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corporation

Safeguard the Physical Integrity of Water Distribution Pipelines, Improve Reliability and Conserve and Protect the Water Supply

Prepared by

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Executive Summary

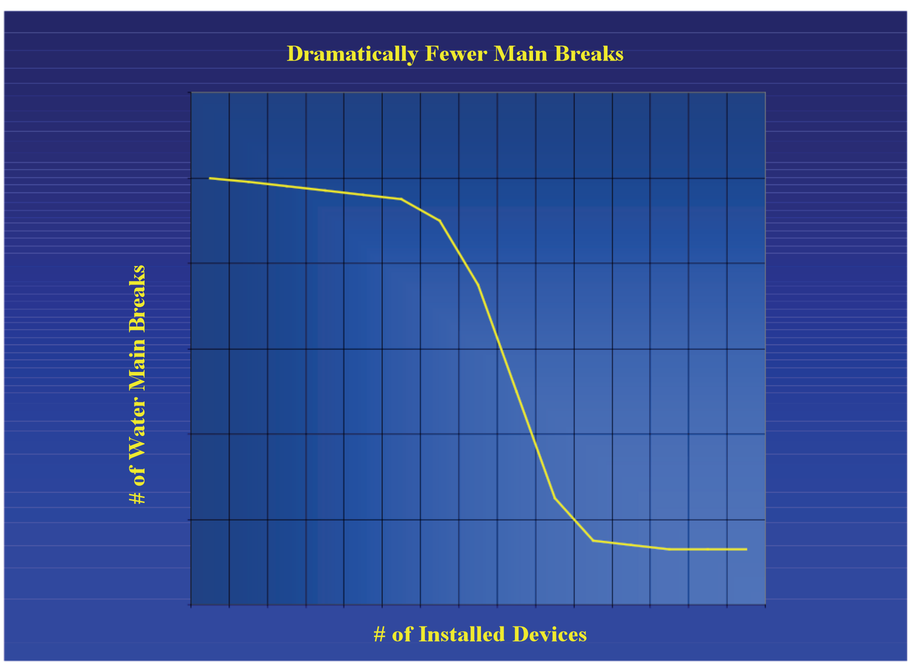
- **"Pressure is the most important risk minimization tool"**
- **"Sufficient Surge Suppression Devices Should Be Installed"[1]**

In July 2007, this observation and preliminary recommendation by researchers to the USEPA's *Total Coliform Rule Distribution Systems Advisory Committee* urgently signals the importance of controlling high and low pressure events in water distribution systems.

Applying this best practice "allows for the greatest risk reduction"[2] available. With clear purpose to enhance the health and well-being of the people, leaders can secure safer and more reliable delivery of potable water.

Industry studies, computer models, and field case experiences show that at least 60% of water main breaks can be prevented. Using an "umbrella" surge protection strategy means installing protective devices at distant points throughout a system where the pipelines are most vulnerable. The results are clear: 1) pipeline stress is reduced, 2) high and low pressure events are calmed, 3) the probability of catastrophic pipe failure is reduced by 50-90%, 4) the replacement timeline of an aging water infrastructure is extended, and 5) the present value of repair and replacement costs is reduced.

"There is great pressure on local government to close the so-called $500 billion to $1 trillion water infrastructure "Needs Gap."[3] Successful water hammer mitigation strategies in the U.S. will likely result in at least 120,000 fewer breaks and save up to $850 million in repair costs annually. This savings helps close the "Needs Gap" by approximately 7%. With new ideas and forward-thinking plans, federal or state money may not necessarily be required.



Alarming Facts

In the United States:

- There are 237,000 water main breaks annually. [4]
- Each day, 6 billion gallons of drinkable, usable water is lost to pipeline failure. [4]
- At the current rate, it will take 300 years to replace water infrastructure. [4]
- Over the next 20 years, it will cost at least $300 billion to replace pipelines. [4]

In North America:

- North America has nearly 1,000 breaks per day.
- In Canada, it has been estimated that 80% of unaccounted water is due to breaks.
- Canadian research teams have stated that the frequency of main breaks is the key indicator of a system's physical integrity.

Across the Globe:

- Two-thirds of the world is water; but less than 1% is drinkable.[5]
- One in five people lack access to safe drinking water. [5]
- More than 2.2 million people, mostly in developing countries, die each year from diseases associated with poor water and sanitary conditions. [5]

Critical Issues:

- Destructive forces attack water systems creating stress and increasing the risk of pipe failure.
- Researchers agree that approximately 60% of all contamination in public water systems occurs during the repair of a main break.
- Negative pressures invite intrusions of contaminants.
- Nearly all breaks show evidence of progressive failure, or signs of long-term wear and tear.

Why Pipes Break

Water Main Break Occurrence Factors

	Controllable?	Affordable?
Chemical Stressors		
Corrosion		
Aggressive Water or Soil	No	No
Microbes	No	No
Stray Currents	No	No
Oxygen Gradients	No	No
Bimetallic Connections	No	No
Physical Stressors		
Damage *during*		
Transport	No	No
Unloading	No	No
Storage	No	No
Installation	No	No
Traffic Loads	No	No
Soil Loads *from*		
Differential Settling by Bedding Washout		
Water Leakage	No	No
Drought	No	No
Expansive Clays	No	No
Landslides	No	No
Radial Loads *(Internal) from*		
Water Pressure Fluctuations	Yes	No
Axial Loads *from*		
Seismic Activity	No	No
Soil Movement	No	No
Water Hammer	**Yes**	**Yes**
Thermal Stress *from*		
Temperature Differences/Water, Pipe, & Soil	No	No
Freezing/Expansion of Water	No	No
Soil Frost Loads	No	No
Damage *by*		
Excavating Equipment Causes/Accelerates Failure	No	No
Damage *to*		
External Coatings Enables Accelerated Corrosion	No	No
Internal Coatings Enables Accelerated Corrosion	No	No
Other Factors		
Aging		
Accumulated affects from		
Chemical Stressors	No	No
Physical Stressors	No	No
Equilibrium Reactions (Brittleness)	No	No
Pipe Flaws *from*		
Design	No	No
Raw Materials	No	No
Manufacturing	No	No
Installation Errors	No	No

Source for factor identification only:
EPA/600/R-05-038, March, 2005; ***Table 1, Main Break Occurence Factors, Pg 6; White Paper on Improvement of Structural Integrity Monitoring for Drinking Water Mains***, Michael D. Royer, Urban Watershed Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory, Edison, New Jersey, 08837-3679; National Risk Management Research Laboratory, Office of Research and Development, National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268

The Impact of Breaking Pipes

Any one break is a random occurrence. Frequent breaks are problematic:

- Residents don't like shutdowns, boil orders, or street and driveway repairs.
- The service reputation of a municipality is compromised.
- Money spent on manpower and materials drains the budget.
- Crew safety requires extra training time and specialized equipment.
- Written notifications are burdensome to the administrators.
- A water system's limits are tested unnecessarily.
- Water is wasted.

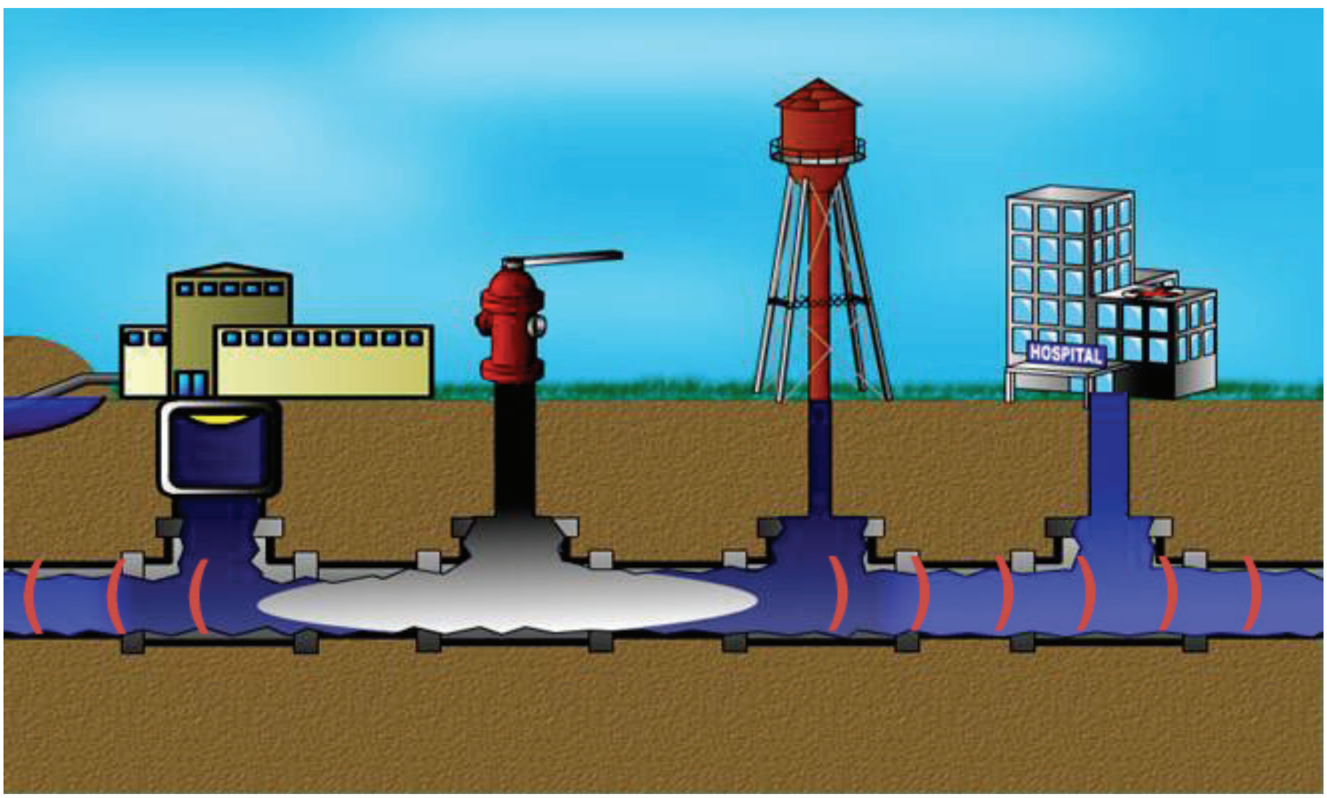
Water Hammer is a Destructive Force

Water hammer - also known as pressure transients, surges, or hydraulic shock - is an understudied and often feared phenomenon.

A pressure transient is the “development of instantaneous low or negative pressure wave due to a sudden velocity change. For sudden valve closure: compression of water on upstream side, decompression on downstream side. **Without relief, the pressure wave travels back and forth until dissipated by friction or other dampening factors**.”[7]

“Potential causes of pressure transients (i.e. the “Driving Force”): pump trip due to power failure, opening and closing a fire hydrant, altitude valve closure, valve operation (closing and opening), controlled pump start-up and shut-down, uncontrolled pump shut-down, and pipeline breaks.”[8]

Many states mandate the installation of air chambers, or surge arrestors, on indoor plumbing. For more than 100 years, these devices have controlled the irritating rumbling and pounding of indoor pipes. More importantly, the strategy effectively delays the impact of long term wear and tear.



Take These Three Steps

1. Education → Knowledge Base

2. Analysis → Data Collection → Understanding
   Analysis → Computer Models → Understanding
   Analysis → Diagnostics & Calibration → Understanding

3. Protection Safeguards → Achievable Solution

Hazard
(Water Hammer)

↓

Peril
(Increased Probability of Water Hammer)

↙ ↘

Catastrophic Failure	**Benign Failure**
↓	↓
Repair or Replace ***Today***	**Repair or Replace** ***Tomorrow***

Modeling Tools for the Engineer

The water industry has not developed a reliable model to predict the random occurrence of a water main break.

For example, using complex mathematical theories such as "fuzzy cognitive maps" is helpful to suggest frequency trends on a macro level, but does not provide an operator with practical strategies.

Using the Method of Characteristics model, HAMMER software shows harmful transient forces before mitigation and the calming effect after mitigation. The software is also noted for its transparent interface with WaterCAD® and WaterGEMS® software.

View a video clip of HAMMER software at http://www.bentley.com/en-US/Products/HAMMER/Overview.htm.

If unable to view the video, please read the complete transcript below:

> "With HAMMER, we are analyzing a water distribution system for transients.
>
> **"A transient is simply a transition between two steady state conditions.** For example, a steady state condition exists with the pumps open and flowing and running at their normal speed. When suddenly there is a shutdown at the pump – either an operator-controlled shutdown or an abnormal shutdown due to a power outage – there is a transition from water flowing through the pipes to the water not flowing anymore.
>
> "What we are simulating here is **an abnormal shutdown** in which after five seconds the pumps suddenly shut off. What you see is the hydraulic grade line dropping down below the knee of the pipeline and causing the pressure to drop below the vapor pressure of the fluid. When the pressure increases again and the vapor pocket collapses you get a high pressure wave coming through and it's alternating back and forth between high pressure, low pressure and sub-atmospheric pressures.
>
> **"Now that's problematic. If you don't have some catastrophic failure like a pipe collapsing or a pipe breaking you will certainly be weakening the pipes. You'll also – when experiencing sub-atmospheric pressures – have the opportunity to introduce ground water into the pipes, and all sorts of problems.**
>
> "So what the engineer wants to do is **install some transient protection devices** – some surge suppression devices – and hammer simulates almost all the available types. What we did here was install a gas vessel. Now we're going to look at the same exact system but with a gas vessel installed, and you'll see that as soon as the pump shuts down, we'll get a low pressure wave, but the low pressure never drops below the elevation of the pipeline, so it never causes sub-atmospheric pressures. We never have any vapor pocket forming and although we do get a high pressure wave coming back; it's not as high as we had in the previous example."

Why Pipes Don't Break

Pipeline integrity begins with a stakeholder commitment to control the water system. Critical thinking, due diligence, willingness to apply proven strategies, and collaboration with other stakeholders are key elements of a successful risk management strategy.

Knowledge about materials, design, hydraulics, best practices, installation, replacement, and financing is helpful. Ultimately, however**, the only meaningful measure of a system's integrity is the frequency of water main breaks.**

Protecting neighborhood assets is as important as securing high cost assets like pumping stations. Pressure spikes seek and find a release point at the weakest link. Without controlled release points to override the system's weak spots, the water always wins, leaving a trail of destruction.

To assess the problem, the only skill needed, despite all the new available technology, is the ability to count the number of breaks during a benchmark and subsequent periods. For peer group comparison, the frequency measure is the annual number of breaks per 100 miles (or kilometers) of distribution system pipeline.

A water distribution system "talks." Listen carefully. When stressed beyond its limits, it breaks; when the calming effect keeps pressures within the pipeline's physical, chemical, and design tolerances it stops breaking. It is that simple.

The public needs to know that *at least half* of all breaks are preventable.
Take the first step to a better outcome.
The people will notice.

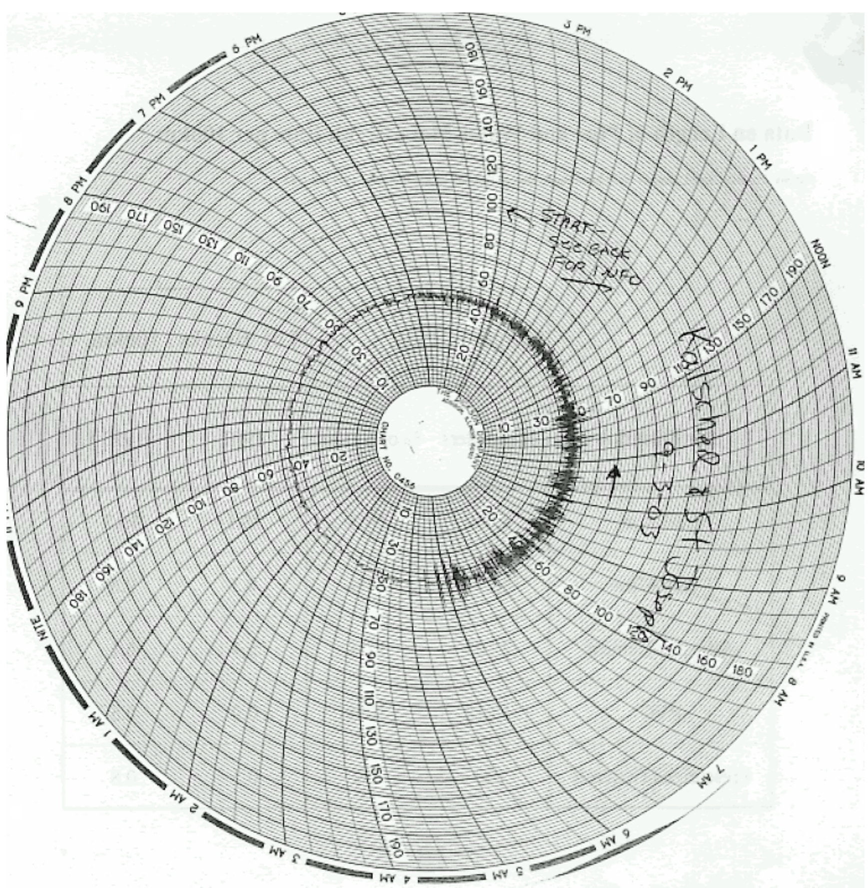
Take Control of the Water Distribution System

Because of the "invisibility of the system," local officials often feel that the political payback of protecting the water system is low. Other public works projects tend to take priority. Unfortunately, before taking action, many people need a "disaster" or "crisis" or other painful situation.[9]

Is it time to take a stand, resist the impediments to action, and do the right thing for the public? There is much value to be won. Consider this story:

> *A regional medical center in Marshfield, Wisconsin was creating significant transient activity during regular working hours from 6:00 AM to 6:00 PM each day. See the measurements below.*
>
> *The pipes on the premises had not been impacted, but the adjacent residential neighborhood was having about six water main breaks per year. The city installed <u>one</u> surge suppressor between the clinic and the neighborhood. In the spring, neighbors asked why they have not had a main break yet this year. Local water system personnel could proudly say they installed a preventative device.*
>
> *What was the monetary cost to eliminate six main breaks per year? Answer: $1,000*

Solving water main problems is simple and the upside is compelling.



Due Diligence Worksheet

Engineers often adopt favorite strategies based on traditional teachings, first-hand experience, and peer recommendations. We recommend they compare evidence without bias.   A rigorous due diligence offers a compelling argument that only surge suppression offers a universal, 100% effective, cost-effective, risk-free solution.

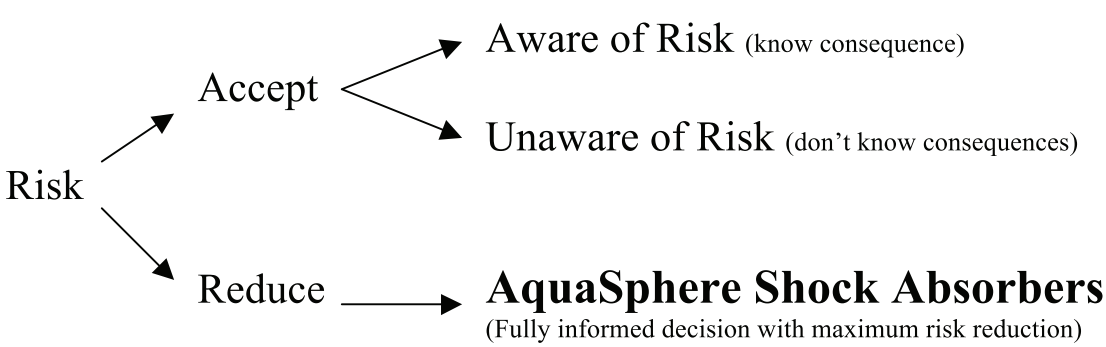
SURGE MITIGATION TOOLS[10]	PRO	CON
Air Release Valves		
Avoiding Check Valve Slam		
By-Pass Lines with Check Valves		
Check Valves		
Combination Two-Way Air Valves		
Minimize Resonance		
Pressure Relief Valves		
Slow Valve Closure Times		
Standpipes		
Surge Anticipation Valves		
Surge Suppressors		
Surge Tanks		
Vacuum Break Valves		

Compare. Contrast. Choose.

Doesn't It Make Sense?

Status Quo ***Without* AquaSphere**	**Action** ***With* AquaSphere**
Same Break Frequency	Lower Break Frequency
Same Number of Service Interruptions	Fewer Service Interruptions
Same Risk of Contamination	Reduced Contamination Risk
Same Water Loss	Aggressive Water Conservation
Same Operating Cost Budget	Under Budget by 50-90%

Make a Decision - *Accept* Risk or *Reduce* Risk



Who Should Install Protection Devices?

Prime beneficiaries include those water systems with: 1) Higher than average break frequency; 2) Larger percentage of older, cast iron pipes; 3) Shortage of funds to meet current pipeline replacement schedule; 4) Other budget priorities; 5) Special situation that elevates risk, 6) Lack or money or qualified staff to acquire and use transient modeling software; 6) Transient analysis results that pinpoint optimum placement of devices; or 7) Strong desire to reduce break frequency by 50-90%. Because the end user controls the scale, scope, timing and cost of installation, there is no transaction risk. In fact, most cities suspend installations as soon as the system stops breaking. This strategy is sensible and cost-effective.

Is your system under stress?

For the benchmark period, record your answers:

Measure	**Benchmark Period**	**Key Question**
Number of Breaks per Year		Can you tolerate this frequency? By permitting preventable breaks, are you compromising public health and safety?
Length of Distribution Syster		Is your pipeline system growing? Are there special design characteristics that increase the chance of loss?
Breakage Index: **# breaks/year/100 miles (km)**		Are you above or below the average of 25/yr/100 miles?
% of System with Iron Pipe		Did you know that iron pipe is 35 times more likely to break those other materials?
Average Monetary Cost **Per Water Main Break**		Have you included estimates for all direct, indirect, and social costs?

Doesn’t the public deserve fewer service interruptions?

Cost Savings Example

Preventing premature pipeline failure pays. All systems have unique physical and performance traits - illustrating several reduction outcomes shows a range of possibilities A **50% break reduction**: 1) a 170% ROI in the first year, 2) with a cost savings over twenty years the **IRR approaches 270%.** An 80% reduction: 1) a 332% ROI in the first year, 2) with a cost savings over twenty years, the IRR approaches 432%.

Assumed Values

60	**# of Breaks per Year -** Benchmark
30	**# of Installed Devices -** Change assumptions and compare
5,000	**Cost per Break -** An estimate of the historical average repair cost
1,850	**Price per Device -** Price subject to quantities, terms, and conditions

300,000	**Annual Cost Benchmark -** # of Breaks per Year X Cost per Break

	Costs *With* AquaSphere Protection					Success Metrics		
When Break Frequency is Reduced by:	Cost of Repair	**Cost of Devices**	Total Cost **with** AquaSphere	**Savings** First Year	**Savings** Each Subsequent Year	**Return on Investment in First Year**	**Payback Period in Months**	**How Much Invested to Save $1.00 in First Year**
-20%	240,000	55,500	*295,500*	**4,500**	**60,000**	8%	148.0	$12.33
-25%	225,000	55,500	*280,500*	**19,500**	**75,000**	35%	34.2	$2.85
-50%	150,000	**55,500**	*205,500*	**94,500**	**150,000**	**170%**	**7.0**	**$0.59**
-75%	75,000	55,500	*130,500*	**169,500**	**225,000**	305%	3.9	$0.33
-80%	60,000	55,500	*115,500*	**184,500**	**240,000**	**332%**	**3.6**	**$0.30**

Easy Installation

To minimize costs, devices are installed during a routine main break repair.

In general, the most effective plan is to "follow the trail of main breaks."   When a pipe breaks, there is a very high probability that the pipes in the immediate vicinity are equally vulnerable to the same forces that caused the current break.

No special installations are required.

In some cases, however, a special installation might be prudent. For example, when an operator knows in advance that a planned valve exercise will create adverse water hammer events, installing a device will likely avoid unwanted consequences.

Placing a customer, or sections of the system, at heightened risk is unnecessary. Avoiding costly damage to customer property or business and the resulting legal liability is a good risk management strategy.

For maximum safety, it is critical that water system personnel use all prescribed best practices during installation. A pipeline's structural integrity is a function of properly managed causal factors throughout design, manufacture, delivery, installation, operation processes, and repair processes.

Strict adherence to protocol is imperative.

Testimonials

La Grange Highlands – *Cook County, Illinois*

"Now if you're talking about a big system, the only thing I could recommend is to try and isolate a problem area, ***make your big system a small system as a test area … and give that a try****."*

"I think word of mouth is more important than any kind of report you can come up with … I would be ***listening more to someone who has experience*** *with it … so I think that's a hands-on operator getting advice from another hands-on operator."*

"I could ***immediately see a decline*** *of main breaks after my first installations. I continued to install two or three each year when changing mains, installing hydrants, or at breaks in the more vulnerable areas."*

" .. Before we put the suppressor in … when the pump would turn on or turn off. you could see the gauge bounce … and now you don't see that gauge move at all. So ***I know there's nothing going on in the system*** *... compared to what used to be."*

"Future plans include installation of two additional suppressors this year. ***I'm impressed*** *with the success of these installations."*

Village of Hodgkins – *Cook County, Illinois*

"We were averaging anywhere ***from 20 to 30 breaks a year*** *and was costing us a lot of money … we started installing them in our system ……at this point in time we probably* ***average one a year*** *on the old system and we haven't had any on the new system …"*

"They ***worked almost instantly*** *after we put the first ones in."*

"We have been able to ***upgrade more of our system*** *. . . put in new mains where we needed to and upgrade our fire hydrants"*

"We just last year spent one hundred ten thousand dollars on electronic radio read meters and a computer system so we don't have to go out and read meters. We'd saved enough money ***to pay for this right out of the budget with no financing****."*

"I know it saved us hundreds of thousands of dollars in the past 10 years.   We finally ***have money in our budget to do other things*** *with and not pay (for) all these repairs."*

Village of Clarendon Hills – *DuPage County, Illinois*

Clarendon Hills first learned about surge suppression when a consulting engineer had specified installation of two suppressors during a water main replacement project.

Dr. Henry of Fauske & Associates, a leading proponent of water hammer mitigation, recommended a surge suppression strategy.

In a particular instance the Village's control system malfunctioned and the rapidly modulated pumps tripped off. With the suppressors installed, **no breaks occurred**. On several subsequent occasions with similar rapid flow changes, no breaks occurred.

Village of Burr Ridge – *DuPage County, Illinois*

*"**Main breaks are terrible** … and used to happen in the middle of the night or on the coldest of days … they were very inconvenient."*

*"**Residents get really angry** when they can't get water out of the sink."*

*"One of the things with a main break …**you're losing water**! It gets expensive!"*

*"It worked for us ….and I'm glad we did it. We saved a lot of money …a lot of time … and we got a lot of **customer satisfaction**."*

Village of Indian Head Park – *Cook County, Illinois*

*"In one particular case, there's a water main within our town that had approximately two dozen breaks … during one of those brakes we decided to install a surge suppressor and since that time **we have not had any more water main breaks** on the 2,500 foot line."*

*"Right now the surge suppressor is the **least expensive** item when the Village comes out to repair water mains."*

*"Your average time to install the necessary fittings and surge suppressor would be … maybe … a half-hour to 45 minutes … so that the **additional cost would be minimal** considering the value of reducing the amount of main breaks, if not eliminating them."*

*"… It's very **easy to install** and the benefits are enormous"*

*" … from a public relations point of view we would think it's appropriate to **be proactive** and not reactive…"*

Evolution of Typical Customer Acceptance

Phase One:

- Excessive breaks requires change of status quo
- Willing to try
- Have ordered a minimum number of devices for trial
- Acknowledged that devices could possibly work

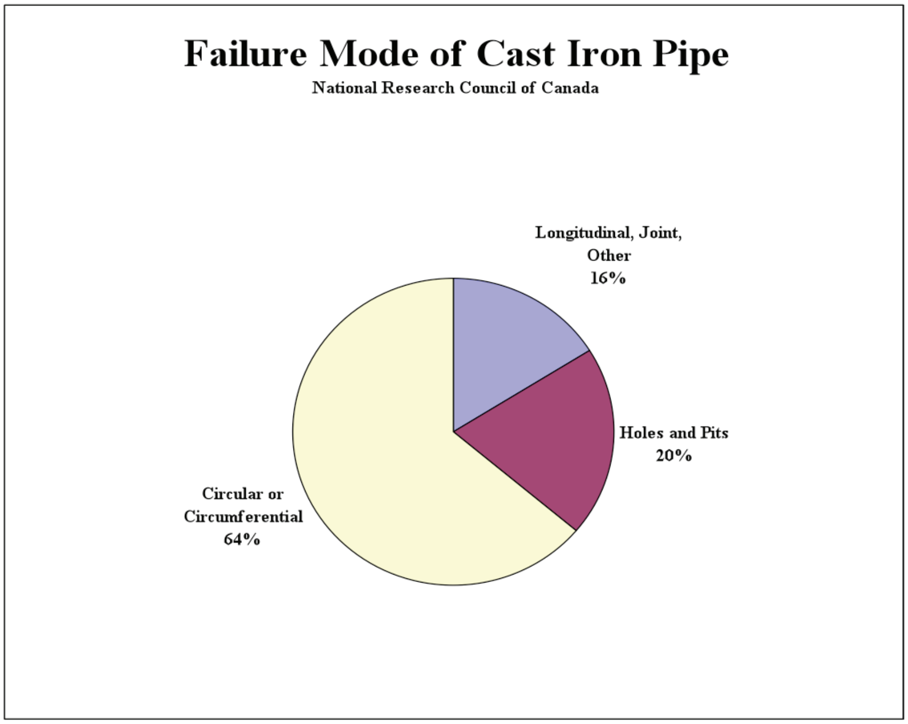
Phase Two:

- Successful results evident
- Willing to expand installations
- Acknowledge that devices definitely work
- May be able to compare before and after experience

Phase Three:

- "Out-of-sight, out-of-mind" approach
- Few, if any recent purchases
- Has had continuing success
- Original staff might be gone
- In general, engineering endorsement is possible

National Research Council Canada (A-7019.1 Final),
Water Main Break Data on Different Pipe Materials for 1992 and 1993



Cast Iron is More Likely to Break than Other Materials
Data on Length of Pipe and Water Main Break Rate per 100 km [11]

	Length of Pipe		# Breaks / 100 km	
Pipe Material	**Kilometers**	**% of System**	**1992**	**1993**
Cast Iron	8,669	50%	**35.1**	**36.7**
Ductile Iron	4,237	24%	9.3	9.8
Asbestos-Cement	2,105	12%	5.4	6.1
PVC	1,818	10%	0.9	0.5
Pressurized Concrete	623	4%	0.5	0.8

What Water Industry Professionals are Saying

(bold emphasis added)

Henry, Dr. Robert E.
"Elimination of Strong Water Hammer Transients in Water Distribution Systems"

> "Pressure transients resulting from water flow transients **can cause substantial damage** to piping, piping fittings and valves **if not properly mitigated**."
>
> "The capabilities to mitigate pressure transients (water hammer events) within a large distribution system are best addressed by having **a series of compressible volumes (gas surge volumes) distributed throughout the system.** With these, the local fluid transients are diffused as a result of the flow into and out of these volumes."
>
> "By far **the most important aspect** of such (mitigation) systems **is field experience**. These types of mitigation systems have been installed in a number of municipal water systems and have been demonstrated to essentially eliminate the strong hydraulic transients that damage fire hydrants. Furthermore, they have also successfully **prevented the rupture of the underground pipes** themselves since the fluid transients are mild and the strong water hammer events associated with a system that is completely filled with water are eliminated."
>
> "The implementation of such a distributable compressible volume system as presented in the patent by Heil can **greatly extend the life of current distribution systems and correspondingly reduce the maintenance cost**."

National Research Council Canada
"Failures in Gray Cast Iron Distribution Pipes"
5/26/2005

> "The surface of the pipe may look to be in perfect condition, but the corrosion product is much weaker that the metal pipe, **leaving the pipe very vulnerable to failure.**" Page 2
>
> "These (longitudinal cracking) failures are **often associated with** unusual water pressure surges, **water hammer** and some type of weakening of the pipe wall, either through corrosion pitting or manufacturing defects." Page 2
>
> "While pipes are often assumed to fail all at once, 95% of the circumferential failures we have examined have shown visual or chemical evidence of **multi-stage failure**. In this case, the pipe cracks part way through and then stops." Page 3

Thomas, Sheldon, Clear Water Legacy, "Air Management in Water Distribution Systems", 1/2003

"Surge suppressor structures are usually placed immediately downstream of pumping stations. These structures **protect the station piping** and fixtures against damaging surge, and will, to some degree, also protect the local piping system downstream of the surge structure. **Unfortunately, the protective influence of (these) surge structures is limited**." Page 13

"A lack of infrastructure funding is all the more reason to **consider innovative measures** to preserve the existing system, and reduce the number of costly repairs." Page 19

Managers will need to guard every dollar, and **employ every reasonable mechanism**, to minimize the cost of operating their utility." Page 19

"Severe water main breaks, heavy intermittent industrial demands, firefighting draw downs, and system operator errors can create damaging fluid oscillation, and even column separation, far out into the system, and well beyond the protective influence of surge towers and structures. **It is at these more distant points that something more has to be added to pipelines to provide umbrella surge protection."** Page 14

Rajani, B.; Kleiner, Y., National Research Council Canada (NRCC-46095), "Toward Pro-Active Rehabilitation Planning of Water Supply Systems", 11/1/2002

"Making decisions on the renewal of a water distribution system is essentially a balancing act between system performance and costs…..**Risk can thus be mitigated by a reduction of failure frequency**." Page 1

"Risk of failure = f(**probability of failure**, costs of failure)" Page 2

"The costs of a water main failure event may be classified into three categories: (a) **direct, (b) indirect, and (c) social costs**." Page 4

"Risk mitigation can be achieved by either reducing both failure probability and/or its cost, as **risk depends both on the probability and the cost of failure**." Page 6

"It appears that mitigating risk on the failure frequency side has a greater potential … It follows that a rigorous decision process should **find a balance between the risk of failure and the cost to mitigate**. Figure 2 illustrates the concept." Page 6

"When the cost of failure is relatively low and failure frequency can be tolerated, it is often (but not always) sufficient to rely on empirical models **using historical breakage patterns to predict future failure rates**. However, high failure costs may justify the use of extra measures to anticipate failure and prevent them in a proactive approach." Page 7

"It seems however, that the industry is **lagging in translating** these (empirical) models **into usable decision tools** and that most utilities still don't use these models in a rigorous way." Page 9

"We also need to **question whether added mathematical complexity** and the associated efforts required for its implementation in a proposed model **provides "better" prediction** of failure frequency." Page 9

Sadiq, R.; Kleiner, Y.; Rajani, B.B., National Research Council Canada (NRCC-47305), "Fuzzy Cognitive Maps for Decision Support to Maintain Water Quality in Ageing Water Mains", 10/28/2004

"The level of uncertainty associated with a system is proportional to its complexity, which arises as a result of:

- **vaguely defined relationships** among various entities
- **randomness** in the mechanisms governing the domain
- the **behavior** of the decision-maker
- the uncertainty in the **added effects** of a decision"

Page 1

"Fuzzy cognitive maps are examined as a **decision support tool** to develop an integrated approach …" Page 1

"**Indications of deteriorating water distribution networks** include the increased frequency of leaks and breaks, taste and odor and red water complaints, reduced hydraulic capacity and increased disinfectant demands." Page 3

"Once a FCM is finalized and 'reasonably' trained, multiple scenarios are generated to study **hidden patterns** stored in the proposed model." Page 9

National Research Council Canada (A-7019.1 Final), "Water Mains Break Data on Different Pipe Materials for 1992 and 1993"

"Table 4 shows that for 1992 and 1993 **the predominant (64%) failure mode in cast iron is circular or circumferential.** Holes and pits represent 20% of the breaks, while the remaining breaks are more or less equally distributed amongst longitudinal, joint, or other (unclassified) failure modes." Page 9

Anderson, Richard F., Mayors Water Council Senior Advisor, U.S. Conference of Mayors, "Major Capital Investment in Water and Wastewater Infrastructure: City Practice and Attitudes Concerning the State Revolving Fund Loan Program", 7/25/2006

> "**There is great pressure on local government to close the so-called $500 billion to $1 trillion water infrastructure 'Needs Gap'** … Despite the high level of municipal expenditures in the water arena, there has been no substantial progress in closing the water infrastructure investment 'Needs Gap.' " Page 3
>
> "A substantial number of survey cities identified **Pay-As-You-Go** as a preferred method to finance major capital investments in water and wastewater projects." Page 10

Remarks for Benjamin H. Grumbles, Assistant Administrator for Water, U.S. Environmental Protection Agency at the Carolina Environmental Program 2006 Symposium – "Safe Drinking Water: Where Science Meets Policy" Chapel Hill, NC, 3/16/2006

> "But there are some important questions in understanding how we can make the best marriage of science and policy. For example, what is the appropriate role of science in policy making? How can policy makers sift through numerous and sometime conflicting studies? When it comes to building a case for a policy decision or regulations, **how do we know when we have enough science to make a decision?** And are there some things that we must do because we believe they are true, but cannot prove?" Page 2
>
> "It's important to understand that we must **focus on the best available science to help inform policy, but science will not necessarily define policy.** Policy must take other factors into consideration." Page 2
>
> "One of my big challenges is working to develop a process …evaluating science and making decisions that address the greatest threats and **allow for the greatest risk reduction**." Page 2

U.S. EPA, "Using DWSRF Funds for Transmission and Distribution Infrastructure Needs", 2/2003

> " 'Out-of-sight, out-of-mind' can explain why many water systems have neglected their transmission and distribution systems…..**sub-surface pipe networks tend to receive little attention until they fail.** When a main breaks and disrupts service, the distribution system typically receives emergency localized maintenance around the failure. These 'patches' do little to address a system's long-term transmission and distribution problems." Page 1

Wood et al; "Constructing Water Main Break Databases for Asset Management", AWWA Journal, January 2007 Volume 99 Number 1, Pages 52-65

> "Data collection on water main breaks is evolving but **industry practices do not yet follow best practices** recommended by the National Guide to Sustainable Municipal Infrastructure (NGSMI, 2002) and the Awwa Research Foundation (AwwaRF;Deb et al, 2002)." Page 52
>
> " 'Knowledge discovery' is the process of identifying valid, useful, and ultimately **understandable patterns** in data." Page 53
>
> "The analysis of water main breaks, although vital to the health of a distribution system, is **limited by common utility challenges-limited personnel and resources, missing and conflicting data, and non-computerized information** (Pelletier et al, 2003; Habibian, 1992; O'Day, 1982).
>
> "Adding a layer of complexity, many utility staff members will be retiring in the coming years, leading to a potential loss of tacit data. Although staff member typically know this type of information and **share it anecdotally, it is not formally recorded**." Page 53

On Complexity and Fuzziness (http://www.ochoadeaspuru.com/fuzcogmap/fuzzycomplexity.php)

> "Fuzzy cognitive maps are also useful when there are so many factors and relationship in the system that nobody, no matter how discerning and knowledgeable, can make **meaningful predictions** about the behavior of the system … he does not know how the whole system behaves." Page 2

Makar et al; "The Effect of Corrosion Pitting on Circumferential Failures in Grey Cast Iron Pipes", AwwaRF Project #2727/Order Number 91053F, Spring , 2005

> "Large levels of changes in soil support were found to produce substantial levels of **bending stress** in the pipes."
>
> "**Thermal stresses** due to temperature changes in the pipes found to be the next most significant factor in producing failure."
>
> "Water pressure, including **water hammer, was not sufficient by itself to cause failures** in water distribution mains."
>
> "**Field tests are needed** to confirm the results of this project."

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4. LeChevalier, Mark W., Ph.D., ibid., slides 120, 123.

5. Dow Chemical Company, Advertising Insert to National Geographic, *H_2O, The Essential Human Element, How Much Water Does the World Have to Go Around?*, source quoted: United Nations, *Population Division, UNDP, and AQUASTAT-FAO*; Population Reference Bureau.

6. EPA/600/R-05-038, March 2005; Table 1, Main Break Occurrence Factors, Page 6; White Paper on Improvement of Structural Integrity Monitoring for Drinking Water Mains, Michael D. Royer, Urban Watershed Branch, Water Supply and Water Resources Division. National Risk Management Research Laboratory, Edison NJ 08837-3679; National Risk Management Research Laboratory, Office of Research and Development, National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH 45268.

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8. Friedman, Melinda, P.E., ibid, slide 8.

9. Cromwell, John E. III; Sperenza, Elisa; Reynolds, Haydn; *The Infrastructure "Crisis"?*, AWWA Journal, April 2007, Volume 99, Number 4, Page 109-115.

10. LeChevalier, Mark W., Ph.D., Director, Innovation & Environmental Stewardship, *Use of Available Information on Intrusion to Characterize Distribution System Problems* presentation to USEPA Total Coliform Rule / Stakeholder Technical Workshop, February 1, 2007, Washington, DC, slide 39 (Conclusions).

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