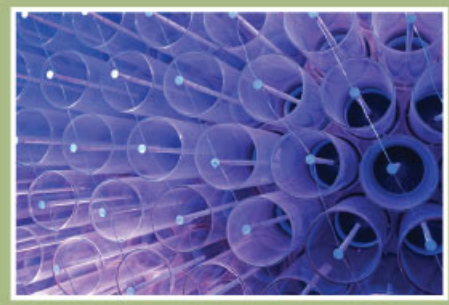
AMERICAN WATER

Estimating the Risk of Virus Intrusion into Drinking Water Systems



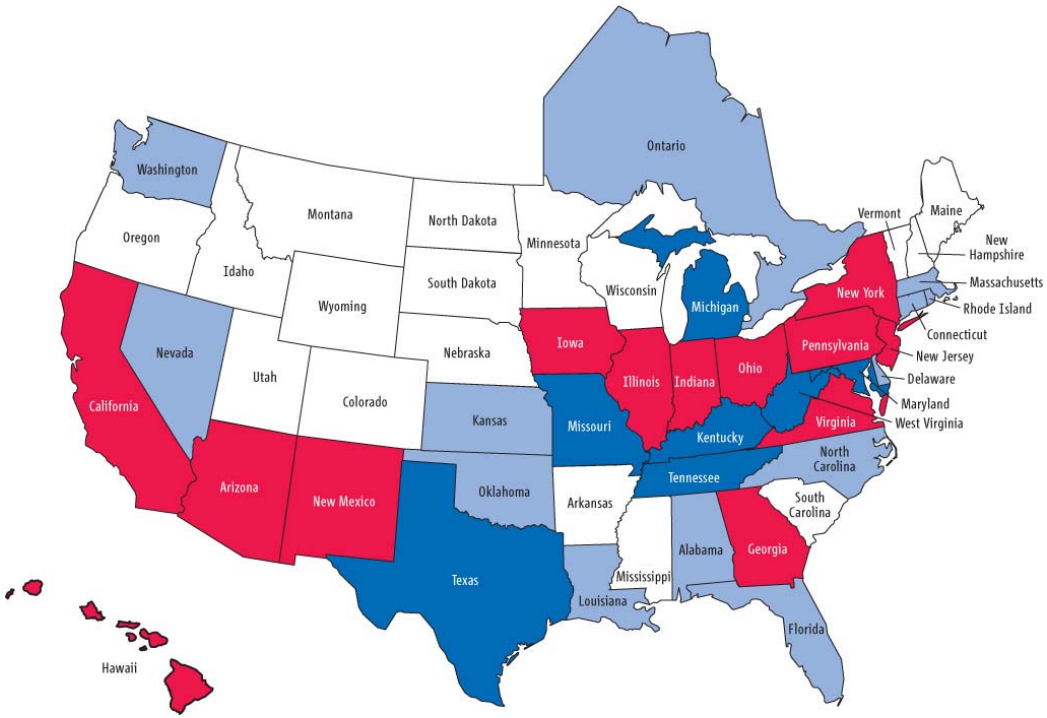
Mark LeChevallier, Minhua Xu, Jian Yang,
***American Water*,**
and Peter Teunis
RIVM, the Netherlands

Presenter Disclosure

I have nothing to disclose

- No relationships to disclose
- No off-label disclosures

AMERICAN WATER



www.amwater.com

American Water is the largest water and wastewater services provider in North America, headquartered in Voorhees, NJ.

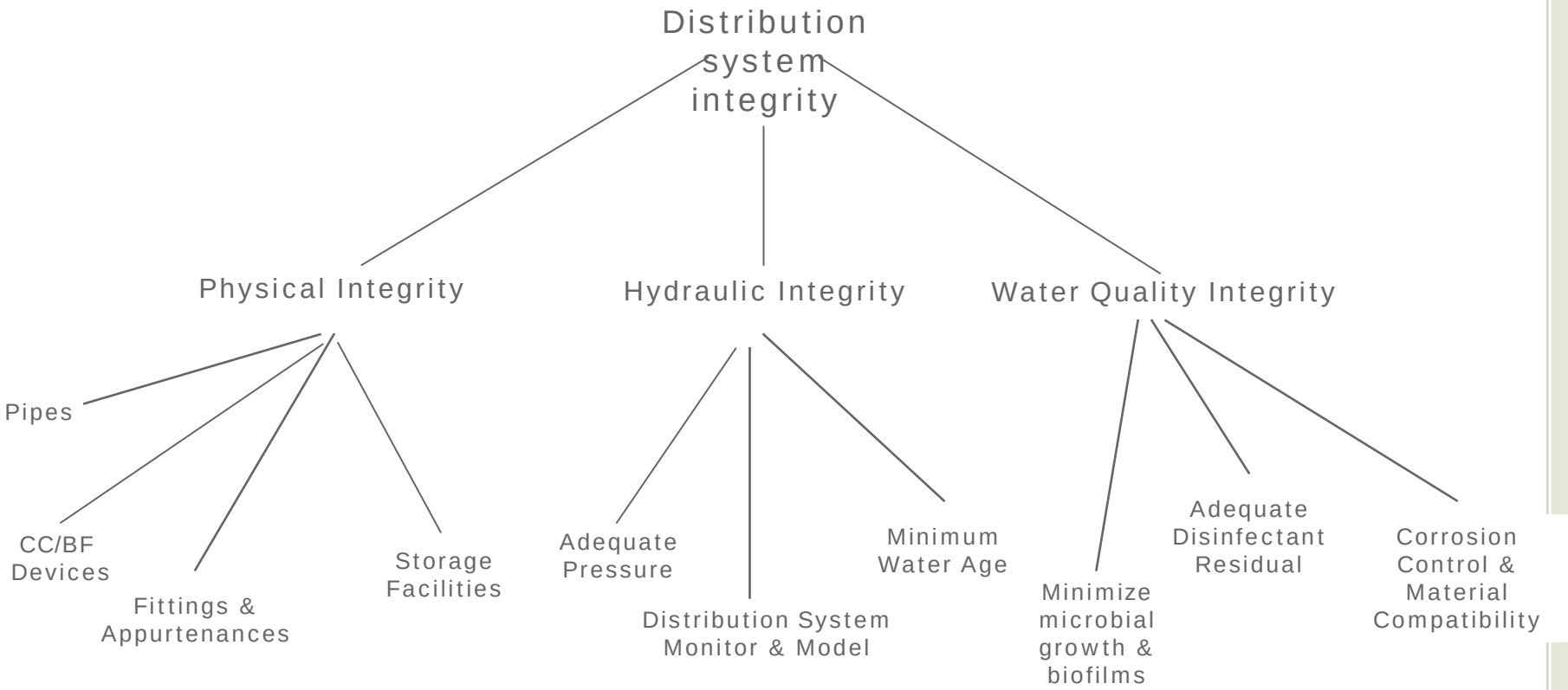
American Water provide services to approximately 15 million people in more than 1,600 communities in 32 states and in Ontario, Canada; and employs nearly 7,000 water professionals.

American Water owns or operates nearly 400 drinking water systems and 300 wastewater facilities.

We treat and deliver over a billion gallons of water daily

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.

Distribution System Integrity



National Research Council. 2006. *Drinking Water Distribution Systems: Assessing and Reducing Risks*. National Academies Press. Washington, DC.

Physical Integrity

- According to water industry statistics, it will take 300 years to renew the existing pipes at the current rate of replacement.
- The USEPA has indicated that >$300 billion will be needed to replace or repair aging infrastructure over the next 20 years.
- The American Society of Civil Engineers reports that an average of 6 billion gallons per day of potable water are lost through the leaky pipes and services in the United States everyday.
- The loss of physical integrity – where the system no longer acts as a barrier that prevents external contamination from deteriorating the internal, drinking water supply
- When physical integrity is compromised, the drinking water supply becomes exposed to contamination that increases the risk of negative public health outcomes.

Hydraulic Integrity

- **The hydraulic integrity of a water distribution system is defined as its ability to provide a reliable water supply at an acceptable level of service—meeting all demands for adequate pressure, fire protection, and reliability of uninterrupted supply.**

- **The most critical component of hydraulic integrity is *adequate pressure* defined in terms of the minimum and maximum design pressure.**
- **A second element of hydraulic integrity is the *reliability of supply,* which refers to the ability of the system to maintain the desirable flow rate even when components are out of service.**

Water Quality Integrity

- For water quality integrity to be compromised, specific reactions must occur that introduce compounds or undesirable microbes into the bulk fluid of the distribution system.
- Even in the absence of external contamination, however, there are situations where water quality is degraded due to transformations that take place within piping, tanks, and premise plumbing

Presentation Outline

- **Explore the concept of pressure transients**
- **Intersection of**
  - physical
  - hydraulic
  - water quality
- **Develop a risk model for pressure transients**
- **Evaluate risk mitigation**
- **Conclusions**

Transient Pressures from Unsteady Flow

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

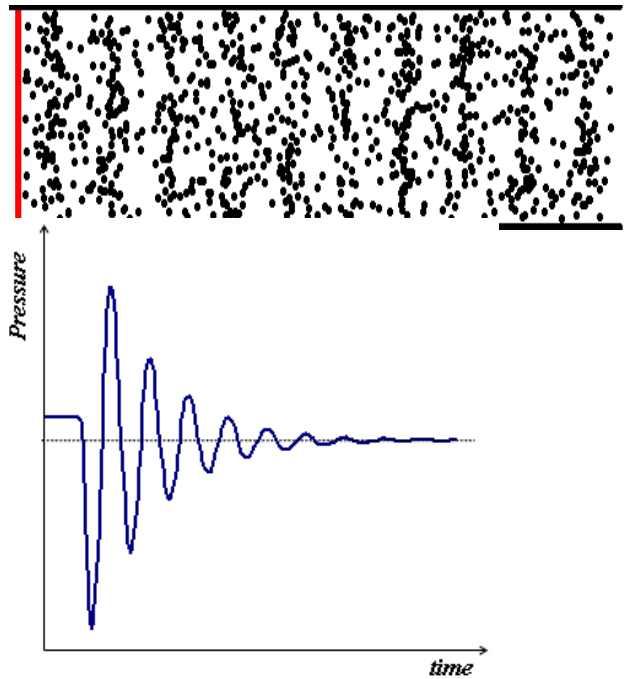
$$\Delta H = (c / g)\, \Delta V$$

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

- Intrusion, backflow of contaminants

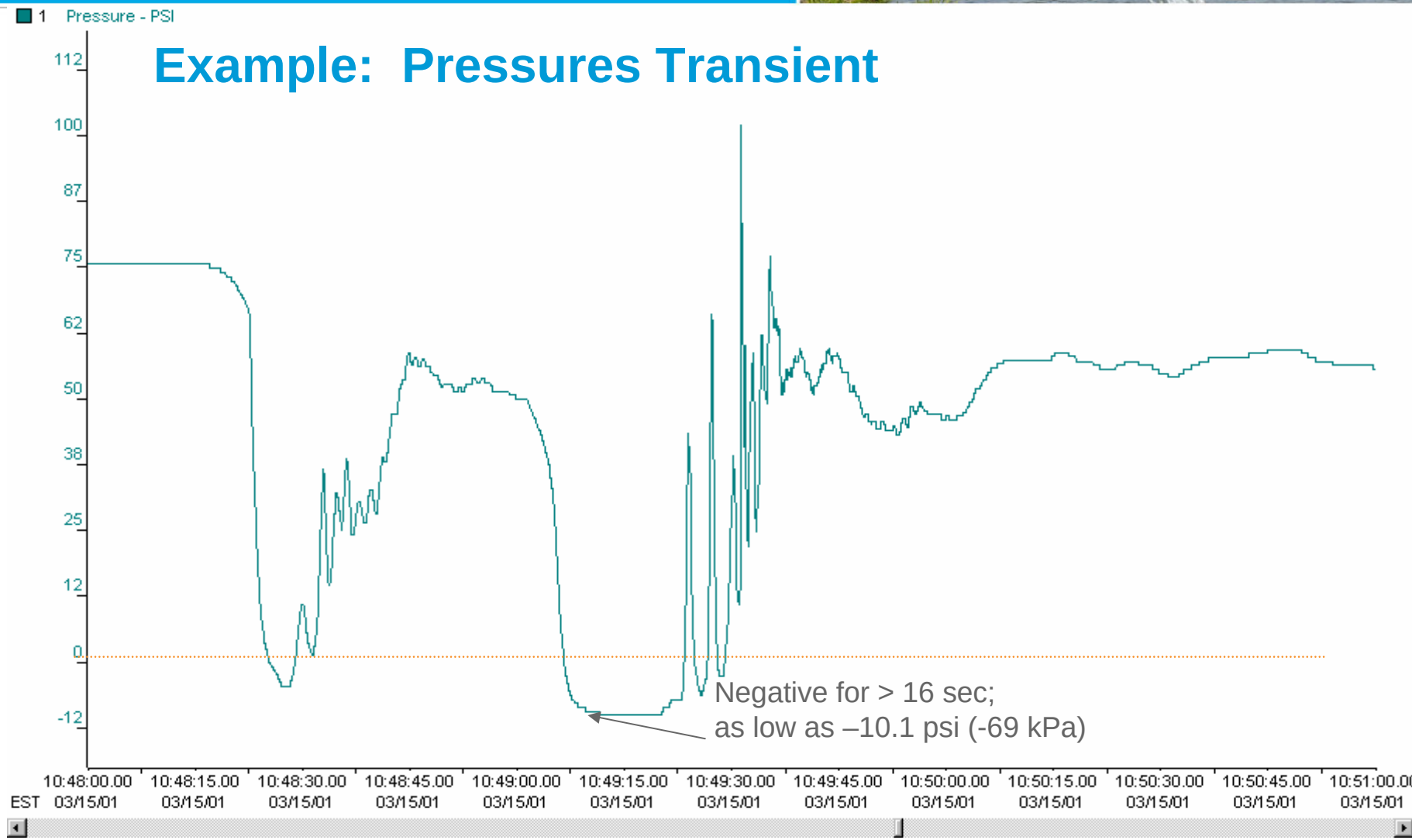
High Pressures Transients

- main breaks
- leaks

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

AMERICAN WATER

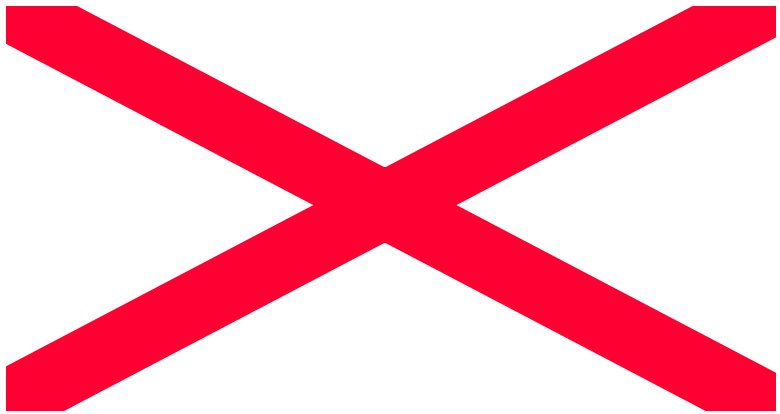
Example: Pressures Transient



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

Source of External Contamination

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



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

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

Intrusion Algorithm

power outage

IDENTIFY INTRUSION LOCATIONS

Set initial pathogen conc. at intrusion locations

Determine pathogen transport

Determine combined pathogen concentration at each node

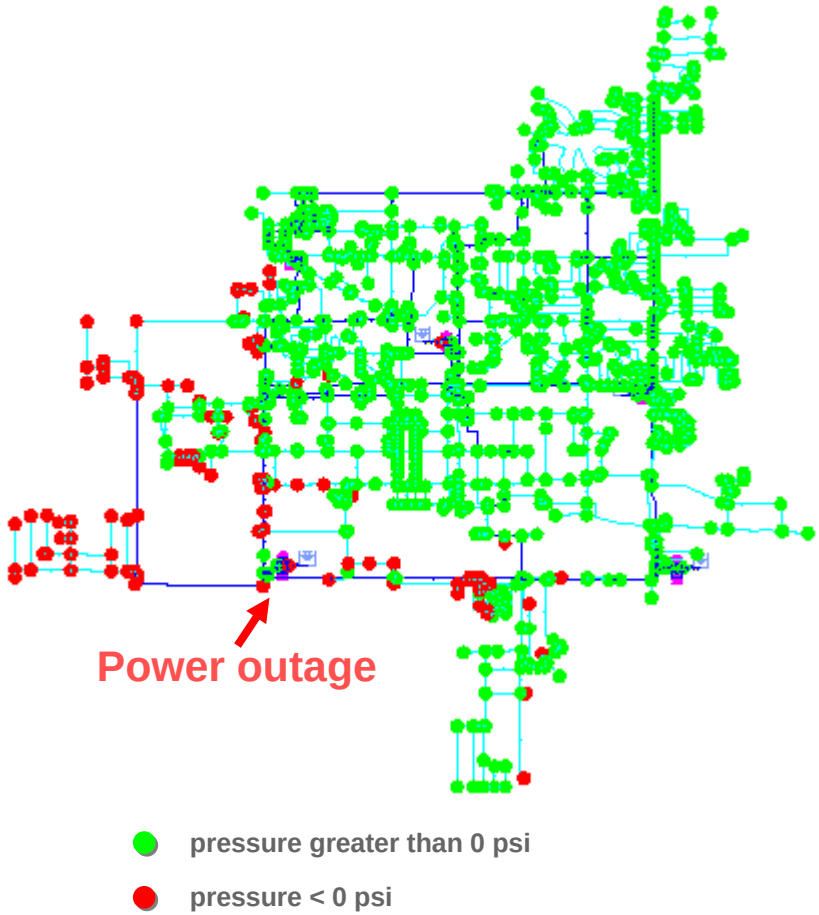
Calculate customer's infection risk

Assumes:

- 10% leakage at 60 psi (414 kPa)
- No residual disinfectant

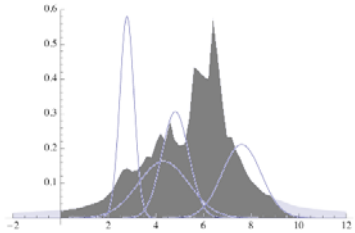
Identify intrusion locations

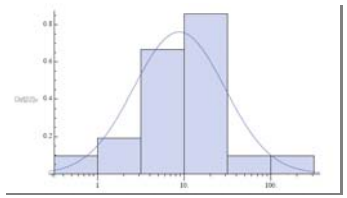
- System has max day flow of 13 MGD
- Serves population of 33,182
- The water system model has 1128 nodes and 1369 pipe segments, representing 167 miles of pipe
- 118 nodes (11%) susceptible to intrusion during power outage at the southwest pump station

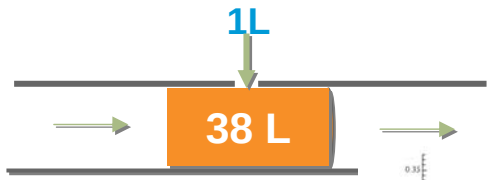


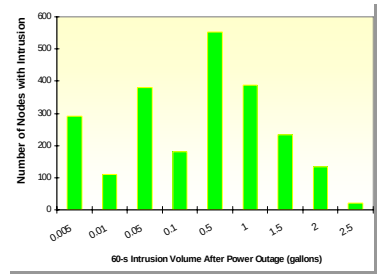
Development of QMRA

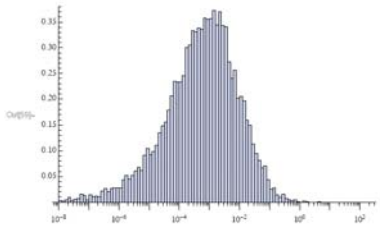
1. External virus concentration
2. Negative pressure duration
3. Intrusion volume
4. Dilution
5. Virus Transport
6. Population Exposed
7. Coincidence of exposure
8. Volume consumed
9. Dose Response
10. Risk Calculation

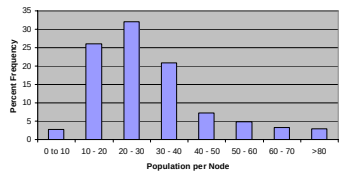


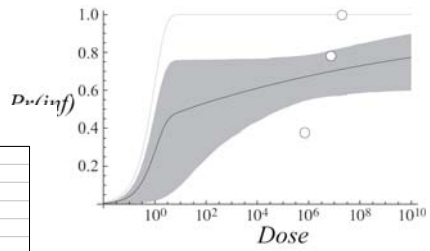


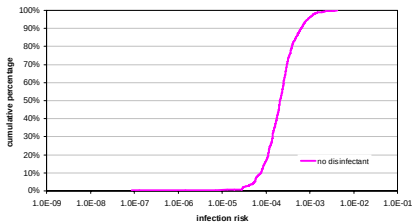


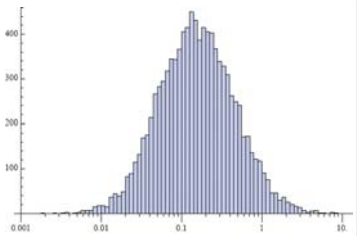




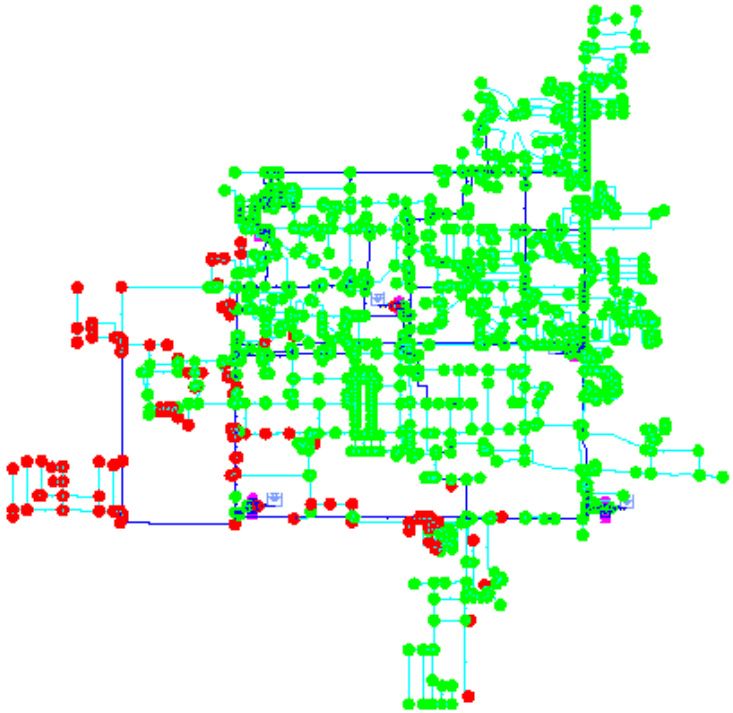




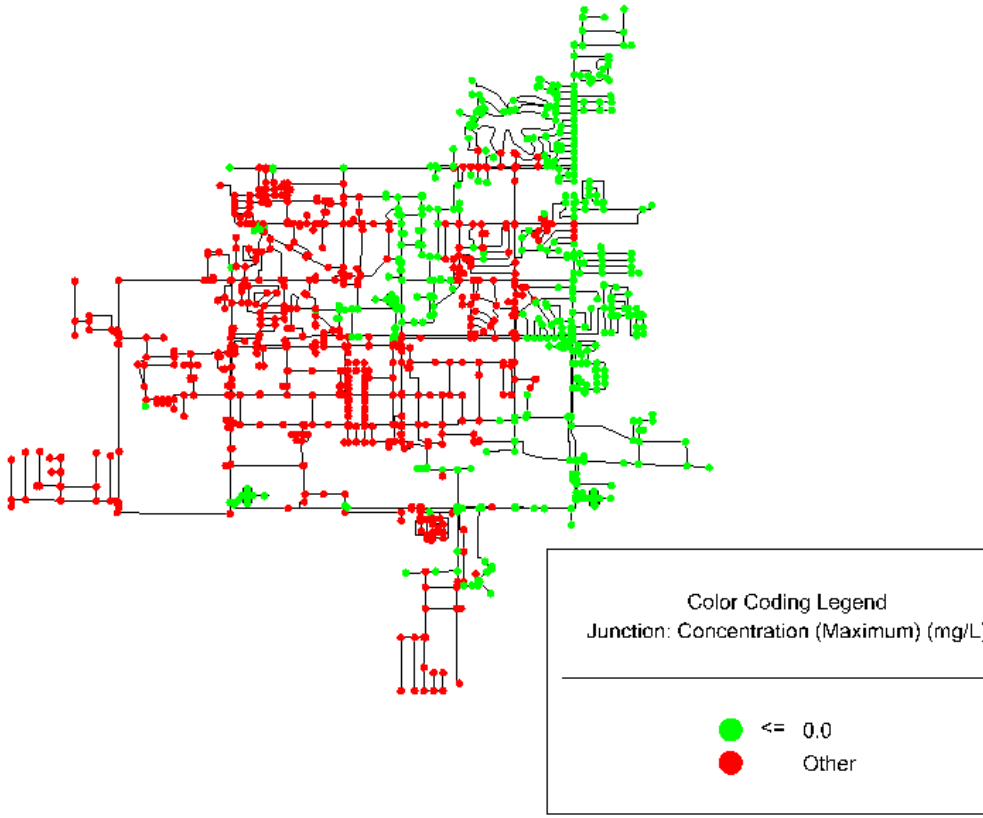




Virus transport without a disinfectant residual



Initial points of intrusion

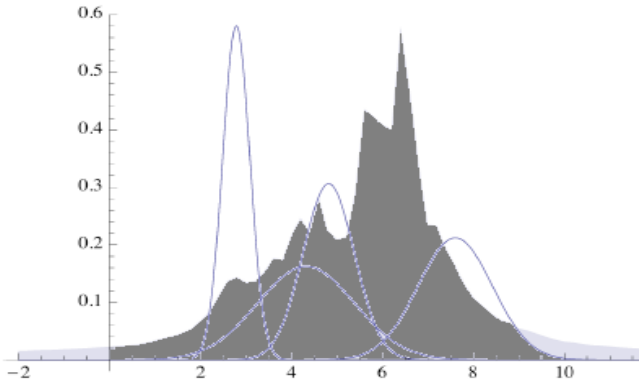


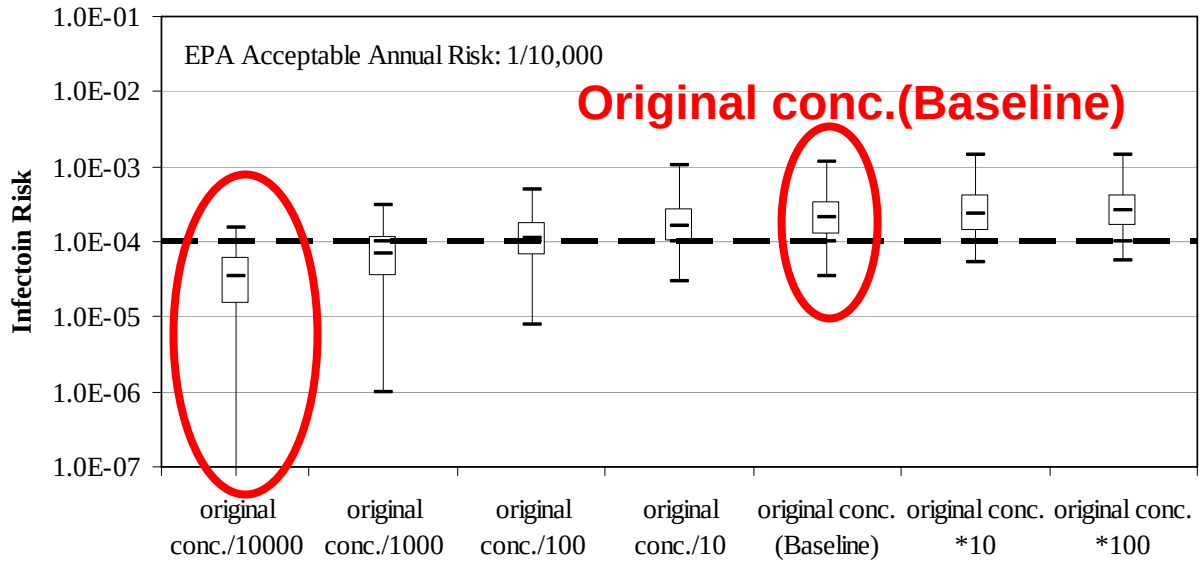
Virus transport after 24 h.

Risk Management Options

- External Virus Concentration
- Negative Pressure Duration
- Selection of Residual Disinfectant
  - Free chlorine
  - Monochloramine
- Minimum Disinfectant Residual
- Orifice size (amount of leakage)
- Number of Nodes Affected
- Pressure Management

Impact of External Virus Concentration



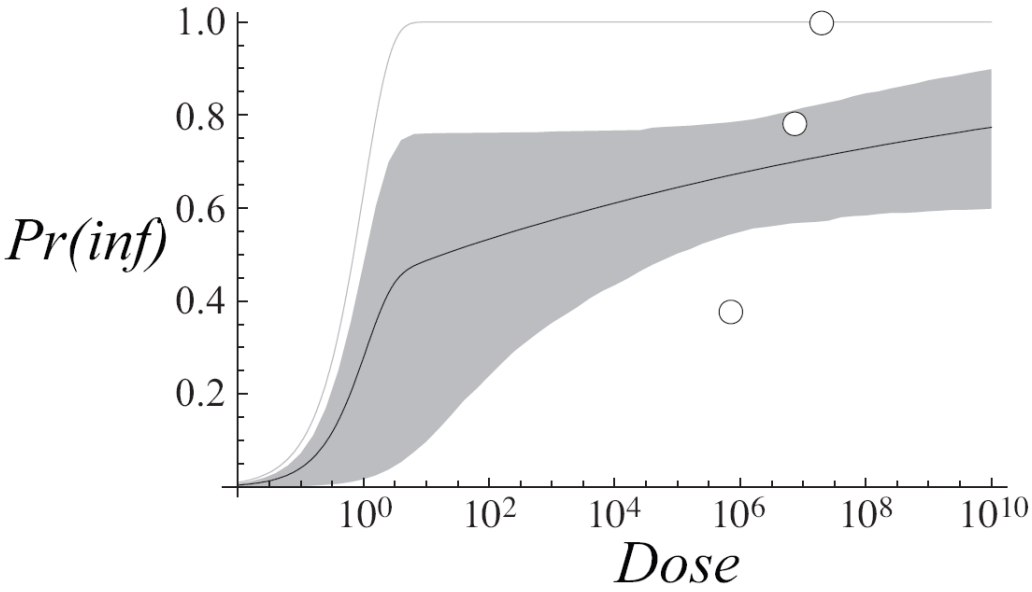


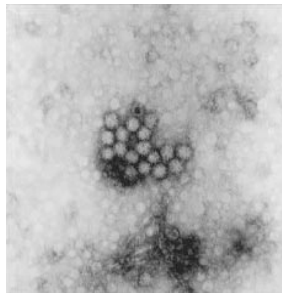
Norovirus:

Geo Mean: 3.86×10^4 /L
Median: 4.94×10^4 /L

Although virus levels decreased 4 orders of magnitude, risk changed less than 10-fold

Norovirus Infectivity



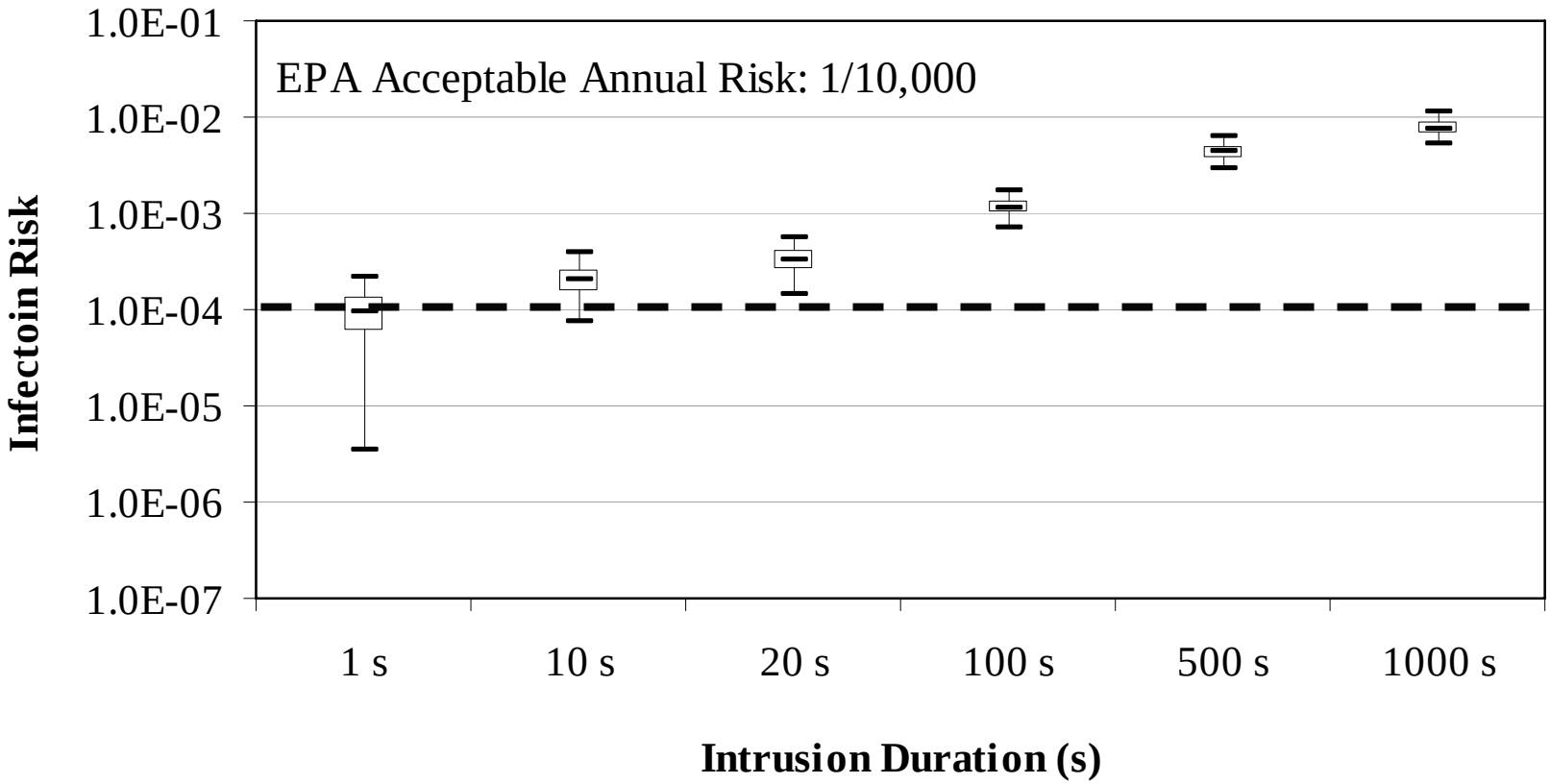


ID_{50} of18 viruses (dispersed)

Infection with Norwalk virus was associated with a 68% probability of illness.

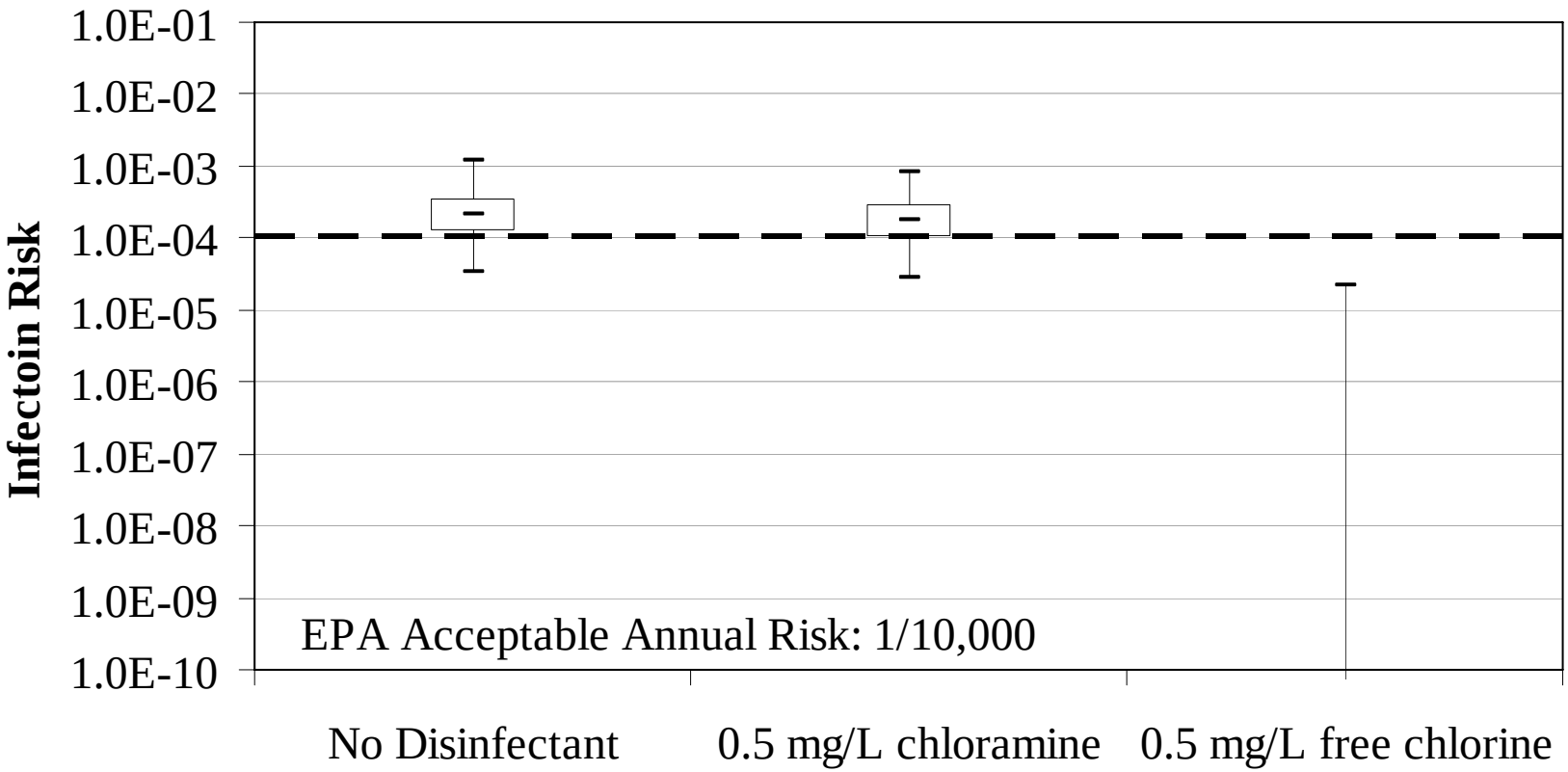
Teunis et al., Journal of Medical Virology 80:1468–1476 (2008)

Negative Pressure Duration



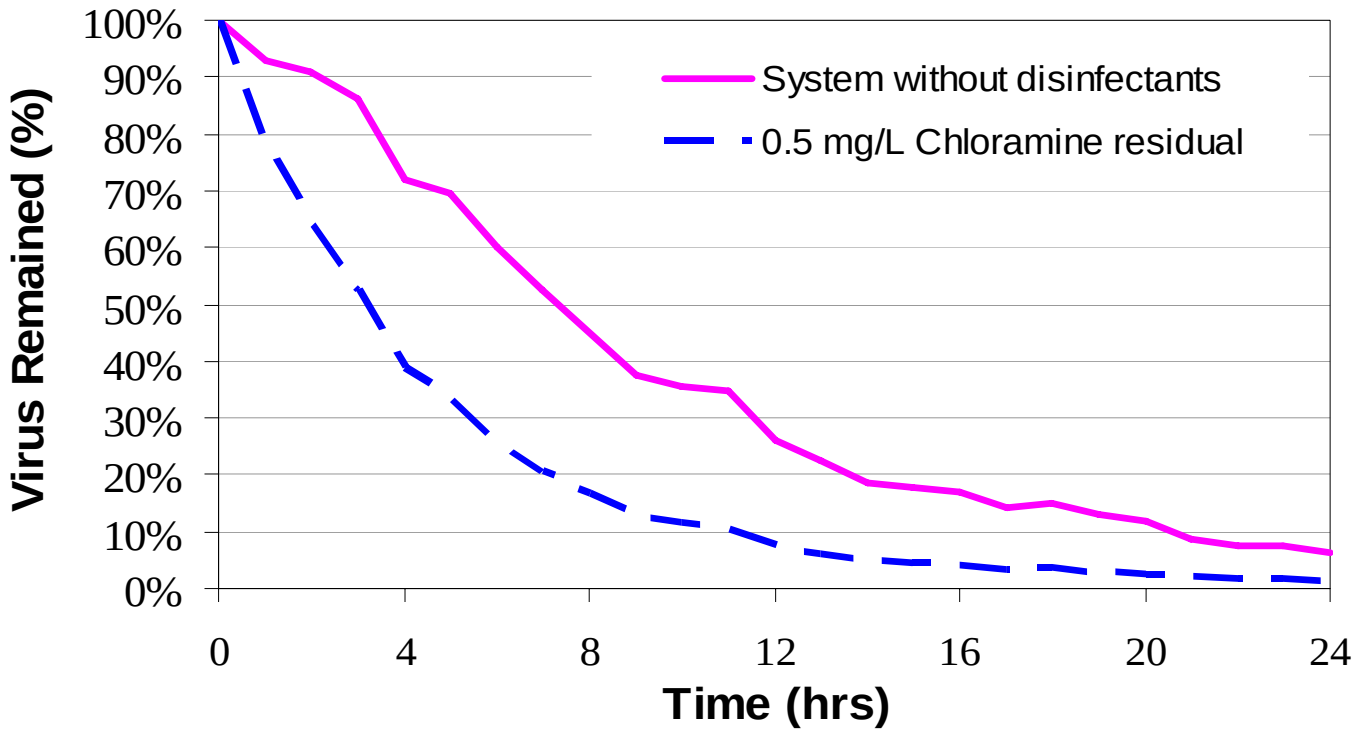
Short negative pressure events (<10 sec) may pose insignificant risk

Role of Residual Disinfectant



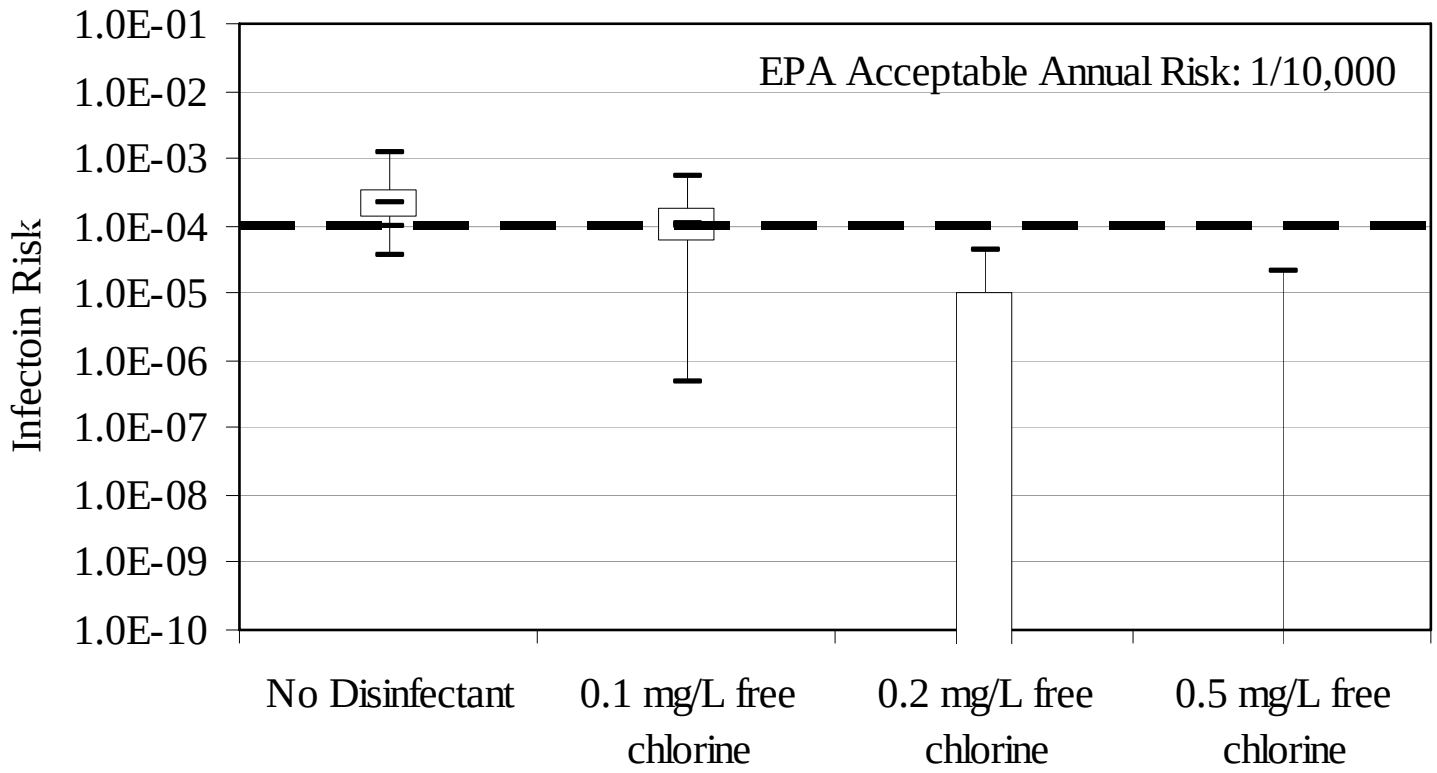
Free chlorine can eliminate virus risk due to intrusion of 0.1% wastewater

Role of Chloramine Residual



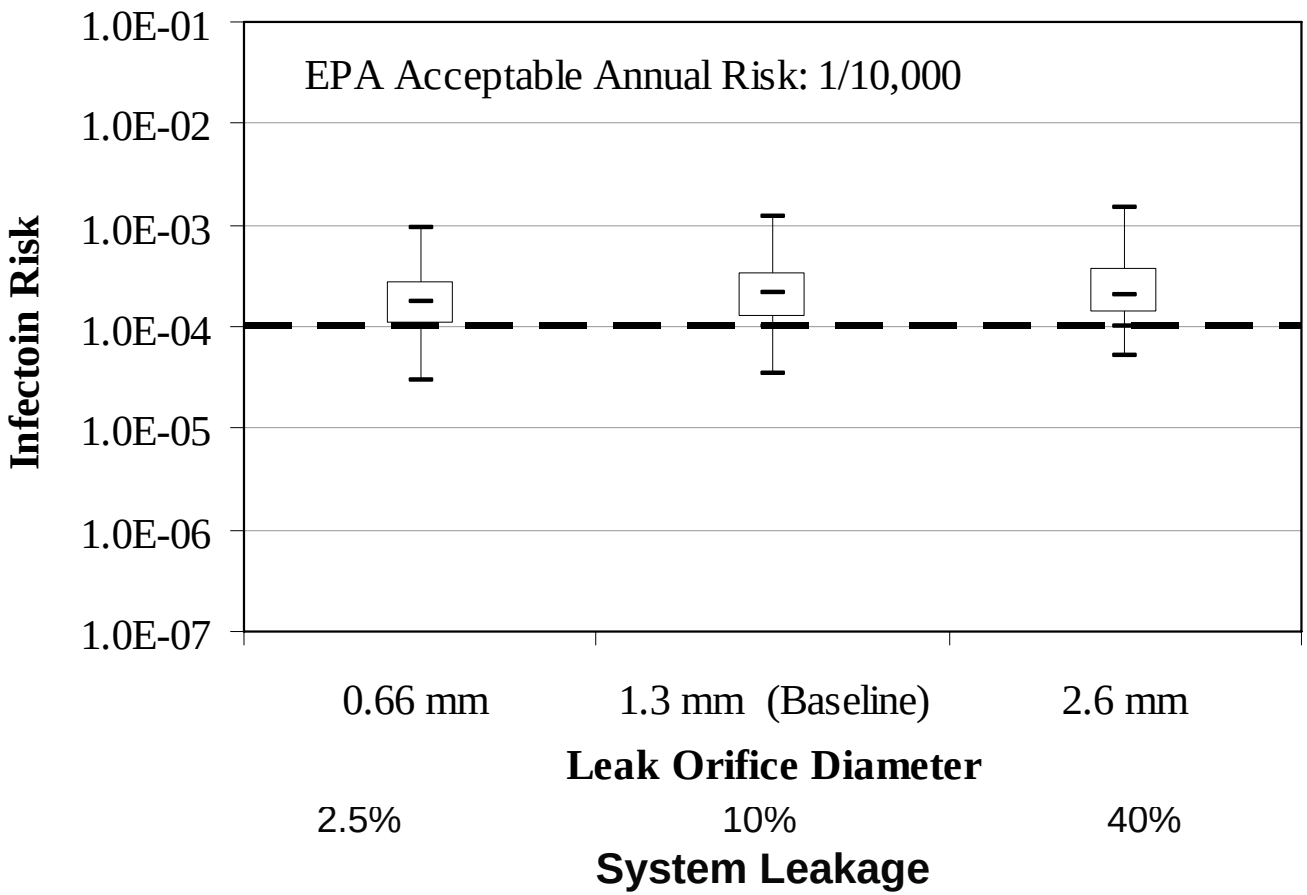
Although chloramines inactivate Norovirus, risk remains as long as some viruses persist in the system

Minimum Disinfectant Residual



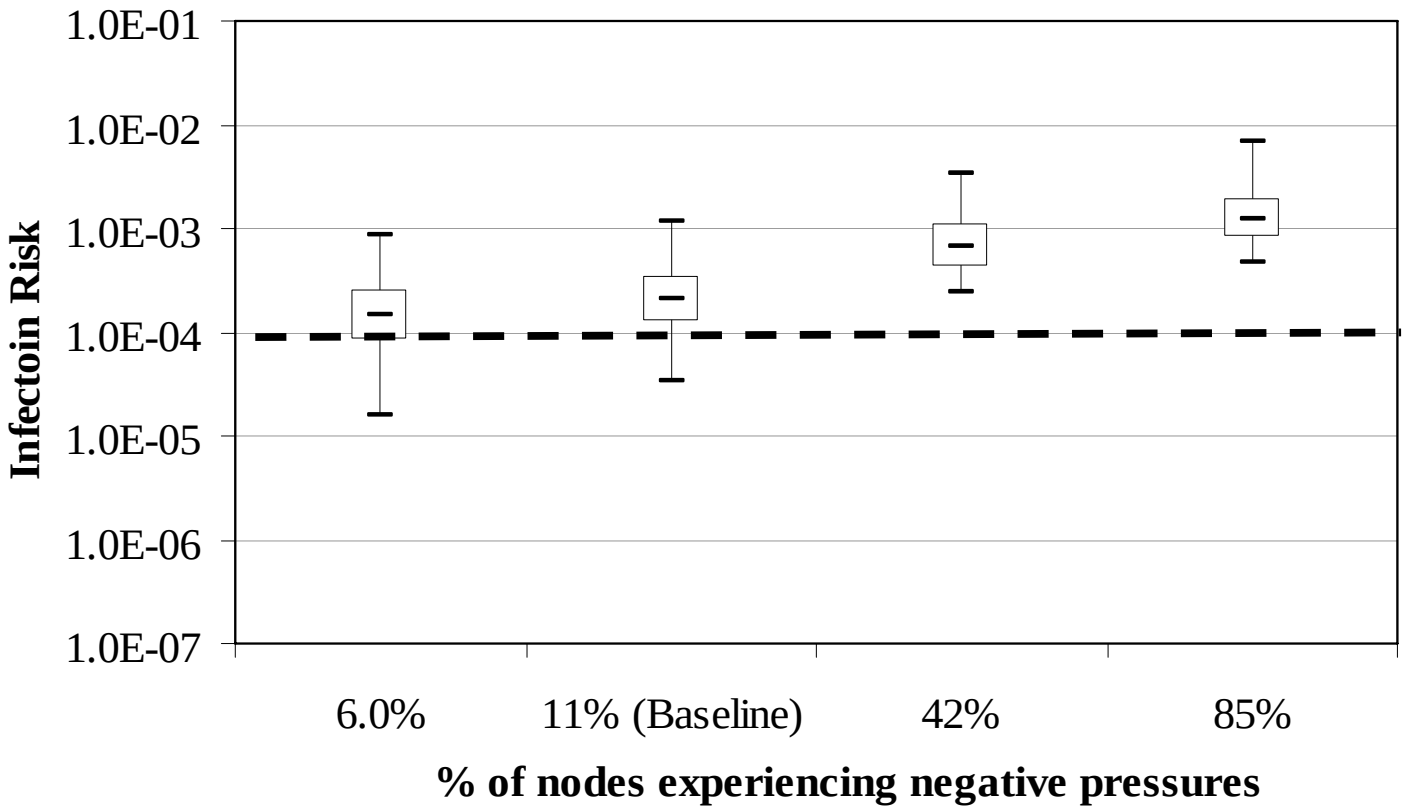
Free chlorine residuals >0.2 mg/L eliminated Norovirus virus risk due to intrusion of 0.1% wastewater

Orifice size (amount of leakage)



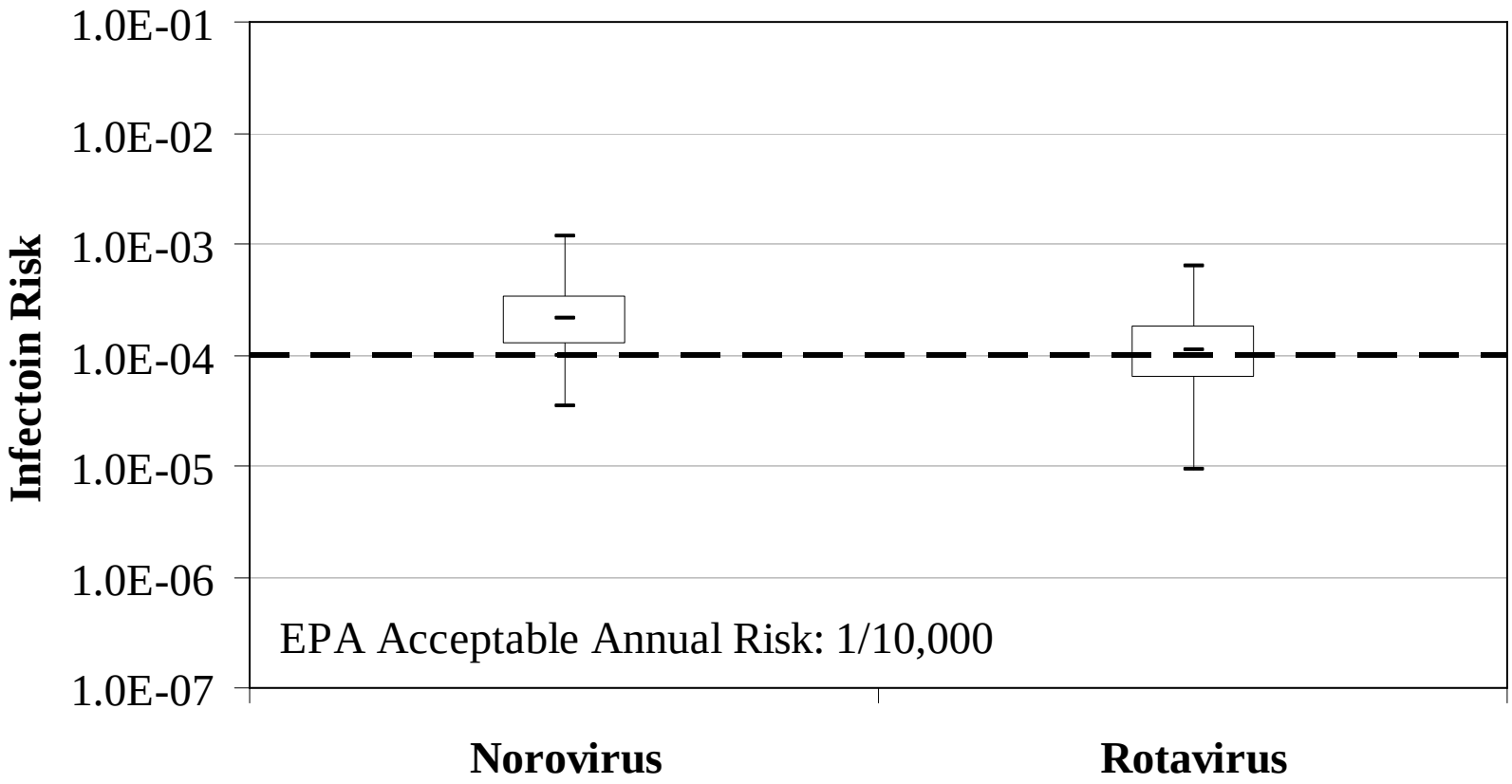
Reducing the orifice size (amount of leakage) had little impact on intrusion risk

Number of Nodes Drawing Negative Pressures



Reducing the number of nodes experiencing negative pressures will reduce risk

Comparison of Norovirus and Rotavirus Risk



Rotavirus risk is similar to Norovirus

Conclusions

- **Sufficient information is available to model risks from intrusion. This study examined just one set of scenarios.**
- **The coincidence of virus consumption and the duration of the negative pressure event are the most critical parameters driving risk.**
  - Single events of short duration pose little risk

- **Maintenance of a free chlorine residual (>0.2 mg/L) provides a protective barrier against low-level intrusions.**
- **A monochloramine residual (0.5 mg/L) does not have a big impact on Norovirus risk reduction due to the highly infectious nature of the viruses.**
- **External virus concentrations, virus infectivity, mixing, or orifice size had little impact of risk.**
- **Pressure management to reduce the extent of negative pressure events is particularly important in chloraminated systems.**

Acknowledgements

Funding for this research was provided by the utility subsidiaries of American Water and the Water Research Foundation (formerly AwwaRF)

Contact Information

Mark W. LeChevallier, Ph.D.
Director, Innovation & Environmental Stewardship
American Water
1025 Laurel Oak Road
Voorhees, NJ 08043 USA
phone: (856) 346-8261
fax: (856) 782-3603
e-mail: mark.lechevallier@amwater.com