The *Dawn* report examined 20 water systems, using a relatively new technique to build what came to be called a "Nessie Curve" for each system. The Nessie Curve, so called because the graph follows an outline that someone likened to a silhouette of the Loch Ness Monster, revealed that each of the 20 water systems faced unprecedented needs to rebuild its underground water infrastructure—its pipe network. For each system, the future investment was an "echo" of the demographic history of the community, reflecting succeeding generations of pipe that were laid down as the community grew over many years. Most of those generations of pipe were shown to be coming to an end of their useful service lives in a relatively compressed period. Like the pipes themselves, the need for this massive investment was mostly buried and out of sight. But it threatens our future if we don't elevate it and begin to take action now.

The present report was undertaken to extend the *Dawn* report beyond those 20 original cities and encompass the entire United States. The results are startling. They confirm what every water utility professional knows: we face the need for massive reinvestment in our water infrastructure over the coming decades. The pipe networks that were largely built and paid for by earlier generations—and passed down to us as an inheritance—last a long time, but they are not immortal. The nation's drinking water infrastructure—especially the underground pipes that deliver safe water to America's homes and businesses—is aging and in need of significant reinvestment. Like many of the roads, bridges, and other public assets on which the country relies, most of our buried drinking water infrastructure was built 50 or more years ago, in the post-World War II era of rapid demographic change and economic growth. In some older urban areas, many water mains have been in the ground for a century or longer.

Given its age, it comes as no surprise that a large proportion of US water infrastructure is approaching, or has already reached, the end of its useful life. The need to rebuild these pipe networks must come on top of other water investment needs, such as the need to replace water treatment plants and storage tanks, and investments needed to comply with standards for drinking water quality. They also come on top of wastewater and stormwater investment needs which—judging from the US Environmental Protection Agency's (USEPA) most recent "gap analysis"—are likely to be as large as drinking water needs over the coming decades. Moreover, both water and wastewater infrastructure needs come on top of the other vital community infrastructures, such as streets, schools, etc.

Prudent planning for infrastructure renewal requires credible, analysis-based estimates of where, when, and how much pipe replacement or expansion for growth is required. This report summarizes a comprehensive and robust national-level analysis of the cost, timing, and location of the investments necessary to renew water mains over the coming decades. It also examines the additional pipe investments we can anticipate to meet projected population growth, regional population shifts, and service area growth through 2050.

This analysis is based on the insight that there will be "demographic echoes" in which waves of reinvestment are driven by a combination of the original patterns of pipe investment, the pipe materials used, and local operating environments. The report examines the reinvestment demands implied by these factors, along with population trends, in order to estimate needs for pipe replacement and concurrent investment demands to accommodate population growth.

Although this report does not substitute for a careful and detailed analysis at the utility level as a means of informing local decisions, it constitutes the most thorough and comprehensive analysis ever undertaken of the nation's drinking water infrastructure renewal needs. The keys to our analysis include the following:

1. Understanding the original timing of water system development in the United States.
2. Understanding the various materials from which pipes were made, and where and when the pipes of each material were likely to have been installed in various sizes.
3. Understanding the life expectancy of the various types and sizes of pipe ("pipe cohorts") in actual operating environments.
4. Understanding the replacement costs for each type and size of pipe.
5. Developing a probability distribution for the "wear-out" of each pipe cohort.

Methodology

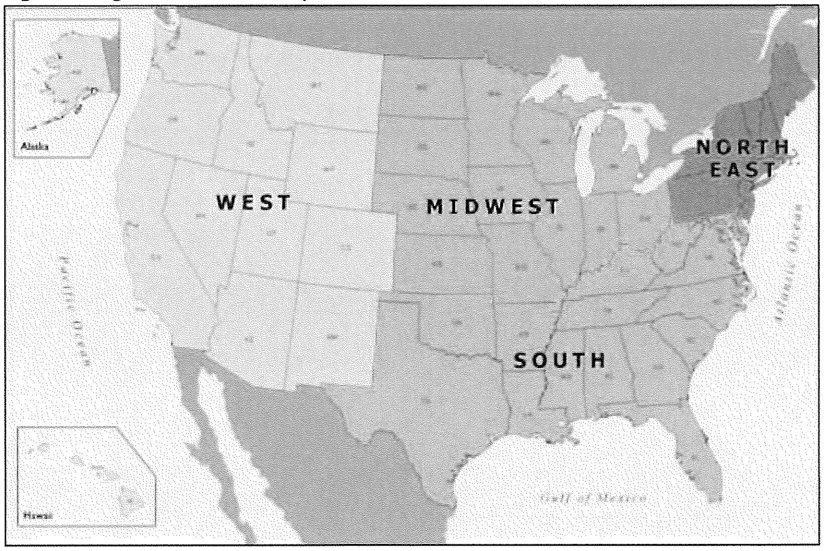
For this report, we differentiated across four water system size categories*:

- Very small systems (serving fewer than 3,300 people, representing 84.5% of community water systems).
- Small systems (3,300 to 9,999 served, representing 8.5% of community water systems).
- Medium-size systems (10,000 to 49,999 served, representing over 5.5% of systems). And,
- Large systems (serving more than 50,000 people, representing 1.5% of community water systems).

** Note that the water system size categories used in this analysis are not identical to the size categories USEPA uses for regulatory purposes. Note also that although data were analyzed based on these four size categories, some of the graphs that accompany this report combine medium-size and small systems. This is done for simplicity in the visual presentation, when the particular dynamics being represented are closely similar for medium-size and small systems.*

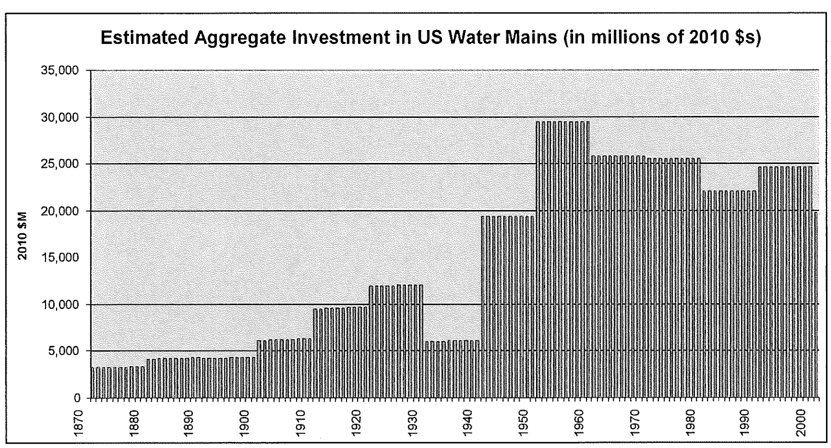
Next, we divided the country into four regions (Northeast, Midwest, South, and West), as shown in Figure 1. These regions are not equal in population, but they roughly share certain similarities, including their population dynamics and the

Figure 1: Regions Used in This Report



historical patterns of pipe installation driven by those dynamics. Data published by USEPA, the water industry, and the US Census Bureau were tapped to obtain a solid basis for regional pipe installation profiles by system size and pipe diameter. The US Census Bureau has produced a number of retrospective studies of the changes in urban and rural circumstances between 1900 and 2000 that proved especially useful in this analysis. The report also used the AWWA Water/Stats database, the USEPA Community Water Supply Survey, and data from the 2002 Public Works Infrastructure Survey (PWIS) as essential inputs in the analysis.

Figure 2: Historic Investment Profile for All US Water Systems, 1850-2000



In addition, we conducted a limited survey of professionals in the field concerning pipe replacement issues and other relevant "professional knowledge." The national aggregate for the original investment in all types and sizes of pipes is shown in Figure 2, while Figure 3 shows the aggregate current replacement value of water pipes by pipe material and utility size, totaling over $2.1 trillion.

Figure 3: Aggregate Replacement Value of Water Pipes by Pipe Material and Utility Size (millions 2010 $s)

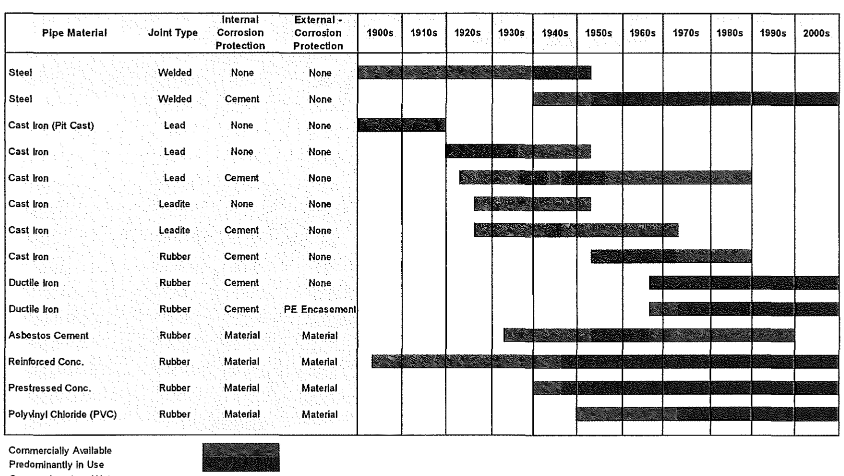
Region	CI	CICL	DI	AC	PV	Steel	PCCP	TOTAL
Northeast Large	48,958	8,995	5,050	2,308	1,875	335	0	67,522
Northeast Medium & Small	66,357	61,755	28,777	26,007	16,084	5,533	6,899	211,411
Northeast Very Small	14,491	15,992	10,661	7,281	7,937	329	462	57,152
Midwest Large	37,413	9,151	3,077	2,504	1,098	784	512	54,539
Midwest Medium & Small	74,654	92,106	51,577	37,248	30,506	8,682	11,152	305,925
Midwest Very Small	37,597	28,943	25,464	12,428	19,720	601	828	125,581
Southeast Large	30,425	28,980	29,569	21,229	14,936	9,337	7,227	141,703
South Medium & Small	54,772	98,608	140,079	103,659	102,804	21,394	17,160	538,475
South Very Small	43,183	24,998	49,791	34,529	47,823	1,461	1,244	203,028
West Large	15,448	16,055	28,949	14,774	14,723	7,443	6,215	103,607
West Medium & Small	15,775	50,145	70,355	50,541	48,885	12,276	9,806	257,782
West Very Small	16,344	11,199	17,910	13,166	17,245	545	453	76,862
Total	455,416	446,927	461,258	325,674	323,637	68,719	61,957	2,143,589

CI: cast iron; CICL: cast iron cement lined; DI: ductile iron; AC: asbestos cement; PV: polyvinyl chloride; PCCP: prestressed concrete cylinder pipe

Finally, we used historical data on the production and use of seven major types of pipe with 14 total variations (Figure 4) to estimate what kinds of pipe were installed in water systems in particular years. This was validated by field checking with a sample of water utilities as well as checking against the original Nessie analysis. Together these steps resulted in the development of 16 separate inventories (four regions with four utility sizes in each region), with seven types of pipe in each inventory, *thus providing the most comprehensive picture of the nation's water pipe inventory ever assembled.* Note that in some of the report's graphs, "long-" and "short-lived" versions of certain pipe materials are combined, for purposes of visual simplicity in the presentation.

In order to consider growth, it was also necessary to examine population trends across rural, suburban, and urban settings over the past century. US Census Bureau

Figure 4: Historic Production and Use of Water Pipe by Material



Source: American Water

projections of demographic trends allowed the development of infrastructure need profiles for growth through 2050 in each of the regions and utility size categories (for the latter purpose, city size was used as a proxy for utility size).

The study generally assumes that utilities continue efforts to manage the number of main breaks that occur per mile of pipe rather than absorb increases in pipe failures. That is, the study assumes utilities will strive to maintain current levels of service rather than allow increasing water service outages. We assume that each utility's objective is to make these investments at the optimal time for maintaining current service levels and to avoid replacing pipes while the repairs are still cost-effective. Ideally, pipe replacement occurs at the end of a pipe's "useful life"; that is, the point in time when replacement or rehabilitation becomes less expensive in going forward than the costs of numerous unscheduled breaks and associated emergency repairs.

With this data in hand and using the assumptions above, we projected the "typical" useful service life of the pipes in our inventory using the "Nessie Model"™. The model embodies pipe failure probability distributions based on many utilities' current operating experiences, coupled with insights from extensive research and professional experiences with typical pipe conditions at different ages and sizes, according to pipe material. The analysis used seven different types of pipe in three diameters and addressed pipe inventories dating back to 1870. Estimated typical service lives of pipes are

Figure 5: Average Estimated Service Lives by Pipe Materials (average years of service)

Derived Current Service Lives (Years)	CI	CICL (LSL)	CICL (SSL)	DI (LSL)	DI (SSL)	AC (LSL)	AC (SSL)	PVC	Steel	Conc & PCCP
Northeast Large	130	120	100	110	50	80	80	100	100	100
Midwest Large	125	120	85	110	50	100	85	55	80	105
South Large	110	100	100	105	55	100	80	55	70	105
West Large	115	100	75	110	60	105	75	70	95	75
Northeast Medium & Small	115	120	100	110	55	100	85	100	100	100
Midwest Medium & Small	125	120	85	110	50	70	70	55	80	105
South Medium & Small	105	100	100	105	55	100	80	55	70	105
West Medium & Small	105	100	75	110	60	105	75	70	95	75
Northeast Very Small	115	120	100	120	60	100	85	100	100	100
Midwest Very Small	135	120	85	110	60	80	75	55	80	105
South Very Small	130	110	100	105	55	100	80	55	70	105
West Very Small	130	100	75	110	60	105	65	70	95	75

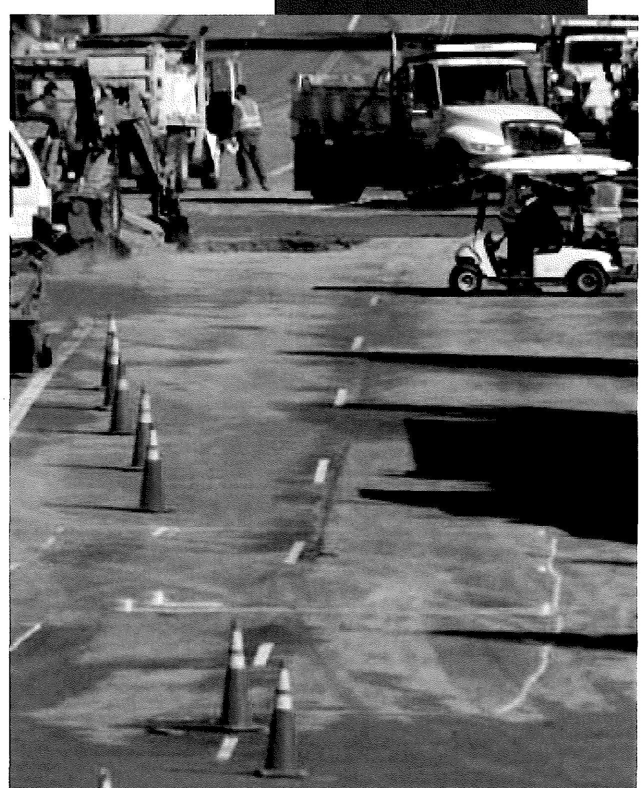
LSL indicates a relatively long service life for the material resulting from some combination of benign ground conditions and evolved laying practices etc.
SSL indicates a relatively short service life for the material resulting from some combination of harsh ground conditions and early laying practices, etc.

Figure 6: Aggregate Needs for Investment in Water Mains Through 2035 and 2050, by Region

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
Total	**$526,438**	**$498,285**	**$1,024,724**

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
Total	**$951,283**	**$802,242**	**$1,753,525**

reflected in Figure 5. Note that the *actual* lives of pipes may be quite different in a given utility. Because pipe life depends on many important local variables as well as upon utility practices, predicting the actual life expectancy of any given pipe is outside the scope of this study. Many utilities will have pipes that last much longer than these values suggest while others will have pipes that begin to fail sooner. However, these values have been validated as national "averages" by comparing them to actual field experience in a number of utilities throughout the country. The model also includes estimates of the indicative costs to replace each size category of pipe, as well as the cost to repair the projected number of pipe breaks over time according to pipe size.



The analysis of pipe replacement needs is compiled in the Nessie Model by combining the demographically based pipe inventories with the projected effective service lifetimes for each pipe type. This yields an estimate of how much pipe of each size in each region must be replaced in each of the coming 40 years. Factoring in the typical cost to replace these pipes, we derive an estimate of the total investment cost for each future year. The model then derives a series of graphs (the Nessie curves) that depict the amount of spending required in each future year to replace each of the different pipe types by utility size and region. Aggregating this information, we derived the dollar value of total drinking water infrastructure replacement needs over the coming 25 and 40 years for each utility size category per region, and for the United States.

Key Findings

1. The Needs Are Large. *Investment needs for buried drinking water infrastructure total more than $1 trillion nationwide over the next 25 years,* assuming pipes are replaced at the end of their service lives and systems are expanded to serve growing populations. Delaying this investment could mean either increasing rates of pipe breakage and deteriorating water service, or suboptimal use of utility funds, such as paying more to repair broken pipes than the long-term cost of replacing them. Nationally, the need is close to evenly divided between replacement due to wear-out and needs generated by demographic changes (growth and migration).

Over the coming 40-year period, *through 2050, these needs exceed $1.7 trillion.* Replacement needs account for about 54% of the national total, with about 46% attributable to population growth and migration over that period.

Figure 6 (previous page) shows aggregate needs for investment in water mains through 2050, due to wear-out and population growth.

2. Household Water Bills Will Go Up. Important caveats are necessary here, because there are many ways that the increased investment in water infrastructure can be allocated among customers. Variables include rate structures, how the investment is financed, and other important local factors. But the level of investment required to replace worn-out pipes and maintain current levels of water service *in the most affected communities could in some cases triple household water bills.* This projection assumes the costs are spread evenly across the population in a "pay-as-you-go" approach (See "The Costs Keep Coming" below). Figures 7 and 8 illustrate the increasing cost of water that can be expected by households for replacement, and for replacement plus growth, respectively. The utility categories shown in these figures are presented to depict a range of household cost impacts, from the least-to-the-most affected utilities.

Figure 7: Costs per Household for Water Main Replacement by Utility Size and Region

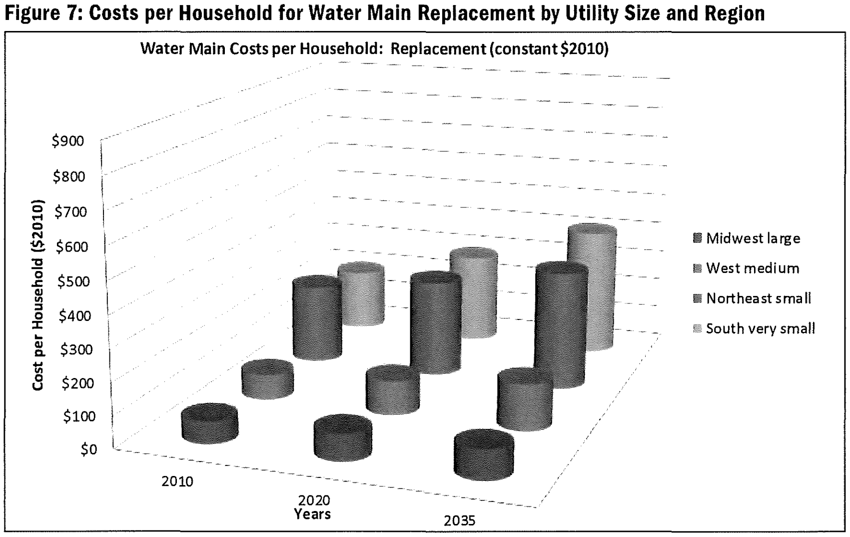
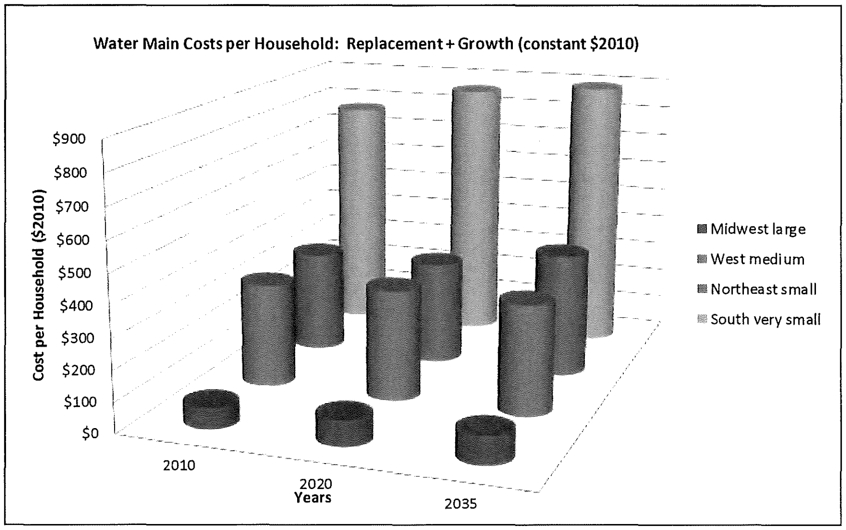


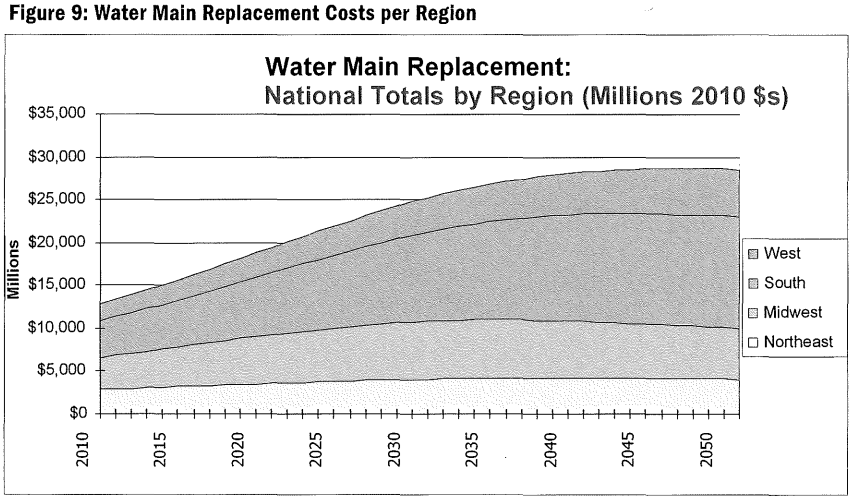
Figure 8: Costs per Household for Water Main Replacement Plus Growth



With respect to the cost of growth, other caveats are important. Many communities expect growth to pay or help pay for itself through developer fees, impact fees, or similar charges. In such communities, established residents will not be required to shoulder the cost of population growth to the extent that these fees recover those costs. *But regardless of how the costs of replacement and growth are allocated among builders, newcomers, or established residents, the total cost that must be borne by the community will still rise.*

3. There Are Important Regional Differences. The growing national need affects different regions in different ways. In general, the South and the West will face the steepest investment challenges, with total needs accounting for considerably more than half the national total (see Figures 6 and 9). This is largely attributable to the fact that the population of these regions is growing rapidly. In contrast, in the Northeast and Midwest, growth is a relatively small component of the projected need. However, the population shifts away from these regions complicate the infrastructure challenge, as there are fewer remaining local customers across whom to spread the cost of renewing their infrastructure.

Figure 9: Water Main Replacement Costs per Region



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