Pressure Management:
Baseline to Optimized
Utility Case Studies

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Minhua Xu, Jian Yang, and David Hughes
Importance of Maintaining Adequate Pressure

Fundamental to providing safe drinking water

- Loss of pressure can allow intrusion of contaminants into the distribution system

Fluctuations in pressure can affect the physical integrity of pipes

- Pressure spikes can result in leaks, main breaks, and premature failure

Pressure management can save money

- Reduced energy costs, system maintenance, leakage, customer complaints, water quality problems

Pressure Management – Optimized Distribution Systems

Distribution System Optimization consists of three focus areas:
- Disinfectant residual, Pressure management, Main breaks
- Impact most of the 19 categories examined

Optimized Pressure Management Goals
- >0 psi during emergencies
- >20 psi under max day and fire flow conditions
- >35 psi under normal conditions
- <100 psi under normal conditions
- Within +/- 10 psi of average, >95% of the time

Optimized Pressure Monitoring
- A minimum of two pressure recorders in each pressure zone placed at the minimum and maximum pressure locations

Friedman et al., 2010. *Criteria for Optimized Distribution Systems*. Water Research Foundation, Denver CO.
#4321 Pressure Management: Baseline to Optimized

**Task 1: Conduct a utility survey**
- Determine prevalence of distribution system attributes leading to undesirable pressure variations

**Task 2: Conduct baseline and optimized pressure monitoring**
- Conduct 12 month baseline (existing) and optimized pressure monitoring at 24 participating systems

**Task 3: Integrate pressure management with other distribution system activities**
- Demonstrate how the cost of an optimized pressure management program can be offset by cost reductions in other system operations (backflow sensing metering, water quality, model optimization, main break/repair activities, customer complaints, etc)

**Task 4: Develop best practice guidance**
- Strong utility focus on best practices and strategies for pressure management.
Task 1: Utility Survey

- Zoomerang online survey
- Distributed to ~330 water utilities (36 responded)
- One third each: small, medium, and large systems
- Surface/Groundwater/Both: 47%, 19%, and 33%

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Median</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td># of service connections</td>
<td>414</td>
<td>20,000</td>
<td>475,371</td>
</tr>
<tr>
<td>Total population</td>
<td>1,040</td>
<td>77,600</td>
<td>2,500,000</td>
</tr>
<tr>
<td>Retail service area (miles²)</td>
<td>&lt;1</td>
<td>28</td>
<td>1,300</td>
</tr>
<tr>
<td>Total lengths of water mains</td>
<td>16</td>
<td>300</td>
<td>5,500</td>
</tr>
<tr>
<td>Average daily delivery (MGD)</td>
<td>0.2</td>
<td>11</td>
<td>245</td>
</tr>
</tbody>
</table>
Survey – Low Pressure Criteria/Goal

- Most States have some requirement for maintenance of pressure

### During Fire Flow

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.7</td>
</tr>
<tr>
<td>20</td>
<td>95.0</td>
</tr>
<tr>
<td>30</td>
<td>2.7</td>
</tr>
</tbody>
</table>

### During Emergency Conditions

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21.0</td>
</tr>
<tr>
<td>0 to 20</td>
<td>2.6</td>
</tr>
<tr>
<td>20</td>
<td>68.0</td>
</tr>
<tr>
<td>30</td>
<td>2.6</td>
</tr>
<tr>
<td>No requirement</td>
<td>5.3</td>
</tr>
</tbody>
</table>

Most have a minimum requirement of at least 20 psi
Highly variable after this point
Survey – High Pressure Criteria/Goal

- No requirement or variable (65-320 psi)
Survey – Pressure Monitoring

- Pressure monitoring locations

<table>
<thead>
<tr>
<th>Location</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water meter</td>
<td>0%</td>
</tr>
<tr>
<td>Fire hydrant</td>
<td>5%</td>
</tr>
<tr>
<td>Pump station</td>
<td>10%</td>
</tr>
<tr>
<td>Storage tank</td>
<td>15%</td>
</tr>
<tr>
<td>PRV station</td>
<td>20%</td>
</tr>
<tr>
<td>System interconnection</td>
<td>25%</td>
</tr>
<tr>
<td>Water production facility</td>
<td>30%</td>
</tr>
<tr>
<td>Other</td>
<td>13%</td>
</tr>
</tbody>
</table>

13% -- Targeted locations

87% -- Convenient locations

Routine Pressure Monitoring Locations
Survey – Pressure Monitoring

- Smallest pressure zone – Are the routine monitors permanently installed?

![Bar chart showing percentage of pressure zones with different numbers of monitors installed permanently or not.]
Survey – Pressure Monitoring

- Monitor calibration

What? You’re supposed to calibrate these things?

<table>
<thead>
<tr>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
</tr>
<tr>
<td>25%</td>
</tr>
<tr>
<td>20%</td>
</tr>
<tr>
<td>15%</td>
</tr>
<tr>
<td>10%</td>
</tr>
<tr>
<td>5%</td>
</tr>
<tr>
<td>0%</td>
</tr>
</tbody>
</table>

Pressure Transducer Calibration Frequency

- Never
- 1-6 Months
- Annually
- 3-5 years
- As needed
Survey – Pressure Monitoring

- Monitor recording

Data Recording Frequency for Permanently Installed Pressure Monitors

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Seconds</th>
<th>Minutes</th>
<th>1-5 Minutes</th>
<th>15 Minutes</th>
<th>1-12 Hours</th>
<th>Day</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>30%</td>
<td>10%</td>
<td>20%</td>
<td>35%</td>
<td>0%</td>
<td>5%</td>
<td>10%</td>
<td>15%</td>
</tr>
</tbody>
</table>
Pressure monitoring data in **1-hour interval**

- **Fire Station #38 - Low Pressure Avg**
- **Fire Station #16 - High Pressure Avg**

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Pressure monitoring data in 2-minute intervals

Much more variation
Task 2: Optimized and baseline monitoring

Approach
- Select a study pressure zone
- Choose two optimized monitoring locations
- Conduct baseline and optimized pressure monitoring over 12 months

Optimized pressure monitoring
- A minimum of two pressure loggers at the min/max pressure locations (WaterRF #4109)

Baseline pressure monitoring
- Existing pressure monitoring (e.g. SCADA pressure monitoring at pump stations or PRV stations)
- A “baseline” monitoring may be already “optimized” (e.g., lowest pressure at monitored tank, highest pressure at monitored pump or PRV station)
Optimized monitoring location selection

- Use hydraulic model, historical pressure data, operational experience, and/or customer complaints
  - Area with min/max pressures or min/max elevations
  - Far away from tanks/pumps
  - Hydrants
  - Alternative locations not subject to freezing

- Pressure recording rate
  - No less than hourly data
  - Most in minutes interval
  - Impulse reading
System has 6 pressure monitors in test zone
CO-1 – Importance of monitor placement

Conventional monitors still do not capture the full range of pressures within the system.
Impact of Monitoring Location: VA-1

Optimized low pressure location

Conventional Monitoring (SCADA) at Tank 591

Optimized high pressure location
Impact of Monitoring Location: VA-1

Low pressure events captured at optimized low pressure monitoring location but missed by conventional monitor. Pressure in system is much higher than anticipated.
CA-1

Optimized Low Pressure Monitoring

Optimized High Pressure Monitoring
CA-1 – Detection of a Low Pressure Event

Jan. 31, 2012: Pressures dropped due to a break on a 4" main; Monitoring of tank levels not as sensitive as pressure monitoring
Conventional Monitoring (SCADA) at Tanks
Impact of Monitoring Location: TX-1

Conventional monitor shows average 55 psi, while optimized monitoring ranges from 40 to 120 psi.
Task 3: Integrate pressure management with other distribution system activities

- System specific

- Purpose
  - Estimate benefits of optimized pressure management

- Examples
  - Link optimized pressure monitors to SCADA for real-time monitoring
  - Collect case study and operational experiences
  - Assist hydraulic model calibration
  - Conduct spatial analysis of pressure, main breaks, backflow events, etc.
  - Correlate low pressures and water quality
  - Evaluate water distribution energy efficiency
Change pump settings: WI-1

Conventional monitor at pump discharge point shows >145 psi, while optimized monitoring locations are 60-80 psi.
Change pump settings: WI-1

• Existing pressure met all pressure criteria
• Propose to reduce the VFD pump setting by 7 psi (~10% pressure reduction)

Expected benefits:
1. Cost minimal to implement the pressure reduction;
2. Reduce water loss by ~10-15%;
3. Reduce main break frequency;
4. Reduce some pumping energy usage.

Potential concerns:
1. Customers sensitive to pressure;
2. Water usage and revenue might go down;
3. This district had minimum water loss and pipe break frequencies, i.e. no need for pressure reduction.
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Pressure and Water Loss (Findings from Philadelphia’s First Permanent District Metered Area)

Provided by George Kunkel, P.E.
Philadelphia Water Department

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Pipeline (all metallic), miles</td>
<td>12.6</td>
</tr>
<tr>
<td>Average age of Pipelines, years</td>
<td>52.6</td>
</tr>
<tr>
<td>Number of Fire Hydrants</td>
<td>117</td>
</tr>
<tr>
<td>Number of Valves</td>
<td>382</td>
</tr>
<tr>
<td>Number of Customer Service Connections</td>
<td>2,261</td>
</tr>
<tr>
<td>Number of separate Fire Connections to buildings</td>
<td>17</td>
</tr>
<tr>
<td>Highest Elevation, ft  (Critical Point)</td>
<td>310 (Magnolia St &amp; Washington La)</td>
</tr>
<tr>
<td>Average Zone Pressure site elevation, ft (AZP)</td>
<td>254 (Mechanic St &amp; Morton St)</td>
</tr>
<tr>
<td>Lowest Elevation, ft</td>
<td>180 (Lincoln Dr &amp; Morris St)</td>
</tr>
</tbody>
</table>

Figure 3
Philadelphia Water Department - DMA5
Flow Modulated Supply Profile

Flow: 0.2 mgd to 1.4 mgd
Pressure: 90 to 60 psi

Primary Supply Feed
Emergency Standby Feed
Flow Modulated Pressure Reduction
DMA5: advanced pressure management turned the water pressure profile “upside down”

Cost/Benefit analysis
Payback period of 6.4 years
Net Present Value (NPV) Analysis
Present worth of $112,258
Internal Rate of Return
Rate of return of 9% realized
Pressure and Main Breaks

Case Study TN 1 – High Pressure Locations

What case studies show?

- Optimized low pressure location (~40 psi)
- Optimized high pressure location (~220 psi)

Legend:
- Pressure
  - Less than 100 psi
  - 100 - 200 psi
  - 200 - 230 psi
- Tank
- Pump
- Pressure Zone Boundary

Pressure Zone:
- 6 INCH OR LESS
- 8 - 10 INCH
- 12 INCH OR MORE

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Spatial Analysis of Pressure and Main Breaks

High Pressure + Pipe Diameter + Pipe Material

==> Main Breaks (or Main Break Hot-Spots)
How Much High Pressure Contributes to Main Breaks?

Predicted Main Break Rate ($R^2=41\%$)

System average of 39 breaks/year/100 miles

- Minor contribution from high pressures (mainly small diameter & cast iron pipes)
- **However, higher impact at higher main break rate** (+3 breaks/10 psi @ zero breaks/yr/100 mi; +10 breaks/10 psi @ 40 breaks/yr/100 mi)
- Weather, soil conditions, etc. not modeled
Pressure and Insurance Claim Cost

Case Study – PA 1

- Reduced peak pressures from 179 psi to 145 psi
- 60% reduction in main breaks
- 30% reduction in non revenue water loss
- $1.4 million per year cost savings

- Overlay system pressure contours
- Insurance claims due to main breaks
- Size of the circle related to cost of the claim
Pressure and Energy Analysis (Case Study – AZ 1)

Pressure = Energy
- Large area of water supplied at high pressure
- System topography allowed
- To create a new pressure gradient/zone

New Boundary
(4 Alternatives)

Cost & Benefit
- Capital, O&M costs, etc.
- Reduce main breaks and NRW
- Reduce energy consumption
Pressure and Energy (Case Study – AZ 1)

Reduced Pressure by ~40 psi and Less Energy Usage

<table>
<thead>
<tr>
<th>Description</th>
<th>Energy usage (kWh/MG)</th>
<th>Energy cost ($/YR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>3,344</td>
<td>$1.2 M</td>
</tr>
<tr>
<td>Alt01</td>
<td>2,000</td>
<td>$0.69 M</td>
</tr>
<tr>
<td>Alt02</td>
<td>3,344</td>
<td>$1.2 M</td>
</tr>
<tr>
<td>Alt03</td>
<td>3,523</td>
<td>$1.2 M</td>
</tr>
<tr>
<td>Alt04</td>
<td>1,404</td>
<td>$0.49 M</td>
</tr>
</tbody>
</table>
The Future of Pressure Management

- Some states are placing greater emphasis on requirements for pressure management

- The USEPA Research & Information Collection Partnership includes emphasis on pressure management:
  - Survey of Distribution System Pressure Management Practices
  - Characterize Propagation of Pressure Events through Water Distribution Systems to Improve Pressure Management Approaches
  - Develop Strategies to Diagnose and Monitor Pressure Fluctuations in Water Distribution Systems
  - Toolkit for Pressure Management

- Partnership for Safe Water
  - Distribution System Optimization
  - [www.awwa.org/Resources/PartnershipDistribution](http://www.awwa.org/Resources/PartnershipDistribution)
Summary

- Pressure management is fundamental to protecting public health, maintaining infrastructure and effective utility management.

- Although pressure monitoring is required by regulations, implementation varies across the industry:
  - Permanently installed monitors do not exist in all pressure zones.
  - Routine pressure monitoring is mostly at convenient locations.
  - Most pressure monitors either never calibrated or calibrated annually.
  - Monitoring frequency will not capture short-term events.

- Negative pressure events may occur:
  - Main breaks, power outages may occur routinely.
  - Power outages may cause regional depressurization events.

- Pressure management has been identified by USEPA as an important topic for distribution system research.

- A program for optimized distribution systems, including pressure management has been formulated by the Partnership Program.
Acknowledgements

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- Frank Blaha (Water Research Foundation) and PAC:
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  - Steve Rupar

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  - Dave Hughes and Norm Ansell (AW)
  - George Kunkel (PWD)
  - Mike Hotaling (NNW)

- Water utility participants (36) of this survey
Questions??

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