# Reducing Risks from Water Contamination in Distribution Systems

Pennsylvania Section

American Water Works Association

# Water Quantity Goal

**To deliver water in the quantity and at the pressures required by the customer and fire protection.**

*J.W. Heavens and J.E. Gumbel. 2002. "To Dig or Not to Dig": Design, Specification and Selection Issues in the Trenchless Renovation of Water Mains. In D.M. Hughes (ed). Assessing the Future: Water Utility Infrastructure Management. AWWA, Denver, CO*

# Reliability Goal

**To deliver water of the expected quality and quantity on a continuous basis with minimum service interruption.**

*J.W. Heavens and J.E. Gumbel. 2002. "To Dig or Not to Dig": Design, Specification and Selection Issues in the Trenchless Renovation of Water Mains. In D.M. Hughes (ed). Assessing the Future: Water Utility Infrastructure Management. AWWA, Denver, CO*

# Distribution System Integrity includes:

- Security
- Reliability
- Water quality
- Water loss
- Water flow
- Water pressure

Thursday, January 1, 2009 THE PHILADELPHIA INQUIRER

LAURENCE KESTERSON / Staff Photographer

**A Philadelphia Water Department** worker looks at a truck in the Johnson Street sinkhole.

File photograph

**A 20-foot sinkhole** at Frankford Avenue and Clearfield Street swallowed a fuel truck in 1951.

## Sinkhole woes, then and now

A section of West Johnson Street in Mount Airy crumbled about 8 a.m. yesterday after a water main broke, trapping a Water Department truck in a shallow sinkhole that by noon had deepened to 10 feet.

The crew escaped without injury, and the truck and its air compressor later were hauled away. Water service was expected to be restored to the area by late afternoon.

In a similar incident, on Sept. 22, 1951, a 20-foot sinkhole at Frankford Avenue and Clearfield Street swallowed a passing fuel truck following the rupture of a nearby storm drain. The astonished driver, Nicholas Potere, escaped after his front wheels caught on a water main long enough for him to scramble to safey. In both cases, rushing water loosened soil beneath the road surface.

AU

IMPOI

# “Distribution System”

- Every water utility’s system is **unique**

- However, the **processes within each system have many common characteristics** that allow us to develop Best Management Practices, Standards and Regulations

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

- **The distribution system is the remaining component of public water supplies yet to be adequately addressed in national efforts to eradicate waterborne disease.**

## Issues associated with distribution system water quality

- Cross connections and backflow events
- Biofilm formation
- Pressure transients and intrusion
- New and repaired mains, and breaks
- Storage facility integrity

# Regulations associated with the distribution system

- Total Coliform Rule (coliform and *E. coli*)
- Surface Water Treatment Rule (chlorine)
- Groundwater Rule (coliform)
- Lead and Copper Rule (and corrosion control)
- D/DBP Rule (TTHM, HAAs and chlorine)
- Sanitary Surveys

# CDC: Centers for Disease Control and Prevention


**2013 – 2014 Waterborne disease outbreaks**

# Drinking water exposure 2013 - 2014

- ***Legionella*** – acute respiratory illness
  - 24 outbreaks
  - 130 cases of illness
  - 109 hospitalizations
  - **13 deaths**
  - **83% of outbreaks associated with public water systems on both surface and ground water** (such as with Flint, Michigan)
  - **3 outbreaks in Pennsylvania at a hospital and at long-term care facilities**

# Cross Connection Control

# Cross Connection/Backflow

**Potential Contamination Due to Cross-Connections and Backflow and the Associated Health Risks Total Coliform Rule Issue**

**Paper by US EPA, August, 2002**

## CDC data: 1981-1998

- **57 waterborne disease outbreaks related to cross-connections**
- **20 from microbiological contaminants**
- **15 from chemical contaminants**

## Craun and Calderon (2001) data: 1971-1998

- **50.6% of distribution system-related outbreaks were caused by cross connections**

# Cross Connection Control

- **"Cross-connection"** – inadvertent connections between non-potable water (or other liquids) and the potable water supply

- **"Backflow"** – entry of non-potable water (or other liquids) through a cross-connection into the potable water supply as a result of
  - Backsiphonage
  - Backpressure

# HYDRAULIC CONDITIONS …

***Backsiphonage:***

Backflow due to a negative or reduced pressure within the potable water supply

***Backpressure:***

Backflow due to water pressure which exceeds the operating pressure of the potable water supply

# New Mains and Repairs

# Community Water System Survey

- **78% of pipe is less than 40 years old**
- **18% of pipe is 40 to 80 years old**
- **Only 4% is more than 80 years old**
- **Replacement rates are less than 1% per year**
- **Despite 47% of all capital expenditures being devoted to distribution and transmission infrastructure.**

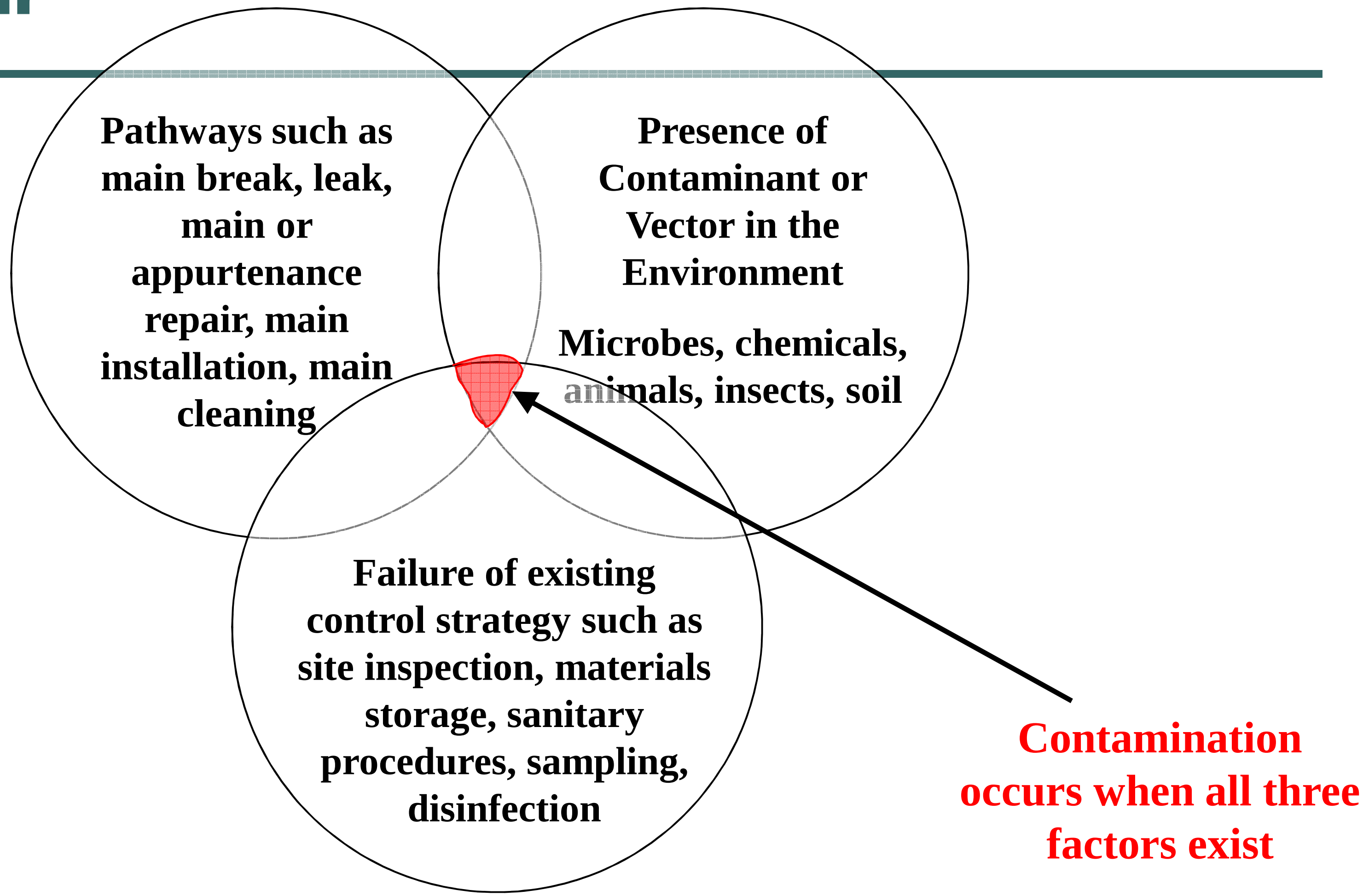
*Distribution System Inventory, Integrity and Water Quality. AWWA Total Coliform Rule Issue Paper for US EPA, January, 2007.*

# Opportunity Exists for Contamination to Occur

New or Repaired Water Mains. AWWA/EES, Inc. Total Coliform Rule Issue Paper for US EPA, 2002

- **In the USA, about 4,400 miles of pipe are replaced every year**
- **About 13,200 miles of new pipe are installed every year**
- **About 237,600 water main breaks occur every year**

# Contamination During Main Installation and Repair



# The environment around mains

- **Soil surrounding buried pipe can be contaminated** with fecal indicator microorganisms and pathogens (Kirmeyer et al., 2001).

- **Runoff from streets and agricultural land** can be highly concentrated with microbiological and chemical contaminants (Makepeace et al., 1995).

- **Leaking sewers can contaminate the soil** and groundwater in the area of a water main or a trench where main activity will take place.

## State of Current Information: New and Repaired Mains

- Number of events is fairly well known:
  - 13,200 miles new main per year
  - (3.5 million events)

Research has documented a low level of contamination that occurs with new main installation and repairs.

# State of Current Information: New and Repaired Mains

- While standards exist for inspection and sanitary practices, these are not adhered to 100% of the time.
- National survey data on effective use of control strategies:
  - **Only 30-35% of inspectors are trained** on AWWA standards and utility specifications
  - However, **70-75% use disinfection** BMPs
  - Yet, **20% maintain water quality data** for new/repaired mains

# New Pipe and Coliform Tests

- Survey of water utilities found:
  - 14% of utilities had coliform positive tests on new mains
  - 1-10 % of samples taken from new mains to approve them for release had total coliforms

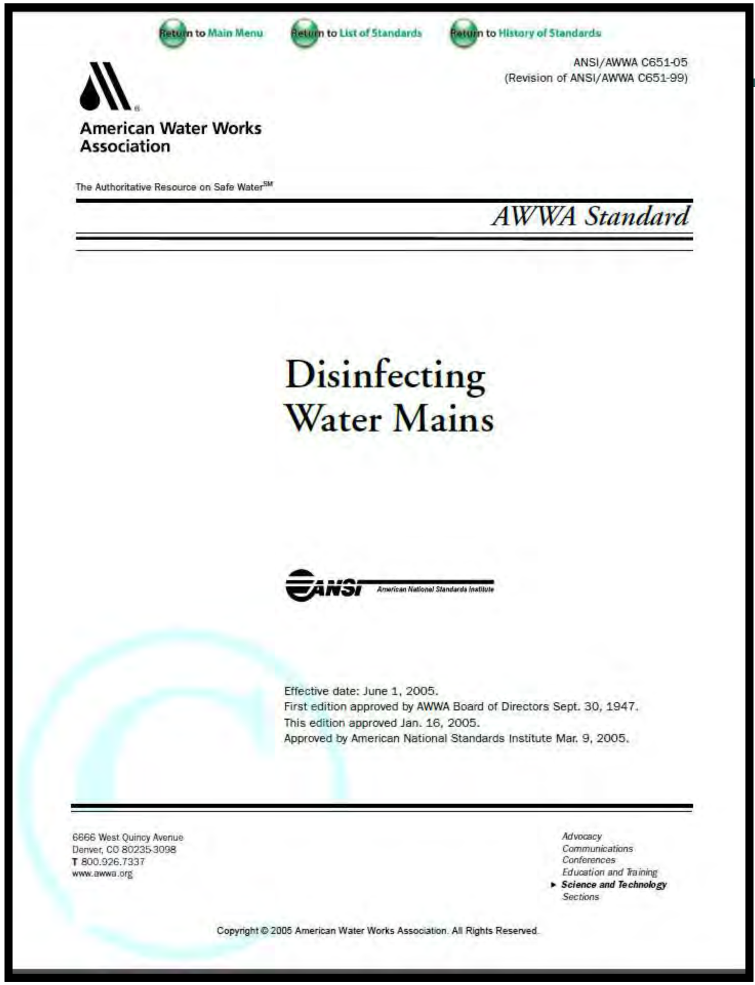
*(Development of Disinfection Guidelines for the Installation and Replacement of Water Mains. C.N. Haas et al., 1998. WRF)*

# New Pipe Contamination

- **Survey of water utilities found:**
  - **Few water utilities protect pipe from contamination during storage and installation**
  - **Few water utilities inspect and clean pipe prior to installation**
  - **New pipe is not sterile**

*(Development of Disinfection Guidelines for the Installation and Replacement of Water Mains. C.N. Haas et al., 1998. WRF)*

# AWWA Standard C-651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ANSI/AWWA C651-05
(Revision of ANSI/AWWA C651-99)

American Water Works Association

The Authoritative Resource on Safe Water[SM]

*AWWA Standard*

Disinfecting Water Mains

ANSI American National Standards Institute

Effective date: June 1, 2005.
First edition approved by AWWA Board of Directors Sept. 30, 1947.
This edition approved Jan. 16, 2005.
Approved by American National Standards Institute Mar. 9, 2005.

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- This standard has been in place since 1947.
- The **1999 version** took into account research and best practices that had been developed for sanitary practices and disinfection during **<u>new main construction</u>**.

# Large-Diameter Transmission Mains

**Spray disinfection can be a viable option for very large transmission mains:**

- See AWWA Standard C-652
- Disinfection of Water Storage Facilities, Chlorination Method 2

# Updated C-651 for Main Breaks

- A **risk management approach** based on the type of main break with guidelines on actions to take.
- **Clearer delineation** between disinfection for new mains versus main breaks.
- Clearer use of **disinfection techniques** such as swabbing and spraying.
- A guideline for obtaining a proper **flushing to remove debris**.
- Clarity on when water sampling is needed and the **water quality tests** that are helpful to use.

# Type of Break & Risk Reduction

| Actions | Leak or Crack; No Pressure Loss Occurs | Main Break with a Controlled Shutdown | Uncontrolled Event with Pressure Loss |
|---|---|---|---|
| **Dry the Trench** | YES | YES | **YES** |
| **Keep pipe under pressure** | YES | UNTIL SHUTDOWN | **NO** |
| **Spray with chlorine** | YES | YES | **YES** |
| **Swab with chlorine** | NO | YES | **YES** |
| **Flush method:** | DISPLACEMENT | SCOUR | **SCOUR** |
| **Need for Disinfection** | NO | NO | **YES** |
| **Warn affected customers** | NO | NO | **MAYBE** |
| **Test water BEFORE release of job** | NO | MAYBE | **YES** |

# Storage Facilities

# Neglected Water Towers Could Leave Bad Taste

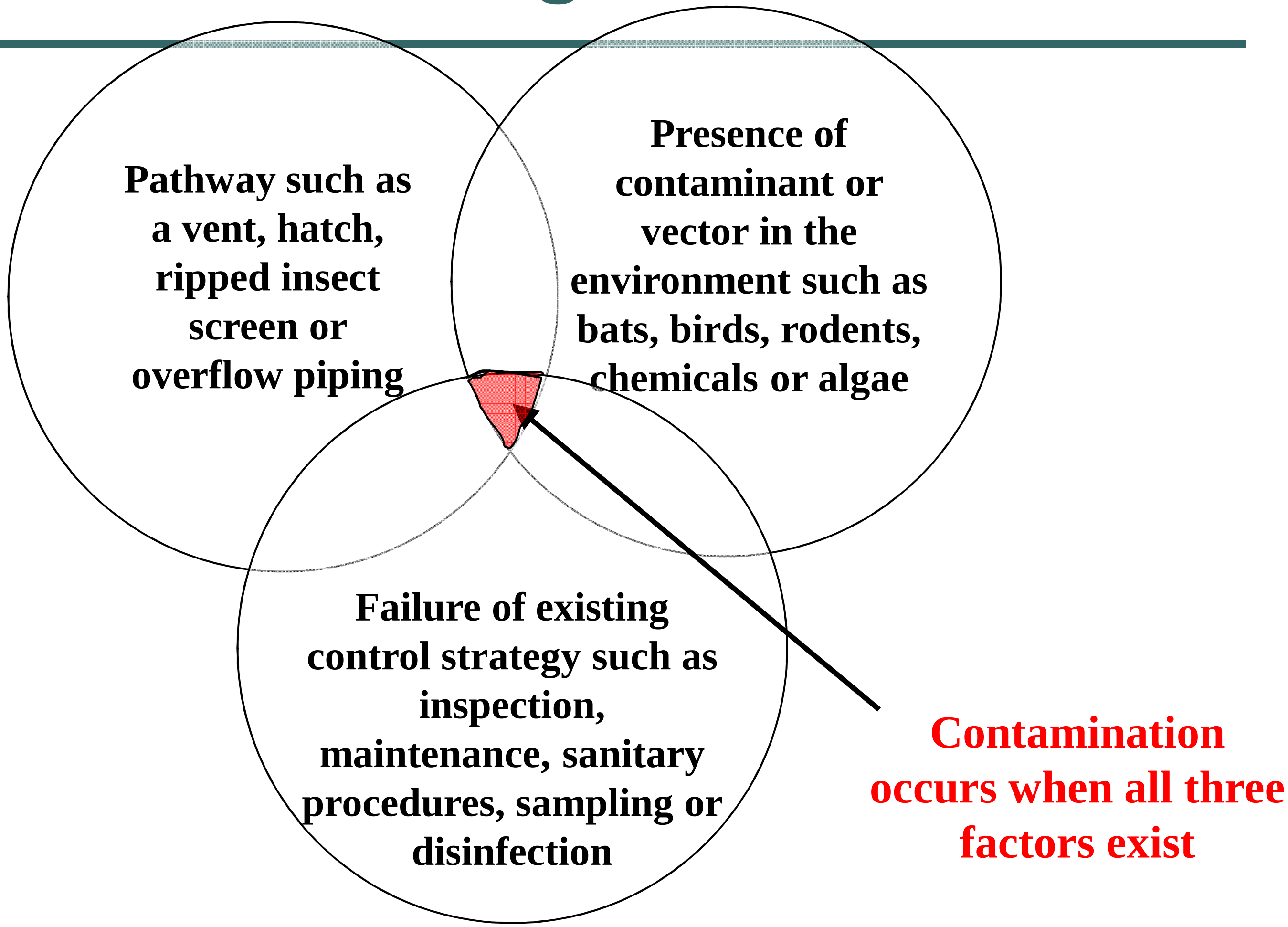
**Monday, April 28, 2008 2:02 PM**

**COLUMBUS, Ohio — 10 Investigates found some central Ohio water towers that have been neglected and have not been inspected or cleaned in years.**

**Rust, dirt and even dead animals were found inside some towers we inspected, 10 Investigates' Paul Aker reported.**

**Martha lives near Darbyville's water tower. She said that she could not remember anyone ever inspecting the tank.**

# External Contamination of Finished Water Storage Facilities



# Establish an Inspection Program for all storage facilities

**Frequent Routine Inspections**

***and***

**Periodic Detailed Inspections**

*(Maintaining Water Quality in Finished Water Storage Facilities. G.J. Kirmeyer et al., 1999. WRF)*

# Pressure Loss and Transients

## Pressure Transients

- **Low and negative pressure transients** occur in distribution systems and can allow contaminants external to the pipe to be intruded into a drinking water main through a leak or orifice.

## Pressure surges or changes can:

- Bring in **external contamination**
- **Dislodge scale** and biofilm
- **Stir up sediment**

# Biofilm Control

# What is a "biofilm"?

- A biofilm is a **mixture of microorganisms, inorganic and organic matter** that adheres to a surface such as a pipe wall.

- **All materials** in contact with drinking water have some level of biofilm since water is not sterile

# Biofilm

Growth is promoted under certain conditions:

- **Temperature of the water** (rule of thumb is >15 °C)
- **Disinfectant type and concentration** (particularly a loss of chlorine residual)
- **Biodegradable organic matter** is plentiful
- **Pipe materials vary in potentail and the extent of corrosion**
- Water chemistry is favorable
- Water hydraulics: flow velocity and flow reversals (under continuous, flow biofilms are enhanced)

# A biofilm can be a source of problems:

- **Elevated HPC bacteria** (however, HPC counts from water samples may not relate to the extent of the biofilm)
- **Total coliform** occurrences
- **Biological nitrification**
- Growth of **opportunistic pathogens** such as *Klebsiella, Mycobacterium,* and *Legionella*.

# A biofilm can be a source of bacteria found in samples:

- Biofilms and/or organisms can detach from the pipe wall and enter the water for a variety of reasons:
  - During increased flows related to fire fighting or main breaks
  - Due to reversal of normal flow direction in pipes
  - In response to a change in water quality

# Mitigation Strategies: System Practices

- **Limit nutrients** entering the distribution system (organic carbon, nitrogen, phosphorus)
- **Control system hydraulics** to:
  - Minimize low flow areas
  - Reduce residence time
  - Maintain consistent flow rates and direction to prevent sloughing
- **Conduct periodic flushing in the areas susceptible to biofilm**

# Issues associated with distribution system water quality

- **DBP** formation and fate
- **Pathogen retention** and transport in the system
- **Lead and copper** release
- **Biological stability** of treated water that could encourage bacterial regrowth
- **Biological nitrification**
- **Water age** and resulting changes in water quality

# Issues associated with distribution system water quality

- **Permeation** of contaminants through pipe and fittings
- **Leaching** of chemicals from materials used in the system
- **Aging infrastructure** and loss of physical integrity
- **Disinfectant residual** and its loss
- Internal pipe **corrosion**

# Other Issues – Permeation and Leaching

# Permeation

- Permeation is the **movement of chemicals from outside the pipe, through the pipe or appurtenance materials themselves** (as opposed to through orifices or leaks, as in intrusion), and into the water.

- **Over 100 incidents of drinking water contamination** resulting from permeation of subsurface mains and fittings have been reported in the United States.

# Permeation

- Permeation contaminants include: **benzene, toluene, ethylbenzene, xylenes (BTEX), and other gasoline-range organics.**

- The most common pipe materials in permeation incidents are **polybutylene (PB), polyethylene (PE), and polyvinyl chloride (PVC).** PVC and PE pipes have increased contamination potential once organic chemicals have permeated. Permeation will not occur through iron pipe although connections of plastic service lines to iron pipe exist and would allow for permeation to occur.

# Leaching

- Leaching is the d**issolution of metals, chemicals, and other materials from the piping, linings and appurtenances** into drinking water.

# Leaching

- **Pre-1977 PVC pipe** contains elevated levels of vinyl chloride monomer known to leach into drinking water. Vinyl chloride is a regulated drinking water contaminant and a known carcinogen.

- **Cement mains and linings**. Cement materials may degrade in acidic or aggressive waters. Many inorganic chemicals in cement leach, such as arsenic, barium, cadmium, and chromium. Several illnesses and 32 percent mortality at a receiving dialysis center were attributed to aluminum leaching from cement-mortar lined pipe.

# Leaching

- **Bituminous coatings and linings**. Solvents added to coatings can diffuse through the coatings into the water. Improperly cured linings can leach organic contaminants into the drinking water.

- **Epoxy coatings and linings**. Epoxy resins, curing agents, fillers, and pigments. A study of five approved epoxy resins showed substantial leaching for three of the five coatings.

# Other Issues - Corrosion

# Internal Corrosion

- Corrosion increases the **corroded surface environment** of iron pipe.
- This in turn **increases the chlorine demand** exerted by that environment.
- This **increases the biofilm** protected within that environment.
- There have been cases of **coliform regrowth** that have affected compliance.

# Iron Release

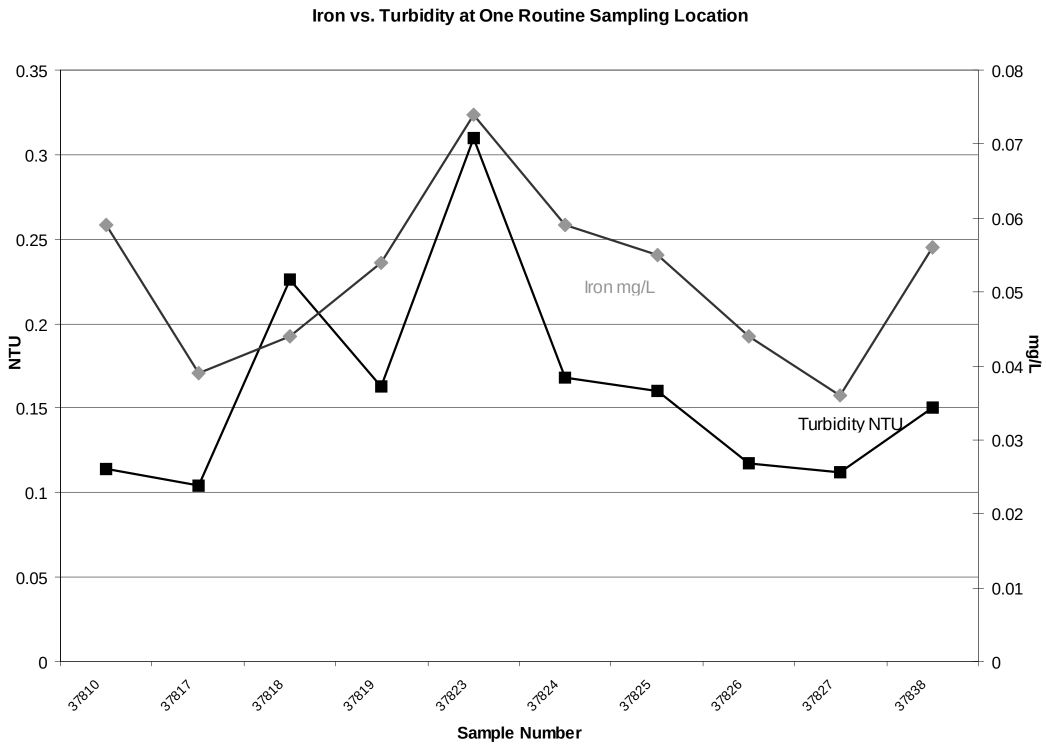
- Iron corrosion and iron release **contribute to the accumulation of sediment** in water mains.
- The condition of the sediment, and its disturbance by flow reversals and changes, can contribute to **“colored water”** problems.
- This iron rich sediment can **harbor other contaminants**.

# Iron Release

- Two indicators of iron release:
  - Total iron content
  - Apparent water color

# Iron Release

- **Turbidity** has also shown to be an indicator of iron release.



# External Corrosion factors

- Soil conditions such as resistivity, pH, and water content
- Occurrence of stray currents
- Contact between dissimilar metals
- Bacterial activity in the environment surrounding the pipe
- Quality of materials as installed

# Other Issues - Nitrification

# Chloramination

- **Chloramination**: Purposeful use of chlorine and ammonia to form monochloramine.
  - Minimizes formation of DBPs
  - Ammonia to chlorine ratio is controlled to favor formation of monochloramine, typically 5:1 $Cl_2$:N

# Nitrification

- **Microbiological process** by which reduced nitrogen compounds (primarily ammonia) are sequentially oxidized to nitrite and nitrate

- **Primarily caused by two groups of naturally-occurring bacteria**
  - Ammonia-oxidizing bacteria (AOB): oxidize ammonia to nitrite
  - Nitrite-oxidizing bacteria (NOB): oxidize nitrite to nitrate

- **Ammonia** is found naturally in some source waters or added during formation of chloramine

# Nitrification

- **Nitrification produces nitrite and nitrate**, which are regulated contaminants
  - Currently monitored at entry point to distribution system only
- Nitrification causes deterioration of water quality because it leads to:
  - **Disinfectant residual decay**

# Understanding Chloramine Decay

- Auto-decomposition (temperature)
- Reaction with organic matter
- Reaction with pipe walls ($Fe^{2+}$)
- Co-metabolism during nitrification
- Reaction with nitrite
- Reaction with biomass (HPC bacteria)

# Nitrification

- Distribution system engineering improvements
  - **Reconfigure inlet/outlet of storage facilities** to minimize water age
  - Application of **mechanical mixers** to reduce stagnant zones in storage
  - **Elimination of dead ends**

# Other Issues – Water Age

## Water quality changes from water age of most concern include:

- **Loss of a disinfectant residual**
- Disinfection byproduct (**DBP**) formation
- **Nitrification** by bacteria
- **Microbial survival and growth**
- **Corrosion** and corrosion by-product formation
- **Sediment** deposition

# Water Quality Tests

# Ways we know there have been changes:

- Chlorine residual loss
- Total coliform occurrences
- Increase in HPC bacteria
- Turbidity increase
- pH changes
- Odors
- Colored water and sediment
- Detection of nitrite and nitrate
- Detection of iron, copper, lead, managanes
- Increase in DBPs

# Best Practices

# Adequate maintenance of the distribution system

*"Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems"*
*World Health Organization (R. Ainsworth, ed), 2004*
*IWA Publishing, London*

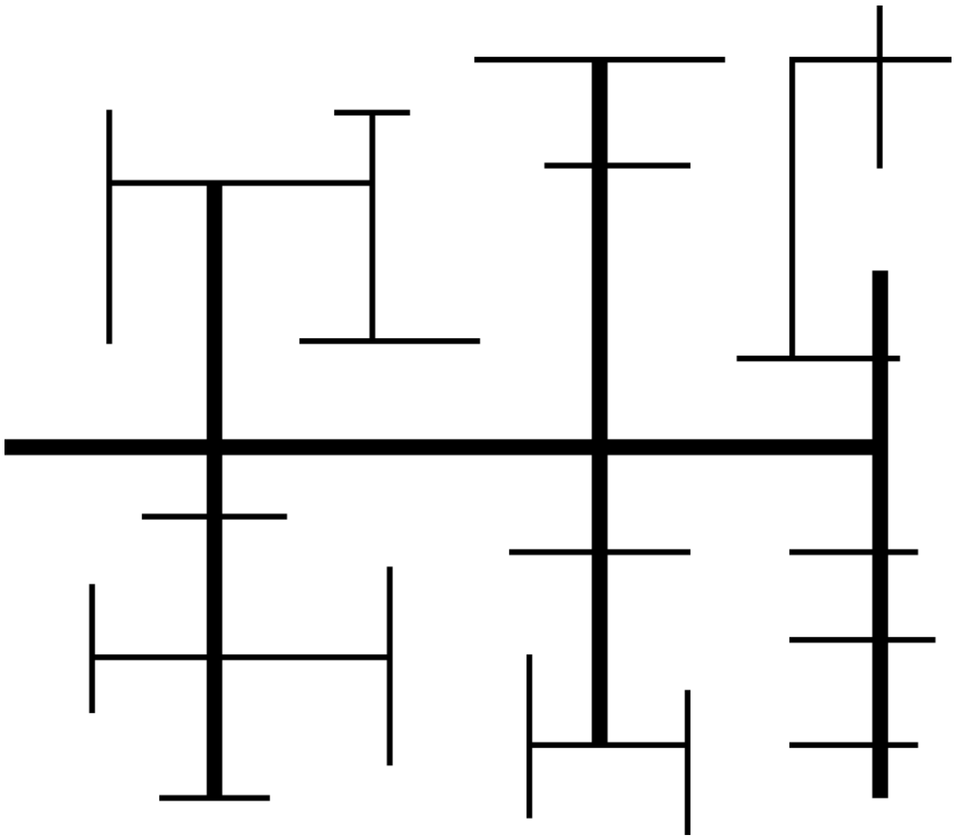
- **Means to remove and prevent accumulation of deposits.**
- **Regular sanitary inspections or surveys, especially for smaller systems.**
- **Sanitary practices for repairs and construction activities.**
- **Maintenance of storage facilities and regular inspections and cleaning.**
- **Valve operation and maintenance.**

# Proper design of distribution

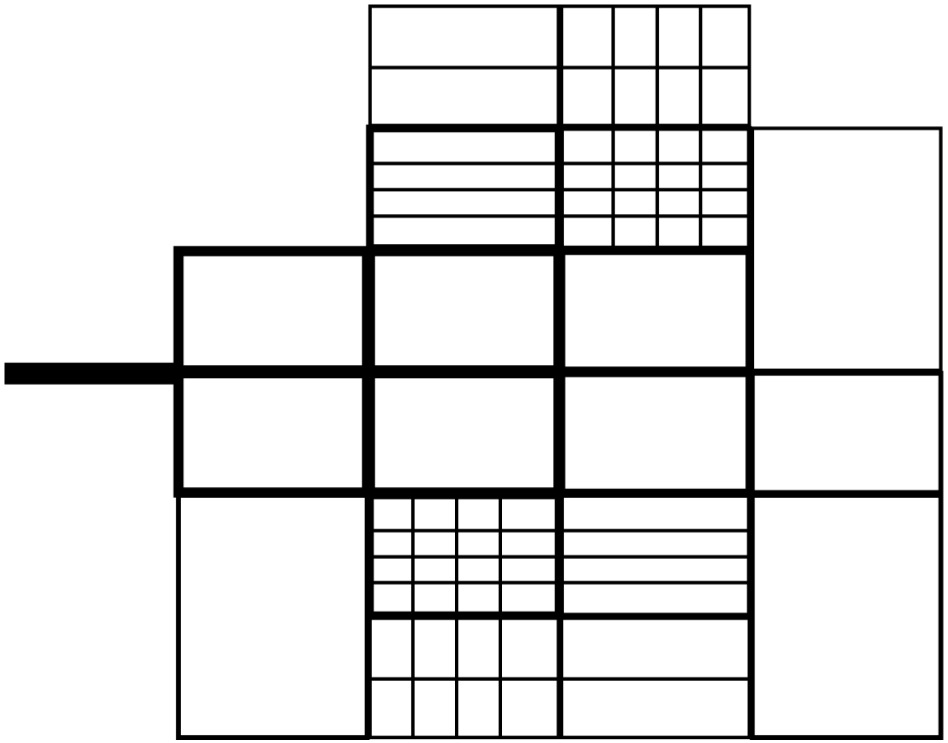
*"Safe Piped Water: Managing Microbial Water Quality in Piped Distribution Systems"*
*World Health Organization (R. Ainsworth, ed), 2004*
*IWA Publishing, London*

- **Reduce excessive capacity and minimize transit times.**
- **Avoid low-flow areas such as dead-ends and loops.**
- **Optimal application of pumps and control valves.**
- **Proper design of storage reservoirs.**
- **Proper zoning or creation of zones within a distribution system.**
- **Proper selection of pipe materials.**

# The layout of the distribution system is important



# The layout of the distribution system affects water quality



# Preventive actions

**Main renewal programs help minimize unplanned failures and thus reduce risk:**

- water main cleaning and lining
- leakage and pressure management
- hydrant and valve inspections
- transmission main inspections

*(Estimating Health Risks from Infrastructure Failures. K.M.E. Emde et al., 2006. WRF)*

# Best practices for reducing risks in distribution systems include:

- Maintain a continuous positive pressure
- Maintain a chlorine residual
- Provide cross-connection control
- Conduct water quality testing beyond the minimum regulatory requirements
- Provide for customer complaint response

# Best practices for reducing risks in distribution systems include:

- **Pressure management**
- **Follow up on main construction and repair**
- **Maintain and inspect storage facilities**
- **Minimize water age**
- **Establish an asset management plan**
- **Establish a corrosion control program**
- **Integrate systems and their data**

# Identifying the Distribution System Priorities for Reducing Public Health Risks

A Summary

# Three Factors for Public Health Risk in Distribution Systems

**2**

Pathways
connect Pathogens
to
Consumers

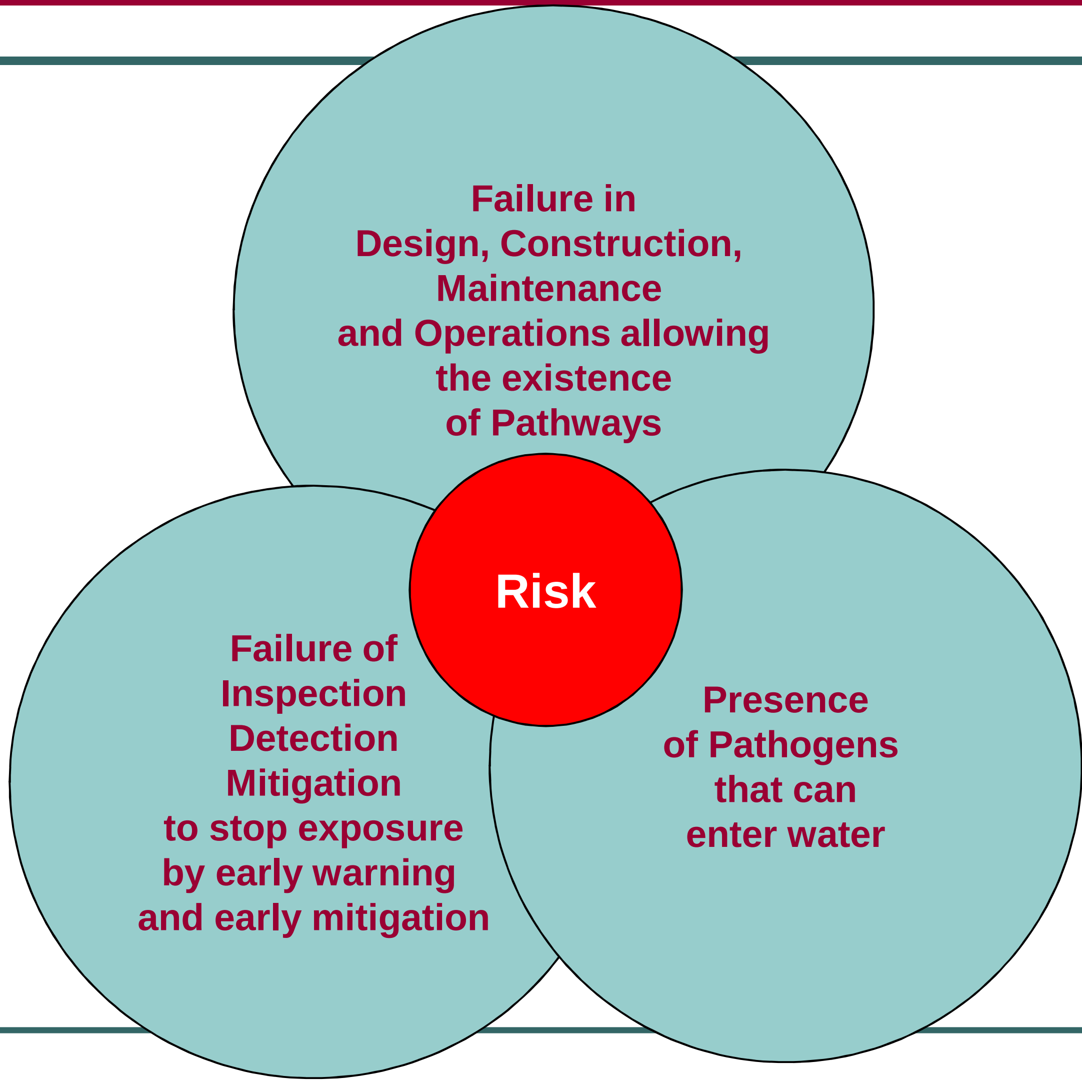
**1**

Pathogens
are Present
in the
Local Environment

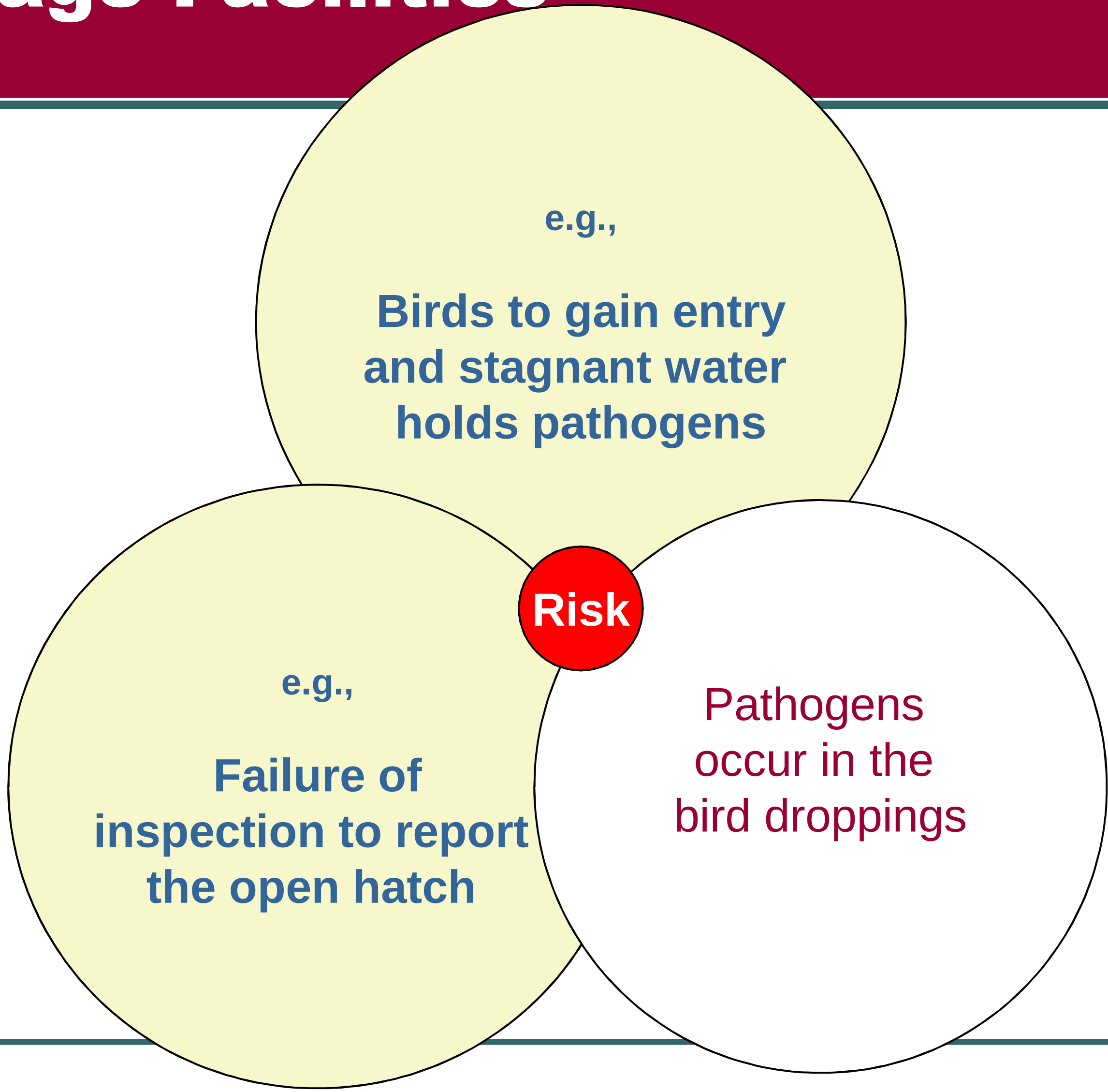
**3**

Failures
to Detect and
Mitigate Contamination
Allow Significant
Public Exposure
to Occur

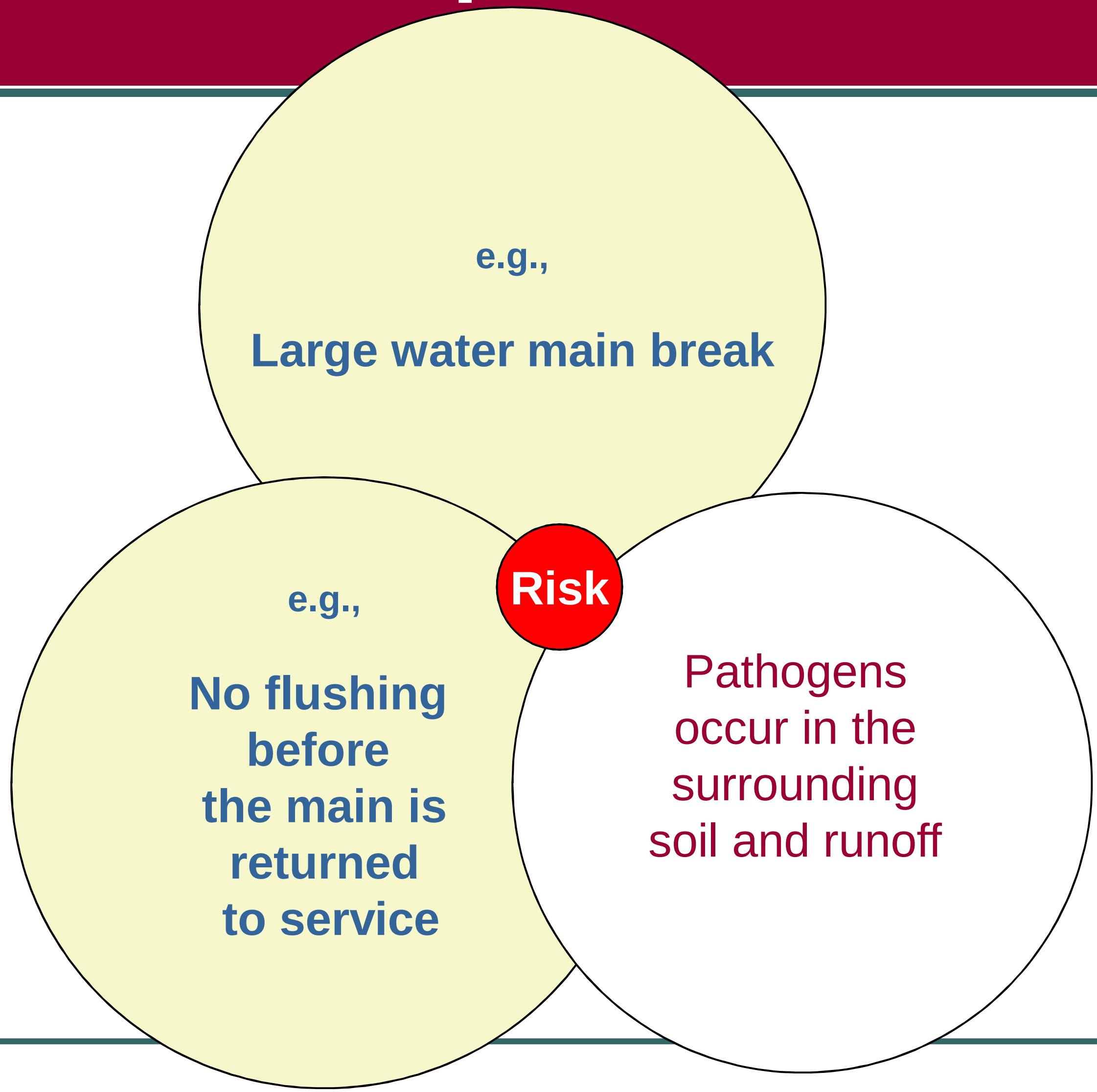
# Public Health Risk Occurs when the Three Come Together



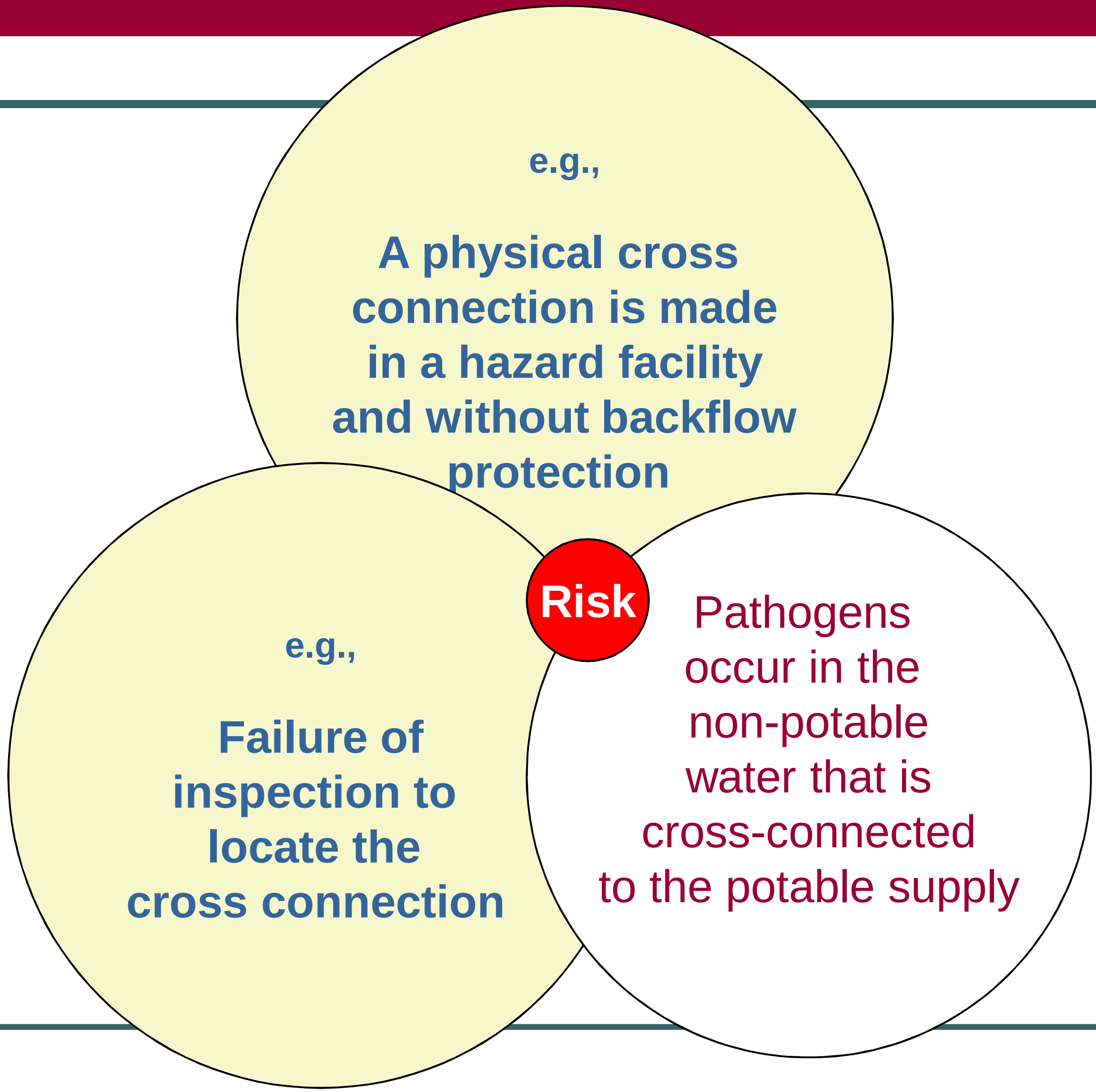
# Storage Facilities



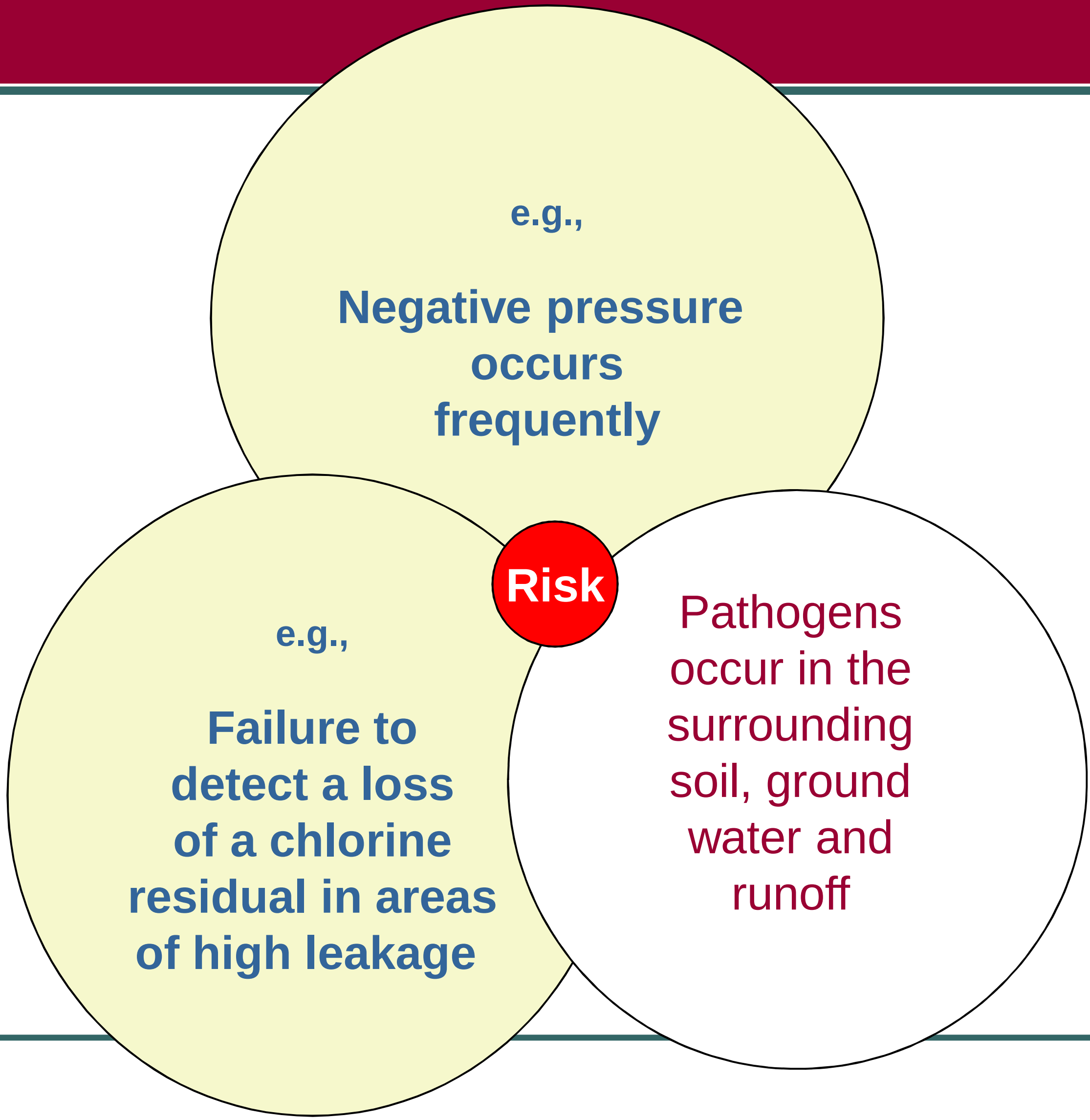
# New Mains and Repairs



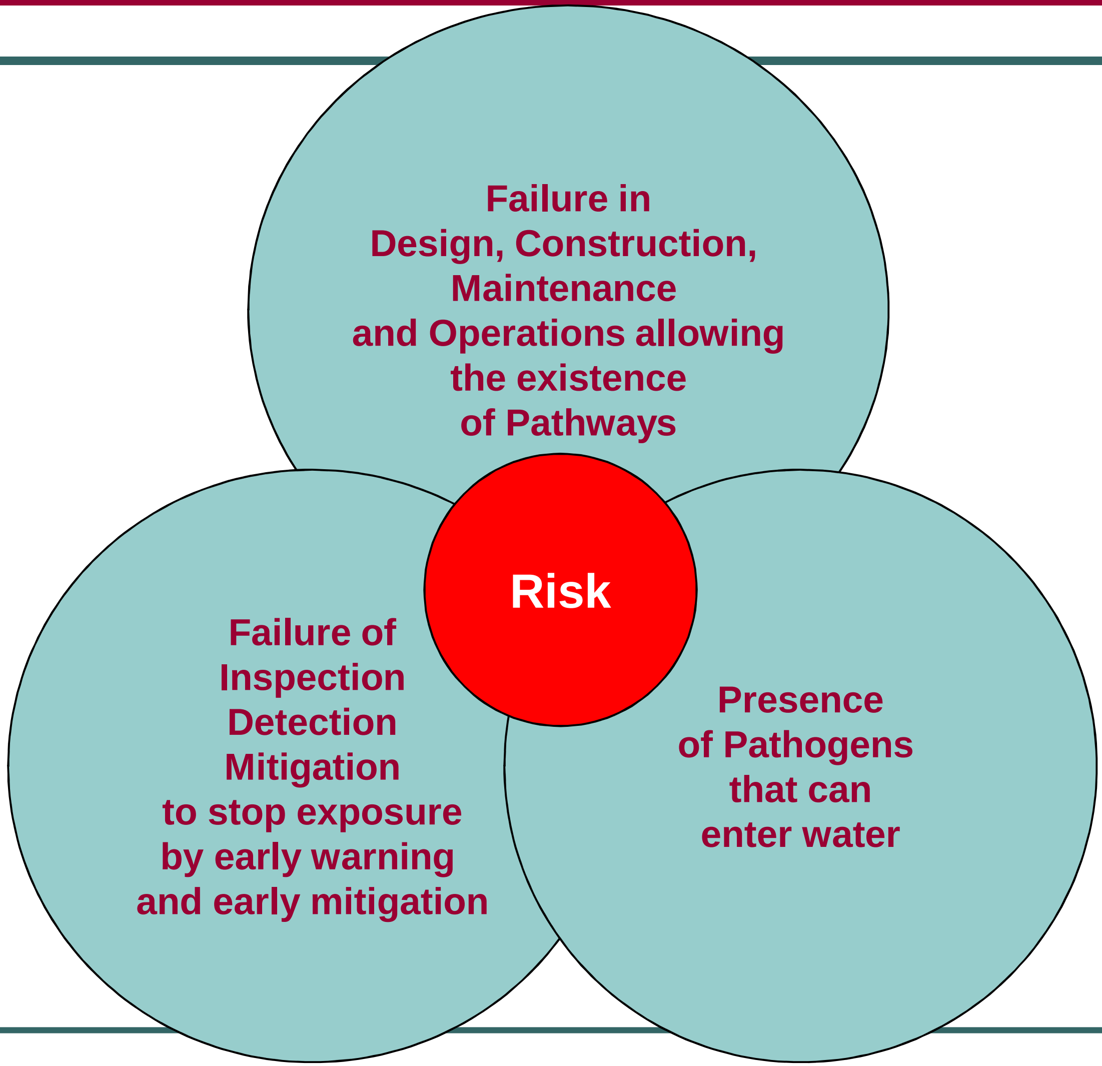
# Cross Connection Control



# Loss of Pressure and Transients



# Remember the Three Factors for Preventing Public Health Risk



## Remember the Four Priorities in Preventing Public Health Risk

1. Cross connections and backflow of contaminated water

2. Contamination due to storage facility design, operation or maintenance

3. Contamination due to main installation, repair or rehabilitation practices

4. Contaminant intrusion due to pressure conditions and physical gaps in distribution system infrastructure