Analysis of Total Cost of Large Diameter Pipe Failures
April 5, 2007

Peter E. Gaewski, P.E., Tata and Howard, Inc., and Frank J. Blaha, P.E., AwwaRF

Abstract

When deciding whether or not to proactively inspect and rehabilitate or replace an existing pipe, a key consideration is the total "reactive" cost in the aftermath of a failure. Larger diameter pipe failures may result in total costs well in excess of what it would have cost to proactively inspect, rehabilitate or replace a pipe in a well planned and controlled environment. The total repair costs should include repair of other facilities impacted or damaged by flooding caused by the pipe break as well as other societal costs. There are limited sources of centralized information of the total costs of large diameter pipe failures. An earlier AwwaRF study (*Costs of Infrastructure Failure*, 2002) had reviewed the types of costs associated with infrastructure failure, and had developed tools to support the tracking of such costs, but the study did not include cost analyses of actual failures. A compilation and analysis of the costs associated with 30 relatively recent large diameter pipe failures (20-inch diameter and up) across North America will be presented. These data are expected to prove useful in helping to define a range of total costs of failure. The data could be used by water utilities in future cost-benefit analyses associated with planning for inspection, rehabilitation or replacement of existing pipe.

Introduction – Why This Topic?

Concern over aging and failing water infrastructure has been increasing. Infrastructure condition and activities receive poor "grades" from the American Society of Civil Engineers, and organizations such as the American Water Works Association are trying to raise general awareness of this issue. Interest in asset management is also growing. A number of workshops and studies have been conducted recently on buried water infrastructure in which concerns about lack of condition assessment tools, lack of cheap and easy-to-use non-destructive inspection devices, and lack of data for use in risk assessment models applicable to pipe replacement decisions have been cited as major impediments to better management of buried pipes. However, the application of these various tools is often based on an implicit or explicit consideration of the risk tolerance of failure of a given pipe. If the failure of the pipe had no negative consequences, there would be no reason to try to prevent failure of that pipe by active management of the asset.

Similarly, while there are many anecdotal stories shared about large diameter failures and the huge consequences and replacement costs often experienced by the local community impacted by these failures, we could find no assessments that actually presented fairly complete data on examples of failures and related costs. Thus, it seemed that this important issue might be illuminated even by a limited data set of actual breaks and related costs. These data could be useful to utilities trying to put the condition of their pipes into a broader perspective, or trying to decide whether or not to engage in the expensive and often disruptive non-destructive inspection of a large diameter pipe, or these data might be used in risk assessment models applicable to pipe replacement decisions.

Definitions

Large Main Failure

The water main failures considered in this study were for pipe diameters of 20-inch to 96-inch.

Total Cost

Total Cost = Direct Costs + Societal Costs

The total cost of large water main failures for the purpose of this study is defined as the direct costs added to the societal costs. The direct costs are those costs related to the failure paid either “out of pocket” by the water utility or through the water utility’s insurance carrier. Societal costs, on the other hand, are costs not paid out of pocket by the water utility or their insurance carrier. Societal costs are paid, either in terms of actual dollar expenditures by others or in terms of the value of lost wages and lost productivity of others. The basis of this is from the authors’ interpretation of the 2002 AwwaRF report entitled “Costs of Infrastructure Failure.” That report developed a computer program called the Grand Central Model (GCM). The GCM was used as a guide in this study to help calculate the value of costs, but especially societal costs, for water main failures (Cromwell, et al, 2002).

A word about terminology. The literature on this topic uses a number of variations to the definition of “total cost” for water main failures. In some cases the total cost is defined as the “direct” plus “indirect” costs. Others may use the terms “tangible” plus “intangible”. Still others say the total cost is the “internal” plus the “external” costs. “Total” cost is sometimes referred to as the “Whole” cost. For the purpose of this study, we decided to use the following: Total Cost = Direct Costs + Societal Costs.

Direct Costs

The categories of direct costs examined by this study included:

- Outside services
- Internal water utility labor
- Purchases for the failure event
- Claims paid and other costs.

Examples of direct costs:

- Outside construction contractors
- Landscaping/restoration costs
- Attorney fees and other legal costs
- Water utility construction staff labor
- Cost of repair materials taken from stock
- Road repair material purchased for the event
- Claims paid by utility or utility's insurance
- Cost of water lost.

Appendix A, the Data Collection Sheet, includes a complete list of direct costs considered.

Societal Costs

Most of the categories of societal costs included on the data collection sheet were costs identified by the GCM. A few additional categories were added to this list by the authors based on some common costs that were identified in newspaper articles for large breaks around the country.

The categories of societal costs examined in this study included:

- Traffic impact (from GCM)
- Customer water outage impacts (from GCM)
- Public health impacts (from GCM)
- Property damage (from GCM)
- Reduced firefighting capability (from GCM)
- Impact on parallel utilities (added by the authors)
- Impact on emergency services (added by the authors)
- Impact on public transportation/parking authorities (added by the authors).

Examples of societal costs:

- Value of people's time delayed in traffic/detours
- Lost production of commercial/industrial work
- Cost of illness and injury
- Cost of flooding damage to structures & cars
- Value of reduced fire fighting capability
- Damage to parallel utilities (not reimbursed by the water utility)
- Cost of police, fire & emergency services (not reimbursed by the water utility)
- Damage to transportation systems (cost for damages to trains, subways, state roads / bridges, and parking facilities not reimbursed by the water utility).

Hard & Soft Societal Costs

Based on the findings of this study, it was found that societal costs could be either "hard" or "soft."

"Hard" societal costs are those costs which are sometimes paid by water utilities as direct costs and sometimes not paid by water utilities, but rather are paid by others. Examples include property damage (typically flooding damage), parallel utility damage, costs for emergency services, and damage to public transportation systems.

"Soft" societal costs are those costs which this study found were never paid by water utilities. Examples include costs for traffic delays, water outage impacts on lost productivity, reduced firefighting capability, injury and illness (medical bills).

Grand Central Model and Assumptions

The Grand Central Model (GCM), a custom program used on the standard Microsoft Excel spreadsheet platform, was developed by the AwwaRF Project No. 2607 and included as a "floppy disk" in the back pocket of the AwwaRF report "*Costs of Infrastructure Failure*" completed in 2002. At first glance, this program can seem a little overwhelming to use. Although it appears to be the best effort to date to develop societal costs for main failures, we did not see any hope in asking water utility managers to go through the effort of learning how to use the GCM to develop the societal costs themselves. Instead, we decided to develop a data collection sheet (Appendix A), that would make it relatively easy and straightforward to provide critical input needed to use the GCM. In certain cases we streamlined the GCM process by asking for "bottom-line" information. An example of this streamlining was to ask for the estimated average number of vehicles delayed or detoured as observed by water utility personnel who were on the scene of the failure rather than going through the GCM process of looking up traffic count data, estimating the proportion of daily trips per hour and then calculating the estimated traffic flow. Once we had the critical input needed to run the GCM supplied from the water utilities, we worked through the program ourselves.

Certain assumptions for values were needed to use the GCM in order to develop the societal costs. These assumptions were made by the authors and not by the water utilities. In some cases these assumptions were based on the best available data publicly available at the time the calculations were made. In other cases we selected from the value range made available from the GCM itself. In all cases assumptions for values needed to use the GCM were conservative in nature, so as not to overstate the societal costs for the water main failures examined. These values were then used consistently for the calculation of the societal costs for all of the main failures so that we would have an "apples to apples" comparison for all of the participating water utilities.

The assumptions/tools for values used in this application of the GCM, along with the source used, are listed below:

Item	**Value**	**Source**
Average Wage Rate		
Labor Cost	$16.88/hour	Bureau of Labor Statistics
		3rd Quarter, 2006
		Median Earnings
Vehicle Operation Cost	$10.00/hour	Author's Assumption
Average Number of	2	Selected from
Occupants/Vehicle		GCM Range 1.5 to 4
Wage Rate/Vehicle Operational	$21.88/hour	Based on Calculation of
Cost per hour/person		Data from Above. Note:
		GCM Range $20 to $50
Purchase of bottled Water	$5.00/residence	Selected from GCM Range
		$2 to $10
Proportion of Outage Time	5 Percent	Selected from GCM Range
Directly Impacting Residents		0% to 50%
Residents Affected Per Property	2	Selected from GCM Range
		0.5 to 4.0 people per property
Relative Probability	100 Percent	Based on Actual Occurrence
Of Residential Outage		
Dry and Wet Industry		
Outage Sensitivity		Selected from GCM Range
Dry Industry/Commercial	4 Hours	2 to 8 Hours
Wet Industry	2 Hours	0 to 4 Hours
Period of Transition between		
Negligible to Full Impact		Selected from GCM Range
Dry Industry/Commercial	6 Hours	2 to 8 hours
Wet Industry	4 Hours	0 to 4 hours

For the Purpose of this Study "Critical Customers" were considered to be "Wet Industrial Customers". The average workforce per business was calculated by dividing the number of business employees affected by the number of businesses affected.

For the Purpose of this Study "Total Population at Risk" was the estimated population notified of a boil water notice (if a boil water notice was issued).

Item	**Value**	**Source**
Work Day	8 Hours	Selected from GCM Range
		7 to 10 hours
Average Value of Life	$4Million	Selected from GCM Range
		$2.6 Million to $20.5 Million
Sub-Total Low Risk Population	73 Percent	GCM Default (National Avg)
Sub-Total High Risk Population	27 Percent	GCM Default (National Avg)

Infection Percent is the number of illnesses reported directly related to the failure divided by the total population at risk (as defined above).

For "Low Risk Population", 100 percent was considered to be "Mild Infection" as defined by the GCM.

For "High Risk Population", 99 percent was considered to be "Mild Infection" and 1 percent was considered to be "Moderate Infection" as defined by the GCM.

Item	**Value**	**Source**
Average Illness Duration		Selected from GCM Range
Mild Infection	3 Days	0 to 5 Days
Moderate Infection	6 Days	5 to 21 Days
Average Patient Costs		Selected from GCM Range
Mild Infection	$100/Day	$0 to $125/Day
Moderate Infection	$200/Day	$125 to $250/Day
Average Hospital Days	3 Days	0 to 7 Days
Average Hospital Daily Charge		Selected from GCM Range
Moderate Infection	$750/Day	$500 to $1000/Day
Severe Infection	$4,000/Day	$1,000 to $4,000/Day

Item	Value	Source
Depth of Flooding in Feet		Selected from GCM Range
At Bottom of Ground Level Floor	1 Foot	-8 Feet to +10 Feet
Contents Value as a percent		
Of Structural Value		Selected from GCM Range
Non-Residential	50 Percent	10% to 300%
Residential	25 Percent	15% to 50%

The Author's assumed the following related to flooding damage:
Residential Structures were assumed to be single story with basement.
Non-Residential Structures were assumed to be two story with basement
Each car damaged by flooding was assumed to have $10,000 in damage.

Item	Value	Source
Probability of Residential fire		Selected from GCM Range
On a particular day	1 in 10,000	1 in 20,000 to 1 in 500
Probability of an Outage	1 in 1	Based on Actual Occurrence
Length of Time Out of Water		Actual Hours as Reported by Water Utility
Average Value of		Based on information provided by utility.
Residential Structure		In some cases value information was Obtained from www.zillow.com.
Probability of a		Selected from GCM Range
Non-Residential Fire	1 in 5,000	1 in 10,000 to 1 in 500
Potential Proportion of Subsequent		Selected from GCM Range
Loss from Lack of Water	50%	0% to 100%

The Data Collection Process

Once the Grand Central Model was streamlined, and an "easy to use" data collection sheet prepared, we sought data from utilities concerning actual large diameter breaks. We felt it was important for the data to come direct from the utilities, since they would have access to the direct costs incurred by the utility. More importantly, however, was the societal cost input data on disruptions caused by a break. These data are necessarily inexact, since no one actually counts the cars delayed by closure of a major road due to flooding or the exact loss of work productivity due to building closure caused by flooding or lack of water. However, people with first-hand knowledge of the break and an understanding of local conditions can fairly accurately estimate these impacts.

On the assumption that most of the larger cities would have experienced several large diameter breaks in the last ten years, we initially contacted large water utilities asking them to share data with us on up to three breaks. The cities initially contacted were those whom we assumed to be interested in this topic and possibly sympathetic to this request based on past interest. We sought geographic diversity in the utilities initially contacted.

We initially contacted these utilities by phone to solicit their involvement. The utilities contacted by phone were receptive to our request for data. A few opined that they thought the data would be difficult to find or develop. We then followed up with the Data Collection Sheet and a deadline for receipt of the data some weeks later. We also sent out reminders as the due date for data approached.

Response was far less than anticipated, and very few utilities reported three large diameter breaks. Reminders were sent to all utilities contacted who had not responded, but response still lagged. One of the utilities, known to have had three interesting large diameter breaks, stated that they could not share data regarding their breaks due to ongoing legal proceedings regarding the breaks. A few utilities responded that they had not had any large diameter breaks.

We then started contacting another set of utilities known to have suffered large diameter breaks from internet news story searches or from personal knowledge. We were especially interested in those utilities that had breaks some number of years ago based on the comments of the one utility citing legal action. We reasoned that utilities might be able to share data about breaks that had happened some years ago if all the legal and financial proceedings had been concluded. We again initially contacted them by phone or email to determine if they were receptive to our request, and then followed up with our Data Collection Sheet.

We continued following up with the utilities. We eventually collected information on 30 breaks - much later than originally hoped.

What the Data Showed

The average total cost of the 30 large diameter pipe failures was approximately $1,700,000. The data ranged from a low of approximately $6,000 to a high of approximately $8,500,000 (Figures 1 and 2). Considering the wide range of costs found, the geometric mean of the data was calculated. The geometric mean places less emphasis on the high and low extremes of the data set. The geometric mean of the 30 failures was approximately $ 500,000 per failure. The total costs for all 30 breaks was approximately $52,000,000, with a fairly even split between direct and societal at $25,000,000 and $27,000,000, respectively. The direct costs were indexed with the U.S. Bureau of Labor

Statistics annual Consumer Price Index (CPI) to (October) 2006 dollars. Societal costs were developed in 2006 dollars within the GCM.

We looked at the breakdown of direct and societal costs. For direct costs (Figure 3), we found the majority of costs (52%) were for claims paid directly by the utility and/or the utility's insurance for property damage. Included with this we grouped other minor costs, such as the cost for forensic studies and reports and the cost of the water lost itself. The next highest group (33%) was for outside services, which included construction contractors hired by the utility to make the needed repairs. This group of costs also included landscaping restoration costs and consulting engineering fees. Water utility labor came in next (10%) which included repairs by in-house construction crews and the multitude of water utility departments involved dealing with the failure, from Customer Service to Public Relations to the top utility executives. Utility purchases for materials, or materials taken from stock related to a failure event came in at 5% of the direct costs.

For societal costs (figure 4), we found the majority of costs (57%) were for property damages (flooding of structures and vehicles) paid by others, such as the homeowners and auto insurance company, or the owner themselves. The next highest group was for the cost of traffic disruption during the failure and repair period (27%). Costs related to customer water outage, such as lost productivity at a factory, came as the next highest cost (11%). The rest of the societal costs in order of cost were other utility damage (parallel utilities) (2%), costs for damage to public transportation systems (1.%), the cost of reduced fire fighting capability (1%) and the cost of emergency services (fire and police not paid in the direct costs) (<1% [0.3%]). There were no costs reported related to Public Health (illness or injury).

The primary type of pipe material for the 30 failures was cast iron (14), followed by pre-stressed concrete cylinder pipe (PCCP) (11), followed by steel (4) and one PVC pipe.

The data showed that the types of pipe failure were primarily "longitudinal splits" (11) related to the cast iron pipe failures and "broken wire/broken cylinder" (9) for the pre-stressed concrete cylinder pipe (PCCP) failures. Reports of "split bells" were included with the longitudinal splits. The next highest type of failure was "hole in pipe" (4). These "hole in pipe" failures were primarily for the steel pipes. The rest of the failures were three "joint leaks", two "ring cracks" a.k.a. "circumferential break" and one "broken saddle."

In terms of total gallons lost, PCCP pipe failures were the highest group, losing an average of approximately 10 million gallons per break, compared to the second largest data set of cast iron pipes at approximately 3 million gallons per break. This is likely due in part to the PCCP pipe data set being mostly larger in diameter than the cast iron data set. The static pressure obviously also contributes to the rate at which water is lost and will tend to increase the total water lost for mains even at the lower end of the large diameter range, with containment time and the "orifice" area of the break being held equal. For the purpose of this study, respondents were only asked for the estimated total gallons lost, not about the pressure at the time of break.

We looked at the containment time data and found that the arithmetic average time from report of the break to shutdown (containment) was approximately 6.5 hours for the 30 breaks. Containment time ranged from 30 minutes to 48 hours. Due to the wide range, we also calculated the geometric mean, which was found to be approximately 3.5 hours.

We examined the relationship of various items to see if there was any sort of trends with the limited data set (Figures 5, 6, and 7). Linear regression analysis did not show strong relationships, however it did indicate that there was more of a relationship between the time to contain the pipe break and total cost than there was between diameter of the pipe and total cost. Also, the relationship between total gallons lost and total cost was stronger than time to contain the pipe break and total cost. Again, the PCCP pipe group having the highest total gallons lost as a group, also were generally higher in total cost. There was another factor; however, that "trumped" the other factors affecting total cost. That factor was location.

While there was not a question on the Data Collection Sheet asking if the location of the failure was in an urban, suburban or rural setting, we were able to make a reasonable estimate using other means. In some cases, utilities supplied supplemental information on this issue, in other cases the setting was clear from our internet searches of newspaper accounts of the failure. Since we did ask for the nearest intersecting street to the street on which the break occurred, we were able to "take a look" at the level of urban density by zooming in using Google Earth and/or Zillow.com. It was noted that the total cost was very much affected by the location of the break. Highly urban settings in general tended to have higher total costs. Failures in highly urban areas greatly increased the total costs when factors such as property damage from flooding, traffic disruption and costs related to water outages come into play. For example, the 54-inch diameter PCCP failure in relatively rural Clay, New York, resulted in a total cost of approximately $100,000. In comparison, the 36-inch cast iron failure in the urban location of downtown Pittsburgh resulted in a total cost of approximately $8.5 million. Of all of the factors we examined, we believe that the location of the failure is the most important factor affecting the total cost. The next most important factor is total gallons lost.

Who Pays? The Concept of "Hard" and "Soft" Societal Costs

Who pays for the costs related to large water main failures? This interesting question came to light as we discovered that some property damage, typically flooding, is paid as direct costs; while some of the same types of costs in a different city are not paid by the utility. This study found that the highest percentage of costs related to large diameter water main failures, approximately 52 percent of the direct costs and 57 percent of the societal costs, were related to property (flooding) damage. We developed the terms "hard" and "soft" societal costs to point out that sometimes costs that the GCM calculates, such as for property damage caused by water main failure induced flooding, can be paid on the other side of the ledger, by the water utility or its insurance company, as direct costs. Other costs, such as those related to traffic disruptions, are (almost) never paid directly by water utilities or their insurance companies. We termed these "soft" societal costs. On our data collection sheet and in our analysis of costs we were very careful not to double count costs.

We found that how water utilities viewed and paid for property damage caused by large water main failure flooding varied. It varied from utility to utility, from state to state, from region to region and it even seemed to be changing over time.

Some utilities make the decision to give their consumers "platinum treatment" when catastrophic large water main failure occurs. Others claim that the failure was an "Act of God" and, as such, they are not responsible to pay the damages. Some states have legislated that water utilities are not responsible to pay the costs related to water main failures unless they were negligent. Some utilities in states with legislation like this tell the property owners that "even though we are not responsible, if you produce valid receipts, we will pay up to a certain limit for your damages" in an effort to be more customer friendly.

Some utilities have been given legal advice by council that they claim "No Notice" when it comes to water main failures. "No Notice" means that they had no prior knowledge of the condition of the water main and therefore they could not be held responsible for its failure. Insurance companies of homeowners sometimes ask water utilities, "When is the last time you inspected the water main which just failed?" Water utilities may respond that they have thousands of miles of mains and could not be expected to inspect them. After all, "the water mains are primarily underground and cannot be inspected." These utilities then state "No Notice." When a given main fails more than once within a close period of time, it becomes more difficult for the utility to claim "No Notice," and they may end up paying a portion of the costs in those cases.

Some utilities we spoke with said that they used to be the "knights in shining armor" when it came to helping out and paying homeowners for the damage caused by the water main failure, but they don't do that any longer. Some say that people have changed from decades past, and that they are claiming more damage than actually occurred. So they have changed their policy to a "No Notice" or "Act of God" position.

Some utilities would rather deal with a professional insurance company seeking reimbursement for a claim the property owner's insurance company paid to a homeowner, as opposed to dealing directly with a home or business property owner. We were told that some insurance companies consider water mains that are more that 50 years old, to be "old" and as such will expect to settle some of the claim with the water utility. Some water utilities have their own Risk Management Departments that spend much of their time working on claims related to water main failures.

What Did We Learn?

There are very few comprehensive cost analyses of large diameter breaks in North America

During the course of this work, we heard about various studies that looked at the cost of large diameter pipe failures. However, once we obtained and reviewed these studies, while they did address pipe and pipe break issues, they typically did not address total cost of failure, and the costs were generally aggregated for all breaks. There are limited sources of centralized information on the total costs of large diameter pipe failures. To complete this study we contacted 33 utilities that agreed to participate. We obtained data on 30 breaks at 15 different utilities in 9 different states.

Utilities typically do not track the cost of breaks.

Through internet searches and other methods, we were able to rapidly identify thirty large diameter breaks, but obtaining data on thirty large diameter breaks was much more difficult. While we had expected many utilities to refuse participation in this study due to either lack of interest or other controversies associated with breaks, very few utilities refused participation citing these reasons. However, a number of utilities that were initially willing to participate in the study did not, in the end, provide data, even though we were aware of breaks in their area. Many of the utilities contacted for this study commented that they do not typically track direct costs associated with a single break. Thus, it was somewhat of an effort to pull together such data. None of the utilities contacted tracked societal costs of a break, nor the data useful to estimating these costs. We infer that these data on costs and societal disruptions are difficult for most utilities to determine.

Utility representatives were divided on their view of how societal costs should be viewed relative to pipe replacement issues.

Interestingly, we had some utility people respond negatively to our study for totally different reasons. One utility representative felt that accumulating information on total cost of failures, including societal costs, would skew future evaluations of pipe replacement programs towards much greater pipe replacement than is currently the case. This would be the outcome even though most of the societal costs are not borne by the utility. The utility representative felt that it was much more appropriate to only consider costs directly borne by the utility as an input into pipe replacement decisions. On the other hand, another utility representative felt that this study would only serve to emphasize how relatively unimportant large diameter breaks are when compared with overall water losses experienced by a utility in the course of a year. This utility representative felt that the data we accumulated would only serve to support a totally reactive approach to large diameter breaks – simply wait until they occur and then respond and correct them. While we thought that these data would be relatively supportive of the need for appropriate proactive work associated with large diameter pipes, our intent for this study was to obtain some data and see what those data might indicate.

While large diameter breaks can be spectacular and expensive, the spectacular and expensive breaks are just a portion of all large diameter breaks.

We initially expected that most large diameter breaks would be highly consequential breaks. However, as is seen in our data with a range of total costs varying from $6,000 to $8,500,000, some of the large diameter breaks had minimal costs. This was especially true for breaks where water flow was shut down quickly. Fifteen of our thirty breaks had total costs less than $1 million, and thirteen of those fifteen had total costs less than $500,000.

A good estimate of the total cost of large diameter main breaks based on these data is $500,000. Flooding damage is the largest type of cost associated with these breaks.

The geometric mean of all costs was $500,000. Of this cost, approximately one-half is associated with damages caused by the break one way or another. Sometimes these damages are paid for by the utility. These include claims paid and other costs, which we found to be approximately 52% of utility direct costs. Sometimes these costs are born by society (property damage, which we found to be approximately 57% of societal costs). Societal costs for these large diameter breaks can be considerable, and some utilities pay for some of the societal costs (as direct costs), although this is variable across the country and variable from utility to utility. Some societal costs, for instance traffic delays, which can have considerable associated costs, were never covered by the utility in any of our thirty examples.

For comparison purposes, the costs associated with all breaks, the vast majority being less than 20 inch diameter mains, has been estimated at approximately $5,000 direct costs and $10,000 total costs. This estimate was arrived at based on previous utility experience of one of the authors and based on the results of surveys of break costs included in an AwwaRF study (Grigg, 2007).

Legal fees were only paid by a utility in one instance.

At the outset of our study, we had expected that lawsuits and legal costs would prove to be considerable in association with large diameter breaks. Only one utility reported paying legal fees associated with a break. While the literature and some utilities that did not report data cited lawsuits and legal issues in association with their breaks, it seems that most of the utilities and/or states have a given approach to handling water line breaks, and these established approaches help to minimize legal costs. Instances were found where the utility simply pays for flooding damage caused by the broken pipe. We also found examples where the utility does not pay for flooding damage, as well as an example where a utility has an established maximum cap it will pay for any sort of flooding damage (without admitting any liability for the flooding damage). In some states there are state laws establishing a utility cannot be held liable for flooding damage costs unless they were legally negligent. We could find no "typical" approach for handling costs of flood damage.

Location of the break seems to be the most important factor in predicting total cost of a break.

Only a small subset of large diameter breaks are highly expensive. A large number of factors impact the exact costs associated with a break, and each break is unique. Nonetheless, based on our limited data, we wanted to better understand which factors appeared more important. The data indicated that pipe diameter, time to shutdown water flow, and the amount of water lost are not very strong predictors of the total cost associated with a break. Of this group, the total amount of water lost was the strongest. However, since approximately half of the costs tended to be related to flooding damage, the type of area in which the break occurs is very important in predicting total costs. We did not actually request data on the type of area in which a break occurred, but not surprisingly, the more urban and highly valued business areas tend to have higher costs associated with flooding. If more work was to be done on this topic, we would request a description of the type of area in which the break occurred. This would be based on broad categories such as rural, suburban, suburban commercial, urban, urban business district, urban manufacturing, urban commercial district, etc.

Based on very limited data, we estimate 500 large diameter breaks per year across the United States.

Based on the estimate of installed pipe in the US, and very limited statistics on large diameter breaks versus small diameter breaks at two utilities, we estimate the number of large diameter breaks at approximately 500 per year (Kunkel, 2006; Philadelphia, 2006; Margevicius and Haddad, 2004). This estimate roughly equates to one large diameter break each year for every utility serving 100,000 or more customers. For perspective, an estimate of total breaks in a year across the US is 300,000 based on 1992 data adjusted to 2006 conditions and considering recent data on pipe breaks (Kirmeyer, et al, 1994; Kunkel, 2006; Grigg, 2007).

Boil water orders were far less commonly associated with large diameter breaks than we had expected, and no injuries of any sort were reported.

We had expected that many of the large diameter breaks would have had boil water orders associated with them. However, in our set of 30 breaks we had no examples of boil water orders. While we found examples in the media of large diameter breaks with boil water orders, we must conclude that boil water orders are much less common in association with large diameter pipe breaks than we had expected. Similarly, we had expected that there would be some injuries, either to workers or to the public, associated with some of these large diameter breaks. Again, while we have limited examples in the media of injuries associated with main breaks, in our thirty breaks we have no examples of injuries of any sort. While obviously injuries can and will occur, they are far less common than we might have expected. Our thirty data points had no public health costs nor any injury costs associated with them whatsoever.

Large diameter breaks are not major sources of lost water.

It has been estimated that the United States loses 5,980 million gallons per day (MGD) of water (Solley, 1998). Based on the data and estimates from this study, however, large diameter breaks constitute only a small portion of overall water losses. Assuming that every large diameter pipe break in a year (estimated at 500 per year) lost the maximum amount of water noted in any of the 30 breaks included in this data set (38,000,000 gallons), large diameter breaks would only account for 52 MGD of losses, or less than 1% of all losses. In leakage circles, the common understanding is that the 24 hours per day, 365 days per year nature of ongoing leaks, even small leaks, in distribution systems and customer service lines leads to far greater water losses than short-duration breaks. Our data support this understanding.

Why are large diameter water main failures relatively rare?

Based on discussions with water utility managers over the course of this study, the authors estimate the number of large diameter water main failures in the United States to be about 500 per year. This compares to the annual number of all main failures of about 300,000 per year (Grigg, 2007).

Why are large diameter water main failures relatively rare? One reason is that there are fewer miles of them. The most common size mains typically found in water distribution systems are six and eight inch diameter mains. Large diameter mains, often referred to as transmission mains or trunk mains, make up a small percentage of the total miles of main in typical water systems.

Large diameter mains are much stronger when it comes to bending forces. Bending forces, which result in “ring crack”, a.k.a. circumferential failures, are the most common type of failure for smaller mains. The larger the pipe diameter, the greater the moment of inertia, and the stronger the pipe is at resisting bending forces. Large diameter water mains rarely fail from bending forces making ring cracks rare.

The wall thickness of large diameter cast iron mains is substantial compared with smaller mains, making them more resistant to direct failure from corrosion. In a 2002 study done by the Cleveland Water Department, they found that “cast iron trunk mains fracture rather than corrode” (Margevicius and Haddad, 2004).

Another factor that may contribute to the rarity of large diameter main failures is the increased level of inspection during installation and the quality of the pipe bedding. The quality of pipe bedding materials, material placement and conditions during construction is often better for large diameter mains than for smaller mains.

Given an average total cost of main failures of approximately $10,000 each, the estimated annual cost of these types of failures combined in the United States is approximately $3 billion (Grigg, 2007). Using the geometric mean cost of $500,000 per large diameter failure from this study, the annual cost of this group of failures is approximately $250 million. Given these values, the annual number of large diameter failures would need to increase from 500 to 5,500 to equal the estimated current annual cost of small main failures in this country.

A National Water Main Failure Database?

While the interest in buried asset management has been increasing for a number of years, there is still relatively little information available on subsurface asset condition and failure rates for US water utilities. Some utilities are generating and tracking information on their subsurface assets, including failures, but this is not a typical approach. Where data have been presented on failure rates, it is often aggregated data for all pipe sizes, and is often based on the results of a survey conducted for a specific purpose. Thus, these data sources are extremely limited, and not generally available.

The authors suggest that it would be helpful for North American utilities to combine data on subsurface assets, especially failures. By establishing certain types of very carefully defined data to collect, record, and share, a database could be created that could be mined for useful information on failure rates, and could answer un-answerable questions that are posed right now. As an example, if the assumptions inherent in the Nessie Curve vision of the future are true, we could use a national break database as a means to quantify whether break rates are really starting to exhibit the considerable increase that is postulated by the Nessie Curve. Data from the database could also be used to ground-truth models of failure to true failure rates for a given utility. Such a database could help all water utilities know which water main materials of various years of manufacture, type and diameter (pipe cohorts) are failing at an increasing rate, and conversely, which ones are not and should not be prematurely replaced simply because “they are more than 100 years old”. The authors believe there would be great value in a national breaks database.

A National Mains Failure Database (NMFD) has been established in the UK. These data have proven useful to water utilities and researchers. At this time an expansion and re-design of the database to a more web-driven database is anticipated.

Where Should Utilities Focus?

This report is based on limited data, but these limited data indicate that to reduce the risk of consequences from large diameter pipe failures, utilities should consider the following inferences based on data from these thirty failures.

- Identify large diameter pipes in high consequence areas (areas where the consequences of flooding are expected to be greater than many other areas, such as upscale business districts, below grade parking and transportation facilities areas, or important industrial areas) for greater attention regardless of the age of the pipe. These pipes should have more focus put on them when doing condition assessment evaluations, non-destructive inspection evaluations, etc.
- Once the subset of higher risk large diameter pipes are identified, review valve locations and valve condition to ensure, to the extent possible, that shutdown of water flow could be completed quickly in case of a break. Develop contingencies in the event the valves you would like to close are not accessible due to flooding.
- Review emergency response procedures to large diameter breaks, especially in high risk areas, to ensure, to the extent possible, that shutdown of water flow and pipe repairs could be completed quickly in case of a break. Use of hydraulic models can help determine which mains are most critical to the water system, as well help plan for redundancy in the piping system in the event of a failure.
- As changes are made to the distribution system, consider re-locating large diameter pipes out of high consequence areas, and routing large diameter pipes around such areas. In many cases high consequence areas could probably be fed with smaller pipes that would have a reduced risk of flooding and other damages associated with failure.

While the risk of failure of any pipe can never be reduced to zero, the utility should consider effective ways to reduce the risk of failure of large diameter pipes in high consequence areas.

Summary/Conclusions

As interest in asset management has grown, the need for better risk management techniques has been highlighted. The expression of this need has taken a variety of forms specific to pipe failure, often being expressed as the "risk tolerance" of the utility, or the "consequences of failure" in some evaluations. However, although there are many anecdotal stories concerning pipe failures, data on failures and their cost was hard to find. Based on a limited sampling of 30 large diameter pipe failures we found:

- The AwwaRF study "Costs of Infrastructure Failure" provides a good basis for estimating the total costs associated with a pipe failure in the Grand Central Model. This study, and the model, particularly focused on how to make good estimates of the "societal costs" associated with a break.
- US water utilities typically do not maintain any central data on cost of breaks, making an assessment of these costs difficult. This is especially true as regards "societal costs" which are not paid by the utility.
- The water main failures included in our study ranged from 20-inch to 96-inch diameter.
- The total cost of failure associated with these 30 breaks ranged from $6,000 to $8,500,000. The data were skewed with many breaks that were less expensive, and a few very expensive breaks.
- Summing the cost of all 30 breaks the total cost of these breaks was approximately $52,000,000, with 48% of that sum being direct costs ($25,000,000) and 52% of that sum being societal costs ($27,000,000).
- The arithmetic average total cost of these 30 breaks was approximately $1,700,000 and the geometric mean was a total cost of failure of approximately $500,000.
- Some costs can be either direct or societal, depending on the utility. This means that there are costs associated with a break that some utilities pay, but other utilities do not pay similar costs associated with their breaks.
- Flooding damage is one cost category that is sometimes paid by the utility (direct cost), and sometimes not (societal cost). Based on our data, regardless of whether they are considered direct (on average 52% of the cost associated with claims paid) or societal costs (on average 57% of the cost associated with property damage) by a utility, these damages are slightly in excess of one-half of the total costs associated with a large diameter break.
- From these data it appears that the most important factor that drives costs is the location of the break, with the second most important factor being how many gallons of water are lost in the break.
- A National Mains Break Database, or other similar national data, would be helpful in further assessing the status of our buried infrastructure.

REFERENCES

Cromwell, J., H. Reynolds, and K. Young, 2002, *Costs of Infrastructure Failure,* AwwaRF and AWWA, Denver, Colorado, 2002.

Bureau of Labor Statistics, *Median Weekly Earnings of Full Time Wage and Salary Workers by Selected Characteristics, Consumer Price Index Calculator, www.bls.gov*, Accessed November, 2006.

Damodaran, N., et al, 2005, *Customer Acceptance of Water Main Structural Reliability*, AwwaRF and AWWA, Denver, Colorado, 2005.

Grigg, N., 2007, *Main Break Prediction, Prevention, and Control*, AwwaRF, Denver, Colorado, 2007.

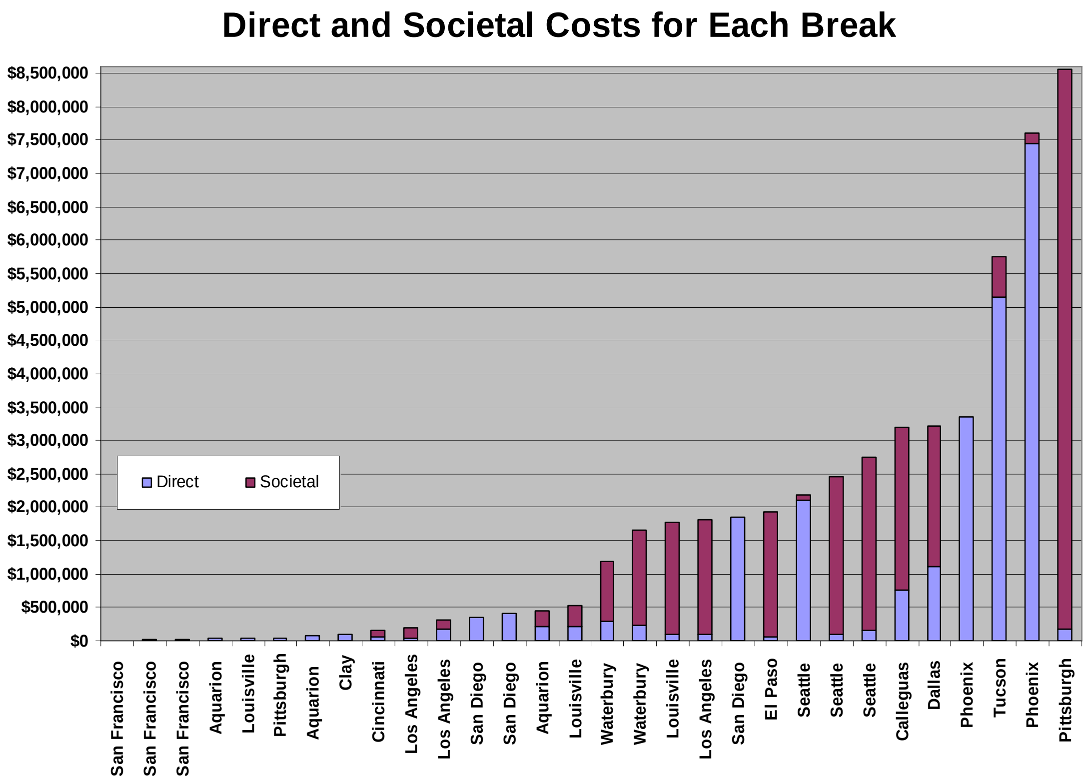
Kirmeyer, G. J., W. Richards, and C. Smith, 1994, *An Assessment of Water Distribution Systems and Associated Research Needs*, AwwaRF and AWWA, Denver, Colorado, 1994.

Kunkel, George, 2006, Personal Communication with George Kunkel of the Philadelphia Water Department, December 8, 2006.

Margevicius, A., and P. Haddad, 2004, *Catastrophic Failures of Cleveland's Large Diameter Water Mains,* Presented as ASCE Pipelines Conference, August 5, 2002, Copyright ASCE 2004.

City of Philadelphia, 2006, *Water Audit for Fiscal Year 2005, July 1, 2004 – June 30, 2005,* City of Philadelphia Water Accountability Committee, February 7, 2006.

Solley, W.B., R.R. Pierce, H.A. Perlman, 1998, *Estimated Use of Water in the United States in 1995*, USGS Circular 1200, 1998.



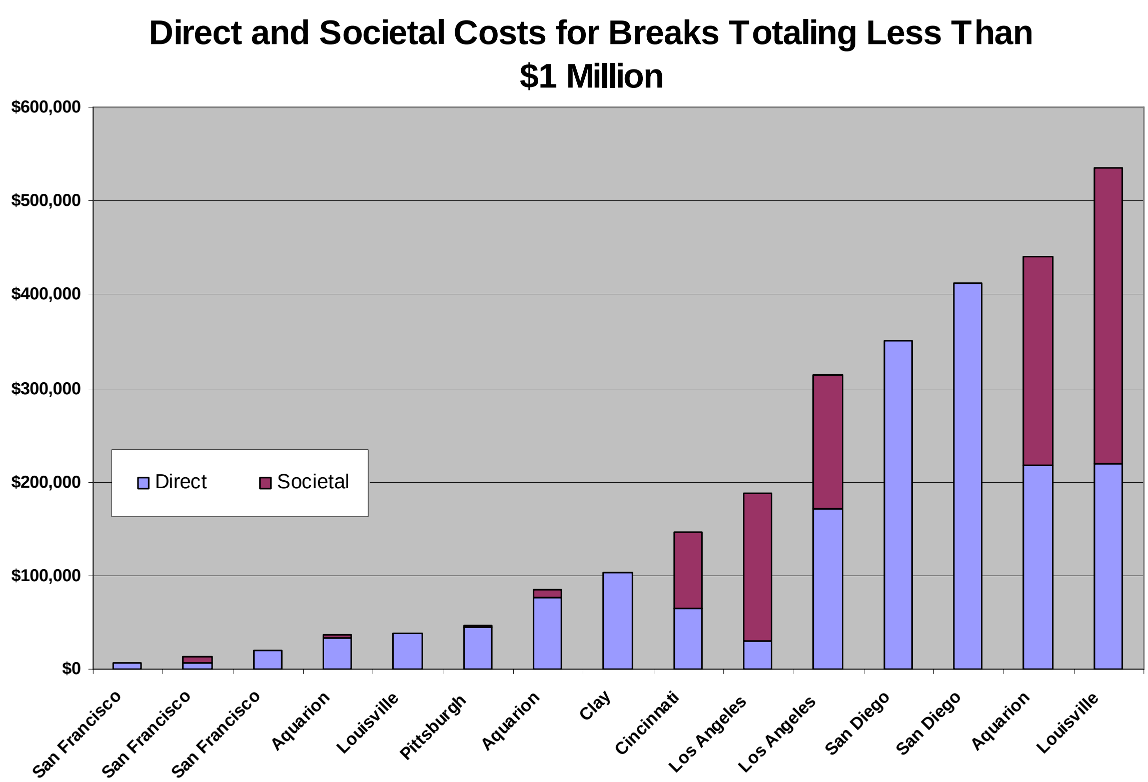
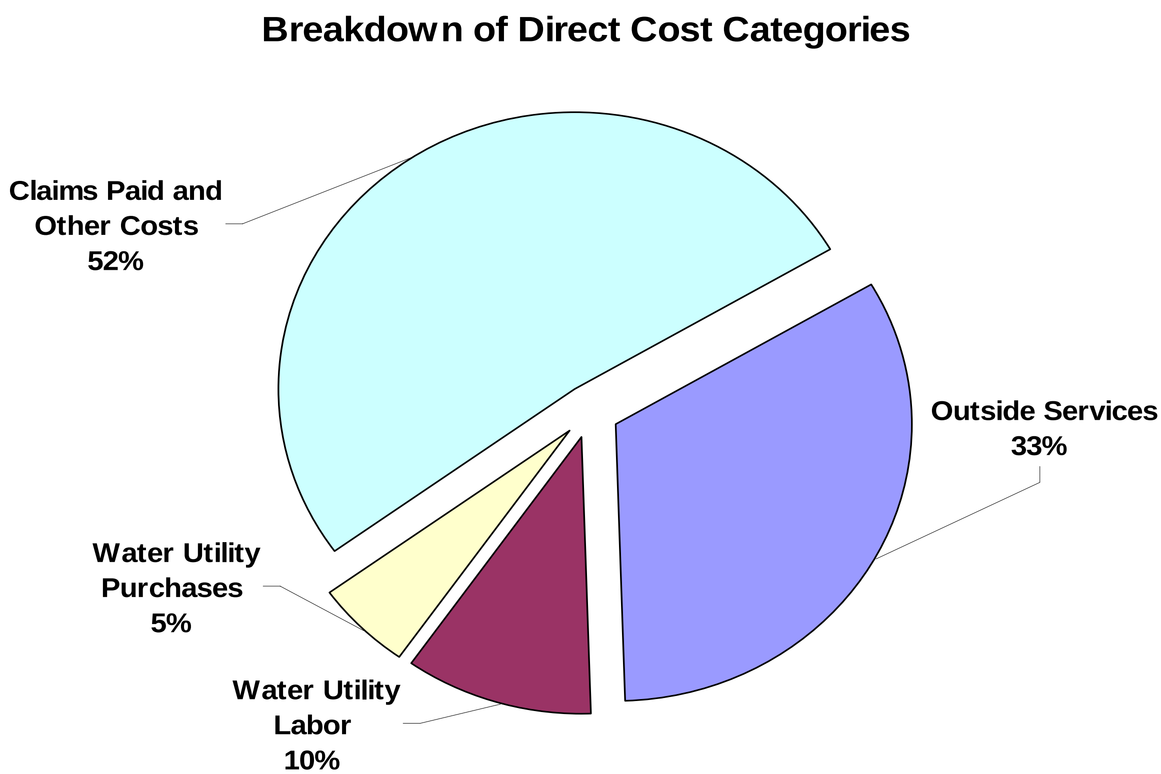


FIGURE 1: Direct and Societal Costs for Each Break (upper figure)
FIGURE 2: Direct and Societal Costs for Breaks Costing Less than $1 Million (lower figure)



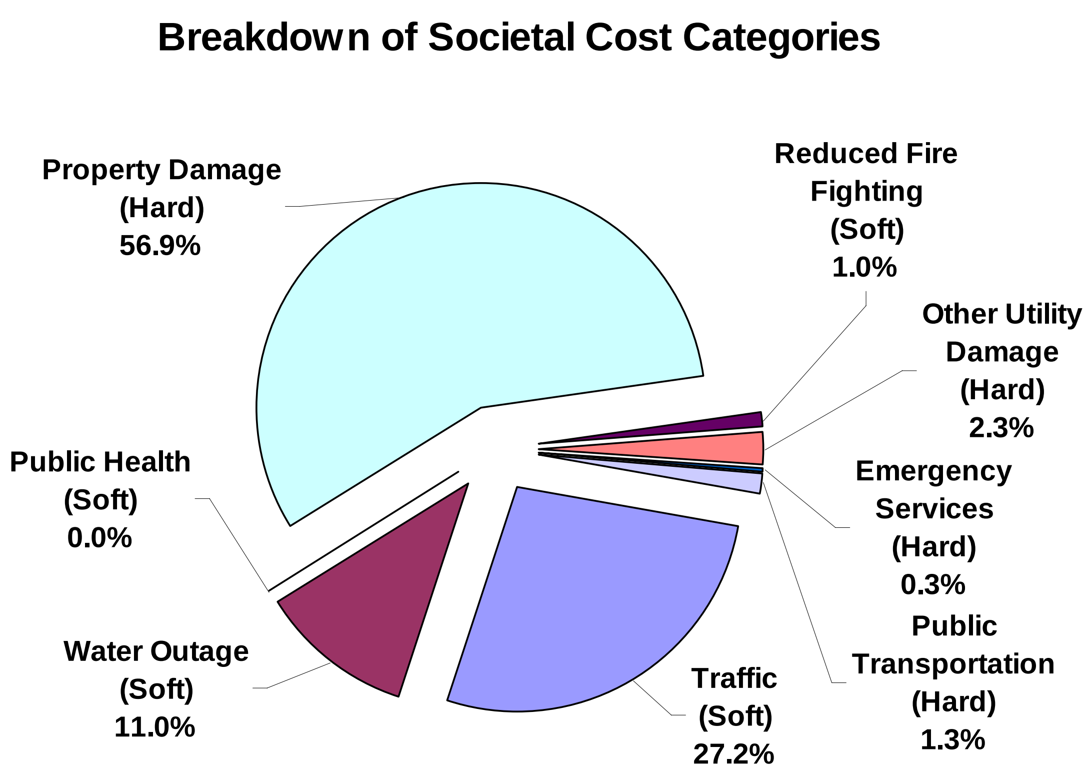
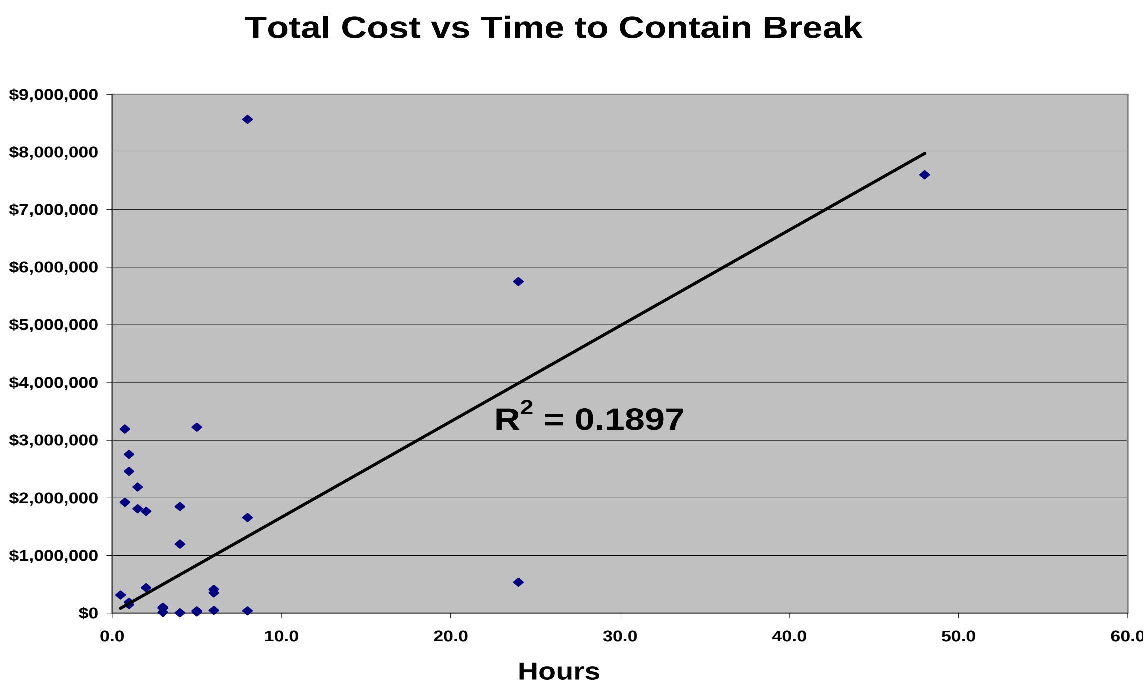


FIGURE 3: Breakdown of Direct Costs (upper figure)
FIGURE 4: Breakdown of Societal Costs (lower figure)



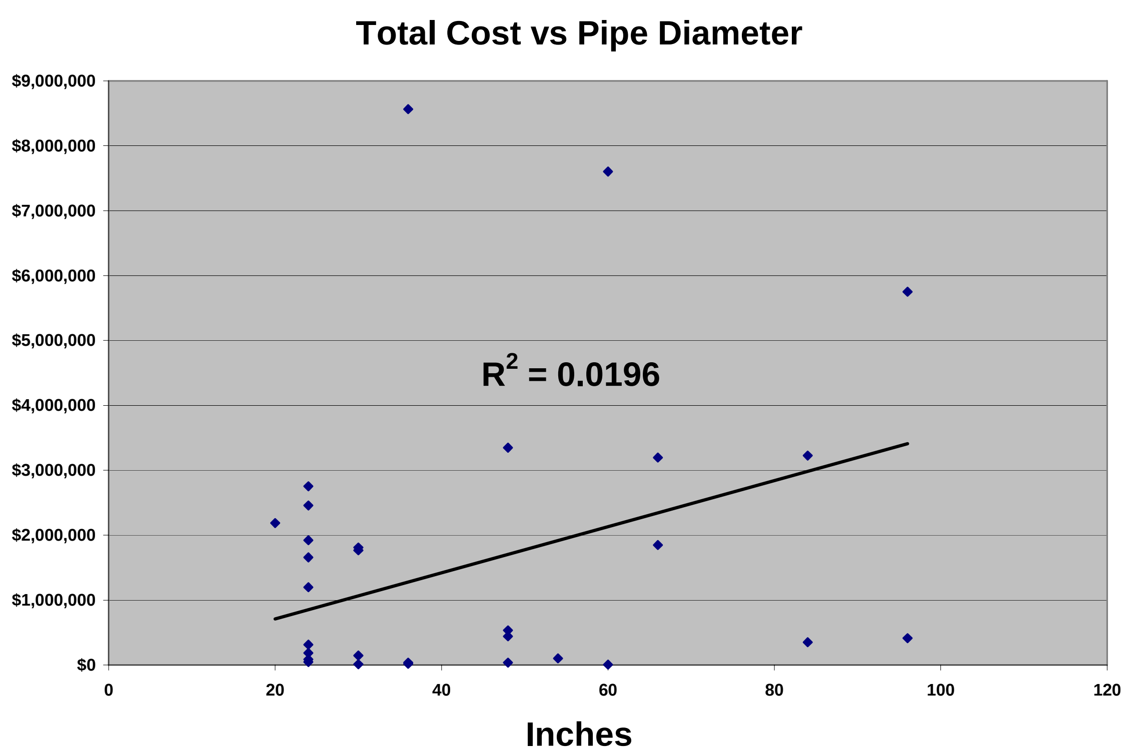


FIGURE 5: Total Cost and Time to Contain Break (upper figure
FIGURE 6: Total Cost and Pipe Diameter (lower figure)

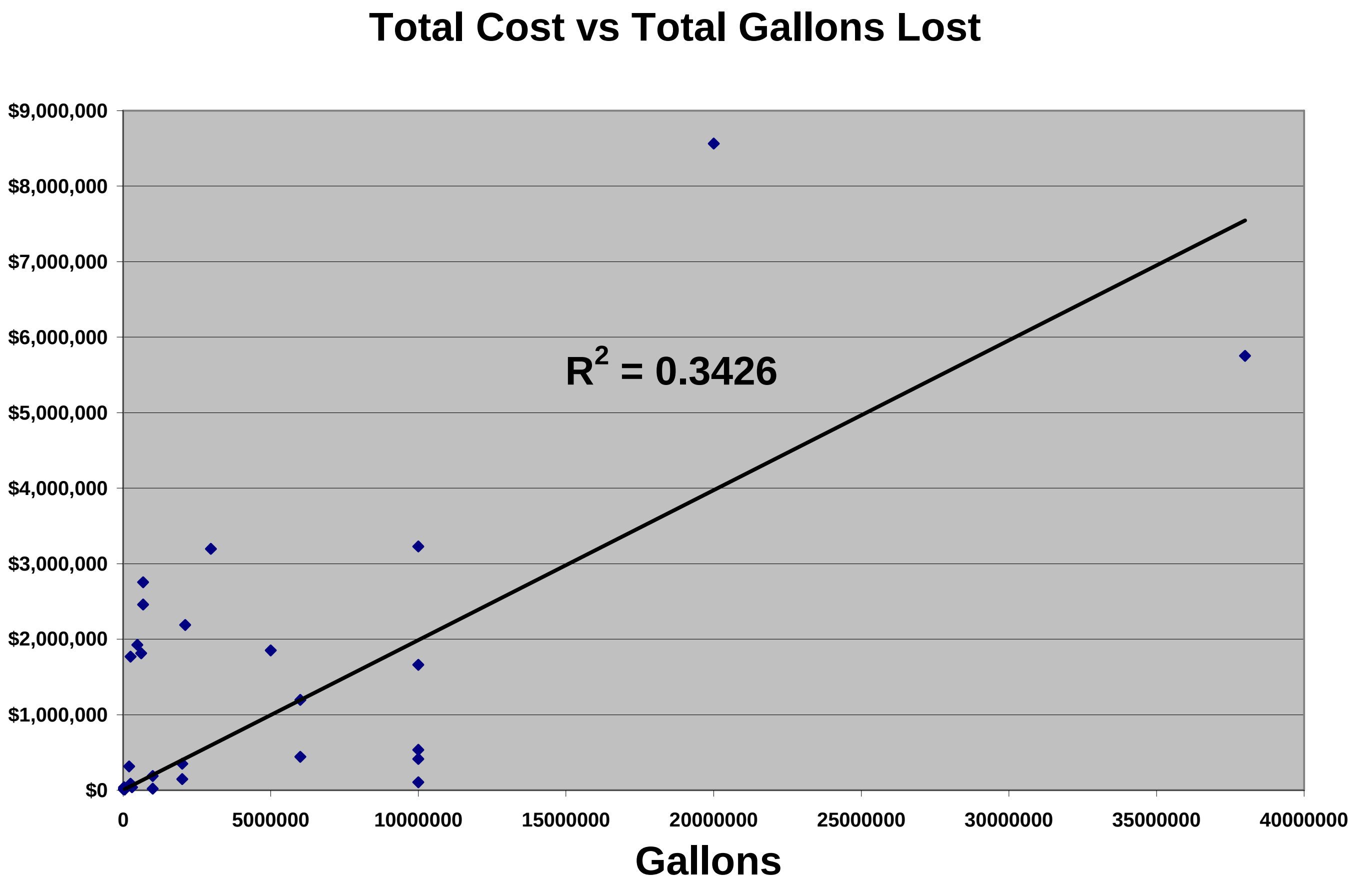


Figure 7: Total Cost and Total Gallons Lost

Appendix A: Example Data Collection Sheet

Data Collection Sheet for "Analysis of Total Cost of Large Diameter Pipe Failures"

Name Of Water Utility	ABC Water Company
Address	123 Main Street, Anytown, Iowa
Water Utility Contact Person	Joseph Engineer
Telephone Number	(999) 999-9999
Email Address	JE@ABCWATER.com

Description of the Water Main Failure

Date Main Failed	1/1/2001	mm/dd/yyyy
Diameter Of Main	24	XX-Inches
Water Main Material	PCCP	Cast Iron, PCCP, Ductile Iron, Steel, or Specify other
Estimated Gallons Lost for Entire Event	10,000,000	Gallons
City/Town and State Where Failure Occurred	Anytown, Iowa	
Name of Street and Closest Intersecting Street	Main Street and Elm Street	
Type of Failure	BW/C,PCCP	Longitudinal Split **(LS)**, Cracked Bell **(CB)**, Broken Wire/Cylinder **(BW/C,PCCP)**, Circumferential Ring Crack **(RC)**, Joint Leak **(JL)**, Hole in Pipe **(HP)** or Specify other

Direct Utility Costs of the Water Main Failure Event

Place actual or best estimated costs next to the line that most closely describes that cost.
If there are costs that do not come close to the descriptions given, please place them under one or more of the "**other**" categories.
Place costs only once, please do not double count.
If your main failure did not incur any costs for a particular line, please leave it blank.

Outside Service Costs by the Water Utility	Actual or Estimated Dollars Expended
Total Costs for Outside Construction Contractors	$ 155,379
Engineering Consulting Costs	$ 23,278
Attorney Fees and Other Legal Costs	$ 100,000
Landscaping/Restoration Services Costs	$ 25,000
Costs for Police Assistance	$ 9,255
Costs for Fire Department Assistance	$ 11,389
Costs for Assistance from other Water Utilities	$ 15,000
Costs for Electric Utility Damages and Services	$ -
Costs for Telephone Utility Damages and Services	$ -
Costs for Gas Utility Damages and Services	$ -
Costs for Wastewater Utility Damages and Servic	$ 1,000
Costs for Other Utility Damages and Services	$ 3,000
Costs for Transportation and Parking Authorities	$ 9,160
Costs for Outside Laboratory Services	$ 1,239
Other Outside Services not listed above:	$ -
Total Outside Services Costs	$ 353,700

Water Utility Internal Labor Costs (including all overheads)

Utility Construction Staff Labor Cost	$	50,000
Utility Field Service Staff Labor Cost	$	125,318
Utility Distribution Staff Labor Cost	$	20,000
Utility Operations Staff Labor Cost	$	-
Utility Engineering Staff Labor Cost	$	10,000
Utility Customer Service Staff Labor Cost	$	8,000
Utility Finance Staff Labor Cost	$	5,000
Utility Public Relations Staff Labor Cost	$	2,000
Utility Laboratory Staff Labor Cost	$	-
Utility Natural Resources Staff Labor Costs	$	-
Utility Information Technology Staff Labor Cost	$	1,000
Utility Executive Labor Cost	$	6,000
Other Water Utility Labor Costs	$	5,000
Total Water Utility Labor Costs	$	232,318

Water Utility Purchases for the Failure Event

Cost of Repair Materials Taken From Stock	$	48,699
Pipe/Valve Material Purchases for the Event	$	2,536
Road Repair Material Purchases for the Event	$	6,000
Total Equipment Rental Costs	$	20,000
Dewatering Equipment Purchased for the Event	$	1,000
Lighting and Generation Equipment Purchased	$	5,000
Line Stopper Equipment Purchased	$	-
Other Purchases for the Failure Event	$	5,000
Total Water Utility Purchases	$	88,235

Other Costs

Claims Paid by Utility (not included above)	$	46,789
Claims Paid by Utility's Insurance	$	150,000
Cost of Forensic Studies of the Failure	$	25,000
Cost of Reports/Presentations on the Failure	$	5,000
Cost of Water Lost	$	8,000
Cost of Disinfection Related to the Failure	$	2,000
Cost to Provide Alternative Supplies	$	4,000
Customer Notification Costs	$	3,000
Costs Associated with Boil Water Notice	$	4,000
Costs for Test Pits	$	10,000
Costs for Providing Bottled Water	$	15,000
Other Costs not included above	$	8,000
Total of Other Costs	$	280,789
Total of all Direct Utility Costs	$	**955,042**

Societal Cost Data Inputs

Please feel free to provide an estimate outside of the typical ranges.
Using Guidance from previous AWWARF studies, we will calculate the Societal Costs from your input.

Traffic Impacts	**Units**	**Typical Range** Low	High	**Specify Value**
Estimated Time Duration from Report of Failure to Containment = "Time A"	Hours	4	48	24
Estimated Time Duration from Containment to Completion of Repairs = "Time B"	Hours	8	72	50
Estimated average number of Vehicles Delayed or Detoured Per Hour, During "Time A"	# of Vehicles	20	20,000	100
Estimated average number of Vehicles Delayed or Detoured Per Hour, During "Time B"	# of Vehicles	20	20,000	200
Estimated Average Vehicle Delay or Detour Time During "Time A"	Minutes	2	30	20
Estimated Average Vehicle Delay or Detour Time During "Time B"	Minutes	2	30	10

Customer Water Outage Impacts	**Units**	Low	High	
Duration of Customer Water Outage	Hours	4	72	48
Estimated number of Residential households who were without water	# of Households	50	5,000	1,000
Estimated number of commercial and "dry" industrial customers who were without water	# of Customers	10	500	25
Estimated number of "wet" industrial and Critical Industrial Customers without water	# of Customers	1	100	2
Estimated number of business employees affected by the failure event	# of Employees	10	10,000	500

Public Health Impacts	**Units**	Low	High	
If a boil water notice was issued, estimated population notified of boil water notice	# of people	100	20,000	
Estimated number of illnesses related to the failure event	# of illnesses	1	500	4
Estimated number of injuries,including injuries to utility employees,related to the failure event	# of injuries	1	50	2
Number of fatalities, including utility employees (if any), related directly to the failure event	# of fatalities	0	5	0

Customer Property Damage (costs not reimbursed by the water utility or the water utility's insurance)	**Units**	Low	High	
Estimated number of residential dwellings damaged by flooding	# of dwellings	1	50	5
Estimated number of vehicles damaged by flooding	# of Vehicles	1	200	2
Estimated number of commercial and industrial properties damaged by flooding	# of properties	1	50	3

Public Impacts from Reduced Firefighting Capability	**Units**	Low	High	
Estimated Average "Tax Appraisal" Value of a Residential structure in Area of the Failure	$/Structure	100,000	1,000,000	$200,000
Estimated Average "Tax Appraisal" Value of a Commercial structure in Area of the Failure	$/Structure	200,000	5,000,000	$1,000,000
Estimated Average "Tax Appraisal" Value of an Industrial structure in Area of the Failure	$/Structure	200,000	20,000,000	$5,000,000

EXAMPLE

Page 4

Impacts on Parallel Utilities
(costs not reimbursed by the water utility or the water utility's insurance)

	Units	Low	High	
Estimated cost impact on nearby Electric Utility	$	0	500,000	$100,000
Estimated cost impact on nearby Telephone Utility	$	0	500,000	$50,000
Estimated cost impact on nearby Gas Utility	$	0	500,000	$100,000
Estimated cost impact on nearby Wastewater Utility		0	500,000	$0
Estimated cost impact on other nearby utilities not listed above	$	0	500,000	$0

Impacts on Emergency Services Agencies
(costs not reimbursed by the water utility or the water utility's insurance)

	Units	Low	High	
Estimated cost impact on local and state police	$	0	100,000	$0
Estimated cost impact on fire departments	$	0	100,000	$0
Estimated cost impact on area hospital/emergency medical agencies	$	0	50,000	$5,000
Estimated cost impact on other Emergency Service Agencies not listed above	$	0	50,000	$0

Impact on Public Transportation/Parking Authorities
(costs not reimbursed by the water utility or the water utility's insurance)

	Units	Low	High	
Estimated cost impact to Subway/Train Systems	$	0	1,000,000	$0
Estimated cost impact to State and Federal Highway Systems	$	0	1,000,000	$4,000
Estimated cost impact to Parking Authorities	$	0	1,000,000	$0
Estimated cost impact to other Public Transportation Systems	$	0	1,000,000	$0

Other Societal Cost Impacts (please specify)
(costs not reimbursed by the water utility or the water utility's insurance)

	Units	Estimated Value
The main failure caused damage to an irrigation pond dam	$	$20,000

End of Data Collection Sheet

*Please save your sheet and email results to: Fblaha@awwarf.org

Note:

After completing worksheet, please save to your pc locally. You can select the above email address, remember to attach the completed file and send.

Thank You For Participating!

Mr. Frank Blaha, P.E. Awwa Research Foundation

Mr. Peter Gaewski, P.E. TATA & HOWARD INCORPORATED