Susceptibility of PWS to Negative Pressure Transients

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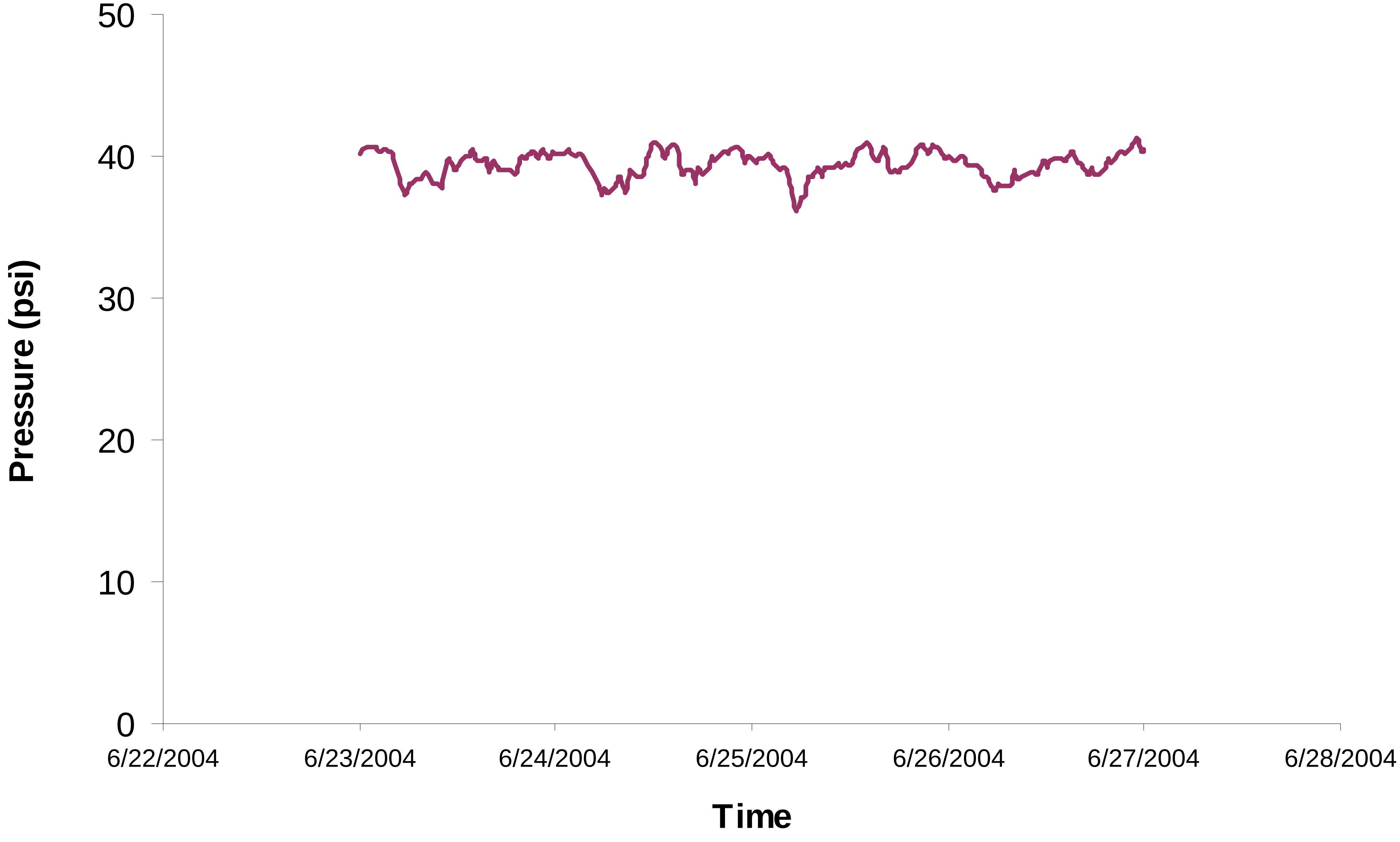
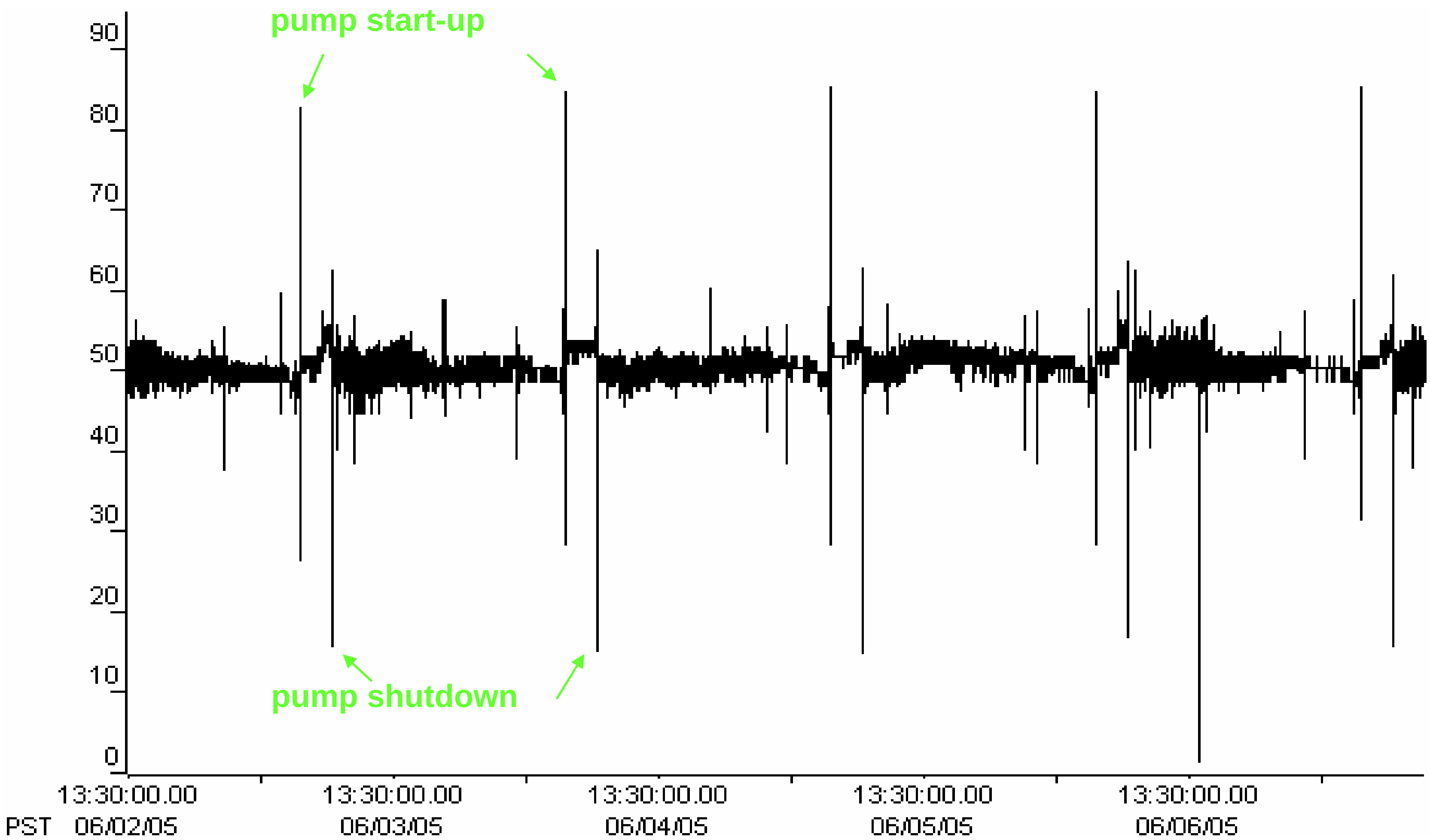
VA AWWA Research Committee Seminar

Monday, October 22, 2007

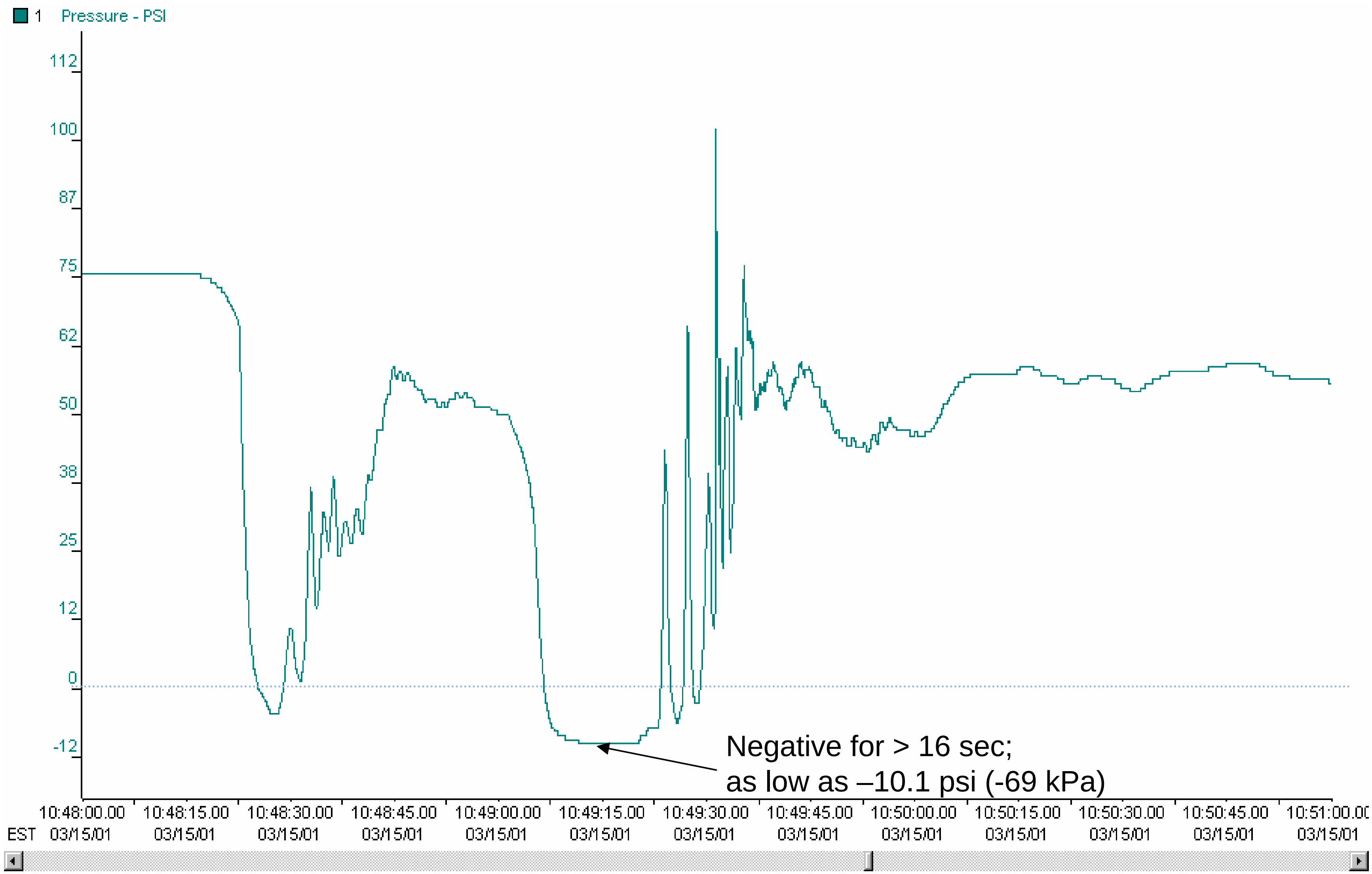
Pump Station 5-min Pressure Recording



DS Monitoring at 1 Reading per sec

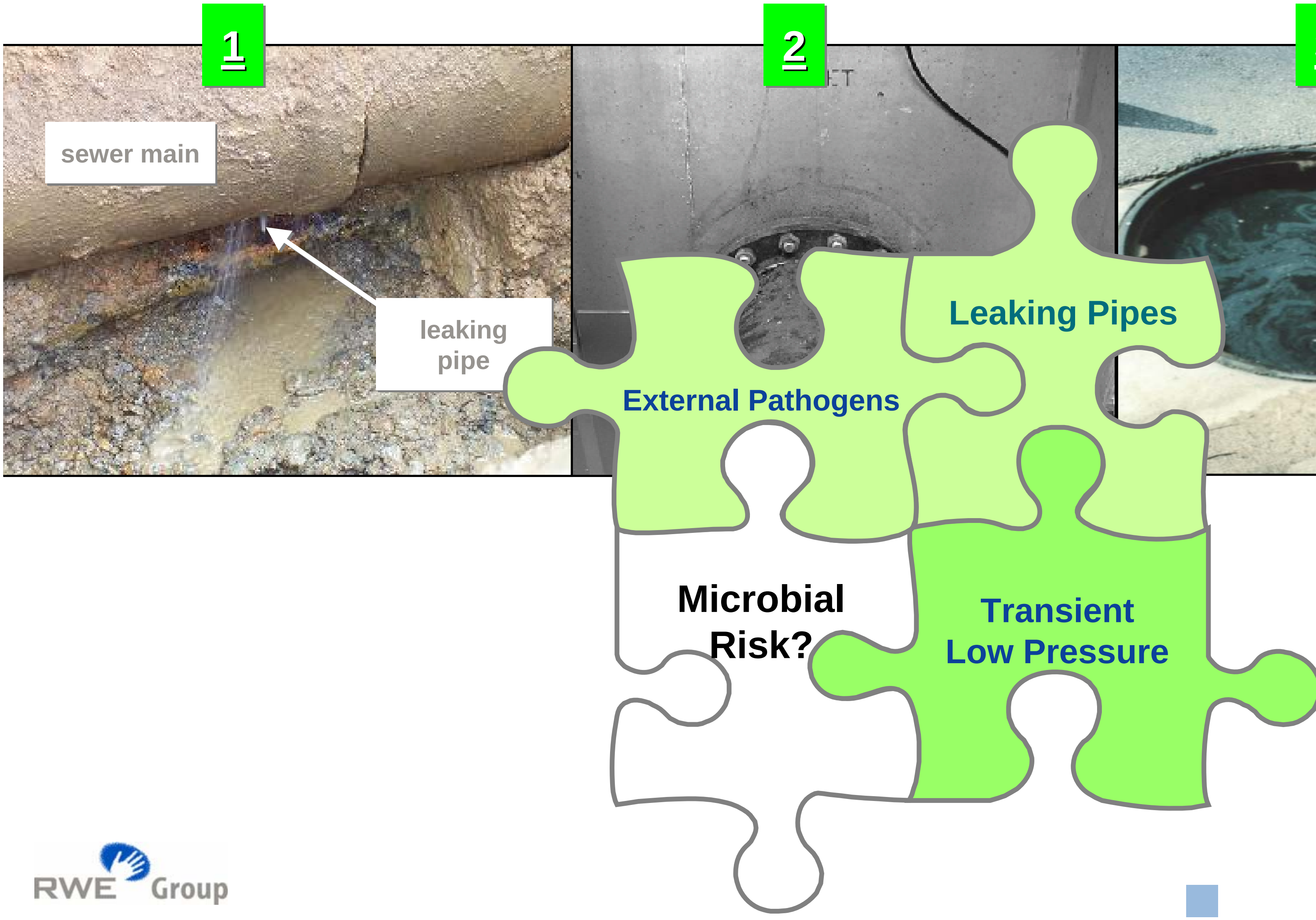


Closer Look at Negative Pressure Profile



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

Why Do Pressure Transients Matter?



Presentation Overview

- **Overview of Transient Pressure:**
  - How do negative transients occur?
  - Evolution of a transient pressure wave
- **Findings of AWWARF Project #3008**
- **IL Case Study:**
  - What locations are impacted when the largest pump station looses power?
  - Which mitigation approach works best?
- **Microbial Risk Assessment**

Sources of Transient Pressures

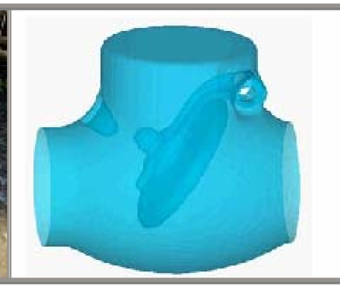
Service interruptions

- 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
- Valve operation: open/close
- Any sudden changes in flow

Transients influenced by fluid properties

- **Fluid Density**
  - water is heavy, large forces required to change flow
- **Fluid Compressibility**
  - water not easily compressed, small mass imbalances cause large forces

Transient Pressures from Unsteady Flow

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

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

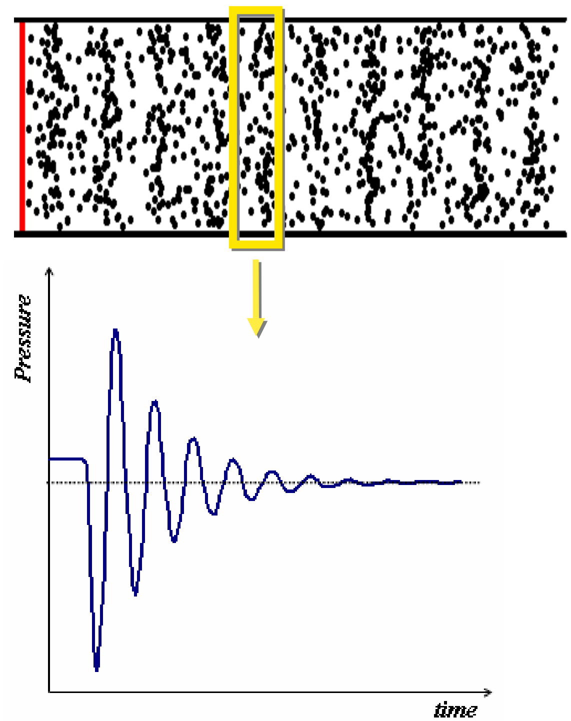
**** only applicable for simple pipeline ****

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

Note: a wave is a disturbance that transmits energy and momentum from one point to another through a medium <u>without significant displacement of matter between the two points</u>

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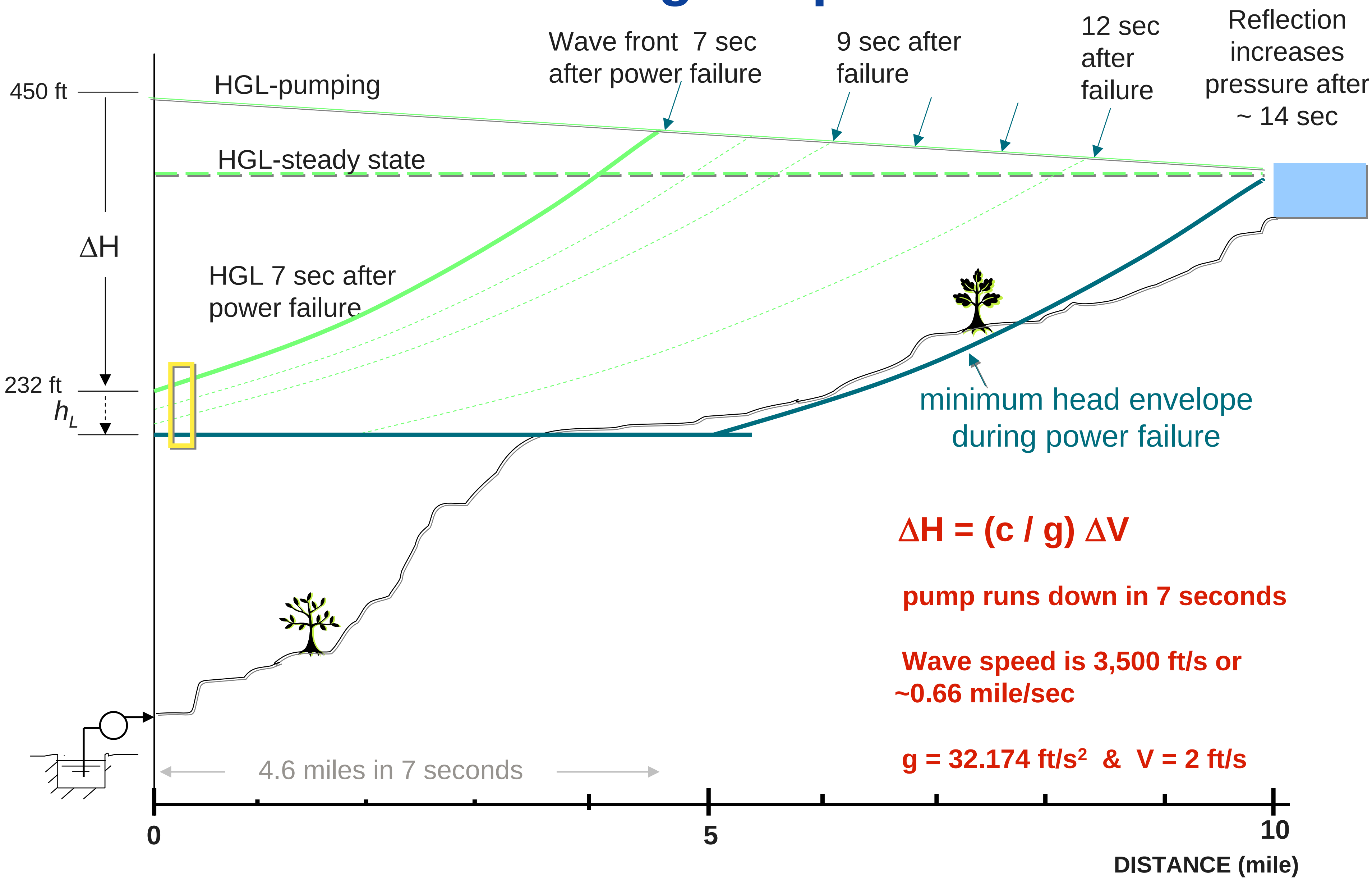
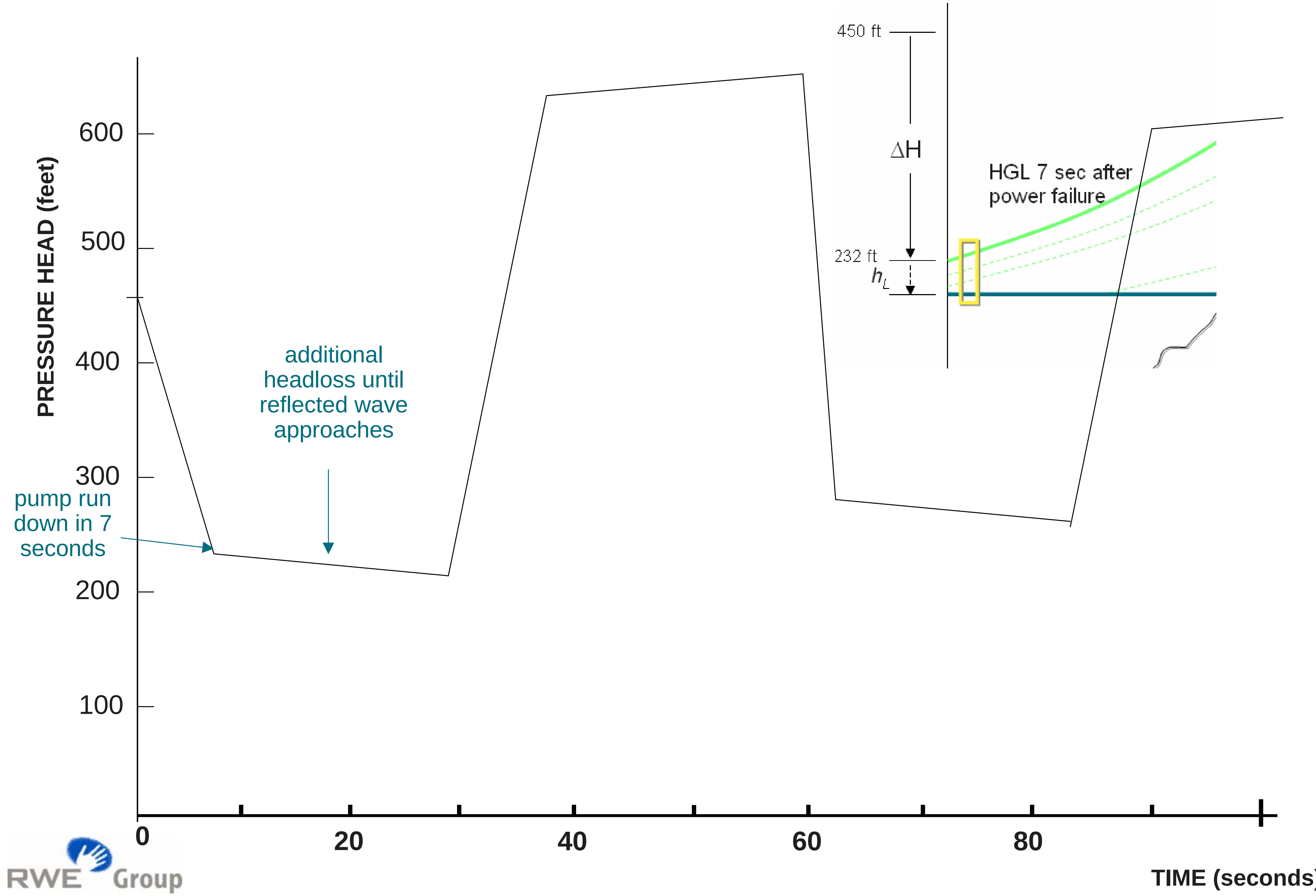
Pressure Wave in Single Pipeline

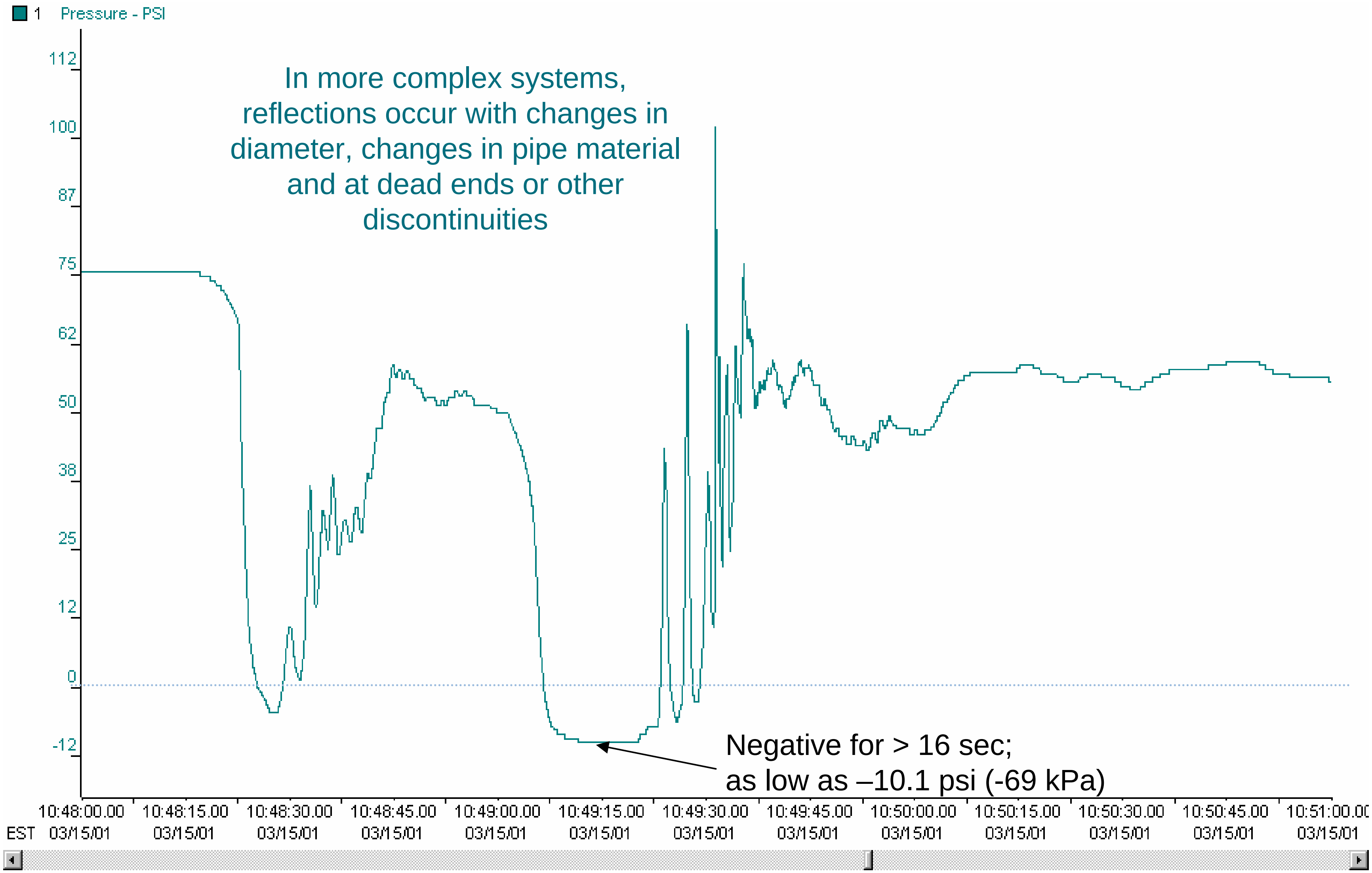


Adapted from Thorley 2006. *Fluid Transients in Pipelines* .

Pressure Wave in Single Pipeline



Negative Pressure Profile



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

Transient Analysis

- Pressure pulses are generated when flow conditions change from one steady state to another
- Pipeline plays a relative passive role, primarily transmitting disturbances from point to point
- Boundary conditions (devices and connections at the end of each line) **play the crucial role in determining the character and nature of system response and propagation**

Hydraulic Modeling

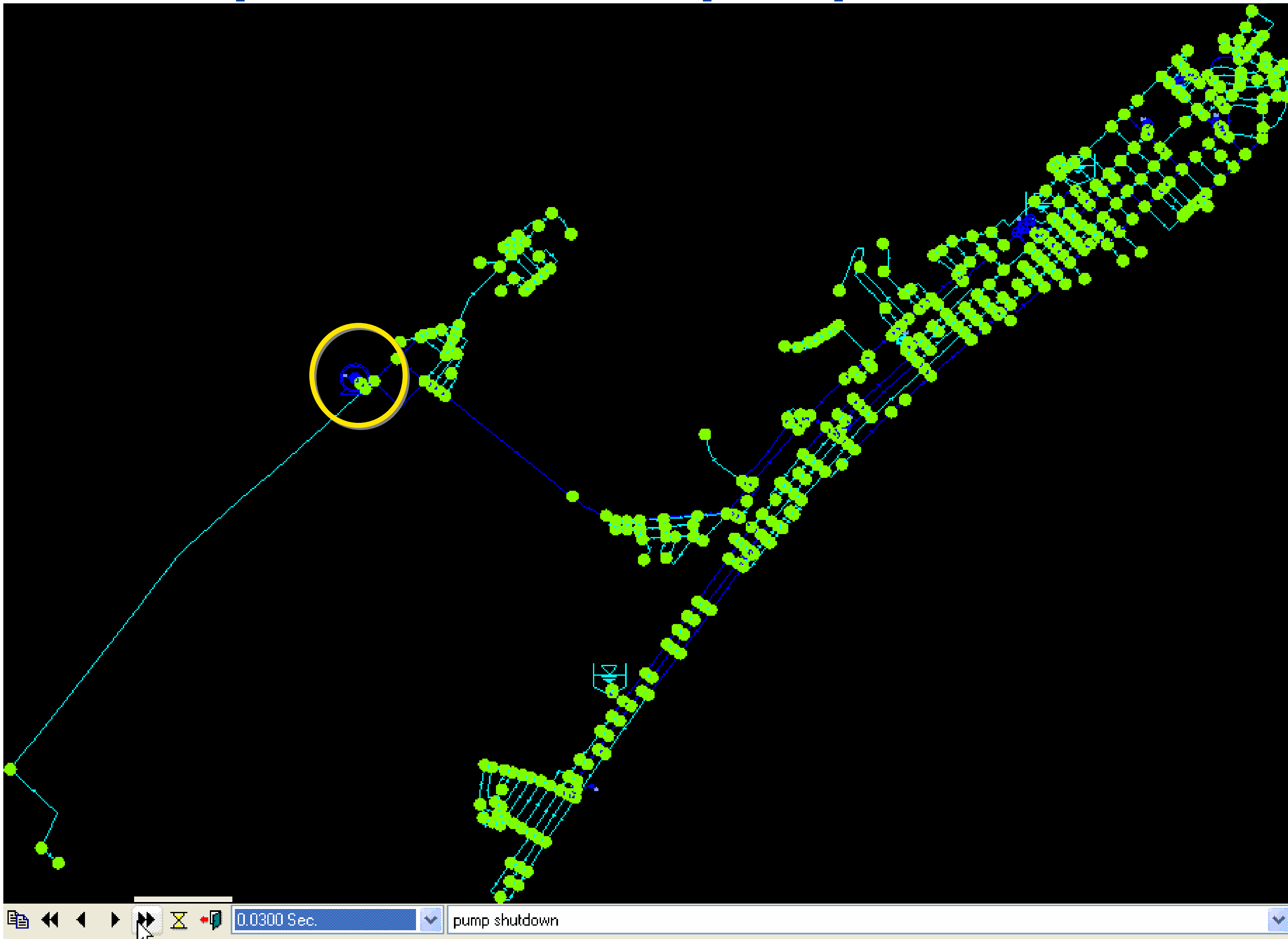
Used to track pressure wave initiation, propagation, reflection…

Modeling is Important !

- If you can model a system, i.e. describe its behavior using mathematical equations, then you can predict future behavior.

- Key Benefits:
  - Identify Problems
  - Optimize System Operation
  - Make Informed Decisions

Model power loss at a pump station



model is desktop representation of real system

use model to understand how pressure and flow vary in the system

Flow Key

Flow < 100 gpm

Flow > 100 gpm

Pressure Key

negative pressure

0 to 20 psi

pressure > 20 psi

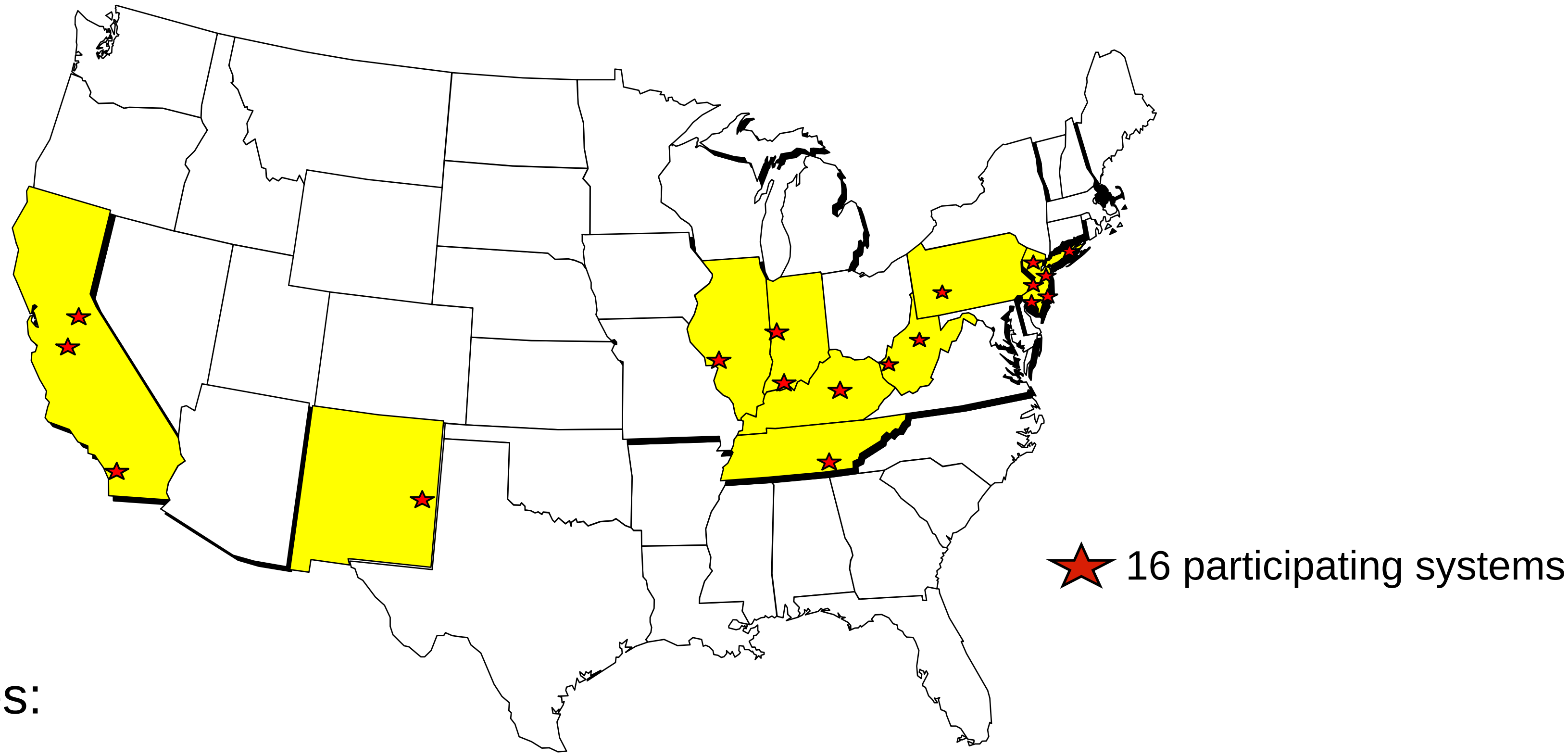
start with steady state or EPS model

The term transient describes unsteady flow.

continuity and momentum equations used to solve unsteady flow problems

Findings from AwwaRF Project # 3008

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

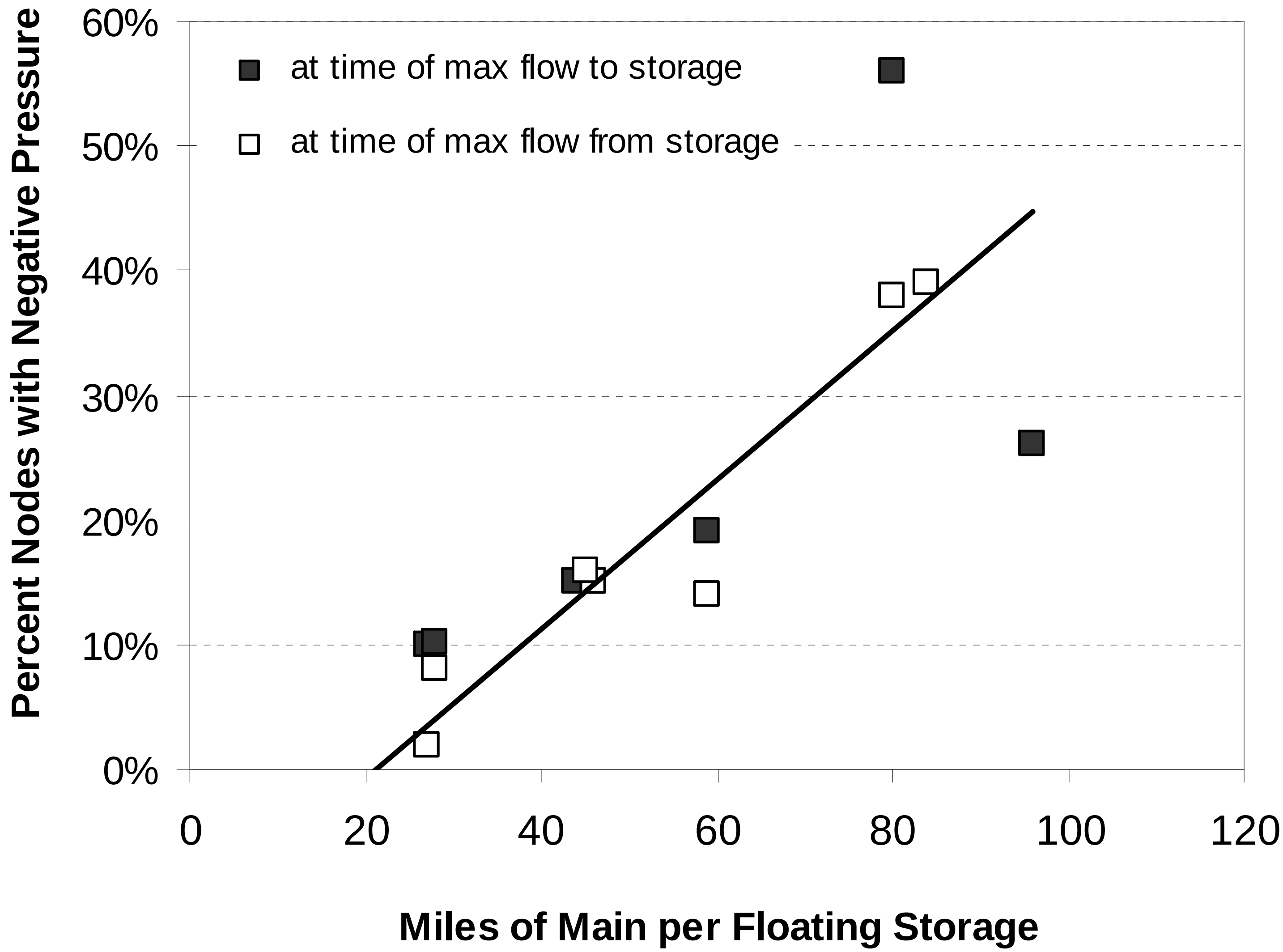
Project # 3008 Significant Findings

- Systems with steady state or EPS models already have the basics to assess potential for transient pressures!

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

- System 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

Storage Reduces Susceptibility



Other factors…

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System Size

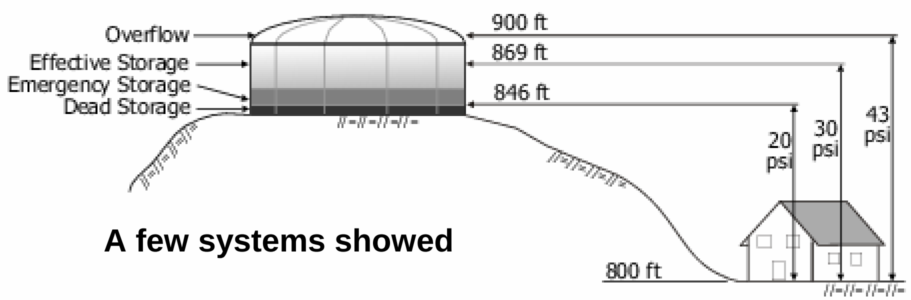
- Smaller systems showed increased susceptibility
- 5 of 6 systems with < 10 mgd system delivery drew negative pressure in greater than 35% of the system with complete loss of pumping power

Surface vs Ground

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

System Config.

- Hilly distribution systems (> 150 ft elevation difference) were less susceptible
- Systems with more floating storage facilities were less susceptible to negative pressures
- Locations at or near dead ends were more susceptible to negative pressures



A few systems showed

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IL Case Study

Using modeling to prevent low/negative pressures after a power outage

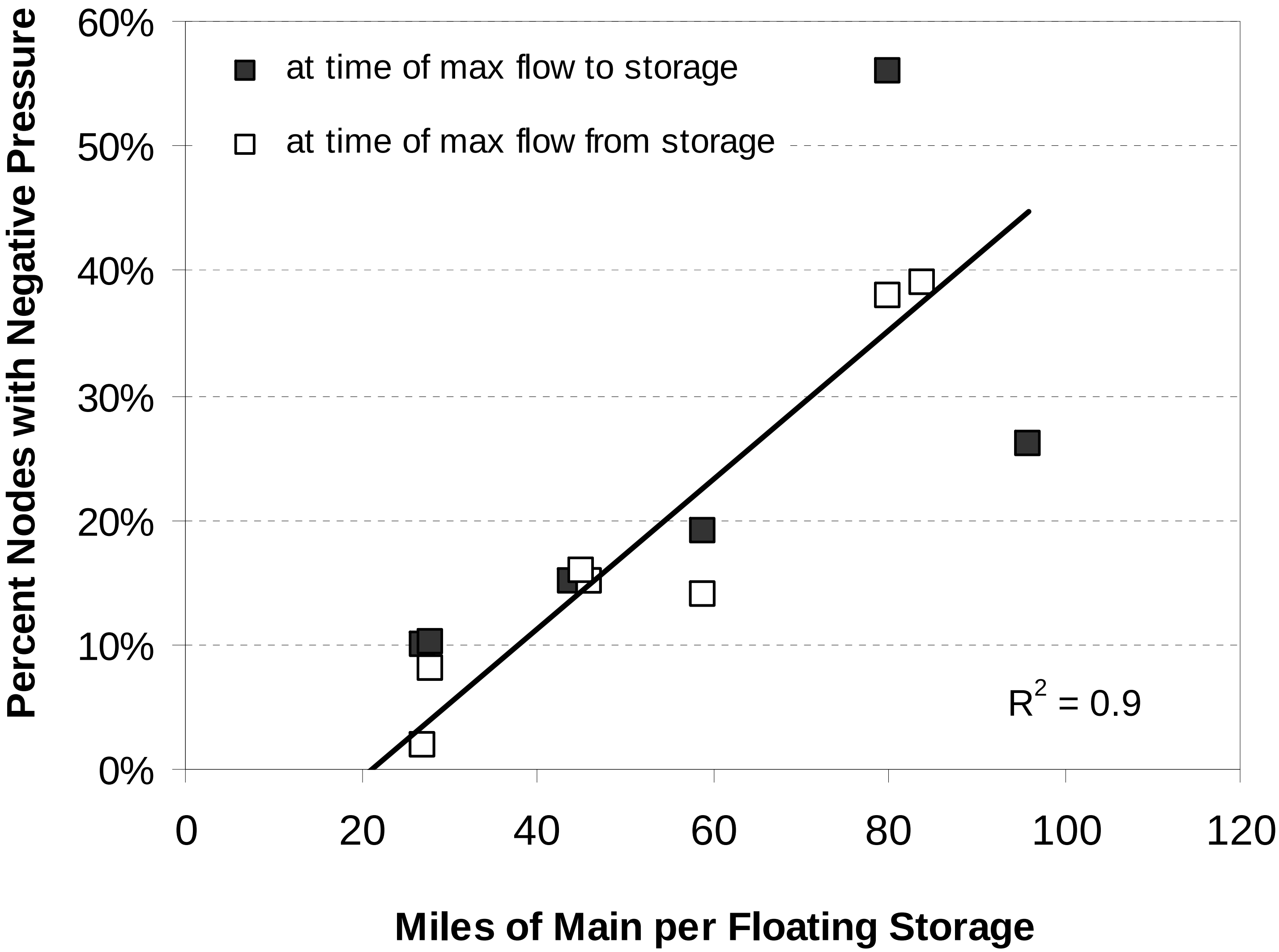
IL Pressure Regulations

- State is currently enforcing the maintenance of pressure greater than 20 psi under all flow conditions.
- If pressure is less than 20 psi for even one second, a Boil Water Notice must be issued.

IL Water System Impacted By Regs

- System fed by surface water and has a relatively flat topology
- Primary pump station has a capacity of 30 MGD
- Under 2006 max day conditions, HGL at plant varied between 899 ft and 906 ft (corresponding to 64 to 72 psi)
- **Primary pump station has unstable power supply.**
- Currently no floating storage in system

More Storage = Less Transient Pressure



Pressure Monitoring Required

Rationale for Selecting Monitoring Locations?

Low Pressure Measured

How to Proceed?

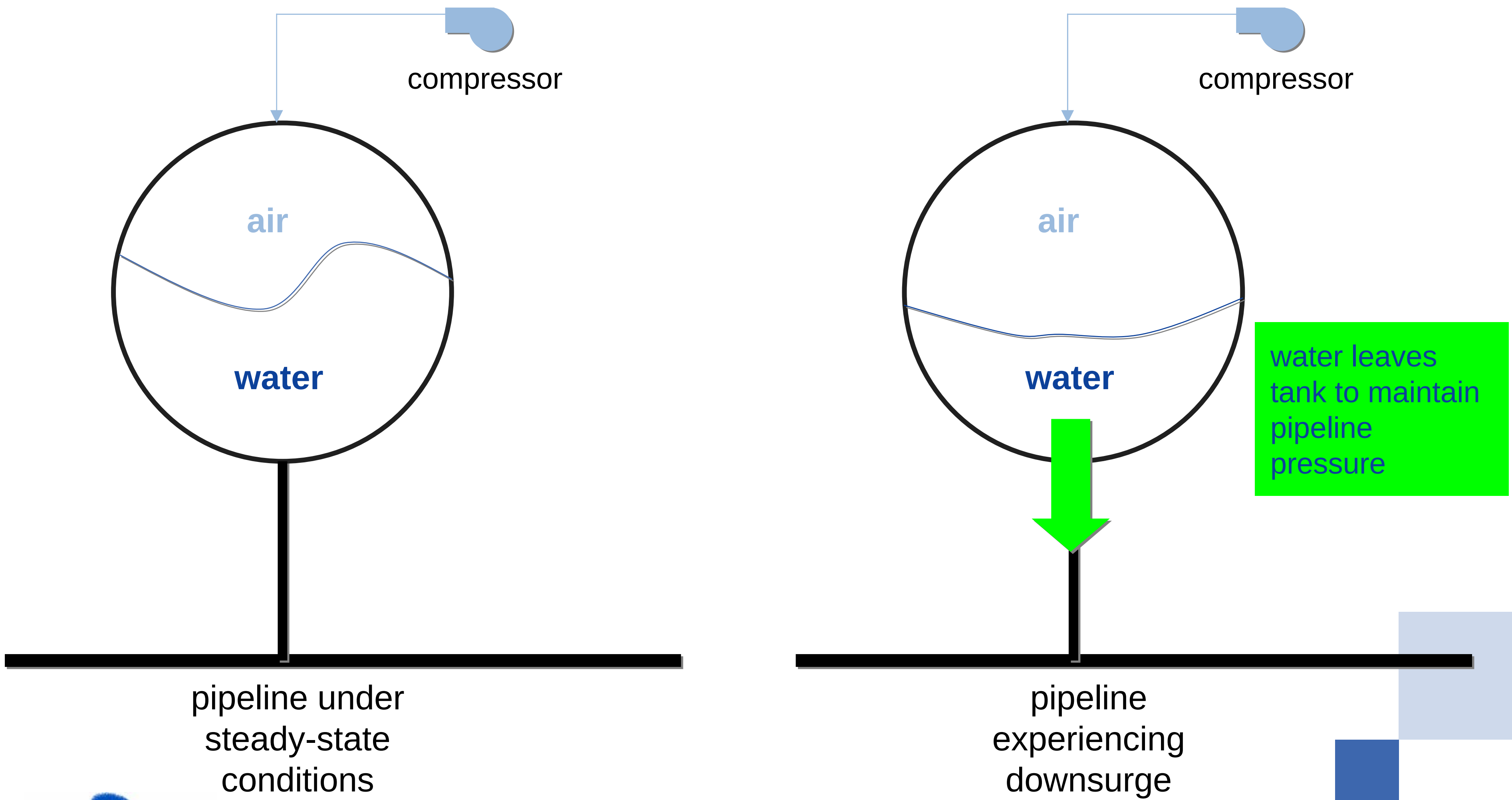
- Quick Fix
  - Lease a generator that operates 24/7
- Long Term
  - Use model to assess extent of transient low pressures and examine range of solutions

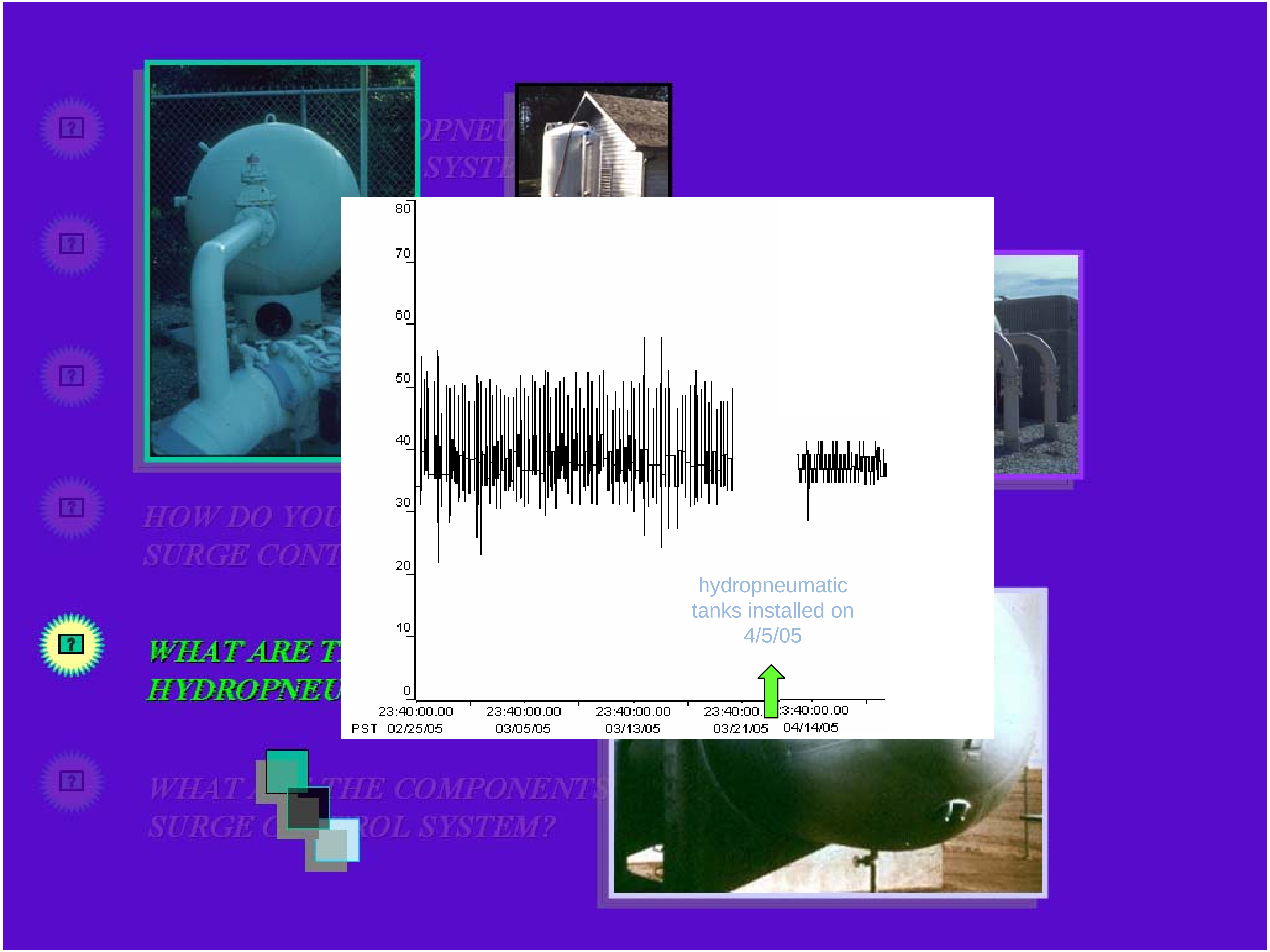
Determine Susceptible Locations

What type of surge mitigation ?

Option 1	Two 20,000 gal hydropneumatic tanks ✓	$ 0.6 million
Option 2	UPS sized to support 9 pumps	$ 1.8 million
Option 3	One 30,000 gal hydro tank & one 1MG elevated tank at Location A	$ 1.5 million
Option 4	One 30,000 gal hydro tank & one 1MG elevated tank at Location B	$ 1.5 million
Do nothing	24/7 generator	$ 30,000 per month

Hydropneumatic Tanks





80
70
60
50
40
30
20
10
0
hydropneumatic tanks installed on 4/5/05
23:40:00.00 PST 02/25/05
23:40:00.00 03/05/05
23:40:00.00 03/13/05
23:40:00.00 03/21/05
3:40:00.00 04/14/05
HOW DO YOU
SURGE CONT
WHAT ARE T
HYDROPNEU
THE COMPONENTS
ROL SYSTEM?

Transients in Distribution Systems

study of unsteady flow of liquids begins in mid-19th century

1 Focus on transients in transmission mains

2 Is occurrence in smaller piping significant ?

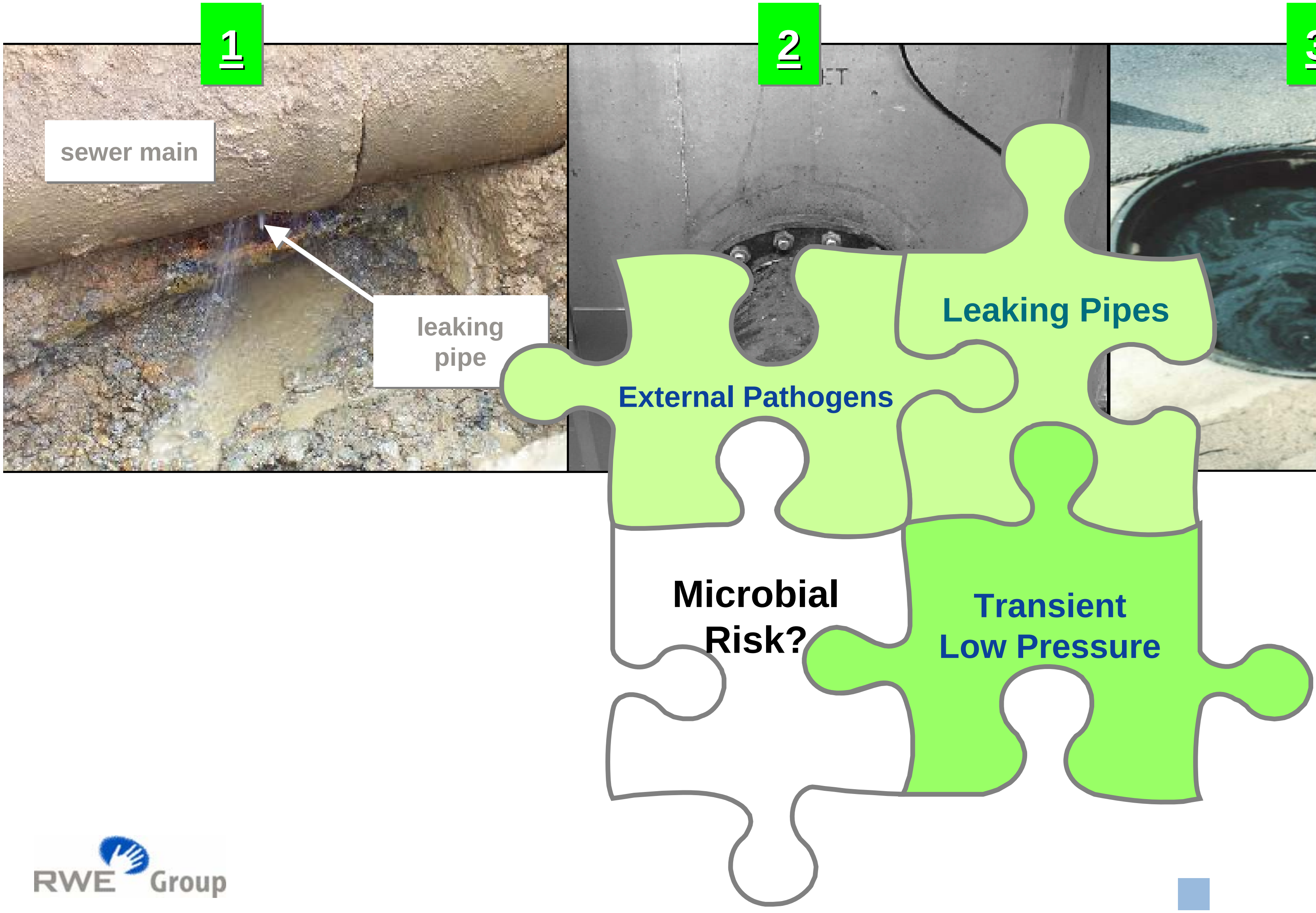
3 What is impact of transients on water quality ?

1 Pre-2000	2 2000 - 2006	3 2006 → future
	AW research demonstrated brief periods (20-50 sec) of low & negative pressure in several systems Characteristics that increase vulnerability to negative pressures investigated	What are typical intrusion volumes? What is final concentration near nodes? Assess Microbial Risk

Microbial Risk Assessment

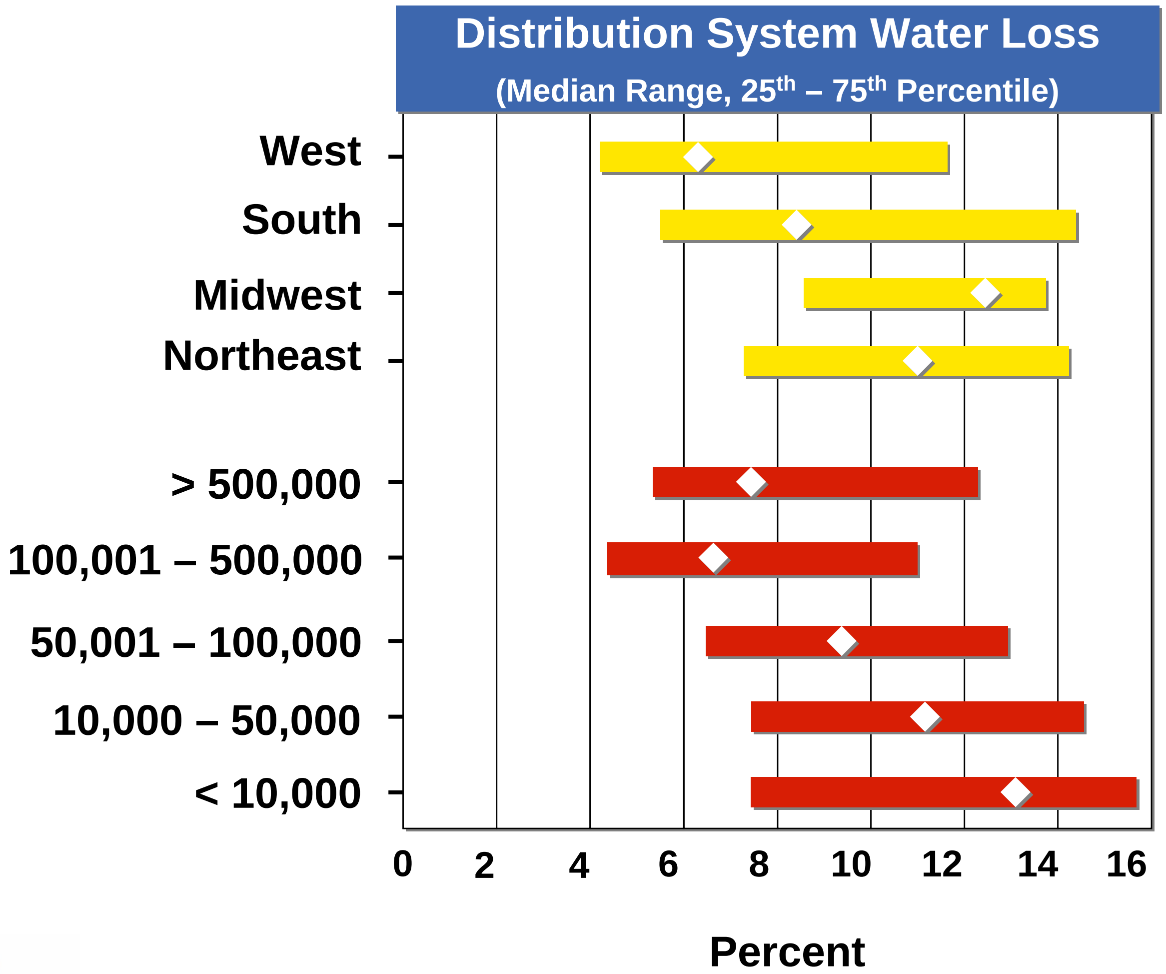
Necessary. Provides logical approach to determine if transients can cause sufficient intrusion to impact the health of water consumers.

Microbial Risk Assessment



We have Leaks…

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

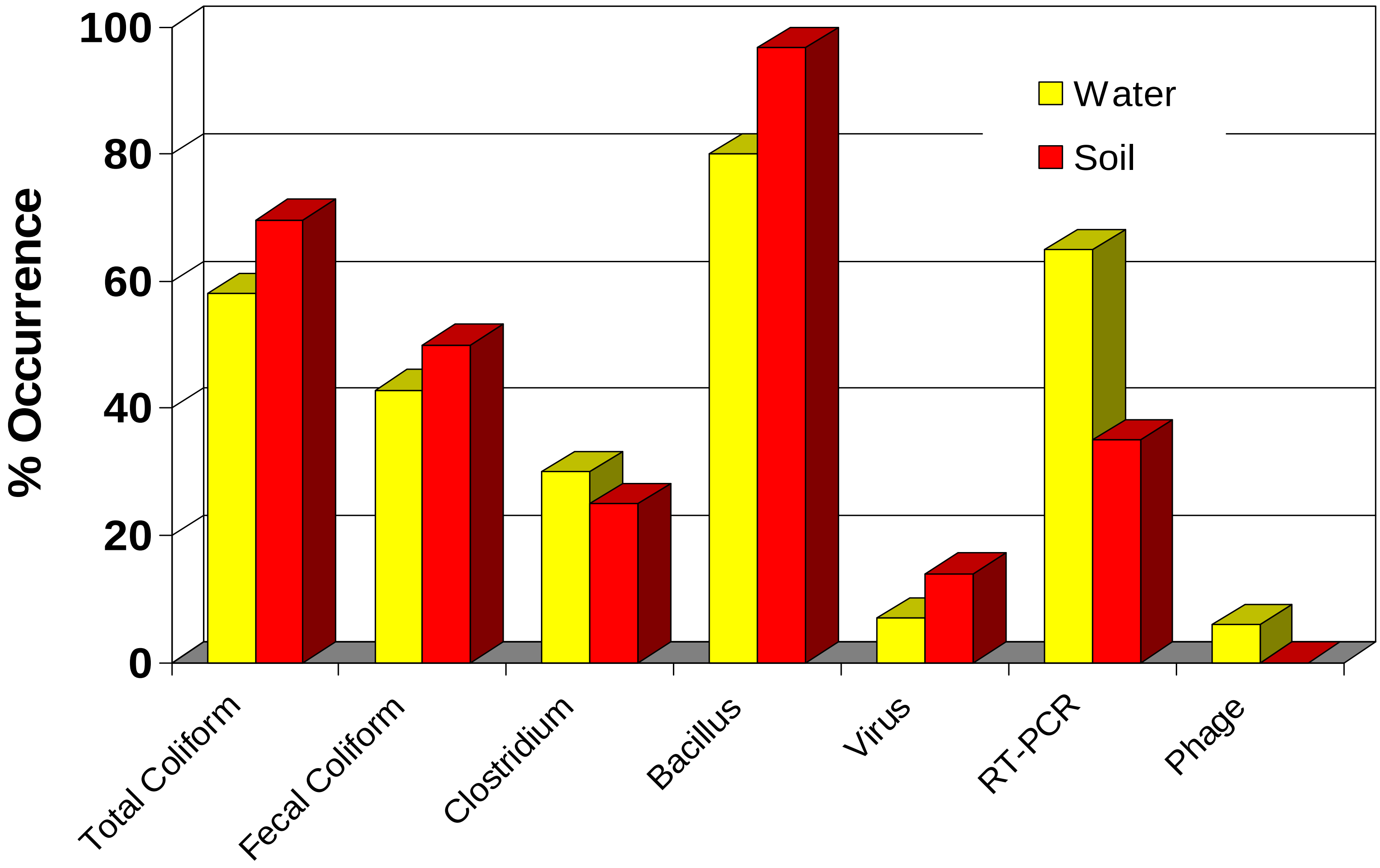


Source: AWWA 2005 – *Benchmarking Performance Indicators for Water and WasteWater Utilities*

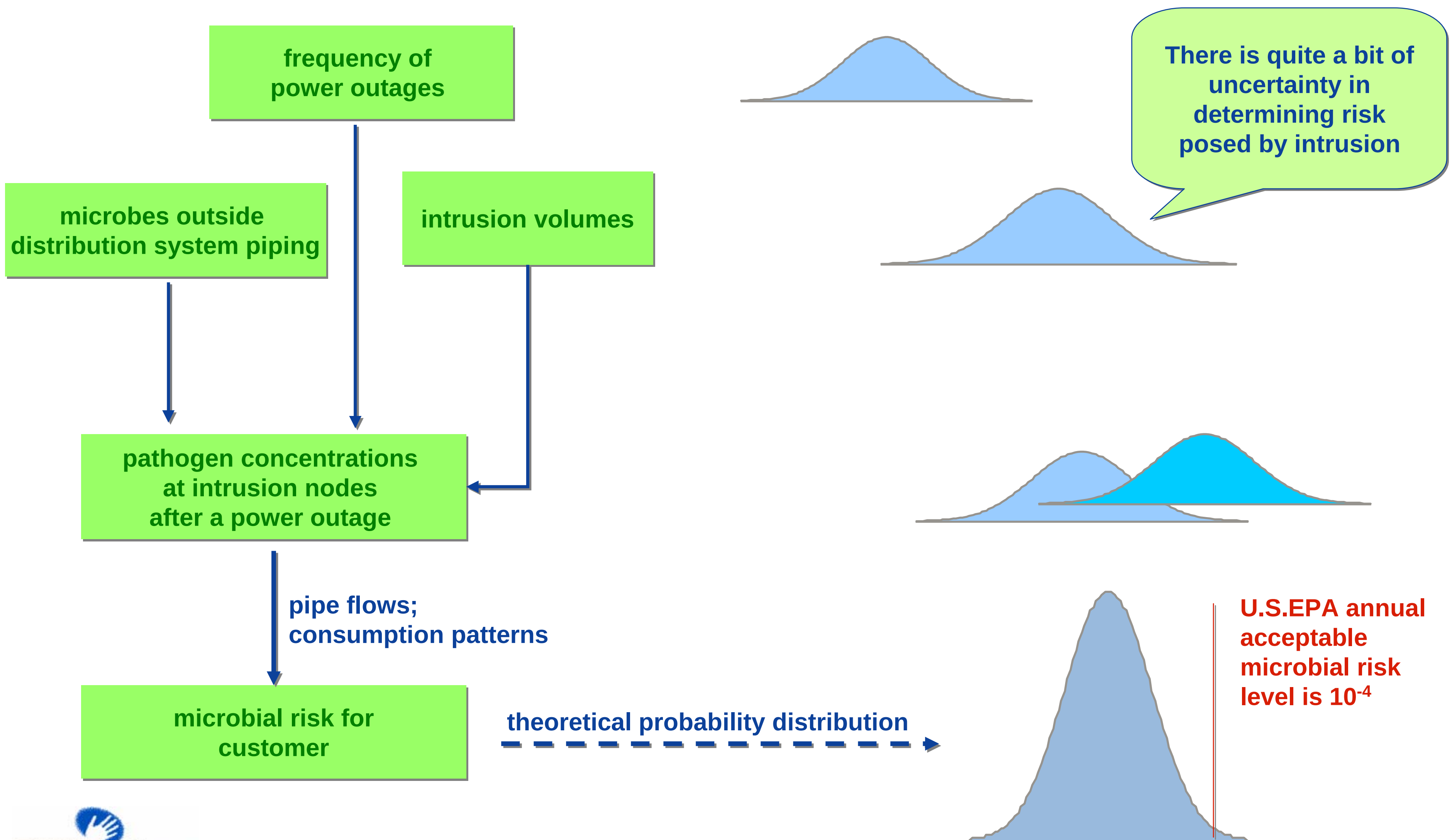
121 Participants

We have pathogens near pipe…

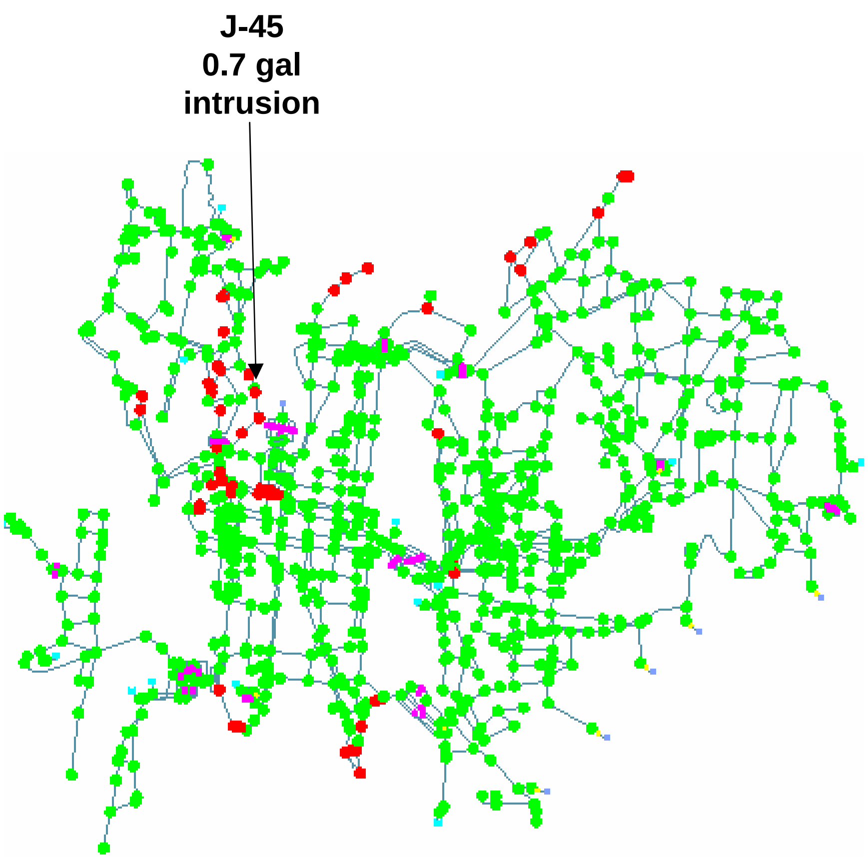
Overall 63% (20/32) of samples were positive for viruses: enteroviruses (Sabin strain), Norwalk, and Hepatitis A virus



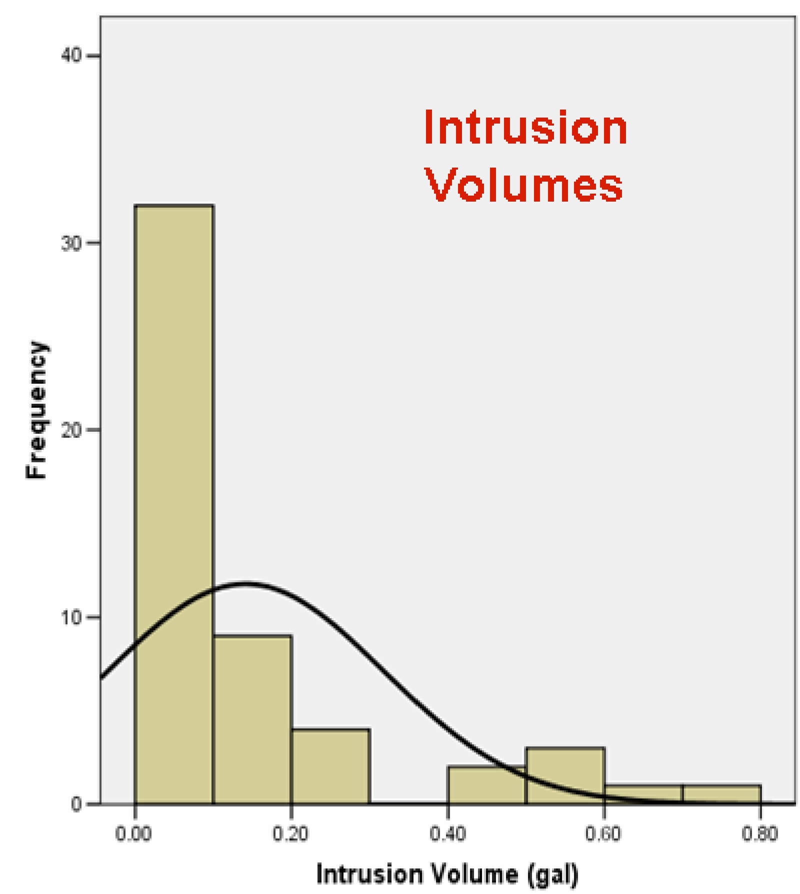
Microbial Risk Assessment



Sustained Power Loss (>3 min)



Intrusion occurs at 54 demand nodes



- Total Intrusion Volume = 7.4 gal (28.0 L)
- 22 nodes (41%) have intrusion volumes of 0.1 gal (0.4 L) or greater
- Highest intrusion volume near customers was 0.74 gal (2.8 L)

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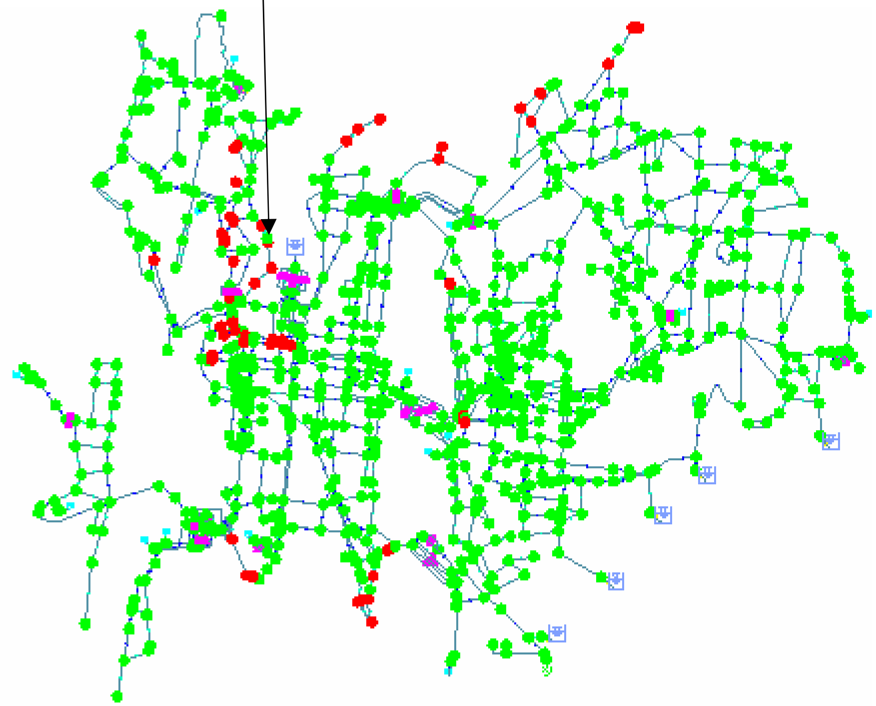
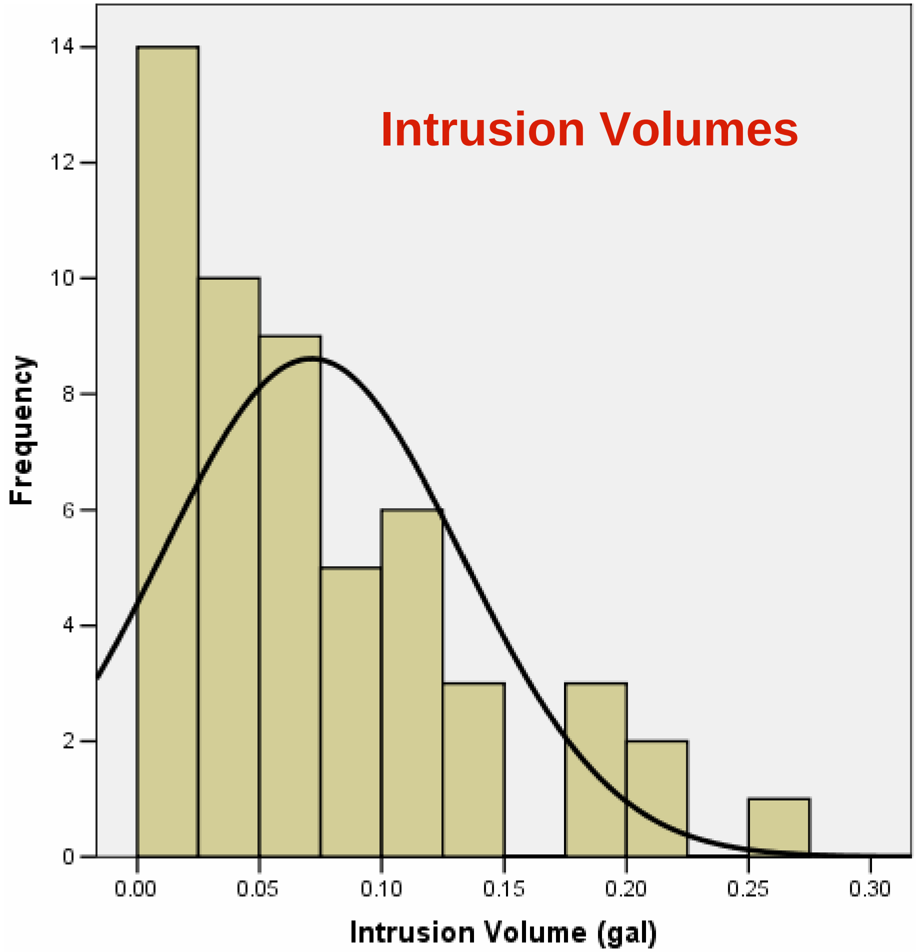
Power restored 2 seconds after power loss

J-45
0.26 gal
intrusion



Intrusion occurs at 53 demand nodes



- Total Intrusion Volume = 3.8 gal (14.4 L)
- 15 junctions (28%) have intrusion volumes of 0.1 gal (0.4 L) or greater
- Highest intrusion volume was 0.26 gal (1.0 L)

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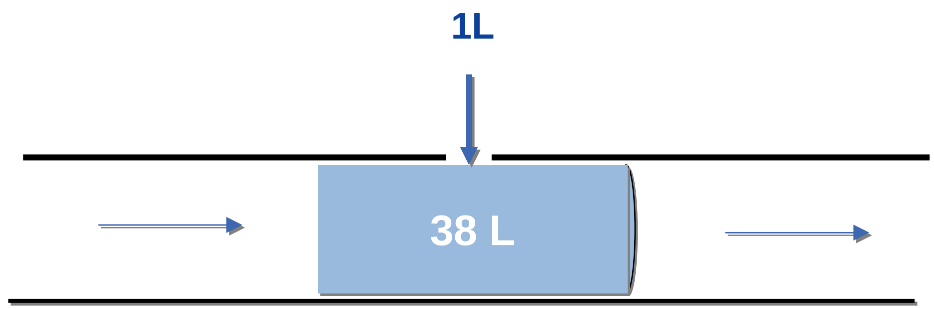
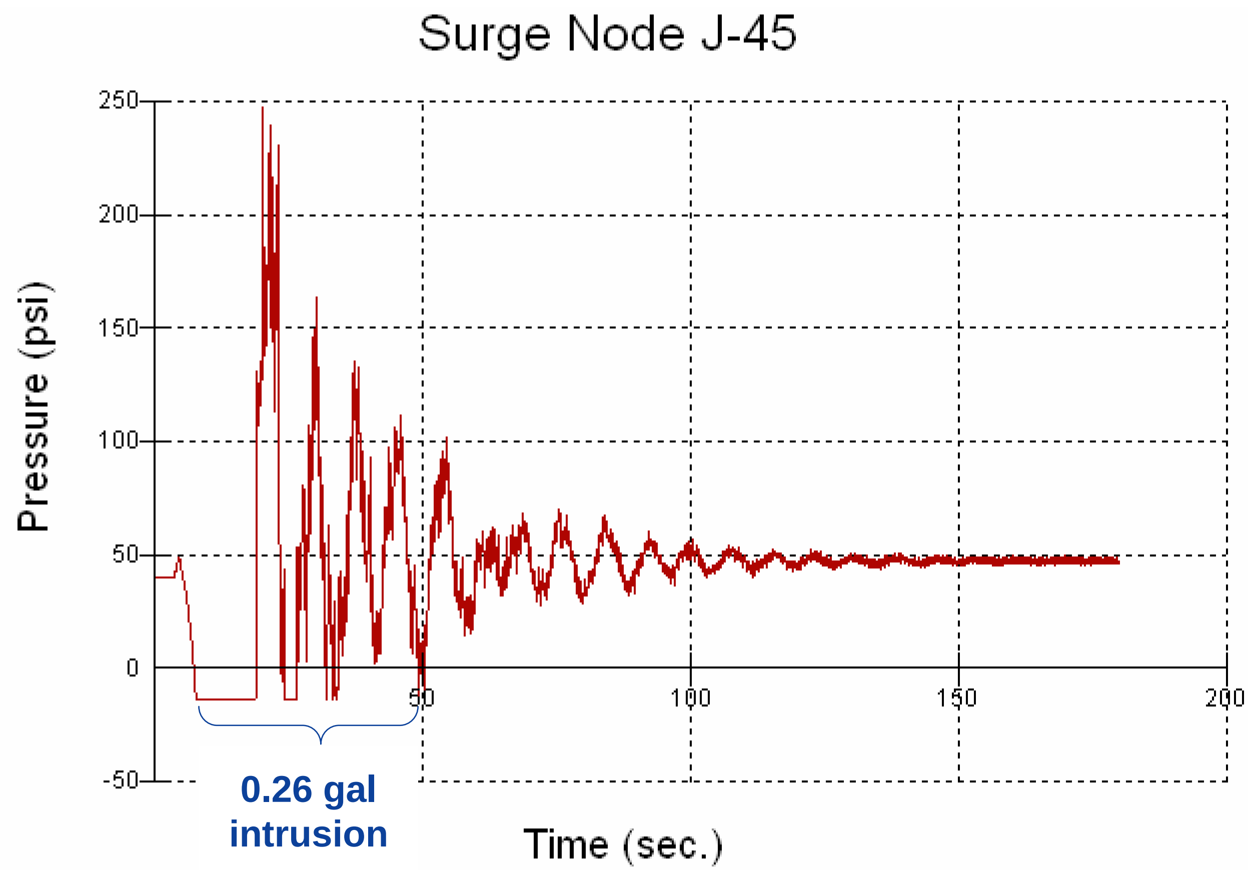
Estimate Dilution Factors

- Intrusion @ Node J-45
  - Duration = 16s
  - avg flow before transient period = 36 gpm
- $V_oC_o = V_fC_f$
  - V_o = 1L
  - V_f = 38 L
- Dilution factor @ J-45 = 2.6 X 10^{-2}





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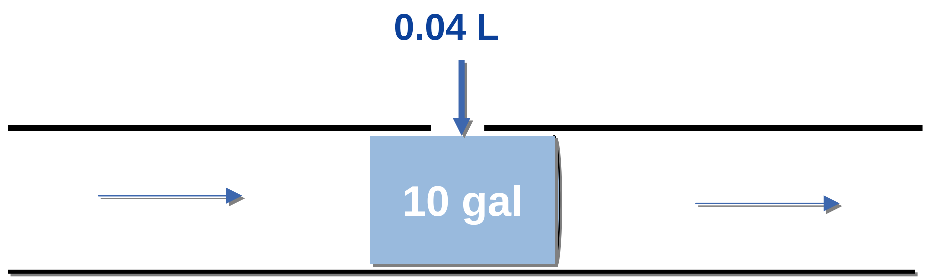
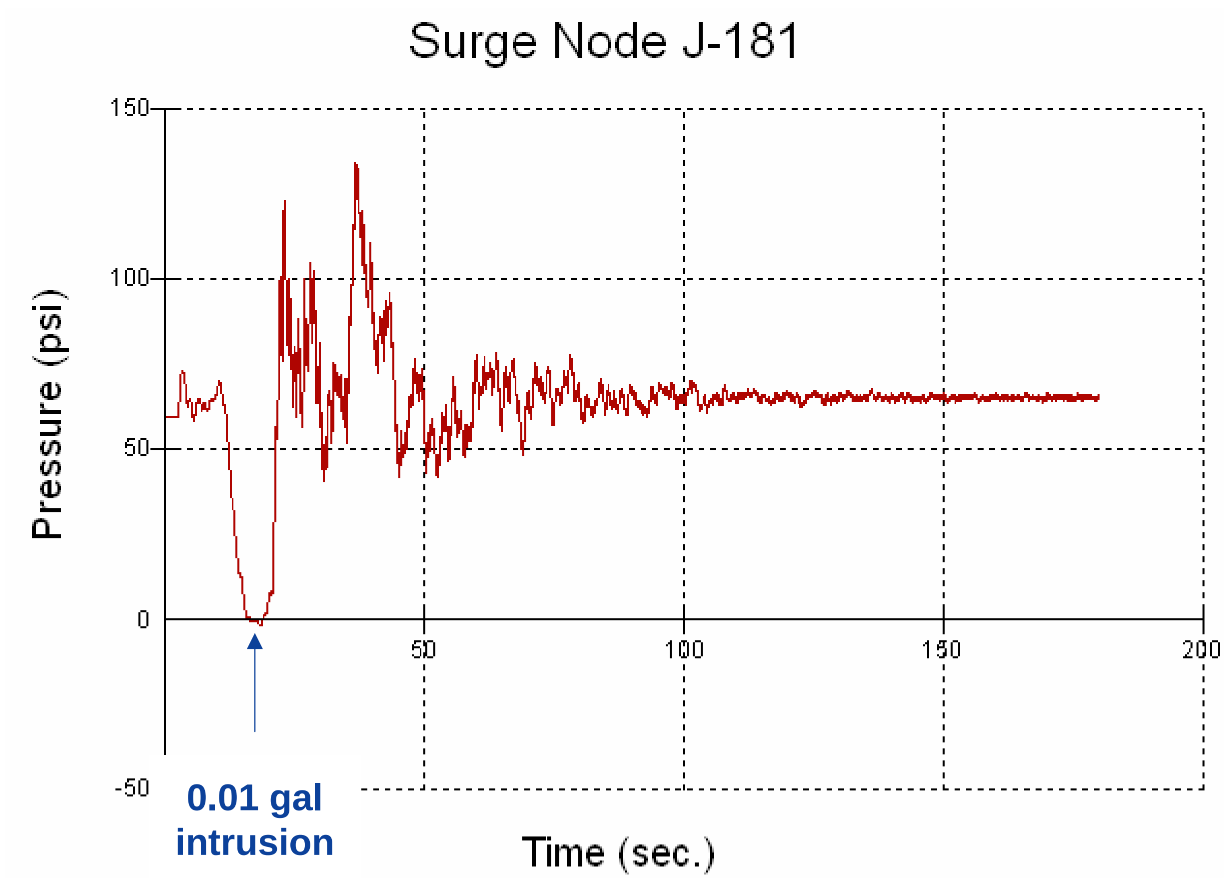
Estimate Dilution Factors

- Intrusion @ Node J-181
  - Duration = 2 s
  - avg flow before transient period = 79 gpm
- $V_oC_o = V_fC_f$
  - V_o = 0.04 L
  - V_f = 10 L
- Dilution factor @ J-181 = 4.0 X 10^{-3}





Intrusion could be responsible for coliform positive samples…

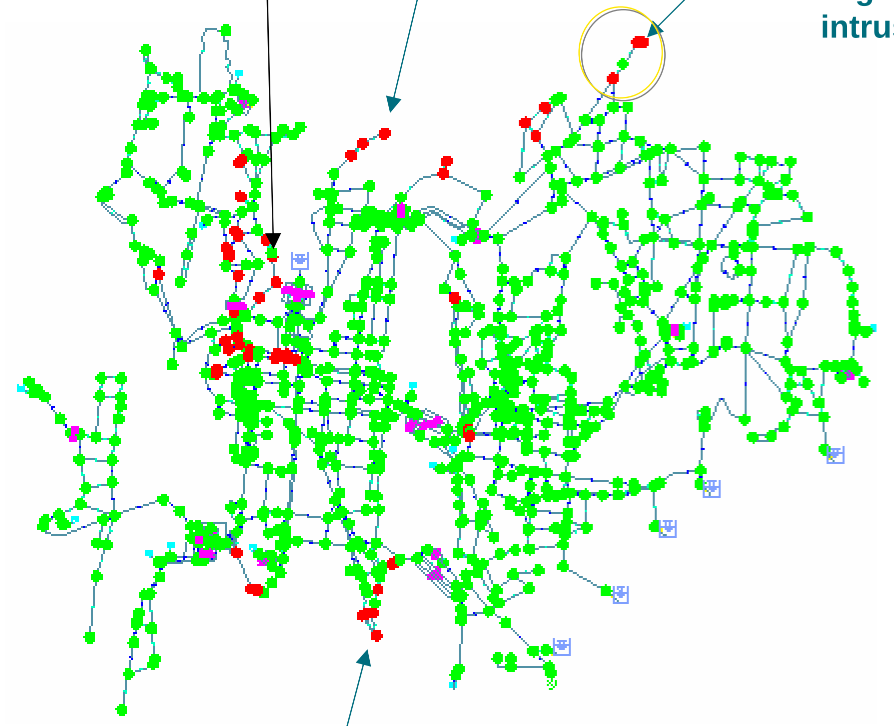
J-45
0.26 gal
intrusion

30 MPN/100 mL

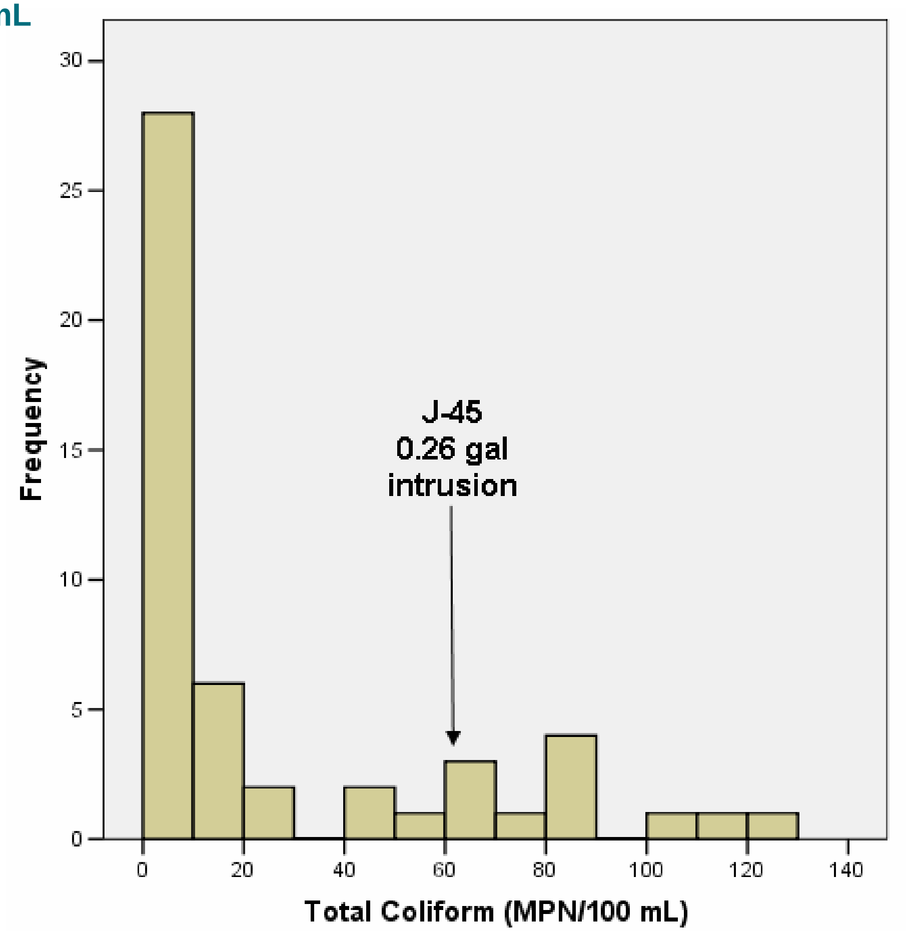
J-613, J-682 & J-683

> 1000 MPN/100 mL

~ .04 gal (1.5 L)
intrusion



106 MPN/100 mL



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

New AwwaRF Project

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"Managing Distribution System Pressures to Protect Water Quality"

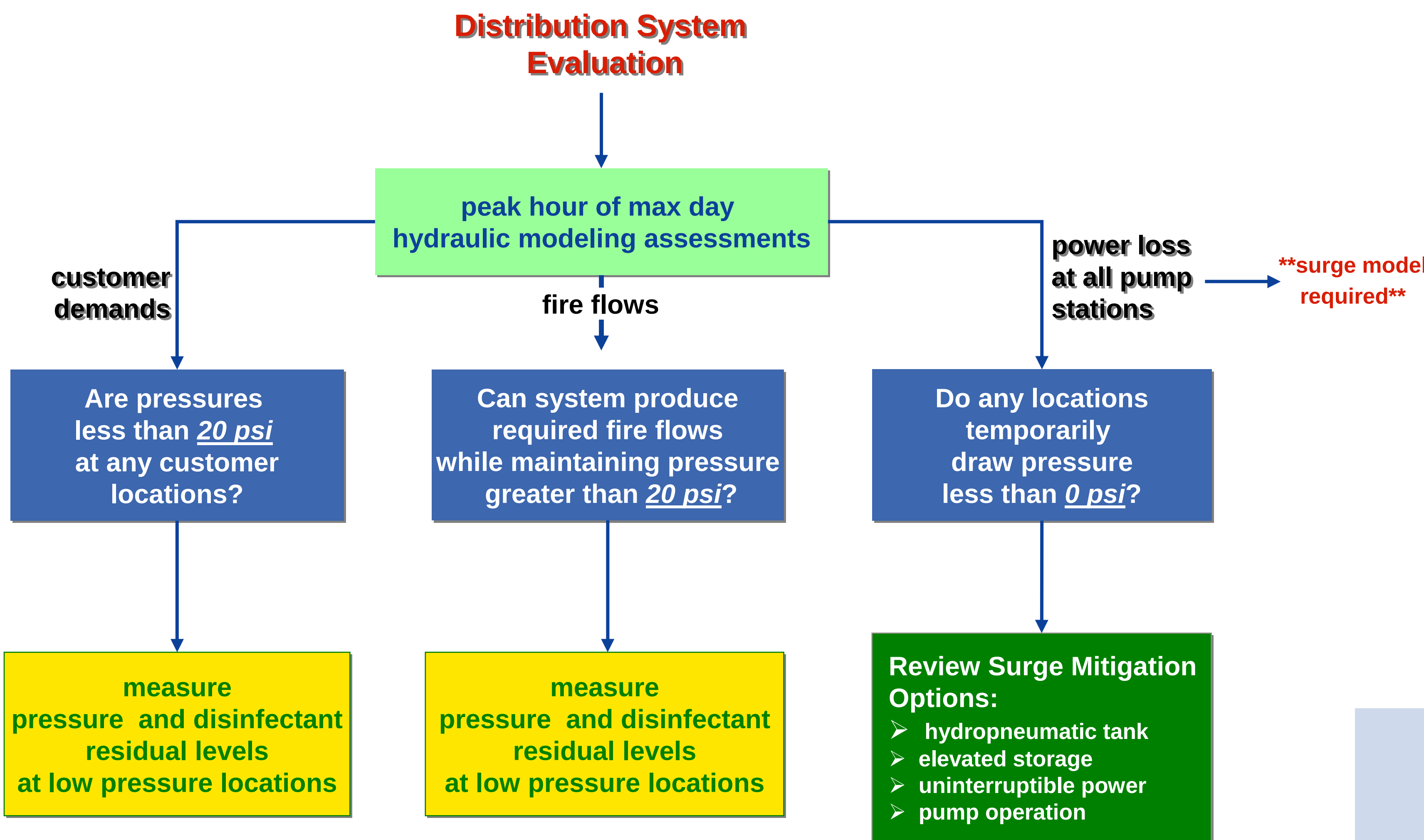
1. Assess microbial intrusion risk
   - Determine daily exposure
   - Use dose response model to determine risk of infection
2. Conduct utility survey to gauge how utility managers use pressure management to protect water quality
3. Monitor pressure & water quality continuously for two months, in six locations, in four different water systems
4. Develop Best Practices for Managing Distribution System Pressures
   - Pressure monitoring
   - Disinfectant residual maintenance
   - Hydraulic modeling

Risk Management

Through

Pressure Management …

Pressure Management Approach



Recap of Key Ideas

- **Transient pressures occur in water systems**
- Hydraulic modeling and pressure monitoring are important assessments that should be conducted to determine if low/negative transient pressures occur in your system
- **Important research questions need to be addressed:**
  - What are the health risks posed by intruded water ?
  - How effective are disinfectant residuals?
  - Do chlorine and chloramine provide the same level of protection from transitory contamination?

Intrusion References

- Fleming K.K. and M.W. LeChevallier. 2007. **Susceptibility of Distribution Systems to Transitory Contamination**. *Drinking Water Research*. Vol 17, No 2. AwwaRF, Denver, CO.
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Acknowledgements

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