Use of Available Information on Intrusion to Characterize Distribution System Problems

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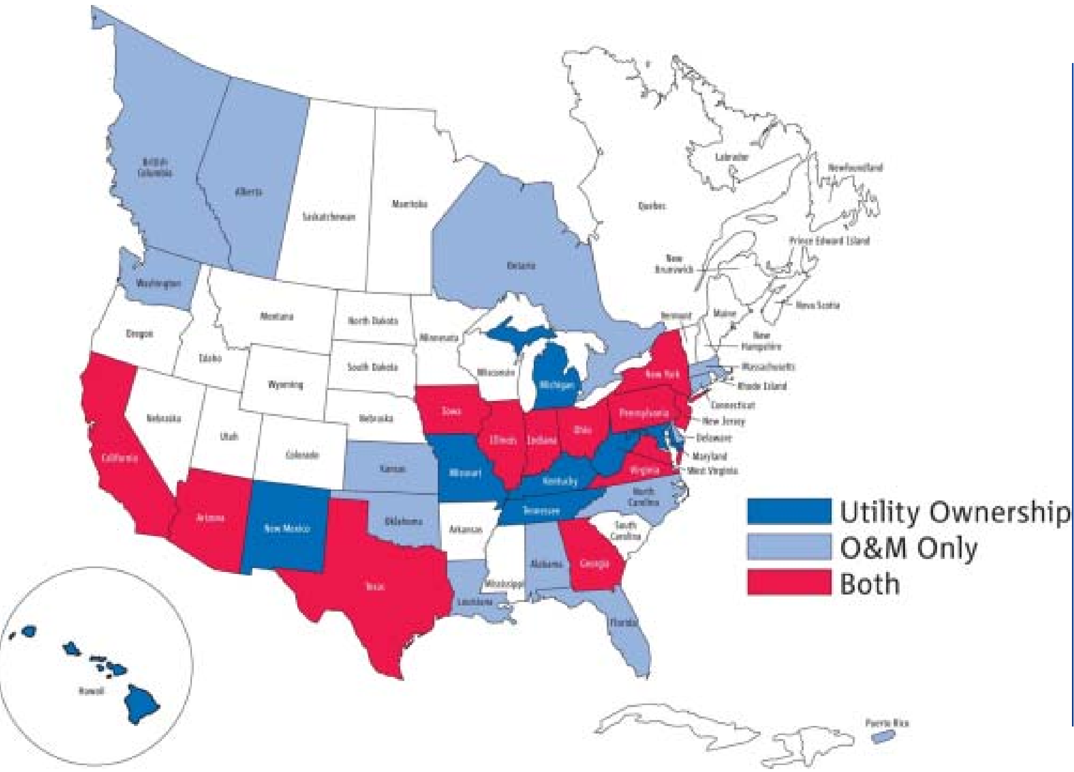
American Water



American Water is the largest water and wastewater services provider in North America, with $2.2 Billion in revenues; headquartered in Voorhees, NJ.

American Water serves over 18 million people in 29 states and 3 Canadian provinces, and employs over 7,000 water professionals.

American Water owns or operates over 847 water treatment plants & 1045 wells and 192 wastewater facilities.

The company conducts over one million water quality tests each year for over 100 regulated parameters, and up to 50 types of water-related tests each day.

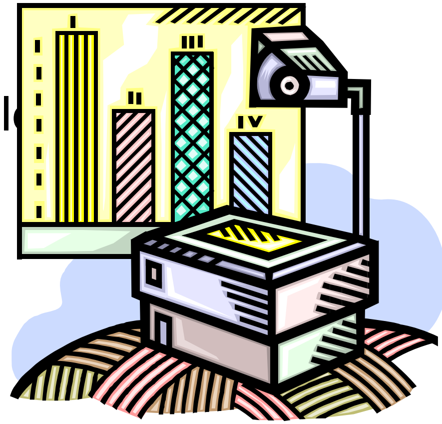
www.amwater.com

Distribution System Challenges

- Increased water quality regulations, security concerns, and cross-connection control while managing an aging infrastructure
- Maintenance of pressure is a critical activity for protection of quality and service delivery
- Spatial and temporal complexity requires collecting and managing data from many points in the distribution system
- Cost-effective approaches, based on sound decision-making processes that add value to the customer, are required

Presentation Overview

- **Transient Pressures:**
  - Steady state pressure vs. transient pressure
  - Description of transient pressure origins
- **Susceptibility of Systems to Transients**
  - Factors that make distribution systems susceptible to low/negative transient pressures
- **Consequences & Control of Transient Pressures**



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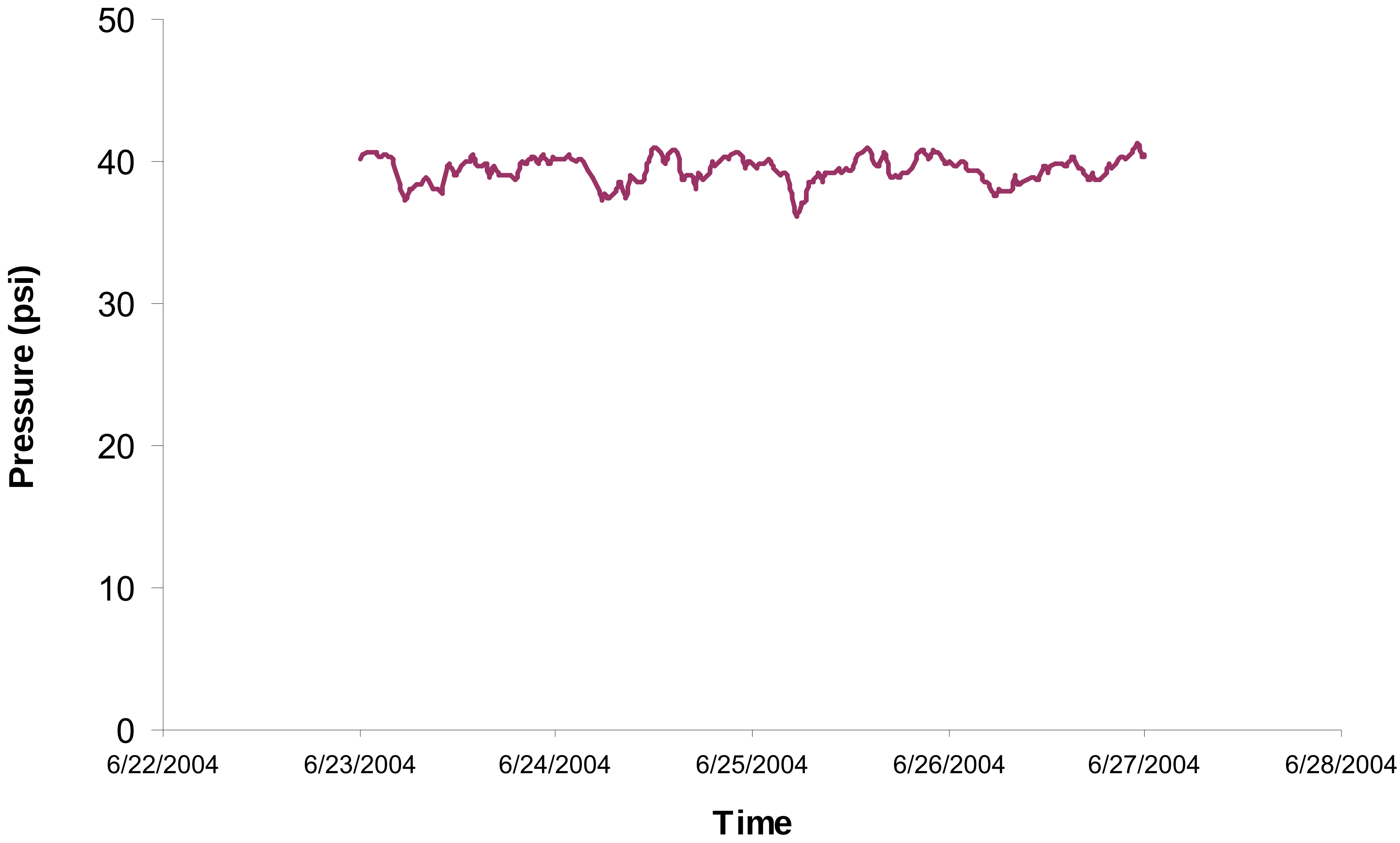
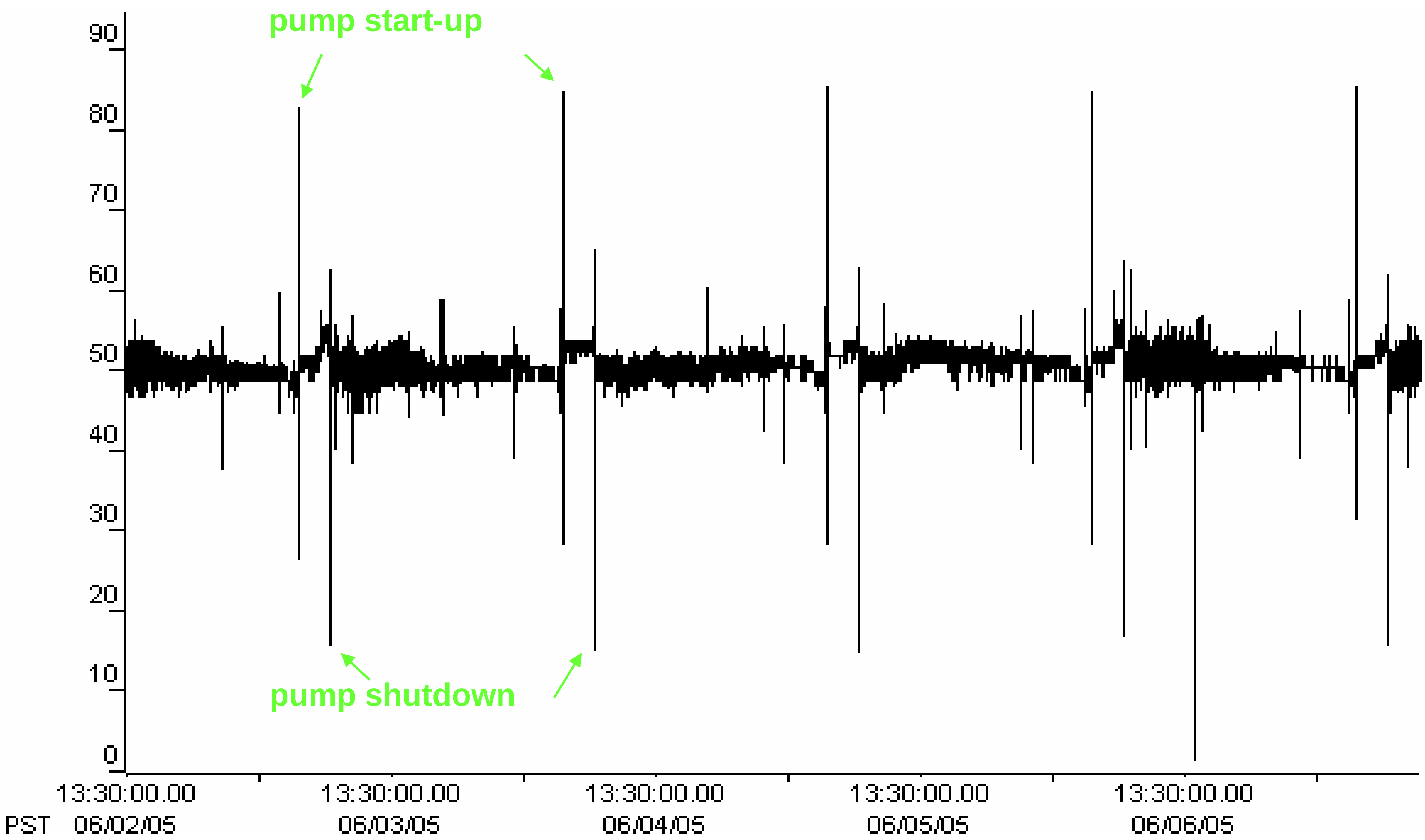
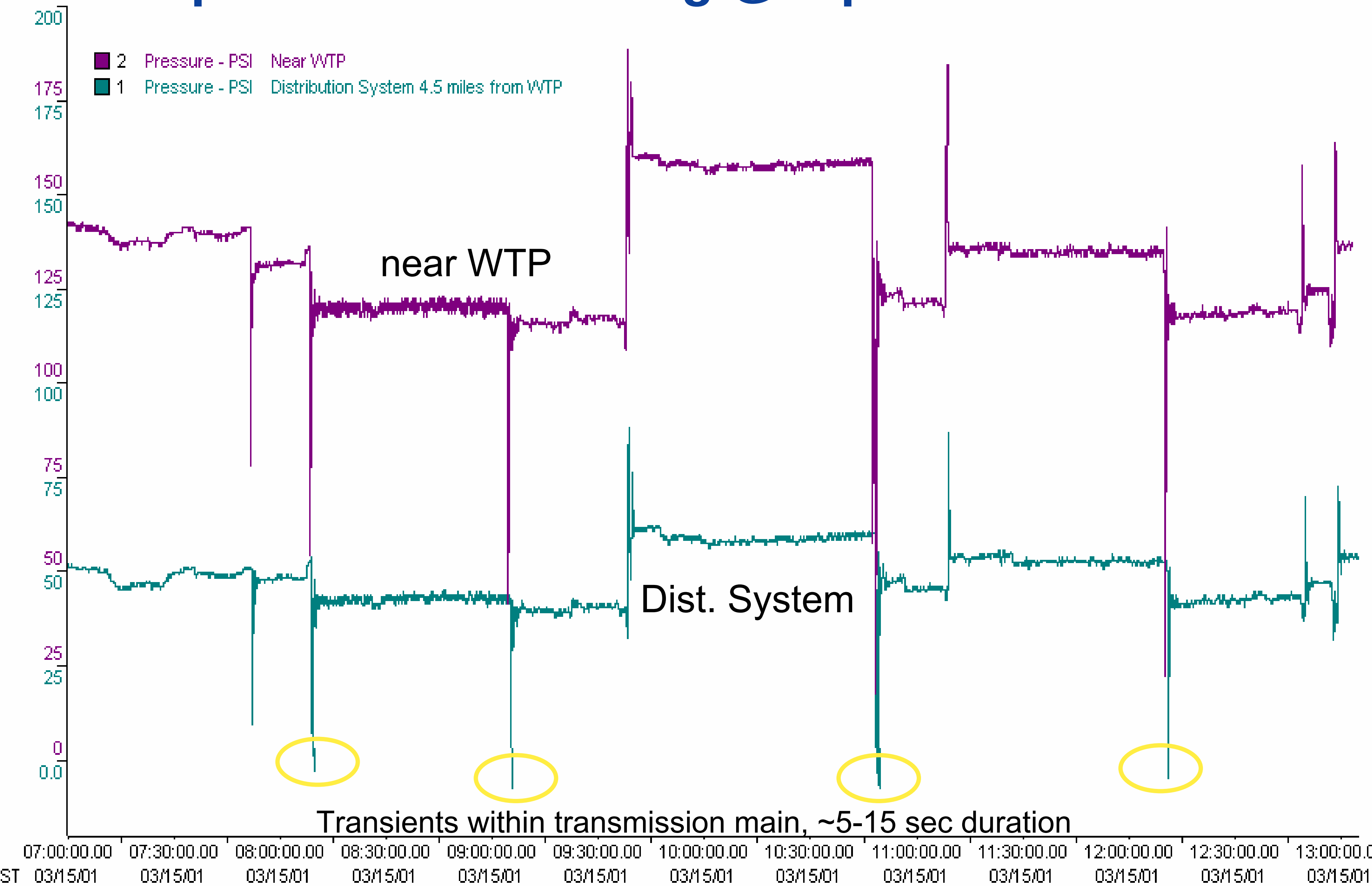
Pump station 5-min Pressure Recording



Distribution System Pressure @ 1 per sec



Pump Drawdown Testing @ 1 per sec



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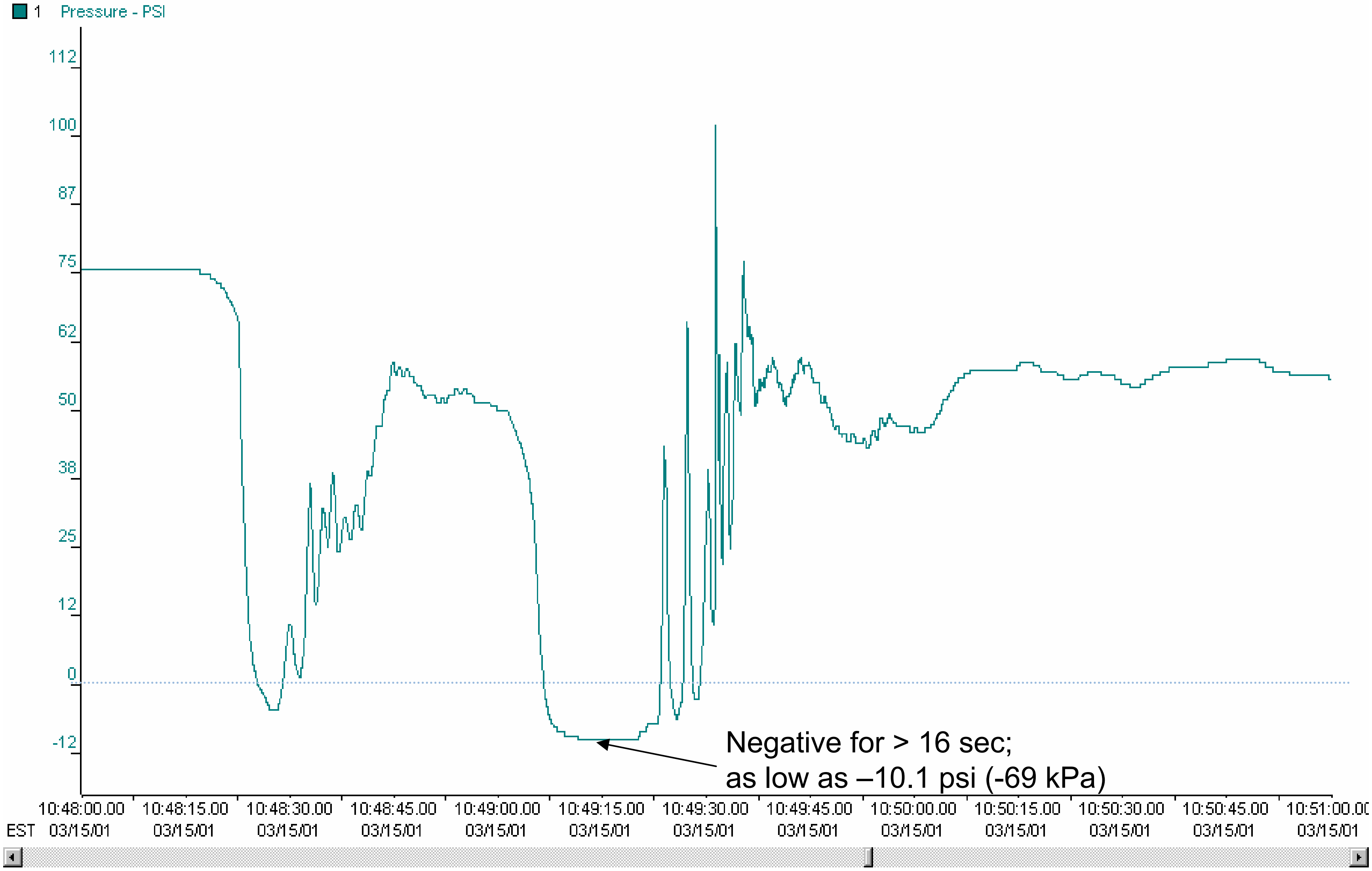

Gullick et al. 2005. *J. Water Supply & Technol. – AQUA* 54(2): 65-81.

Transient Pressures from Unsteady Flow

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power loss at pump → **velocity change** → **pressure wave**

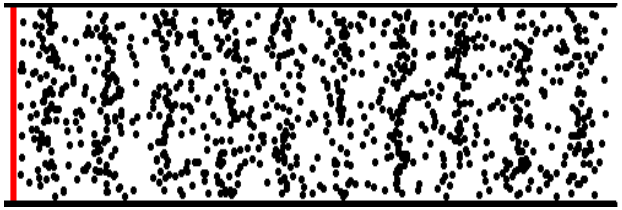
$$\Delta H = (c / g)\, \Delta V$$

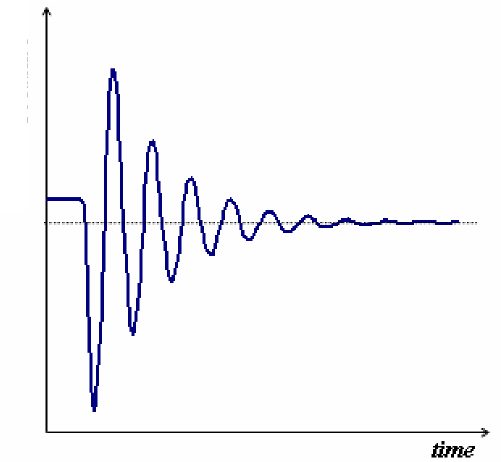
ΔH = instantaneous pressure head change downstream of pump

c = wave speed

g = acceleration

ΔV = change in velocity





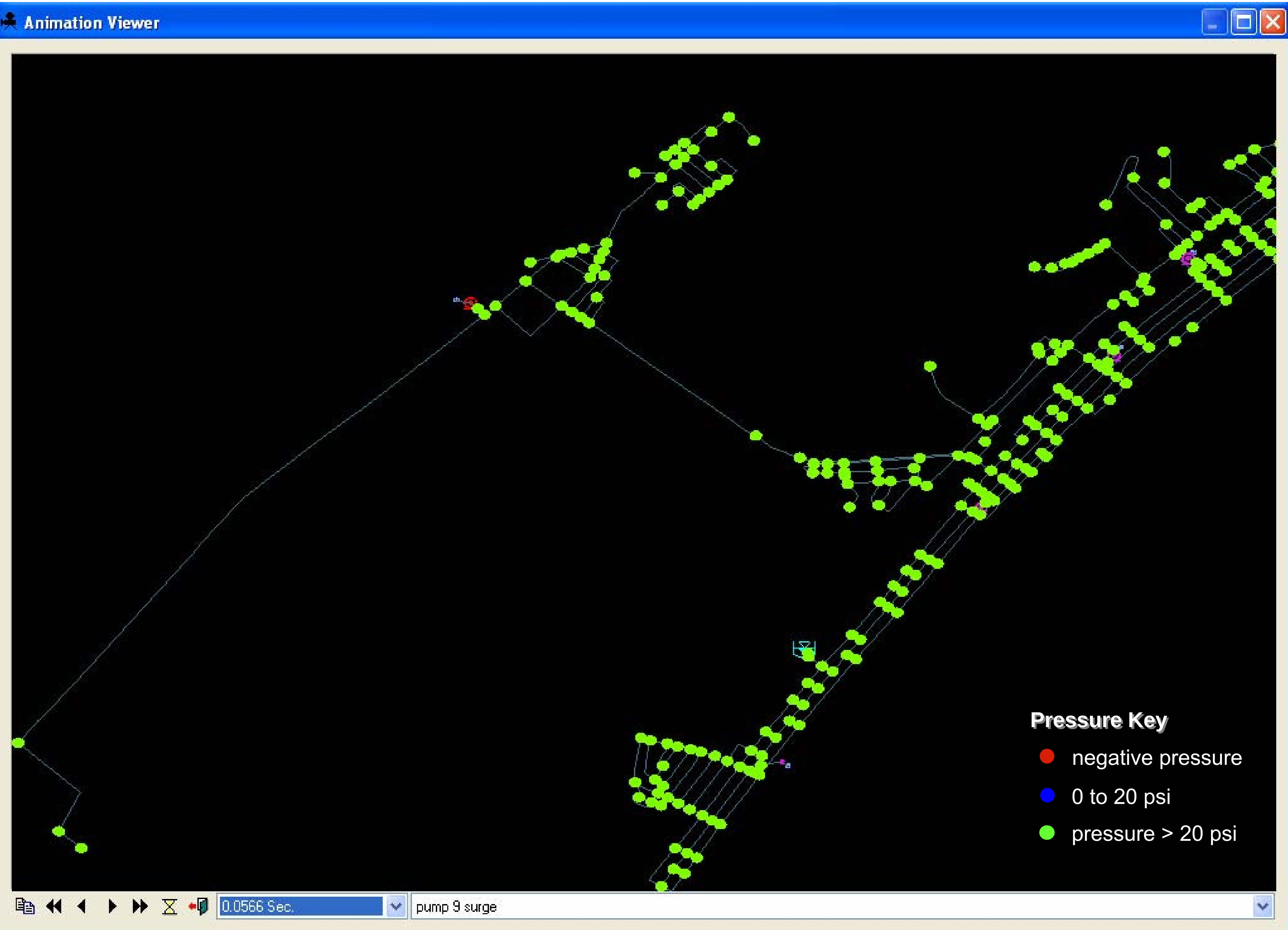
http://www.kettering.edu/~drussell/Demos/waves/wavemotion.html

Low Pressure Transients

- backflow of contaminants

High Pressures Transients

- main breaks
- leaks


Animation Viewer
Pressure Key
negative pressure
0 to 20 psi
pressure > 20 psi
0.0566 Sec.
pump 9 surge

Sources of Pressure Transients

Service interruptions

- Power failure
- Main breaks

Sudden change in demand

- Flushing operations
- Opening and closing a fire hydrant

service interruptions

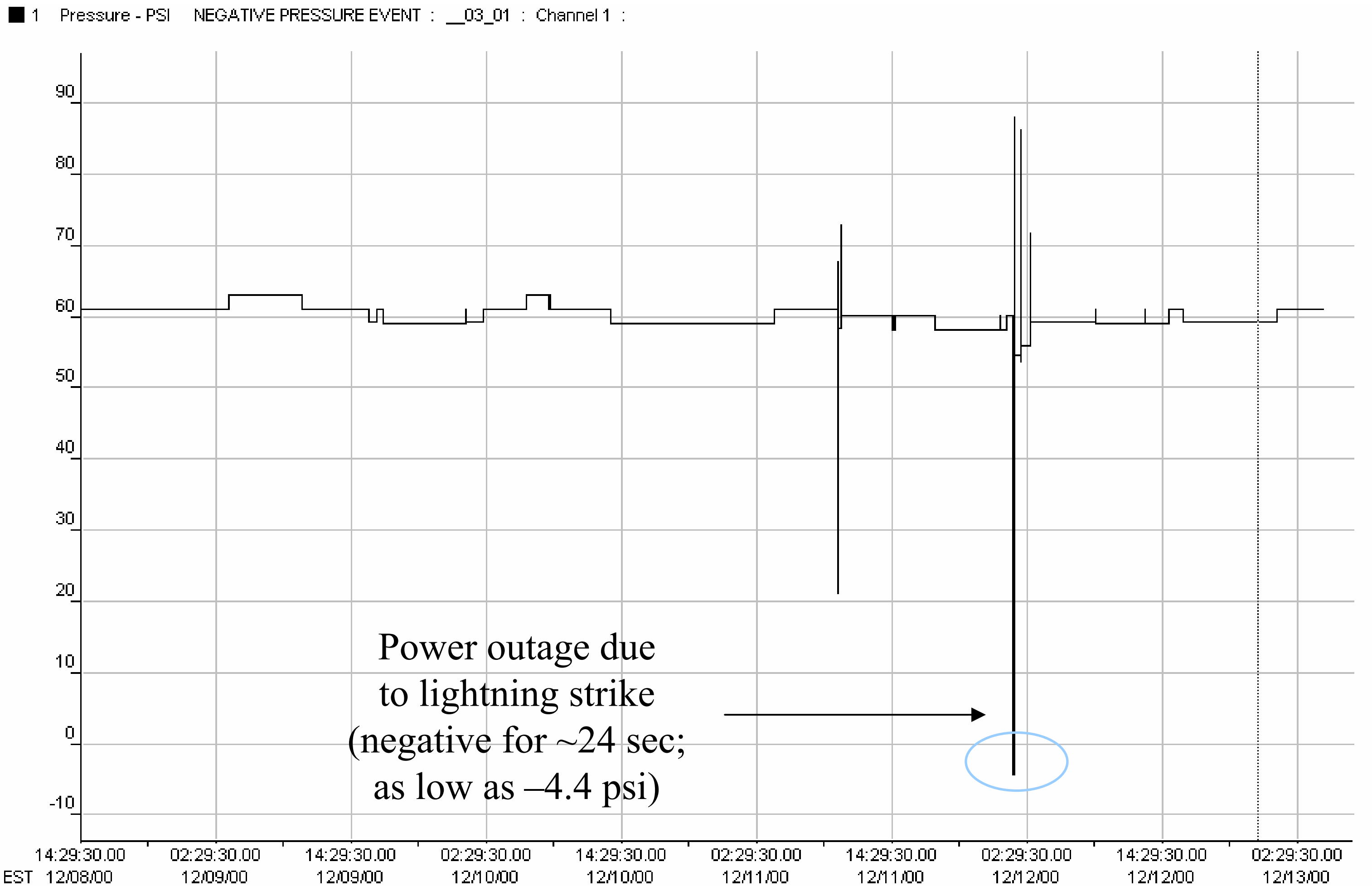
routine operations

demand change

Routine distribution system operation

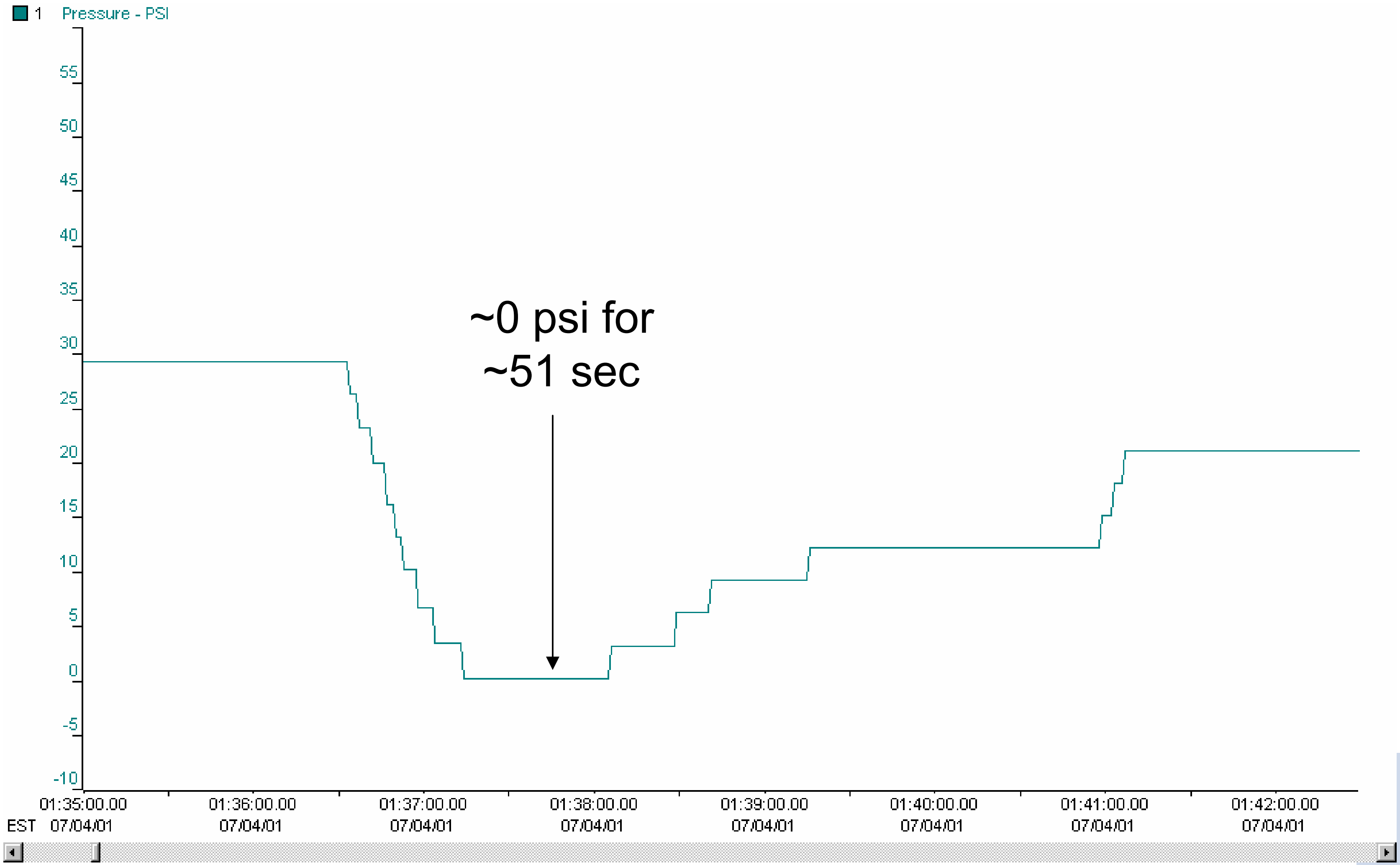
- Pump startup and shut down
- Feed tank draining
- Surge tank draining
- Valve operation: open/close

Power Outage – Case #1



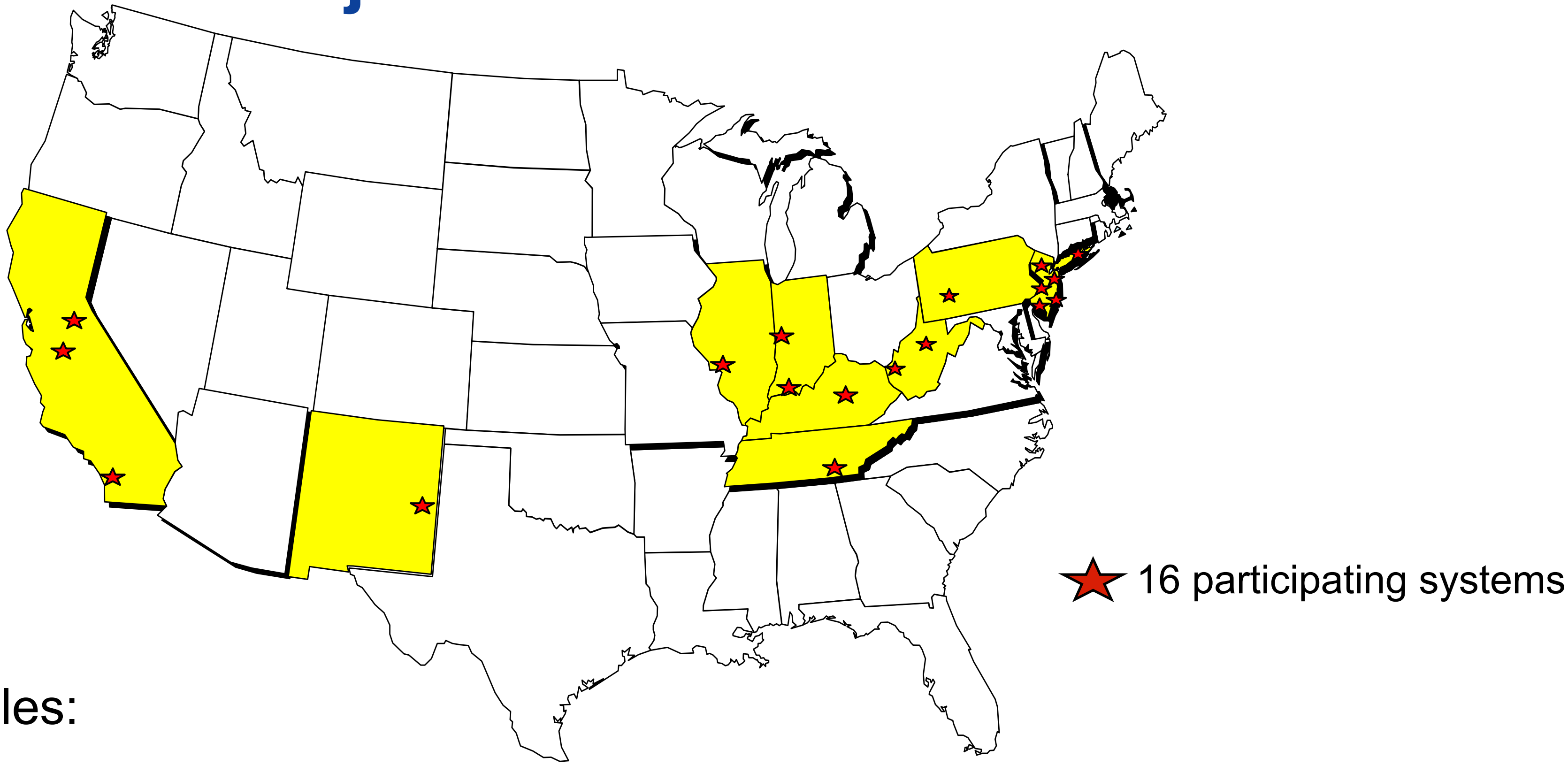
Transient follows a power outage at a pumping station

Power Outage – Case #2



Transient follows a power outage at the treatment plant

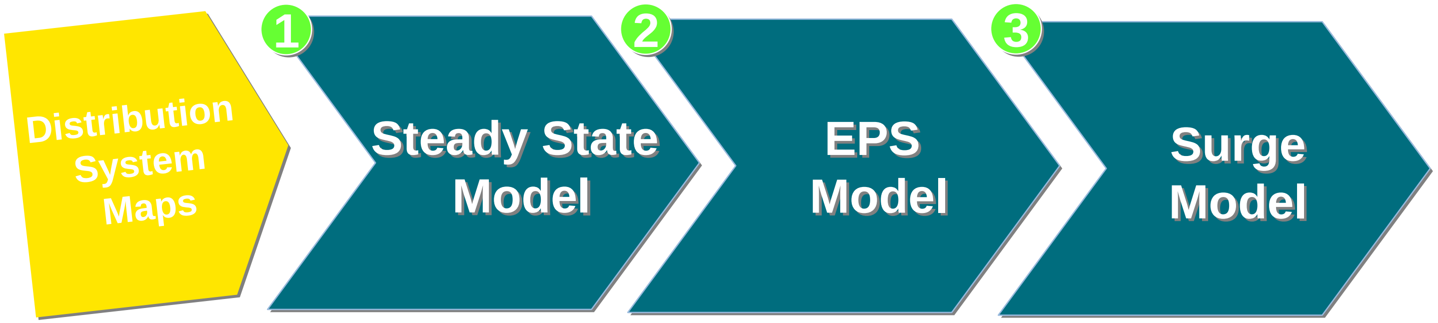
AwwaRF Project # 3008 Overview



Variables:

- system size: 0.1 – 39 mgd
- number of pumped sources (1 to 29)
- pressure zones (1 to 24)
- topography/elevation (flat, moderate, hilly)
- distribution storage facilities (0 – 18 floating tanks)
- Surge relief features

Evolution of a Surge Model



1 **Steady State Model**

Key step for all other modeling steps

Establishes physical system

Snapshot of only one time

2 **EPS Model**

Extended period simulations typically capture system operation over 24 hours

3 **Surge Model**

Determines how sudden changes in flow impact system pressures

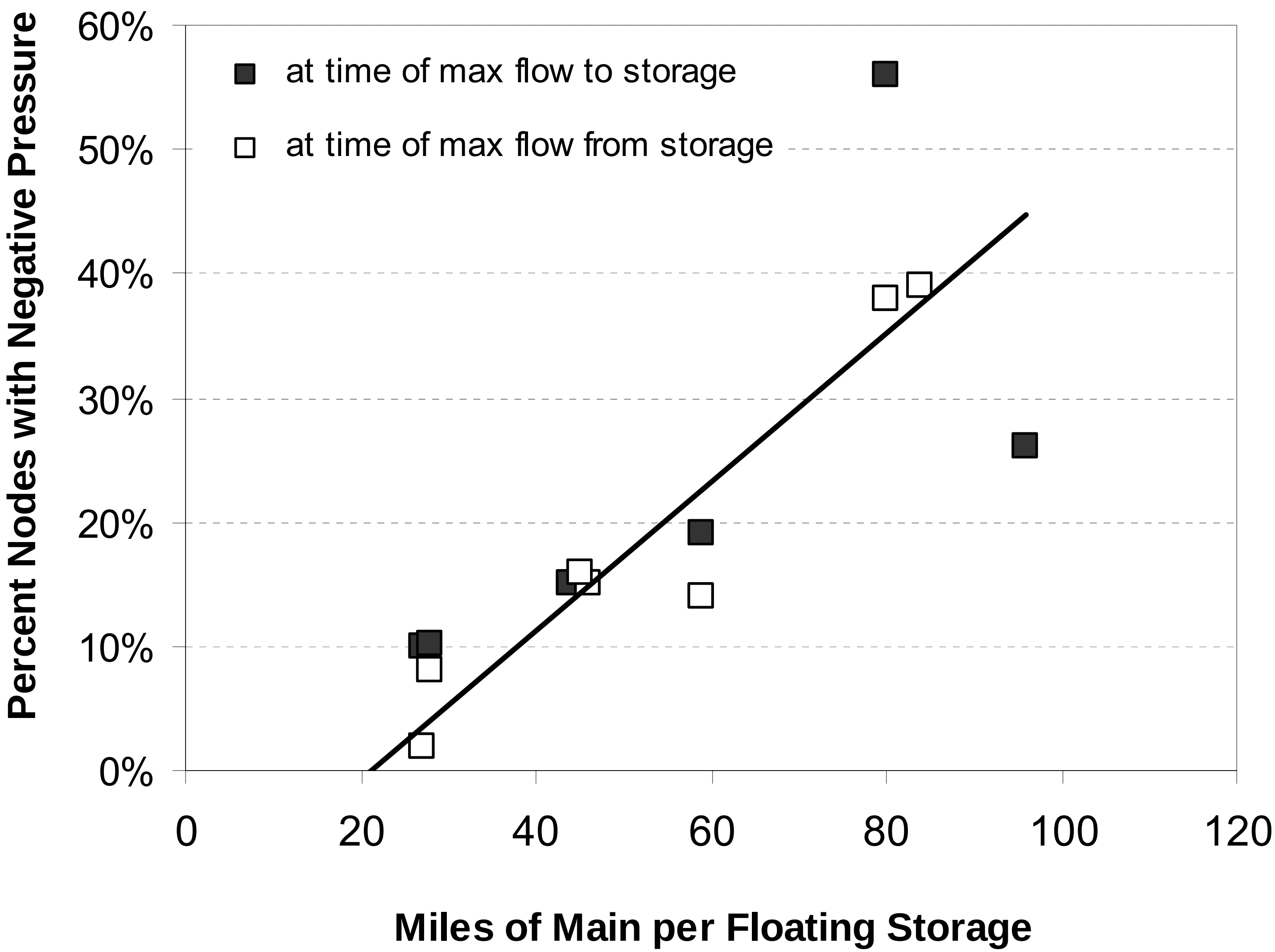
Transient Modeling: Significant Findings

- In the absence of surge mitigation at pump stations, all distribution systems were susceptible to low/negative pressure fluctuations

- Susceptibilities ranged from 1% to 98%
  - water velocity, number of floating storage facilities, number of source inputs and system configuration influence system vulnerability
  - Velocities greater that 3 ft/s downstream of pump stations increase the risk of low/negative transient pressures

Fleming et al. 2006. *Susceptibility of Distribution Systems to Negative Pressure Transients.* Awwa Research Foundation, Denver, CO.

Storage Reduces Susceptibility



Other Factors Influencing Susceptibility

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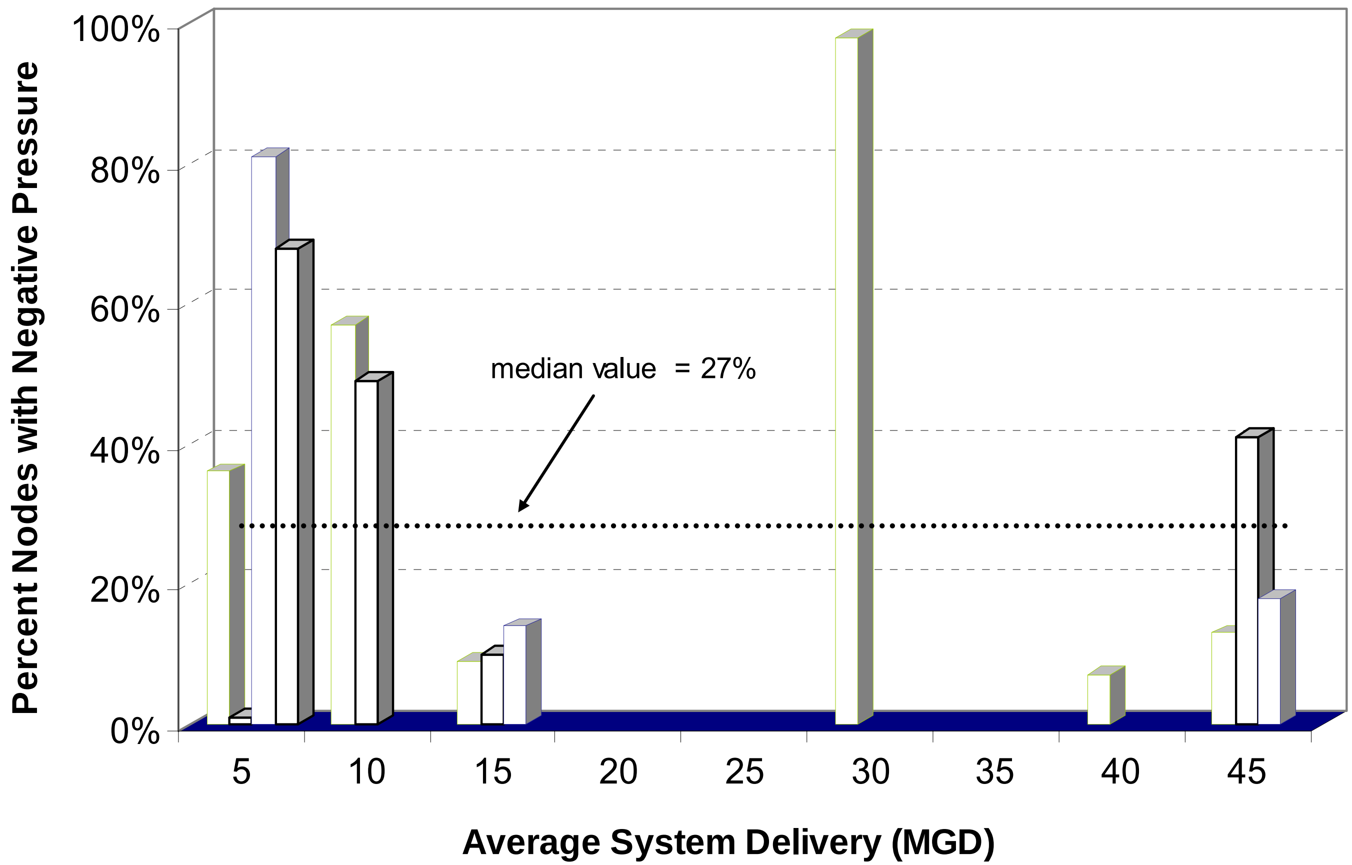
System Size

- Smaller systems showed increased susceptibility
- Presence of fewer floating storage facilities per miles of distribution system mains may explain the observation



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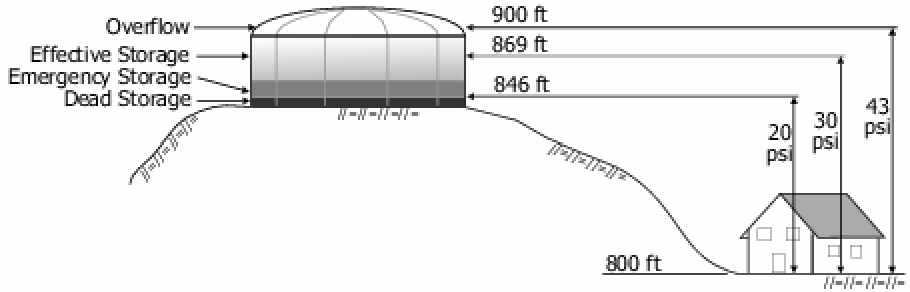
Surface vs Ground

- Groundwater systems may have an increased susceptibility to low/negative pressure transients



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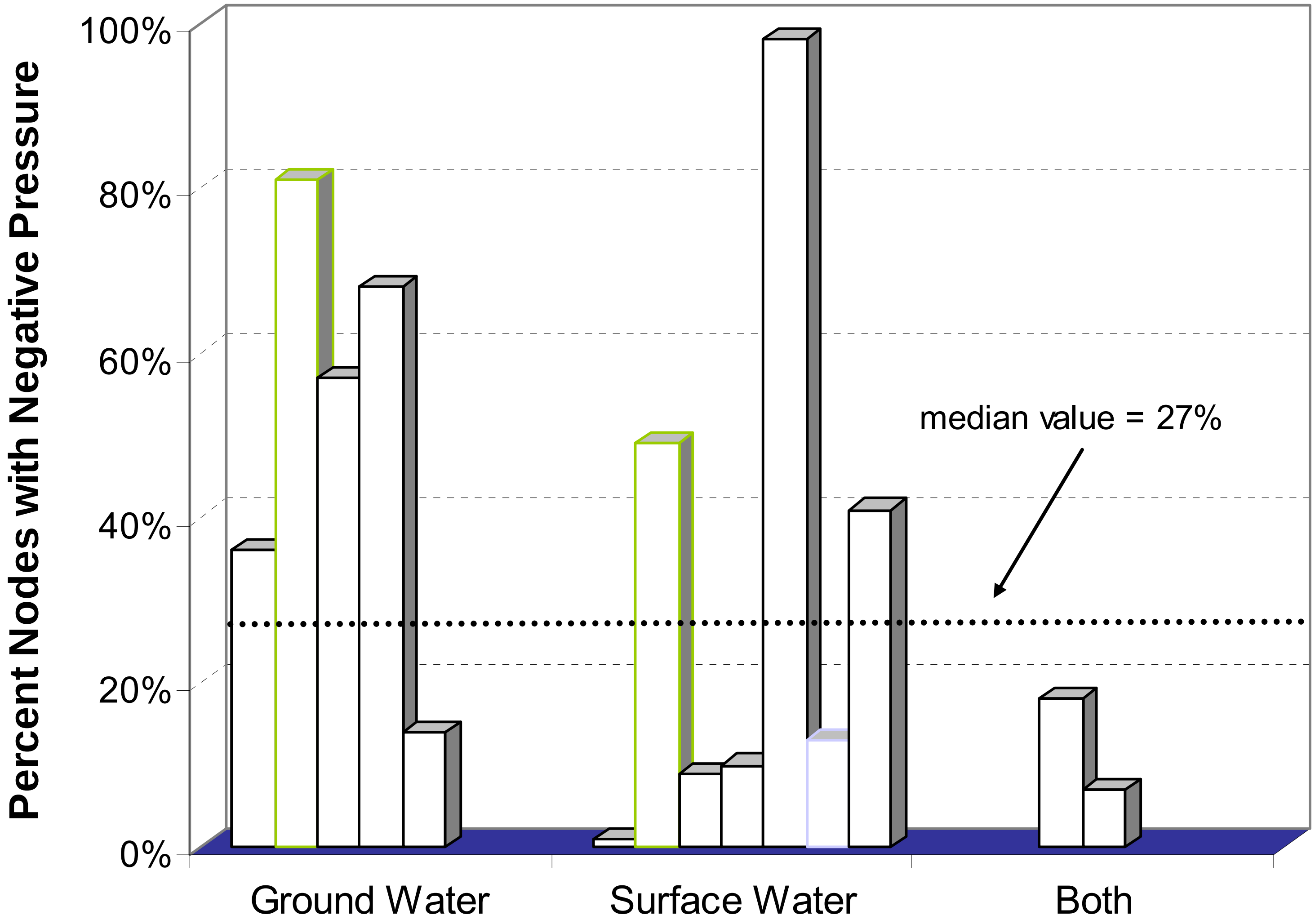
Surface vs Ground Water Source



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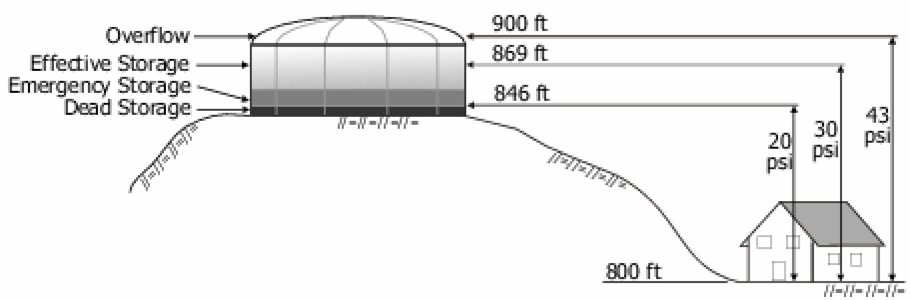
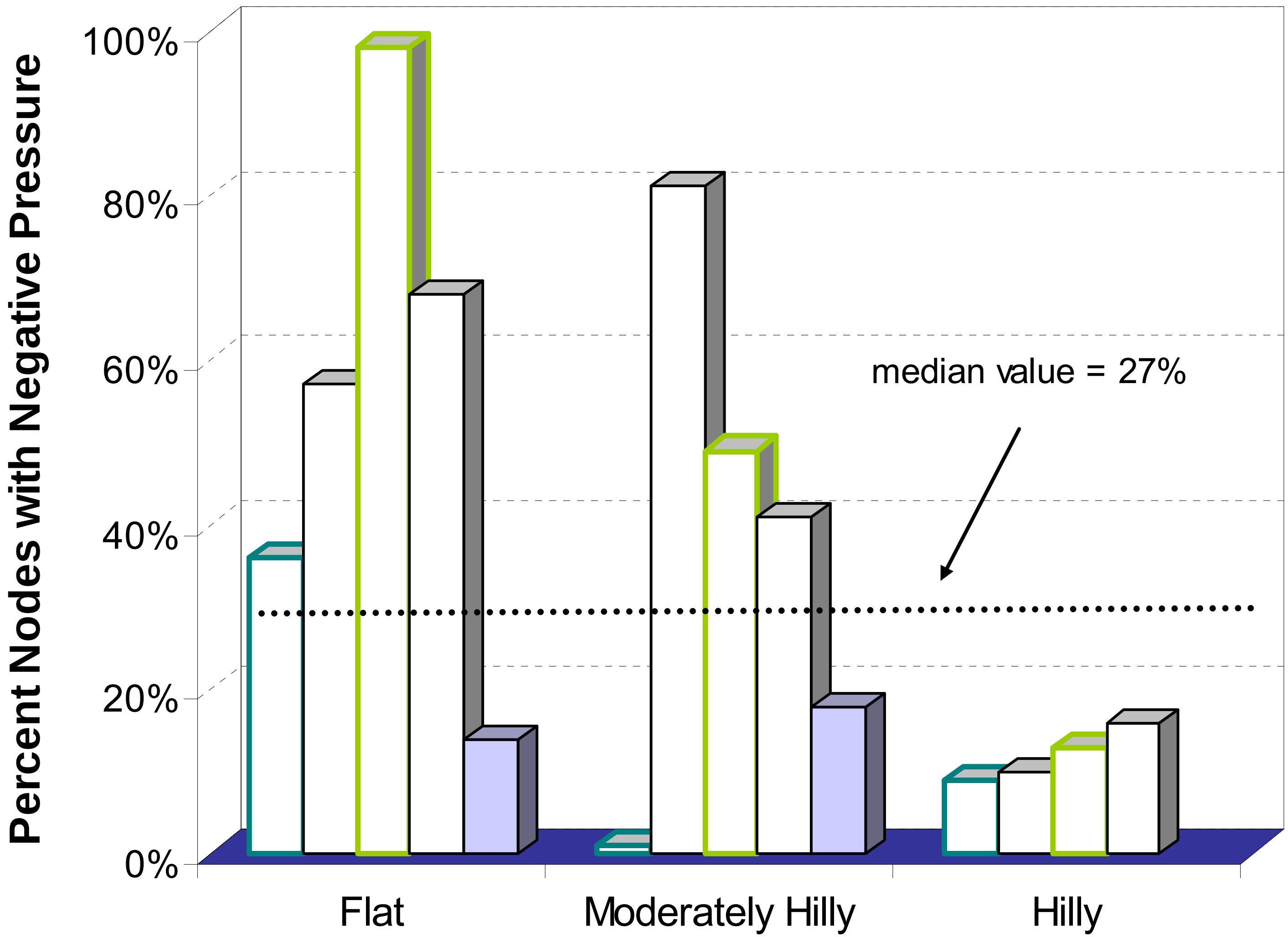
System Config.

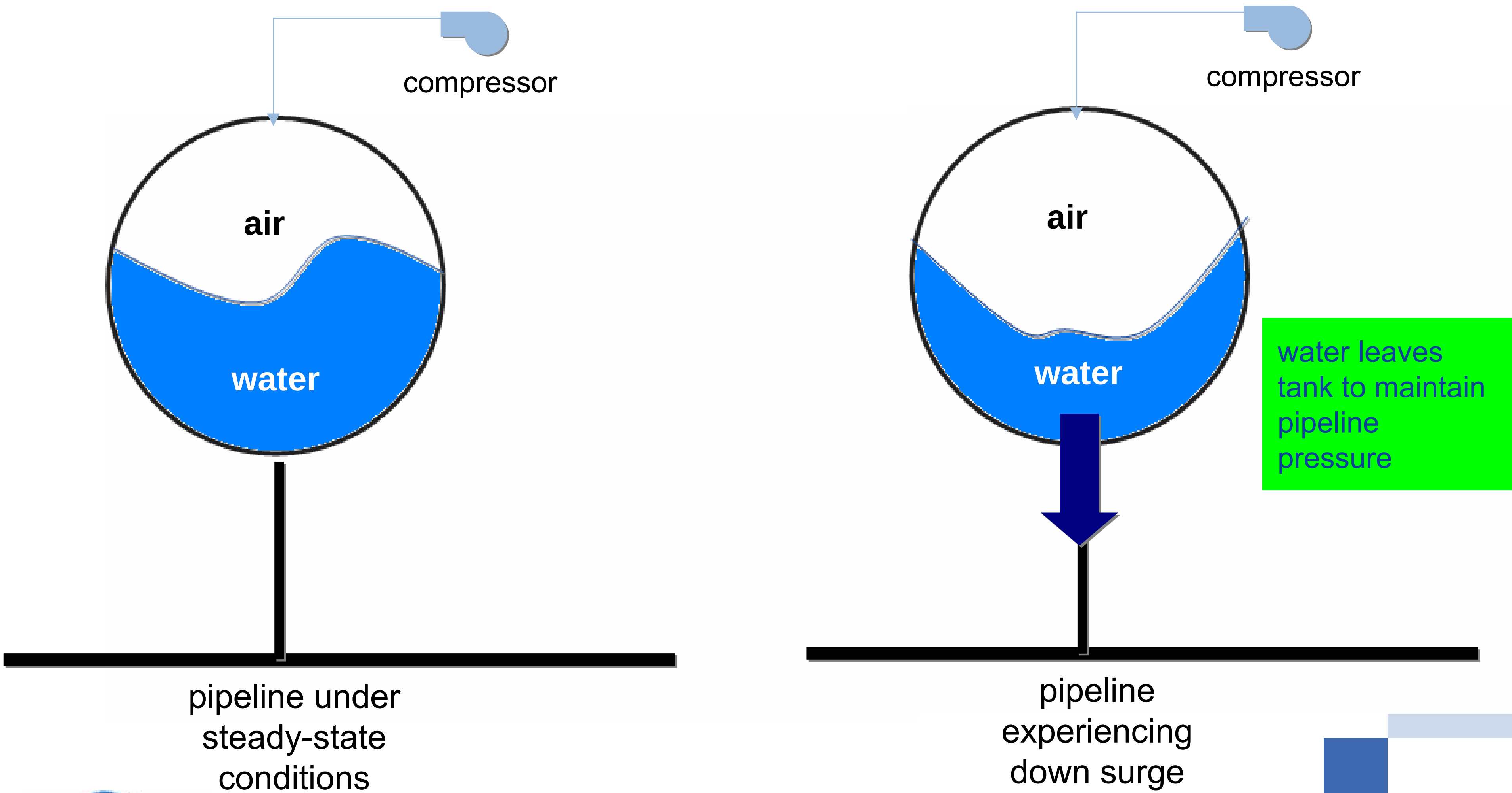
- Hilly distribution systems (> 150 ft elevation difference) showed less susceptibility
- Locations at or near dead ends were more susceptible to negative pressures

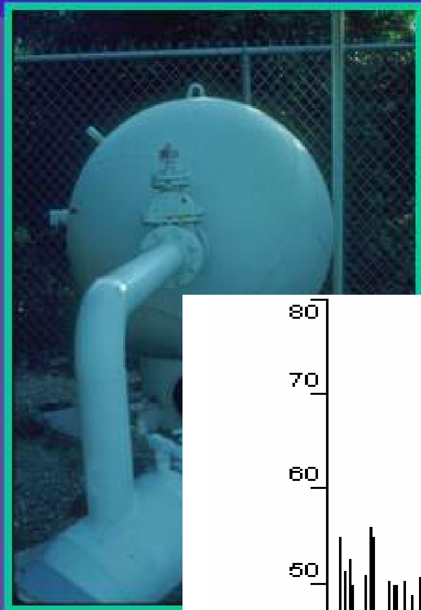


System Configuration

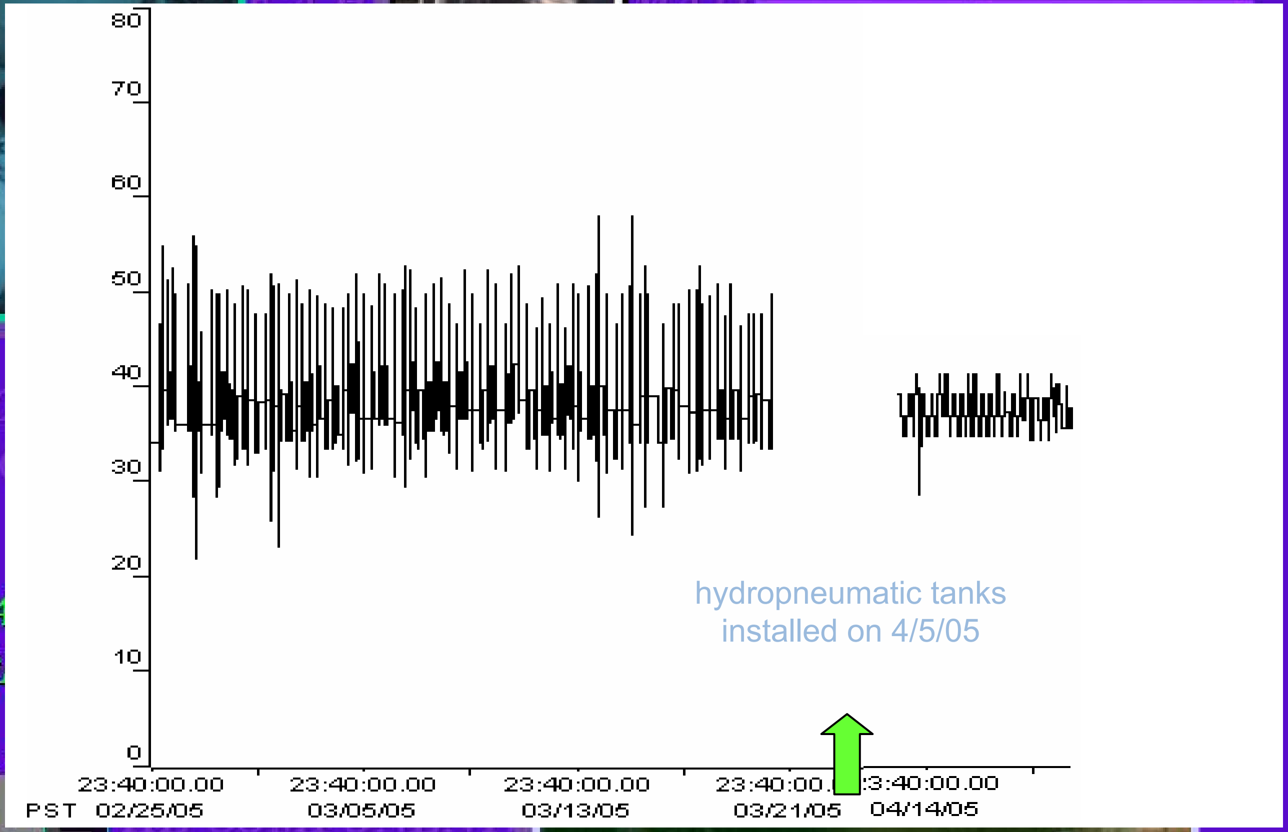


Surge Control: Hydropneumatic Tanks





In modeling simulations, relatively small hydropneumatic tanks (1,000 gal or less) reduced the magnitude of down surges in many systems

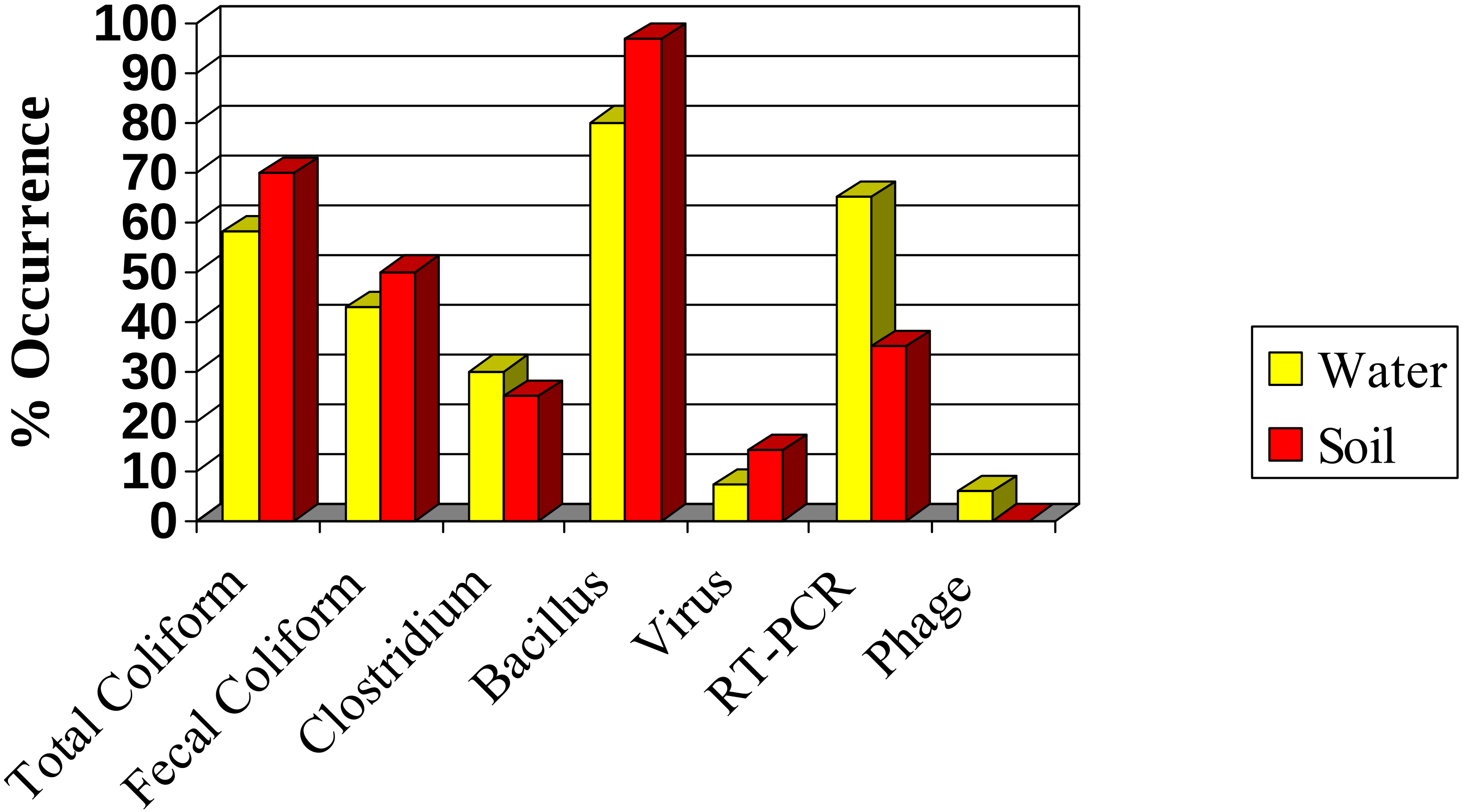


Pressure Surges as a Potential Contamination Route

- Intrusion of outside water into the distribution system may potentially occur during periods of low or negative pressures if there is an opening in the pipe (e.g., a hole or crack) and the external head > internal head

- Studies (Karim et al. *JAWWA* 95(5): 134-146, 2003) have shown that soil and non-potable water surrounding distribution pipes can contain a variety of microbiological pathogens, including fecal indicators and culturable human viruses

Microbial Occurrence



Overall 56% (18/32) of samples were positive for viruses: enteroviruses (Sabin strain), Norwalk, and Hepatitis A virus

Microbe Concentration in Water & Soil

Microbes	**Water** CFU or PFU/100 ml	**Soil** CFU or PFU/100 gm
Total coliform	2 - > 1.6×10^3	20 - > 1.6×10^4
Fecal coliform	2 - 5×10^2	20 - > 1.6×10^4
Clostridium	5×10^2 - 2.5×10^3	5×10^3 - 1×10^5
Bacillus	5×10^2 - 4.6×10^6	6×10^4 - 1.2×10^8
Phages	2.5×10^2 - 1×10^4	0

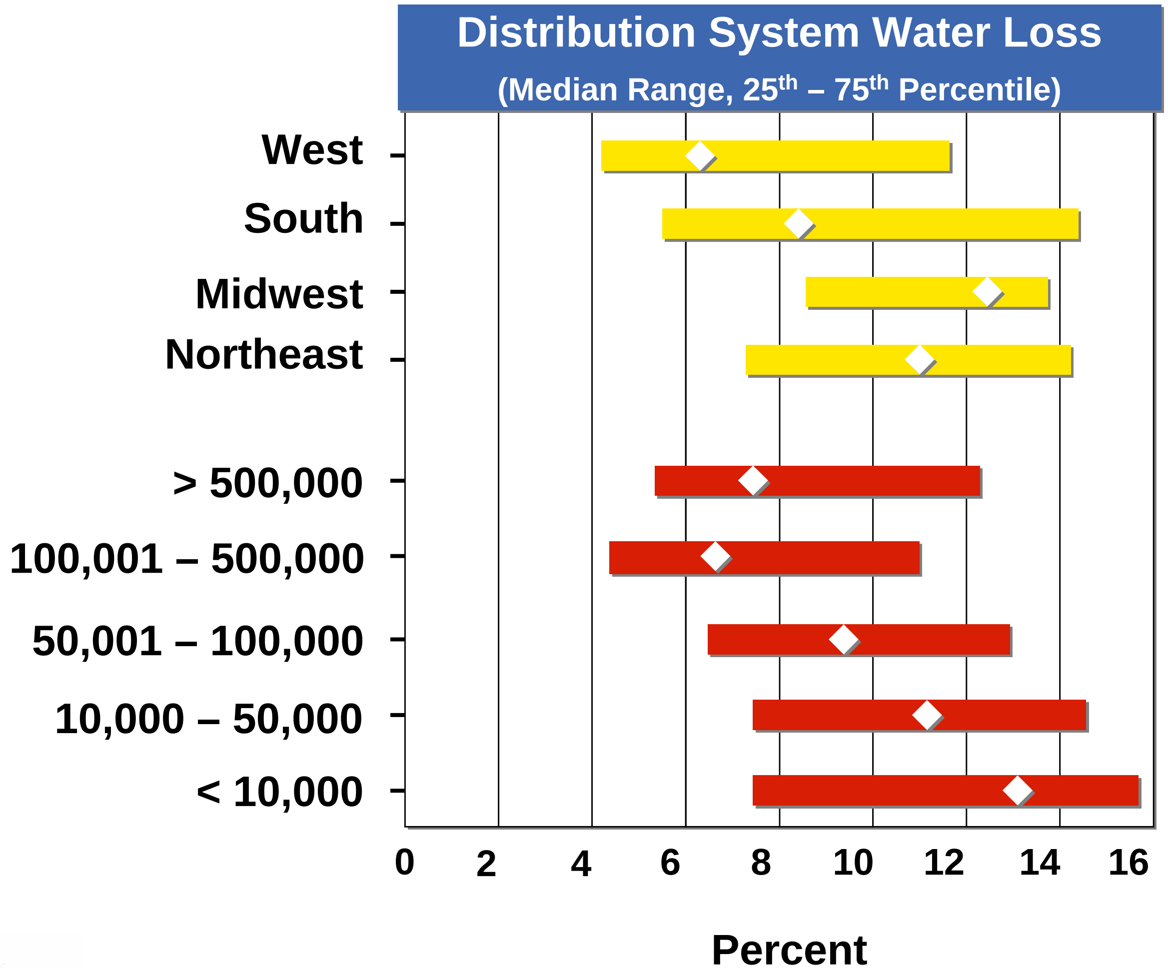
Karim et al. 2003. *JAWWA* 95(5): 134-146.

Separation from Sewer Lines

- Typical separation distance: 10 feet (3 m)
- Standards allow for minimum of 18 in. (0.5 m) separation

Leakage Facilitates Intrusion

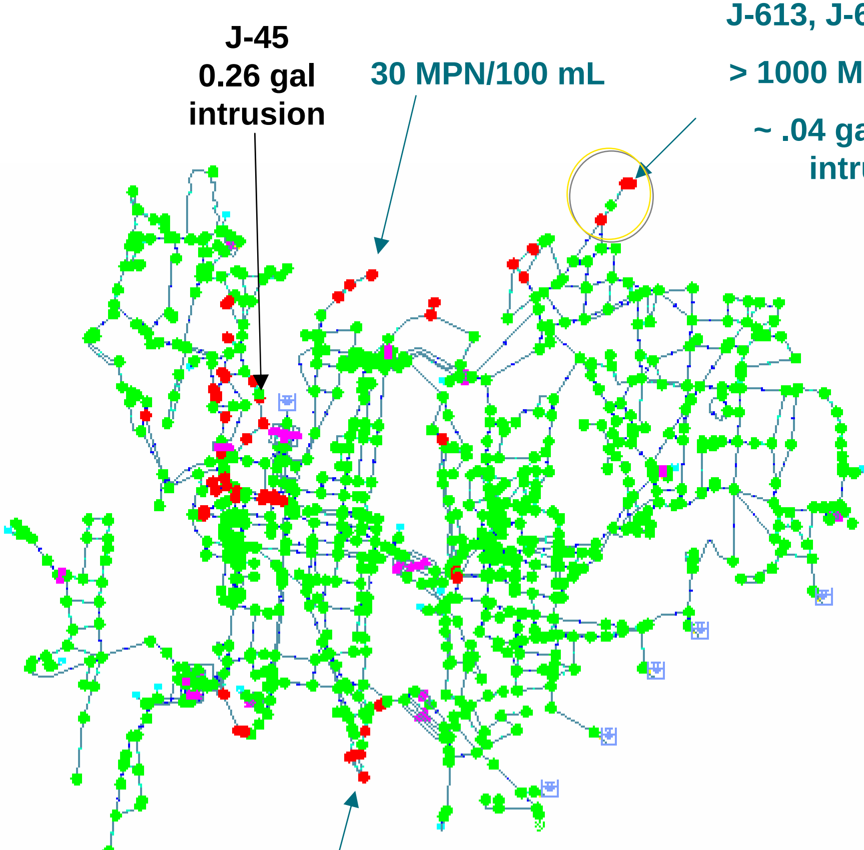
$$\text{distribution water loss (\%)} = 100\left[\frac{\text{volume distributed} - (\text{volume billed} + \text{volume unbilled but authorized})}{\text{volume distributed}}\right]$$

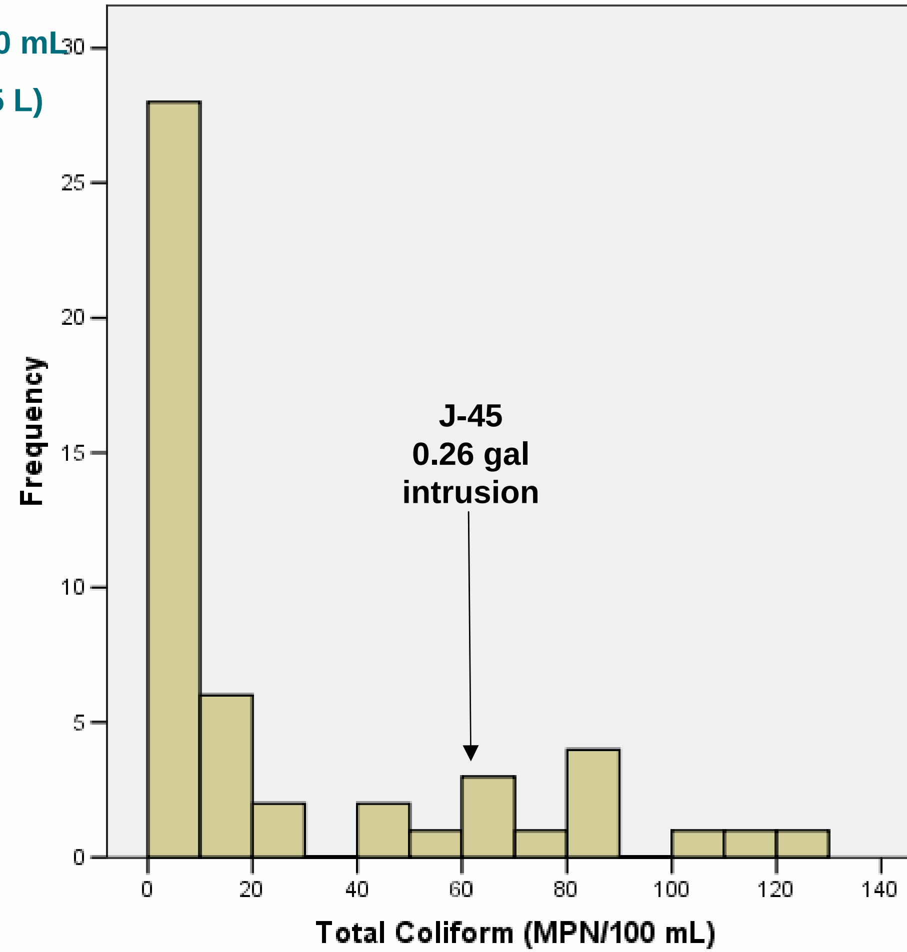


Source: AWWA 2005 – *Benchmarking Performance Indicators for Water and Wastewater Utilities*

121 Participants

Intrusion Could be Responsible for Some Coliform Positive Samples…

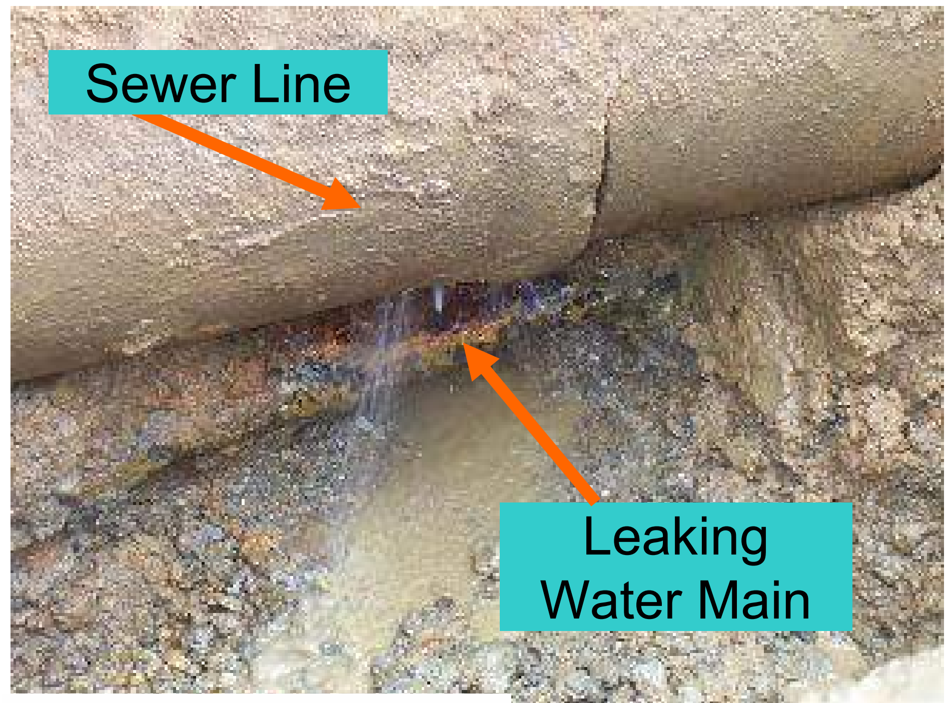


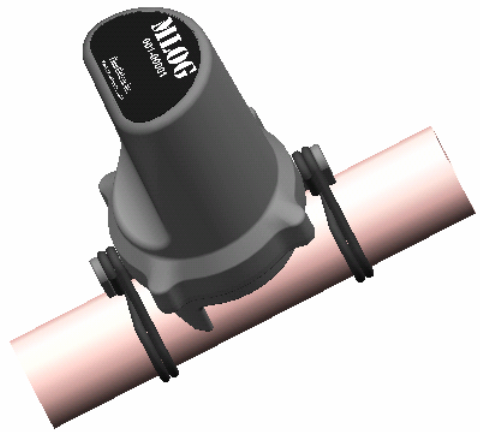


For intruded volume, assume total coliforms = 1.6×10^3 MPN/100mL & fecal coliforms = 5×10^2 MPN/100mL

Acoustic Monitors can Detect Leaks

- A pilot study of 500 MLOG units in Connellsville, PA has detected 46 leaks, 50% of the annual non-revenue water loss, within the first 6 months of monitoring.
  - 24 leaks before surfacing
  - 10 leaks surfaced before repairs
  - 12 leaks surfaced without an acoustic signature
- NRW dropped from 25% to <10%, representing an annual reduction of $250,000 in purchased water expense. Estimated pay-back in 6-8 months.





Morgan, W. 2006. JAWWA 98(2): 33-35.

Examples of Acoustic Signatures

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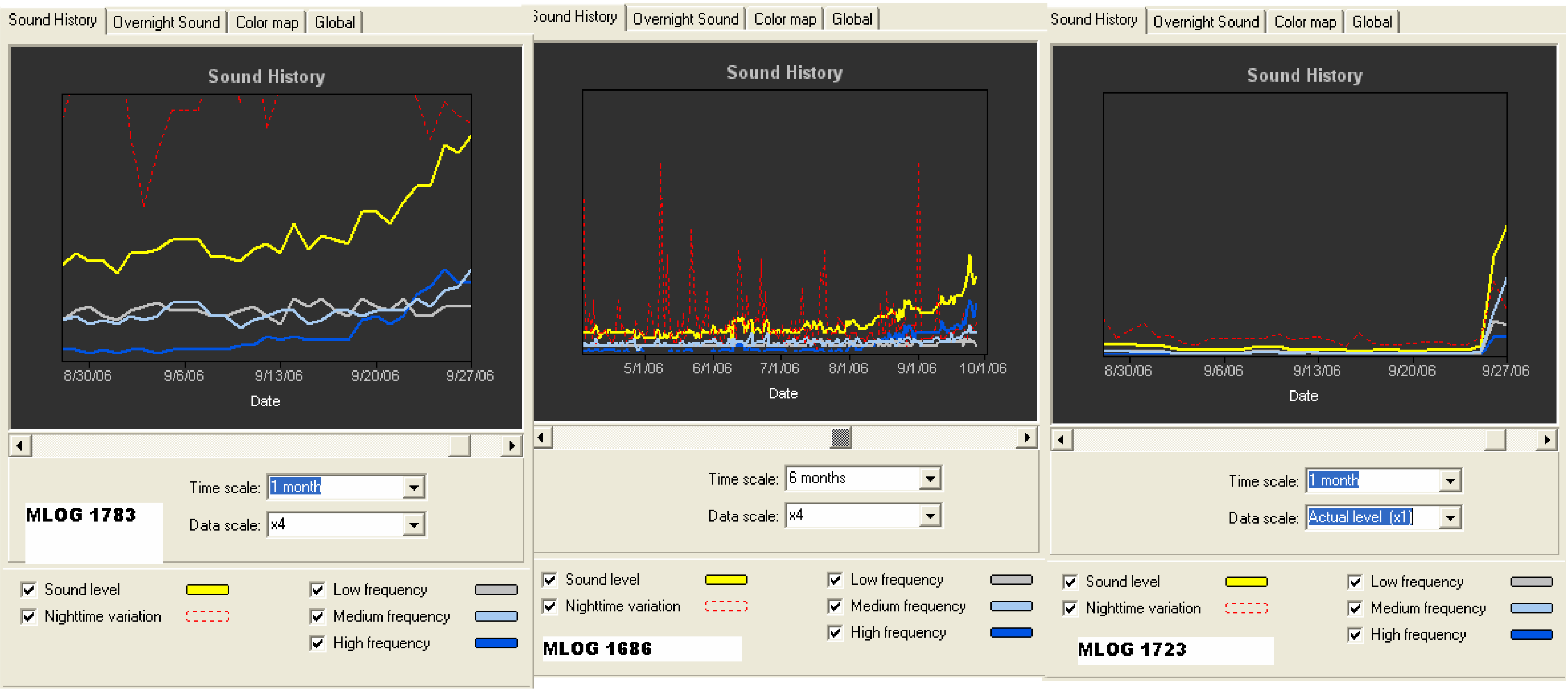

- Research will evaluate whether most winter breaks are actually unseen leaks that can be repaired before the disruptive main break ever begins

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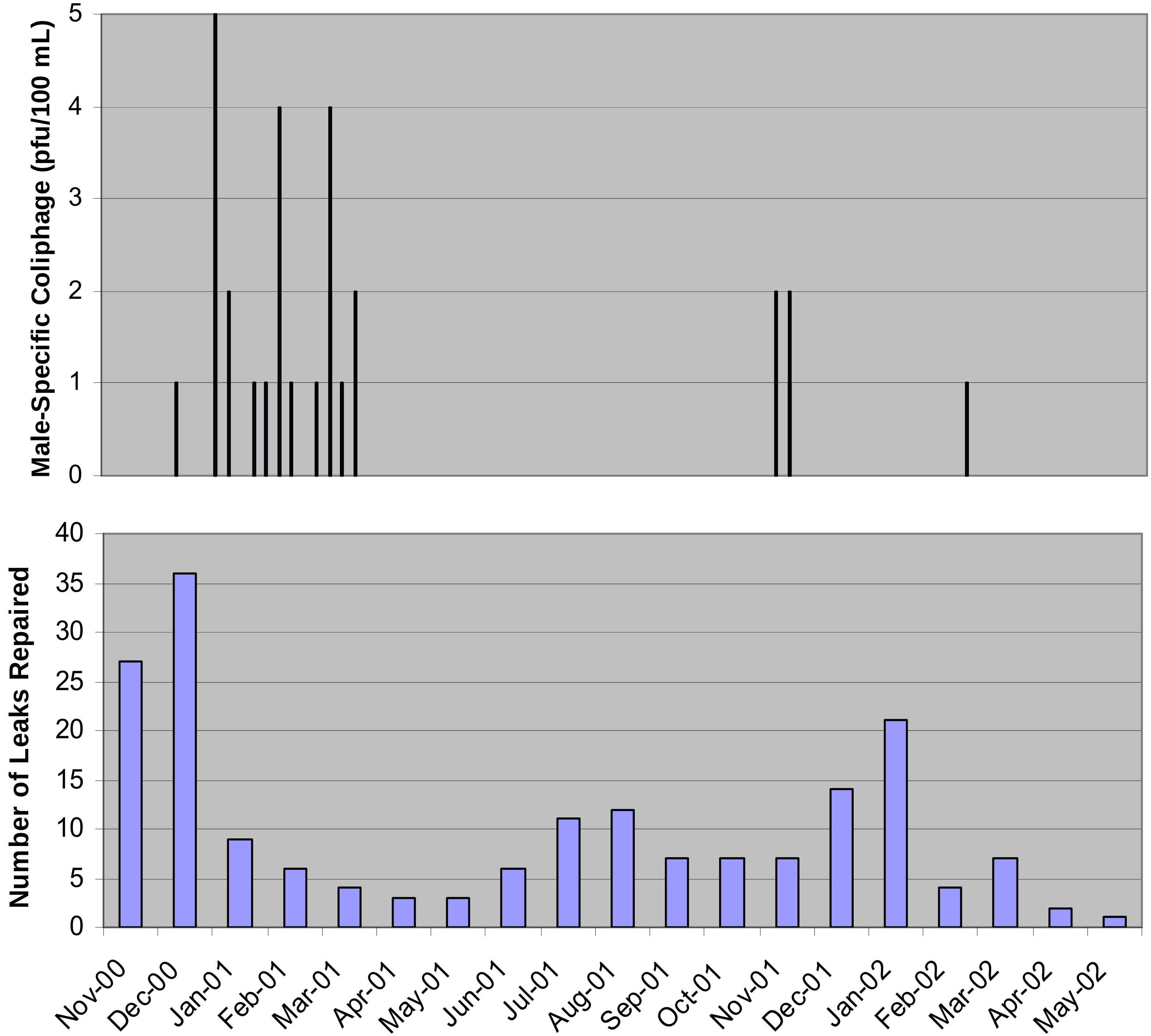
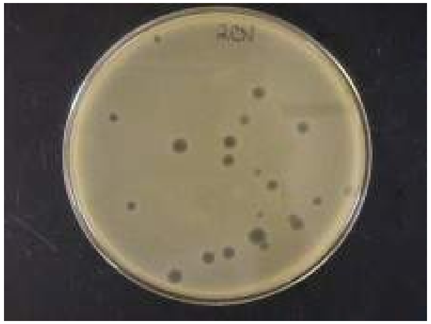


Male-Specific Coliphage (pfu/100 mL)
0
1
2
3
4
5
Number of Leaks Repaired
0
5
10
15
20
25
30
35
40
Nov-00
Dec-00
Jan-01
Feb-01
Mar-01
Apr-01
May-01
Jun-01
Jul-01
Aug-01
Sep-01
Oct-01
Nov-01
Dec-01
Jan-02
Feb-02
Mar-02
Apr-02
May-02

Coliphage as Indicators of Distribution System Integrity

- Over 77% of the positive coliphage samples occurred with 72 hours of a main break.



- For December 2000 through February 2001, between 2 and 13 main breaks occurred in the 7 days prior to the positive coliphage result.
- 91% of main breaks on the day prior to the positive coliphage results were in the pressure zone that fed the sampling locations
- For chloraminated water (1 mg/L residual at 5^{o}C) viruses could survive for 39 hours chloramines (CT_{99} of 2,334 mg·min/L based on MS2 in laboratory-grade water).
- Strains isolated from human feces are typically groups II and III, while groups I and IV are usually found in animal feces. All isolates were serotype 1.

LeChevallier. 2006. *JAWWA* **98(7):** 87-96.

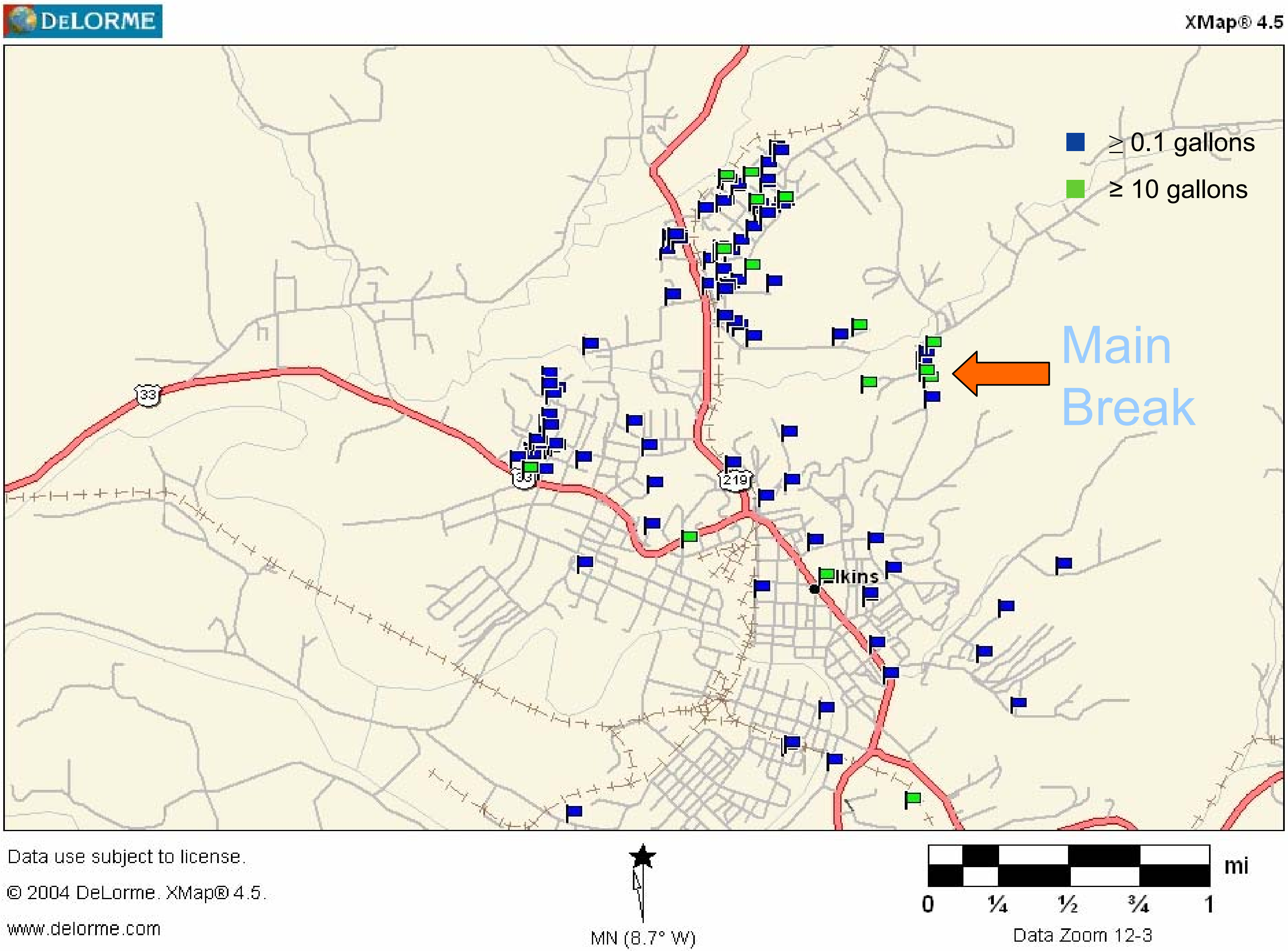
Evidence of Backflow – West Virginia

- A community of 3900 customers outfitted with Neptune backflow sensing meters providing continuous monitoring for a 35 day period.
  - Low level event 0.10 gallons of backflow in any 15 minute interval

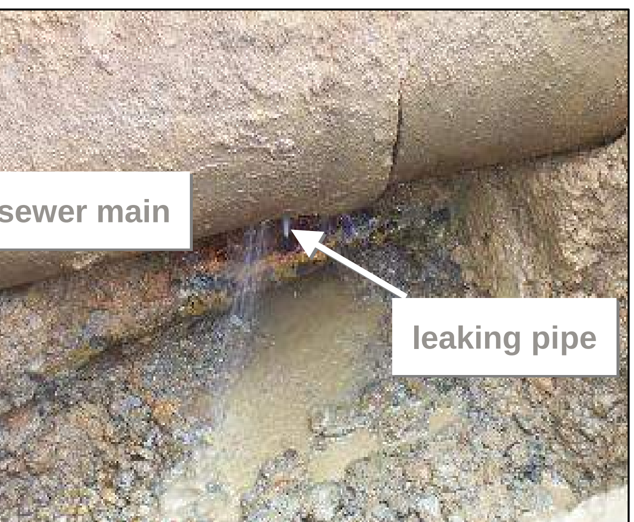
  - High level event 10.0 gallons in any 15 minute internal
- In one data set there were 199 events (5.1%) of population apparently clustered given address locations.
  - 163 locations with low level backflow (4.2%)
  - 36 locations with high level backflow (0.9%)

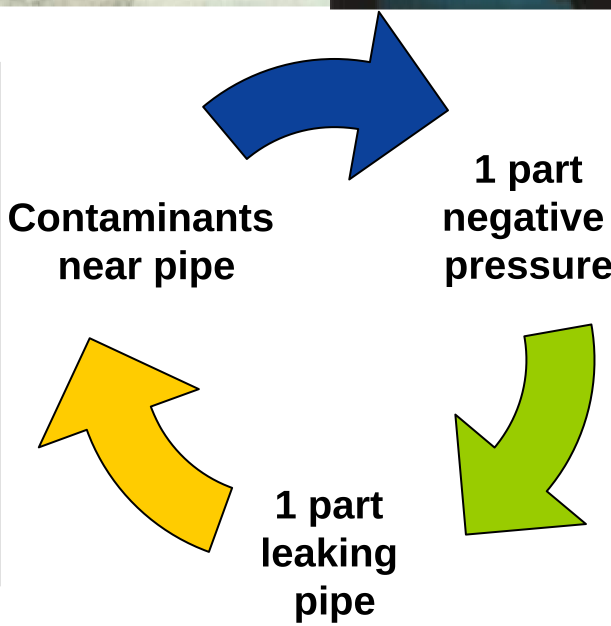
Backflow Sensing Meters

American Water



Intrusion Summary





Conclusions

- **Recognize that intrusion is a possible contamination mechanism**
- **Maintain effective disinfectant residual throughout distribution system**
- **Application of high speed pressure recorders**
  - Determine effect of routine operations on system pressures
  - Develop internal control strategies/SOPs to minimize low pressure surges
  - Use data to calibrate surge models
- **Leak detection and main repair/replacement**
  - Water and sewer lines

Conclusions

- **Application of surge mitigation measures**
  - slow valve closure times, avoiding check valve slam, minimized resonance, pressure relief valves, surge anticipation valves, air release valves, combination two-way air valves, vacuum break valves, check valves, surge suppressors, and by-pass lines with check valves, surge tanks or standpipes
- **Role of Surge modeling**
  - Determine system vulnerability
  - Identify regions of system where negative pressures develop
  - Prioritize O&M activities in these areas
  - Evaluate surge control options
- **Personnel training for valve use**
  - Prevention of unauthorized hydrant use
  - Maintenance and repair

Acknowledgements

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Contributions by: Dr. Kala Fleming; David Hughes, PE; Dr. Orren Schneider

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