for each mile of water main installed.

SURVEY SAMPLE SIZE
The total length of water main pipe reported by the 188 survey participants was 117,603 mi (the survey did not include sewer or force mains). In 2007 the US Environmental Protection Agency (USEPA) reported that there are approximately 880,000 mi of distribution main pipe.
pipe in the United States (USEPA, 2007). The following year, a second report (Royer, 2008) estimated the amount of installed water main pipe in the United States to be more than 1 million mi. The current population of the United States is 312 million (US Census, 2011). Using the estimate from the previous section of 264 people served per mile of water main, the length of water mains can be estimated to be 1.18 million mi ([312 million people]/[264 people/mile]). With the use of this last estimate, the total length of pipe in the survey sample size is significant and should provide reliable results. The Canadian provinces comprised 8,423 mi of pipe in this survey, or 7.4% of the total.

**PARTICIPANTS CLASSIFIED IN FOUR CATEGORIES**

The average utility surveyed had 626 mi of water main, with the largest having 4,468 mi and the smallest having 2 mi. This survey quantified the size of a utility based on the number of miles of water main pipe installed. Four categories were established according to miles of pipe: small (up to 500 mi), medium (500–1,000 mi), large (1,000–3,000 mi), and very large (more than 3,000 mi). Each survey participant was allocated to one of the categories. Figure 3 shows the distribution of total miles according to these categories.

**PIPE MATERIALS**

Many pipe products have evolved over time, and most of these could be broken down into subcategories on the basis of processing and surface treatments. These changes, along with new installation techniques, should affect the life expectancy of the pipe. The basic survey was intended to be relatively simple to complete in order to encourage wide participation. Most utilities have limited records as to which specific pipe materials were installed decades ago. Therefore, subcategories of material types were not tracked in the survey. The results reported in this article represent generic pipe material performance, but may not represent a specific product on the market today.

The distribution of pipe materials based on miles of pipe is shown in Figure 4. Pipe material distribution as a percentage of the total length for both the basic and detailed surveys is shown in Figure 5. The detailed survey had a smaller number of respondents but still gave a similar material distribution. The “other” category in Figures 4 and 5 includes materials such as high-density polyethylene, galvanized steel, and copper. Eighty percent of the installed water mains are a combination of cast-iron at 28%, ductile-iron at 28%, and polyvinyl chloride (PVC) pipe at 23%. The amount of concrete pressure pipe (CPP), steel, and asbestos–cement (AC) material types were also reported. The length of high-density polyethylene pipe reported rep-
resented only 0.14% of the total and thus was not tracked as a separate group.

Figure 6 shows the regional distribution of pipe material type as a percentage of the total length of piping in that region. Significant differences can be seen in the type of pipe material used in the regions. 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 a significant player in regions 2–5, and 7.

Pipe age and diameter. The detailed survey asked respondents to provide the age distribution of installed pipe. Four age groups were provided: 0–10 years, 10–20 years, 20–50 years, and more than 50 years. Figure 7, which lists the percentage of water main length that fits in each age category, indicates that approximately 43% of installed pipes are in the 20–50-year age category and 22% are more than 50 years old.

Respondents were also asked to break down the fraction of total installed pipe length by five pipe-diameter categories. Figure 8, which shows the percentage of water mains that fit into each size range, indicates that approximately 66% of the installed pipe is 8 in. or less in diameter.

Delivery pressure. On the basis of results received in the detailed survey, the average delivery pressure was determined to be 77 psi. The range of values reported for average delivery pressure was 45–150 psi. Respondents were asked to select one of three ranges provided in the detailed survey to indicate how much the water pressure fluctuates at any given point in their systems during a typical day. The survey indicated that approximately 83% of respondents are able to limit pressure fluctuations to less than 20 psi, 11% had pressure fluctuations between 20 and 40 psi, and 6% have pressure fluctuations in excess of 40 psi.

PIPE FAILURE

Most common failure mode, material, and age. The detailed survey asked the respondents to identify the most common water main failure mode by selecting from one of the following categories: circumferential crack, corrosion (pits or holes), longitudinal crack, leakage at joints,
fatigue, or other. Figure 9 shows that circumferential cracks are the most common mode of failure, followed by corrosion. The detailed survey also asked respondents to identify which pipe material failed most often. Figure 10 shows that slightly more than 55% of respondents identified cast iron as the pipe material that failed most often (likely because it is one of the two most commonly used pipe materials and on average is the oldest pipe material in use), followed by AC at 17%. Respondents also reported that the typical age of a failing water main was 47 years, with a range of values from 20–86 years. The survey also asked what the respondents believed the expected life should be for newly installed pipe. Respondents expected new pipe to have an average life span of 79 years, with responses ranging from 30 to 200 years.

**Computing failure rates.** The basic survey asked respondents to consider a water main failure as one in which leakage was detected and repairs were made. However, they were asked not to report failures caused by joint leakage, construction damage, or tapping of service lines. The goal of the survey was only to examine the performance of properly installed pipe.

Utilities reported the number of failures over a recent 12-month period according to pipe material and the installed length of 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 1,176.03 hundreds of miles). Thus the overall failure rate is 12,963/1,176.03 ≈ 11.0 failures/(100 miles)/year. Figure 11 shows the failure rate at each utility for all pipe materials and indicates that utilities can experience widely

### TABLE 1 Summary of failure data over a 12-month period

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Length—mi</th>
<th>Number of Failures</th>
<th>Failure Rate Number/(100 mi)/(year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>33,611.0</td>
<td>8,204</td>
<td>24.4</td>
</tr>
<tr>
<td>Ductile iron</td>
<td>33,238.7</td>
<td>1,620</td>
<td>4.9</td>
</tr>
<tr>
<td>Polyvinyl chloride</td>
<td>26,840.3</td>
<td>689</td>
<td>2.6</td>
</tr>
<tr>
<td>Concrete pressure pipe</td>
<td>2,355.3</td>
<td>128</td>
<td>5.4</td>
</tr>
<tr>
<td>Steel</td>
<td>4,300.1</td>
<td>581</td>
<td>13.5</td>
</tr>
<tr>
<td>Asbestos–cement</td>
<td>13,502.8</td>
<td>954</td>
<td>7.1</td>
</tr>
<tr>
<td>Other</td>
<td>3,755.3</td>
<td>787</td>
<td>21.0</td>
</tr>
<tr>
<td>Total</td>
<td>117,603.4</td>
<td>12,963</td>
<td>11.0</td>
</tr>
</tbody>
</table>
different failure rates for the same pipe material. This finding should not be surprising. Several significant variables affect pipe performance, including age, soil types (corrosive or noncorrosive), corrosion prevention techniques, installation practices, and climate. Thus a utility may have a significantly different failure rate from those reported here. To compute an average failure rate for a given pipe material, a large number of respondents are needed.

**Failure rates for each pipe material.**
The basic survey measured pipe failures over a recent 12-month period, broken down by material type. Table 1 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 12 shows the failure rates as a function of material type, and Figure 13 classifies the failure rates by material type and by US and Canadian respondents. When the failure rates per 100 mi of pipe per year were compared for cast-iron, ductile-iron, PVC, concrete, steel, and AC pipes, PVC was shown to have the lowest overall failure rate.

**Plans for replacing water mains.** The detailed survey asked whether respondents had a plan for regular replacement of water mains that are nearing their end of useful life. More than 77% reported they do have a replacement plan in place. The survey also asked what percentage of water mains are beyond their useful life but have yet to be repaired/replaced because of a lack of funds. Respondents reported that from zero to 75% of their pipe was beyond its useful life. The average of all respondents showed that 8.4% of the pipe is beyond its useful life.

**Contractor experience.** Proper installation is important to getting the maximum life out of a water main. The survey asked whether the respondents’ utilities used contractor experience as a weighting factor during the selection process. Sixty-six percent of respondents do consider contractor experience. Many of those respondents who do not consider contractor experience reported that state or local laws prevented them from doing so.

It is imperative that utilities make wise choices when repairing and replacing pipe, and benchmarking can provide guidance in making those decisions.

**Allowed pipe materials.** Results from the survey indicated that 87.2% of utilities would allow installation of ductile iron, 59.6% of PVC, 38.3% of concrete pressure, and 36.2% of steel pipe. Typical comments regarding pipe exclusion included “corrosion issues for ductile iron and steel” and “strength,
FIGURE 6  Regional percentage of length of pipe classified by material type from the basic survey

AC—asbestos-cement, CI—cast iron, CPP—concrete pressure pipe, DI—ductile iron, PVC—polyvinyl chloride
tapping difficulties, and bedding concerns for PVC.” Comments regarding CPP included “difficult to install, tap, and repair” and “has corrosion issues.”

**Leak-detection methods.** The detailed survey asked respondents whether regular leak-detection methods were used at their utility, and 57% indicated that they were. The methods of leak detection 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 whether there are one or more regions in their service area with soils that are corrosive. A total of 75% of the respondents reported that they have at least one area with corrosive soils. Thus, corrosion is a significant problem for most of the respondents. The survey also asked what kind of corrosion treatments they are currently using. Typical corrosion prevention treatments for DI pipe included polywrap and the installation of magnesium anodes. Covered bedding improvements, type 50 concrete, coatings, and the use of anodes were common treatments for CPP. Steel pipe corrosion treatments listed impressed current, anodes, and protective coatings.

**Effect of ambient temperature on failures.** The detailed survey asked whether the utility observed an increase in water main failures with extreme ambient temperatures, either warm or cold. The results 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.

**CONCLUSION**

To capture statistically significant water main break data that can provide an accurate portrayal of current pipe behavior and water
utility practices requires a large number of participants. The total miles of pipe covered by this survey is almost 10% of that in use in the United States. From these data many observations can be made at a national level and applied to individual utilities as possible internal benchmarks.

- There are approximately 264 people who are served per mile of water main pipe, which is an average number representing both rural and urban populations.

- The primary water main pipe materials in use today are cast iron (28% of the installed base), ductile iron (28%), and PVC (23%). The survey results indicate that the type of pipe material installed varies significantly across the regions; approximately 90% of the pipe in the northeastern United States is either ductile or cast iron, whereas PVC is the dominant pipe in Canada.

- Water main pipe characteristics uncovered by the survey indicate that more than 22% of currently installed pipe is more than 50 years old and that about 66% of water mains are 8 in. or less in diameter. The average age of a failing water main was only 47 years, with 8.4% of pipes classified as being beyond their useful life. These results are in sharp contrast to respondents’ beliefs that new pipe should last 79 years on average.

- The average delivery pressure is 77 psi and 83% of utilities keep water pressure fluctuations at less than 20 psi.

- The survey also found various limitations placed by utilities on pipe materials. The percentage of utilities allowing installation of specific pipe materials is as follows: ductile-iron pipe—87%, PVC pipe—60%, concrete pressure pipe—38%, and steel pipe—36%.

- Utilities exhibit a large variation in water main failure rates.

- Approximately 75% of utilities have at least one region in their service area with corrosive soils.

- This survey found that on the basis of the number of failures per 100 mi of pipe per year, PVC pipe currently has the lowest overall failure rate.

Information from this survey is intended to assist utilities in seeing how they compare with national norms. The amount of pipe approaching the end of its life is growing. It is imperative that utilities make wise choices when repairing and replacing pipe, and benchmarking can provide guidance in making those decisions.
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FIGURE 12 Failure rates of each pipe material per 100 mi over a one-year period

FIGURE 13 Failure rates reported in this survey by US and Canadian respondents